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Diversity of Coccinellids in Cereals, Pulses, Vegetables and in Weeded and Partially Weeded Rice-Cowpea ecosystems in Madurai District of Tamil Nadu

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Studies were undertaken on diversity of predatory coccinellids in two agro-ecosystems comprising cereals, pulses and vegetables in Madurai District of Tamil Nadu. Field experiments were conducted in weeded and partially weeded irrigated (rice) and garden (cowpea) ecosystems at Agricultural College and Research Institute, Madurai. A total of nine species of predatory coccinellids were recorded. Three common species *viz., Coccinella transversalis* Fabricius, *Menochilus sexmaculatus* Fabricius and *Brumoides suturalis* Mulsant were found in cereals, pulses and vegetable crops. Tomato and bhendi had rich abundance of coccinellids in Madurai, while chillies, cowpea, blackgram and bitter gourd in Alagarkovil. Diversity was high in crops like tomato, bhendi, chillies, blackgram and bittergourd in Madurai and in rice and cowpea in Alagarkovil. Rank abundance values revealed that *C. transversalis, Micraspis discolor* and *B. suturalis* were the dominant taxa in weeded and partially weeded rice ecosystem. *M. sexmaculatus, C. transversalis* and *B. suturalis* were the dominant taxa in weeded and partially weeded cowpea ecosystem. The diversity of coccinellids was greater in partially weeded plots than in weeded plots, particularly during the successional stage of crop growth and less during early vegetative stage and before harvesting. Rates of community turnover of coccinellids increased in both the weeded and partially weeded canopy with the crop age but at a faster rate in partially weeded canopy. This study suggests that partially weeded rice or cowpea ecosystem could be a better choice for conserving predatory coccinellid fauna instead of complete weeding, which would play a vital role in the natural suppression of insect pests.

Key words: Diversity, coccinellids, cereals, pulses, vegetables, weeded, partially weeded, rice, cowpea

Natural enemies are self regulating and once they are established further investments in control are not necessary (Pimental, 1991). Among the predators, coccinellids, the coleopteran members are important components of natural enemy complex of many agricultural and horticultural crop pests such as aphids, mealybugs, scale insects and mites. They are commonly known as lady birds, lady beetles, lady bugs or lady bird beetles belong to the family Coccinellidae, with 330 genera that include about 4,500 species, distributed across the world (Booth *et al.,* 1990). The value of coccinellids in biological control of insect pest is enhanced by the predaceous habit of both adults and grubs, which contribute to the destruction of pest at a greater density. They act as predominant and efficient biosuppression agents particularly where homopterans are serious pests. Biodiversity provides both opportunities and challenges for studying local ecological communities, which are affected by environmental perturbations. So studies were undertaken to know the diversity of predatory coccinellids in cereals, pulses and vegetables in the Madurai district of Tamil Nadu and to understand their role in weeded and partially weeded rice and cowpea ecosystems.

Materials and Methods

Field survey

Field surveys were undertaken in two

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locations one at Agricultural College and Research Institute (AC&RI), Madurai and the other at *Alagarkoil* of Madurai District in a radius of 10 km for the occurrence and distribution of predatory coccinellids on rice, maize, sorghum, pearl millet, cowpea, black gram, redgram, lablab, tomato, chillies, bhendi, bittergourd and brinjal. At each location roving survey was taken up once in 15 days. In roving survey, the occurrence of predatory coccinellids and their associated prey insects were assessed by taking observations on five randomly selected plants.

Assessment of coccinellids

Diversity of coccinellids was assessed under weeded and partially weeded conditions in irrigated (Rice) and garden land (Cowpea) ecosystems. The field experiment was laid out in an exploded block design with ruling rice (ADT 36) and cowpea (Co 2) cultivars in two treatments namely weeded plot (protected plot) and partially weeded plot (partially protected plot). Two-metre area around the experimental field was maintained as weedy area (stabilizing area) to augment the population of the coccinellids as suggested by Kandibane (2003). Predatory coccinellids in rice ecosystem were sampled by using sweep net (30x60x45 cm). Twenty-five sweeps were made diagonally across each plot and samples were placed in separate plastic sachets. Predatory coccinellids in cowpea ecosystem were sampled by fixed plot survey. The number of beetles feeding on aphids on a plant was recorded, and the counts were taken from five plants at weekly intervals from transplanting till the harvest. A total of 12 samplings were taken up in a crop season.

Estimating the abundance of coccinellids

Species diversity (H). In order to study the proportion of each species within the local community, species diversity was computed based on Shannon-Wiener formula, also been called the Shannon index or Shannon-Wiener index (Humphries *et al*., 1996).

$$H = -\sum_{i=0}^{S} P_i \log_e P_i$$

Where, H is the Shannon-Wiener biodiversity index; P_i is the proportion of each species in the sample (relative abundance); $\log_e P_i$ is the natural log of P_i; and S is the number of species in the community.

Species evenness (J). With a view to understand the measure of how similar the abundance of different species, species evenness was calculated to estimate the equitability component of diversity (Pielou, 1969).

$$J = \frac{H}{\log_e S}$$

Where, H is the Shannon-Wiener biodiversity index; and S is the number of species in the community.

Species richness (Ma.) In order to assess how the diversity of the population is distributed or organised among the particular species, this index was calculated (Pielou, 1975).

$$Ma = \frac{S-1}{\log_e N}$$

Where, S is the total number of species collected; and N is the total number of individuals in all the species

Simpson's diversity index This accounts for both richness and proportion (per cent) of each species in the local community. The index has been defined in three different ways (Simpson, 1949).

Simpson's index (D). This denotes the probability that two randomly selected individuals in the community belong to the same species.

$$D = -\sum P_i^2$$

Where, P_i is the proportion of each species in the sample (relative abundance)

Simpson's index of diversity (1-D). This measures the probability that two randomly selected individuals in a community belong to different species.

Simpson's reciprocal index (1/D). This estimates the number of equally common species that will produce the observed Simpson's index.

C_j (Jaccard) index of similarity. The taxonomic similarity between protected and unprotected canopy was calculated using qualitative informations on the presence of a species in a sample. The values of C_j ranged from 0 (no similarity) to 1.00 (perfect similarity) as suggