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Enhancing floral and habitat diversity for augmenting natural enemies in rice ecosystem of Thanjavur, Tamil Nadu, India

R Nalini * and S Porpavai

Soil and Water Management Research Institute (Tamil Nadu Agricultural University), Thanjavur, Tamil Nadu, India

****Corresponding author e-mail: naliniento@gmail.com***

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ABSTRACT

Field experiments on "Enhancing floral and habitat diversity for augmenting natural enemies in Thanjavur rice belt" was conducted during kharif (2017 and 2018) and rabi (2017). In habitat diversified rice crop, the main crop of rice was maintained along with flowering vegetation in field bunds viz., cowpea, green gram, black gram, sunflower, gingelly, bhendi, cluster bean, maize and marigold. Weeds mainly from Umbelliferae, Leguminosae and Compositae that support natural enemies were also maintained adjacent to rice bunds. Non-crop habitat included straw heaps on rice bunds. Daincha was planted in rogue spacing and bird perches installed to encourage both the natural enemies and insectivorous birds. The mean value of insect pest population was about 56 per cent lower in habitat diversified rice crop (7.39 insects /5 sweeps) than that of pure rice crop (16.87 insects /5 sweeps). In the case of mean value of natural enemy population, habitat diversified rice crop (26.74 individuals /5 sweeps) recorded two times higher population than that of pure rice crop (13.40 individuals /5 sweeps). In habitat diversified rice crop the pest-defender ratio was high in all the periods of observation compared to pure rice crop. The mean pest:defender ratio was 1: 3.74 in habitat diversified rice crop as compared to 1: 0.89 in pure rice crop. The mean grain yield recorded was 4.99 t/ha in habitat diversified rice crop as compared to 4.36 t/ha in pure rice crop. In habitat diversified rice crop, the per cent increased grain yield recorded over pure rice crop ranged from 10.43 to 21.18.Crop diversification and non-crop habitats certainly encouraged natural biological control by supplementing food resource and shelter. Over the years complex food web would persist leading to sustainable and ecofriendly insect pest management in rice ecosystem.

Key words: *Habitat diversified rice crop, yellow stem borer, green leafhopper, natural enemies, pest-defender ratio*

INTRODUCTION

India contributed 21 per cent (155.4 million tons) of world's rice production (738.2 million tons) during 2015 (FAO, 2016). Tamil Nadu has produced 7.91 million tons of rice from an arrea of 1.83 million hectares in 2014-15 (Vaithilingam, 2015). Thanjavur district plays a key role in Tamil Nadu by producing about one-fourth of the total output of rice in the state and is rightly called the 'Granary of South India'. Thanjavur district lies in the Cauvery delta, the most fertile region in the state and is the main rice producing region in the state.

In Thanjavur district, rice cultivation is done extensively in *kharif*, *Samba* and *thaladi* whereas in summer season to a lesser extent. Of the various biotic constraints in rice production, insect pests play a foremost role. Significant rice yield losses are caused by stem borers, leaf folders, gall midges and planthoppers. Of all, the rice stem borers particularly yellow stem borer, *Scirpophaga incertulas* (Walker) is the key devastator and found throughout the year paralleling the availability of the food plant. Augmentation and conservation of the pool of native and released natural enemies through habitat diversity would form a cheap, remunerative and promising component in the IPM programme.

Diverse cropping systems encourage complex food webs that involve more interactions among

vegetation, pests, and natural enemies, providing resources for a diverse group of organisms and allowing for alternative resources and food sources. Thus, polycultures and natural ecosystems with higher diversity tend to be more stable and less subject to fluctuations in pest and disease populations (Altieri and Nicholls, 2004). As an example of this, Beizhou et al. (2011) recently reported that intercropping pear orchards with aromatic plants significantly reduced pest abundance and increased the ratio of natural enemies to pests when compared to orchards with only natural grass or clean tillage. They also found higher abundance of natural enemies and reduced numbers of major pests in intercropped orchards.

A well-designed flowering border adjacent to a crop field will provide necessary resources and alternative food source for natural enemies during periods when crop pest and crop flower numbers are low, thus maintaining high populations of natural enemies supported by the provision of nutrients throughout the season (Isaacs et al., 2009; Hogg et al., 2011).

Many beneficial insects, including natural enemies, require access to alternate hosts, overwintering habitats, a constant food supply, and appropriate microclimates in order to survive (Johnson and Triplehorn, 2005). The majority of predators and parasitoids are omnivores and require non-prey food, such as pollen and nectar, as part of their diet. Natural enemies from a broad range of orders including Hymenoptera, Diptera, Coleoptera, Heteroptera, Neuroptera, Araneae and Acari have been observed to require and/or benefit from access to flowering resources (Wäckers et al., 2005). Access to pollen and nectar sources can significantly increase the activity, longevity, and fecundity of these predators and parasitoids (Wäckers et al., 2008; Hogg et al., 2011), and thus, the availability of flowering resources can be essential to natural enemy efficacy in biological control of pest insects (van Rijn and Sabelis, 2005).

Habitat management is a strategy to conserve natural biological control by improving the availability of non-rice resources for predators. Non-rice habitats and non-crop areas adjacent to the rice field may be important refuges for less mobile predators like the spiders. Diverse food and weed plants growing on farm margins contribute to the diversity in the agro-ecosystem, which can influence the diversity and abundance of insect herbivores and associated natural enemies in crop systems. Maintenance of undisturbed vegetation on the bunds of irrigated rice fields, and trimming after crop establishment may encourage beneficial species to move into the field, which is likely to enhance natural biological control of rice insect pests.

The importance of non-rice habitats for carryover of natural enemies that are significant in rice pest management has also been emphasized by Lan et al., 2001. Non-crop habitats are relatively undisturbed and temporally permanent areas to act as biodiversity reservoirs for plants, insects, birds and mammals. Non-crop habitats support a diversity of natural enemies, including carabid beetles, staphylinids, spiders, coccinellids, syrphids, chrysopids, predatory mites, parasitoids, predacious Heteropterans and insectivorous birds. Natural enemies and pest species also use non-crop habitats for hibernation. The moderate microclimate in combination with presence of nectar sources in wooded edges result in higher parasitoid longevity, early season abundance and higher levels of parasitism as compared to field centres.

Certain weeds (mostly Umbelliferae, Leguminosae and Compositae) play an important ecological role by harbouring and supporting a complex of beneficial arthropods that aid in suppressing pest populations (Altieri, 1999). The role of weeds assumed significance as they are reservoirs for most of the parasitoids, particularly in case of *Platygaster oryzae* as its host *Orseolia* spp. thrives on a wide variety of weeds (Das et al., 1987). *P. oryzae* was dominant in *Paspalum* sp., *Mnesithea laevis*, and *Echinochloa crusgalli*. Scelionids and trichogrammatids visited ornamental plants. Female parasitoids of *T. schoenobii* responded to the flowers of *Hyptis* sp. a common weed in rice fields. Natural enemy habitat protection and development are more active methods of conserving natural enemies (*e.g.*, owl houses, mulching for spiders, floral nectaries for parasites).

With this background, emphasis was given on flowering vegetations and weeds on the bunds as well as non-crop habitats to enhance natural enemy population for sustained and ecofriendly management of insect pests in rice ecosystem.

MATERIALS AND METHODS

Three field experiments on "Enhancing floral and habitat diversity for augmenting natural enemies in Thanjavur rice belt" were conducted during *kharif*, 2017 (ADT 43); *rabi*, 2017 (ADT 46) and *kharif*, 2018(ADT 43) at Soil and Water Management Research Institute, Thanjavur. Two treatments *viz*., habitat diversified rice crop and pure rice crop were compared for the natural enemy abundance. In habitat diversified rice crop, the main crop *i.e.*, rice was maintained along with flowering vegetation in field bunds *e.g.*, cowpea, green gram, black gram, sunflower, gingelly, bhendi, cluster bean, maize, marigold. Weeds mainly from Umbelliferae, Leguminosae and Compositae that harbour and support a complex of beneficial arthropods were also maintained adjacent to rice bunds. Non-crop habitat included straw heaps on rice bunds. For every ten rows of paddy, 30 cm rogue spacing was maintained in which Daincha was planted to encourage natural enemies and insectivorous birds. Bird perches was installed 2 to 3 feet height in vegetative stage at the rate of 50 perches/ ha. Other agronomic practices were followed as per the TNAU Crop Production Guide, 2012. Each treatment was maintained in one acre plot size. Assessment of insect pest and natural enemy population were done in main rice field using sweep net at fortnight interval from five locations (four in the corner and one in the middle). For testing whether there existed any differences between the habitat diversified rice crop and rice crop alone, paired t-test was used.

RESULTS AND DISCUSSION

Herbivore population in the experimentalrice field

During *kharif* the habitual herbivores that affected the rice crop were yellow stem borer (YSB), *Scirpophaga incertulas* (Walker), Crambidae, Lepidoptera; Short horned grasshopper, *Acrida exaltata* (Walker), Acrididae, Orthoptera; Stink bug, *Menida versicolor* (Gmelin), Pentatomidae, Hemiptera; green leafhoppers (GLH), *Nephotettix* spp., Cicadellidae, Hemiptera; Earhead bug, *Leptocorisa* sp., Alydidae, Hemiptera and Black bug, *Scotinophora lurida*, Pentatomidae, Hemiptera. Similarly during *samba* the yellow stem borer and green leafhopper were alone recorded.

In *kharif* 2017 field trial, the number of yellow stem borer adult moths were high in the first fortnight of July (7.3 moths / 5 sweeps) in habitat diversified rice crop, while in pure rice crop it was high in the second fortnight of June (11.3 moths /5 sweeps) (Table 1). Moreover in each crop during *samba*, 2017, more YSB adults were recorded in the second fortnight of October. But in terms of population density, comparatively high density was recorded in the pure rice crop (13 moths /5 sweeps) as compared to 6 moths / 5 sweeps in habitat diversified rice crop (Table 2). The similar trend was observed in *kharif* 2018 field trial, as the YSB adults captured was high to the tune of 3.2 moths/5 sweeps in pure rice crop as against 0.6 moths/5 sweeps in habitat diversified rice crop (Table 3). Invariably, in the all three field experiments, the more YSB adults were recorded in the tillering stage of the crop.

Green leafhopper population was ranged from 1.3 to 8.3 hoppers/5 sweeps in habitat diversified rice crop as compared to 4.0 to 13.7 hoppers/5 sweeps in pure rice crop maintained in *kharif* 2017. Similar trend was reported in the field trial conducted during *samba*, 2017. The population was ranged from 2.3 to 8.3 hoppers/5 sweeps in habitat diversified rice crop as compared to 3.0 to 18.3 hoppers/5 sweeps in pure rice crop. In *kharif* 2018, the green leafhopper population was meager both in habitat diversified rice crop (0 to 0.2 hoppers/ 5 sweeps) and pure rice crop (0 to 1.6 hoppers/ 5 sweeps).

Stink bug, shorthorned grasshopper, earhead bug and black bug were of minor importance.

The mean value of insect pests in pure rice crop (16.87 insects/5 sweeps) was about 2 times higher than that of habitat diversified rice crop (7.39 insects/5 sweeps).

Natural enemy population in the rice field

Braconid wasps, *Stenobracon nicevillei* and *Macrocentrus* sp., Braconidae, Hymenoptera; Assassin bug, *Polytoxus* sp., Reduviidae, Hemiptera; Long horned grasshopper, *Conocephalus* sp., Tettigoniidae, Orthoptera; Tachinidfly, *Argyrophylax* sp.,Tachinidae, Diptera; Rove beetle, *Paederus fuscipes*, Staphylinidae, Coleoptera; Ground beetle, *Ophionea nigrofasciata*, Carabidae, Coleoptera; Coccinellids, *Micraspis* sp. and *Menochilus*

Table 1. Incidence of insect pest and natural enemies in rice ecosystem at Thanjavur during *kharif*, 2017.

Period	Insect pests (no./5 sweeps)					Natural enemies (no./5 sweeps)												P:D ratio
	YSB moth	Short horned grasshopper	Stink bug	GLH	TOTAL	Braconidwasp	Assassin bug	Long horned grasshopper	Dipterans	Ichneumonid	Rove beetle	Coccinellid	Damselfly	Dragonfly	Owl fly	Spider	TOTAL	
T1 - Habitat diversified rice crop (rice + bund crop + weeds)																		
2nd fortnight of June, 2017	4.0	2.0	1.3	2.7	10.0	1.0	0.3	0.3	0.3	0.0	0.0	11.7	8.7	0.3	0.0	7.0	29.7	1:2.97
1st fortnight of July, 2017	7.3	1.7	7.0	5.7	21.7	3.7	1.0	1.7	1.0	1.0	0.0	22.0	7.0	0.0	1.0	8.3	46.7	1:2.14
2nd fortnight of July, 2017	2.0	3.7	2.7	8.3	16.7	7.7	3.7	2.7	3.3	3.0	2.0	65.0	11.0	1.0	0.0	13.3	112.7	1:6.65
1st fortnight of Aug, 2017	0.0	0.0	2.0	3.3	5.3	3.3	0.0	0.0	0.0	0.0	0.0	7.3	3.7	0.0	0.0	6.7	21.0	1:4.20
2nd fortnight of Aug, 2017	0.0	0.0	2.7	1.3	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	6.3	8.7	1:2.25
Mean	2.66	1.48	3.14	4.26	11.6	3.14	1	0.94	0.92	0.8	0.4	21.2	6.54	0.26	0.2	8.32	43.76	1:3.64
T2 - Pure Rice crop																		
2nd fortnight of June, 2017	11.3	3.0	9.3	4.7	28.3	0.0	0.3	1.0	1.0	0.0	0.0	5.0	3.0	0.3	0.0	5.7	16.3	1:0.57
1st fortnight of July, 2017	8.0	3.7	11.3	7.7	30.7	0.0	1.0	0.0	1.0	0.0	0.0	8.7	4.3	0.0	0.0	8.3	23.3	1:0.74
2nd fortnight of July, 2017	3.7	1.3	16.3	13.7	35.0	1.0	1.7	0.0	3.0	0.0	0.0	15.3	4.7	1.0	0.0	3.0	29.7	1:0.86
1st fortnight of Aug, 2017	0.0	2.7	4.0	4.0	10.7	0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.0	0.0	0.0	6.0	12.0	1:1.09
2nd fortnight of Aug, 2017	1.3	0.0	8.3	7.3	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	3.7	5.0	1:0.31
Mean	4.86	2.14	9.84	7.48	23.94	0.2	0.6	0.2	1	0.0	0.0	6.4	3.26	0.26	0.0	5.34	17.26	1:0.71
t value	**2.67**	**1.08**	**4.23**	**2.19**		**-3.53**	**-0.95**	**-1.85**	**0.11**	**-2.35**	**-1.38**	**-3.00**	**-3.05**	**-**	**-1.38**	**-1.79**		

*Mean of five replicationst critical value (one-tail) - 1.76; t critical value (two-tail) - 2.14.

sexmaculatus, Coccinellidae, Coleoptera; Damselfly, *Agriocnemis* sp., Coenagrionidae, Odonata; Dragonfly, *Diplacodes* sp., Libellulidae, Anisoptera, Odonata; Owl fly, Ascalaphidae, Neuroptera and Ichneumonids, *Trichomma cnaphalocrocis* and *Xanthopimpla* sp. lchneumonidae, Hymenoptera. Of the spiders (Order Araneae), *Oxyopes* sp., Oxyopidae; *Argiope* sp. and *Araneus* sp., Araneidae; *Tetragnatha* sp., Tetragnathidae and *Lycosa* sp., Lycosidae, were recorded.

Natural enemy population recorded in *kharif* 2017 trial was ranged from 8.7 to 112.7 individuals/5 sweeps in habitat diversified rice crop as compared to 5.0 to 29.7 individuals/5 sweeps in pure rice crop (Table 1). Among the natural enemies recorded, coccinellids were the most profound predator followed by damselflies and spiders. In *samba* 2017 field trial, the natural enemy population was ranged from 14.3 - 37.3 individuals/5 sweeps in habitat diversified rice crop as compared to 4.7 - 20.7 individuals/5 sweeps in pure rice crop (Table 2). Here spiders were the most predominant natural enemy group followed by the damselflies and coccinellid beetles. In the field trial conducted in *kharif* 2018, the natural enemy population was ranged from 9.0 to 15.8 individuals/5 sweeps in habitat diversified rice crop as compared to 5.2 to 17.0 individuals/5 sweeps in pure rice crop (Table 3).

Mean value of natural enemies, in habitat diversified rice crop (26.74 individuals/5 sweeps) was found approximately two times higher than that of pure rice crop (13.40 individuals/5 sweeps).

Pest defender ratio

In *kharif* 2017 field trial, the pest:defender ratio ranged from 1: 2.14 to 1:6.65 in habitat diversified rice crop as compared to 1:0.31 to 1: 1.09 in pure rice crop (Table 1). The maximum ratio was recorded (1: 6.65) during 2nd fortnight of July, in habitat diversified rice crop as compared to 1:0.86 in pure rice crop.In Samba 2017 field trial, the highest pest:defender ratio was (1:8.54) reported during 1st fortnight of November in habitat diversified rice crop whereas in pure rice crop it was maximum (1:1.66) during 1st fortnight of October (Table 2). With respect to field trial of *kharif*, 2018, the pest:defender ratio ranged from 1:1.88 to 1:4.80 in habitat diversified rice crop as compared to 1:0.81 to 1:1.44 in pure rice crop. It was maximum (1:4.80) during

Table 2. Incidence of insect pests and natural enemies in rice ecosystem at Thanjavur during Samba, 2017.

Period	Insect pests (no./5 sweeps)			Natural enemies (no./5 sweeps)						P:D ratio
	YSB moth	GLH	TOTAL	Coccinellid beetle	Rove beetle	Damselfly	Dragonfly	Spiders	TOTAL	
	T1 - Habitat diversified rice crop (Rice + bund crop + weeds)									
2nd fortnight of Sep. 2017	0.7	3.0	3.7	5.0	0.0	5.3	0.0	8.0	18.3	1:5.00
1st fortnight of Oct. 2017	1.3	3.0	4.3	7.3	1.0	7.7	1.7	13.3	31.0	1:7.15
2nd fortnight of Oct. 2017	6.0	8.3	14.3	12.3	0.7	9.7	1.0	13.7	37.3	1:2.60
1st fortnight of Nov. 2017	2.0	2.3	4.3	8.0	0.7	11.0	0.7	16.7	37.0	1:8.54
2nd fortnight of Nov. 2017	1.0	4.7	5.7	3.0	0.0	8.0	0.3	9.3	20.7	1:3.65
1st fortnight of Dec. 2017	2.7	2.7	5.3	3.0	0.0	8.3	0.0	6.0	17.3	1:3.25
2nd fortnight of Dec. 2017	0.7	3.3	4.0	5.0	0.0	7.0	0.3	6.0	18.3	1:4.58
1st fortnight of Jan. 2018	0.3	7.7	8.0	3.7	0.0	7.7	0.0	3.0	14.3	1:1.79
2nd fortnight of Jan. 2018	0.0	6.3	6.3	4.7	0.0	5.7	0.0	4.3	14.7	1:2.32
Mean	1.63	4.59	6.21	5.78	0.27	7.82	0.44	8.92	23.21	1:4.32
	T2 - Pure Rice crop									
2nd fortnight of Sep. 2017	2.3	7.0	9.3	4.0	0.0	4.3	0.0	5.3	13.7	1:1.46
1st fortnight of Oct. 2017	0.0	10.7	10.7	5.3	0.0	5.0	0.0	7.3	17.7	1:1.66
2nd fortnight of Oct. 2017	13.0	18.3	31.3	3.7	0.0	2.3	0.3	8.7	15.0	1:0.48
1st fortnight of Nov. 2017	12.0	13.3	25.3	4.0	0.0	3.7	0.0	13.0	20.7	1:0.82
2nd fortnight of Nov. 2017	9.0	10.0	19.0	3.3	0.0	2.0	0.3	8.3	14.0	1:0.74
1st fortnight of Dec. 2017	9.0	12.7	21.7	2.3	0.0	3.0	0.3	5.0	10.7	1:0.49
2nd fortnight of Dec. 2017	9.0	13.7	22.7	3.3	0.0	2.0	0.0	5.0	10.3	1:0.46
1st fortnight of Jan. 2018	1.0	9.3	10.3	2.0	0.0	4.7	0.0	2.0	8.7	1:0.84
2nd fortnight of Jan. 2018	0.3	3.0	3.3	1.3	0.0	2.3	0.0	1.0	4.7	1:1.40
Mean	6.18	10.89	17.07	3.24	0.0	3.26	0.1	6.18	12.83	1:0.93
t value	**5.47**	**5.55**		**-3.19**	**-2.27**	**-6.74**	**-2.08**	**-3.50**		

* Mean of five replicationst Critical one-tail - 1.71; t critical two-tail - 2.06

Table 3. Incidence of insect pest& natural enemies in rice ecosystem at Thanjavur during *kharif*, 2018.

Period	Insect pests (no./5 sweeps)							Natural enemies (no./5 sweeps)									P:D
	GLH	YSB moth	Stink bug	Earh-ead bug	Black bug	Shorth-orned grassh-opper	TOTAL	Ground beetle	Coccin-ellid	Ichneu-monid	Long horned grassh-opper	Drago-nfly	Dams-elfly	Wasp	Spider	TOTAL	ratio
T1 - Habitat diversified rice crop (rice + bund crop + weeds)																	
2nd fortnight of June, 2018	1.0	0.2	1.4	0.2	1.6	1.0	5.4	0.2	6.4	0.4	0.2	0.4	1.0	1.4	1.2	11.2	1:2.07
1st fortnight of July, 2018	0.6	0.2	1.4	0.2	0	0.6	3.0	1.4	2.0	0.8	0	2.2	4.2	1.6	2.2	14.4	1:4.80
2nd fortnight of July, 2018	0.4	0.2	1.4	0.8	0	0.8	3.6	2.0	3.0	0.6	0.2	1.8	4.2	0.6	3.4	15.8	1:4.39
1st fortnight of Aug, 2018	0	0	3.0	1.6	0	0.4	5.0	2.2	3.0	0.4	0.4	2.4	1.4	0.6	5.4	15.8	1:3.16
2nd fortnight of Aug, 2018	0	0	2.6	2.2	0	0	4.8	2.0	2.0	0	0	0.8	2	0	2.2	9.0	1:1.88
Mean	0.4	0.12	1.96	1	0.32	0.56	4.36	1.56	3.28	0.44	0.16	1.52	2.56	0.84	2.88	13.24	1:3.26
T2 - Pure Rice crop																	
2nd fortnight of June, 2018	3.0	1.2	3.4	1.6	3.4	0.4	13.0	1.4	4.2	0.6	0.0	0.8	3.4	0.2	2.0	12.6	1:0.97
1st fortnight of July, 2018	3.2	1.6	2.8	2.0	0.8	1.4	11.8	1.8	2.8	0.6	0	3.8	3.8	1.6	2.6	17.0	1:1.44
2nd fortnight of July, 2018	2.0	1.0	3.8	1.0	0	0.8	8.6	1.6	1.8	0	0	1.6	2.2	0.2	1.6	9.0	1:1.05
1st fortnight of Aug, 2018	0.6	0.6	3.4	3.0	0	0.8	8.4	0.8	1.0	0	0	0.6	1.6	0	2.8	6.8	1:0.81
2nd fortnight of Aug, 2018	0	0	3.4	2.8	0	0	6.2	0.2	0.8	0	0	0	0.6	0	3.6	5.2	1:0.84
Mean	1.76	0.88	3.36	2.08	0.84	0.68	9.6	1.16	2.12	0.24	0.0	1.36	2.32	0.4	2.52	10.12	1:1.02
t value	**4.11**	**3.26**	**3.79**	**3.26**	**2.12**	**0.39**		**-1.02**	**-2.28**	**-1.04**	**-2.14**	**-0.57**	**-0.51**	**-1.79**	**-0.83**		

* Mean of five replicationst critical value (one-tail) - 1.71; t critical value (two-tail) - 2.06

1st fortnight of July, 2018 in habitat diversified rice crop as compared to 1: 1.44 in pure rice crop (Table 3). In habitat diversified rice crop the pest-defender ratio was high in all the periods of observation compared to pure rice crop.

Grain yield

In *kharif* 2017, the grain yield recorded was 5.4 tons/ha in habitat diversified rice crop as compared to 4.8 tons/ha in pure rice crop (Table 4). In *samba* 2017, the grain yield recorded was 4.7 tons/ha in habitat diversified rice crop as compared to 4.2 tons/ha in pure rice crop. In *kharif* 2018, habitat diversified rice crop the grain yield recorded was 4.9 tons/ha whereas pure rice crop recorded 4.1 tons/ha. In habitat diversified rice crop, the per cent increased yield recorded over pure rice crop was ranged from 10.43 to 21.18.

In a rice monocropping belt, where floral diversity as well as faunal diversity are lacking the monophagous insect pests tends to peak with several outbreaks. This is mainly because of continuous availability of food and shelther. It has forced to the insecticide use indiscriminately over the past two decades. Average pesticide use per area of crop land was 0.25 kg/ha in 2000, 0.33 kg/ha in 2010 and 0.36 kg/ha in 2014 (FAOstat, 2019).

The high dependence on insecticide has elevated several issues such as insects developing resistance as well as resurgence along with air pollution, soil pollution, residues in food produces and bye-products. Release of toxic chemicals and pollutants into the environment lead to biomagnification and human hazards like cancers, liver and kidney failures, respiratory disorders, birth defects, brain damages and

Table 4. Grain yield in habitat diversified and pure rice crop at Thanjavur.

Season	Grain yield (tons/ha)		% increased yield over pure rice crop
	Habitat diversified rice crop	Pure rice crop	
Kharif, 2017	5.40	4.80	12.50
Samba, 2017	4.66	4.22	10.43
Kharif, 2018	4.92	4.06	21.18
Mean	4.99	4.36	11.03

*Mean of five replications

heart diseases.

The current scenario promotes to have a diversified floral and faunal diversity which encourages a pool of beneficial predators and parasitoid. Enriched floral and faunal diversity ensures natural biological control through complex food webs and sustained ecosystem accomplished. In this research paper, in the extensive paddy monocrop growing areas like Thanjavur enriching floral diversity through non-rice flower crop stretch in the bunds as well as retention of flowering weeds was aimed to promote natural biological control. In addition non-crop habitats were also considered for sheltering of natural enemies and insectivorous birds.

In the Thanjavur belt, the habitual herbivore with major status was yellow stem borer, *Scirpophaga incertulas* (Walker), Crambidae, Lepidoptera. Other insect pests included were Short horned grasshopper, *Acrida exaltata* (Walker), Acrididae, Orthoptera; Stink bug, *Menida versicolor* (Gmelin), Pentatomidae, Hemiptera; green leafhoppers (GLH), *Nephotettix* spp., Cicadellidae, Hemiptera; Earhead bug, *Leptocorisa* sp., Alydidae, Hemiptera and Black bug, *Scotinophora lurida*, Pentatomidae, Hemiptera. The natural enemies pool included Braconid wasps, *Stenobracon nicevillei* and *Macrocentrus* sp., Braconidae, Hymenoptera; Assassin bug, *Polytoxus* sp., Reduviidae, Hemiptera; Long horned grasshopper, *Conocephalus* sp., Tettigoniidae, Orthoptera; Tachinid fly, *Argyrophyla* sp., Tachinidae, Diptera; Rove beetle, *Paederus fuscipes*, Staphylinidae, Coleoptera; Ground beetle, *Ophionea nigrofasciata*, Carabidae, Coleoptera; Coccinellids, *Micraspis* sp., and *Menochilus sexmaculatus*, Coccinellidae, Coleoptera; Damselfly, *Agriocnemis* sp., Coenagrionidae, Odonata; Dragonfly, *Diplacodes* sp., Libellulidae, Anisoptera, Odonata; Owl fly, Ascalaphidae, Neuroptera and Ichneumonids, *Trichomma cnaphalocrocis* and *Xanthopimpla* sp. lchneumonidae, Hymenoptera. Of the spiders, *Oxyopes* sp., Oxyopidae; *Argiope* sp. and *Araneus* sp., Araneidae; *Tetragnatha* sp., Tetragnathidae and *Lycosa* sp., Lycosidae, Araneae were recorded.

Along with the main rice crop, maintaining a stretch of non-rice flower crop in the bunds as well as flowering weeds in the adjacent areas supported 51.54 per cent lesser herbivore population when compared to the pure rice crop (Fig. 1). The mean total insect

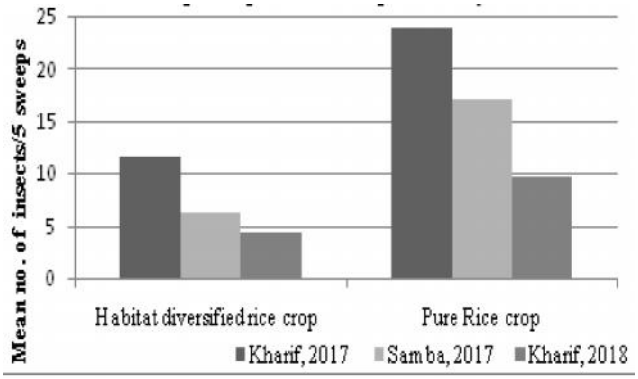

Fig. 1. Insect pest population in habitat diversified rice crop and pure rice crop at Thanjavur

pest count was more in the pure rice crop (3.3 - 35 insects/5 sweeps) when compared to the habitat diversified rice crop (3.0 - 21.7 insects /5 sweeps). On the other hand, the natural enemies' population was 1.31 to 2.54 times more in the habitat diversified rice crop compared to the pure rice crop (Fig. 2). The mean total natural enemies population was more in the habitat diversified rice crop (26.74 individuals /5 sweeps) when compared to the pure rice crop (13.40 individuals/5 sweeps).

The non-rice habitats, particularly the narrow bunds with vegetation cover surrounding each field, seem especially important as a source of natural enemies, particularly early arriving species such as spiders, and predators such as *Cyrtorhinus*

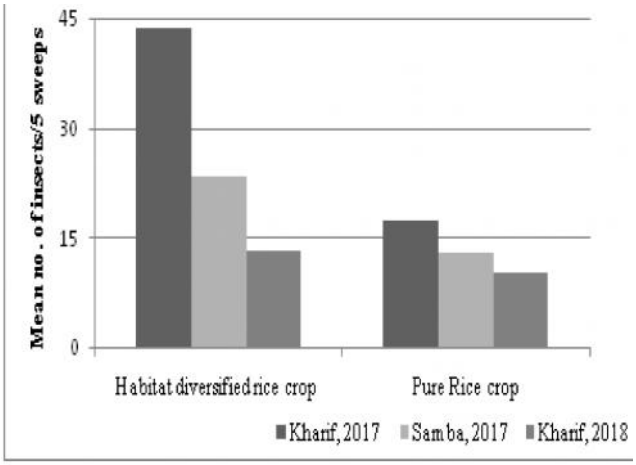

Fig. 2. Natural enemies population in habitat diversified rice crop and pure rice crop at Thanjavur.

lividipennis that can seasonally concentrate on rice (Way and Heong, 1994). Many co-workers have also reported that a well-designed flowering border adjacent to a crop field will provide necessary resources and alternative food sources for natural enemies (Isaacs et al., 2009; Hogg et al., 2011).

Certain weeds are important components of agro-ecosystems because they positively affect the biology and dynamics of beneficial insects. They offer many important requisites for natural enemies such as alternative prey/hosts, pollen, or nectar as well as microhabitats that are not available in weed-free monocultures. Herbivore-natural enemy interactions occurring in a crop system can be influenced by the presence of herbivores on associated weed plants (Altieri and Letourneau, 1982). Altieri (1999) reported that certain weeds (mostly Umbelliferae, Leguminosae and Compositae) play an important ecological role by harbouring and supporting a complex of beneficial arthropods that aid in suppressing pest populations.

In the non-crop habitats, plenty of ground beetle, rove beetle, crickets and spiders were recorded. Non-rice habitats for carryover of natural enemies that are significant in rice pest management have also been emphasized by Lan et al., 2001. The size and composition of non-rice habitats adjacent to rice fields may have positive effects on natural enemies in rice fields (Xiaoping et al., 1995). Whether or not the non-rice habitats in the rice ecosystem are beneficial sources of rice pests (Way and Heong, 1994), they need to be explored for their preservation and possible manipulation to favor natural control of rice pests.

The ideal indicator pest-defender ratio was high in habitat diversified rice crop compared to pure rice crop in all the periods of observation. Crop diversification may increase the effectiveness of generalist enemies by increasing alternate food or prey availability (Sheehan, 1986). The movement behavior of natural enemies has a strong influence on their response to agroecosystem diversification (Corbett, 1998).

Thus rice fields enriched with broad-leaved flowering vegetation *viz*., cowpea, green gram, black gram, sunflower, gingelly, bhendi, cluster bean, maize, marigold in field bunds as well as retention of flowering weeds and affording non-crop habitats augmented natural enemies and insectivorous birds. Crop diversification and non-crop habitats certainly encouraged natural biological control by supplementing food resource and shelter. Over the years complex food web would persist leading to sustainable and ecofriendly insect pest management. Bund crops would also provide additional remuneration to the farming community.

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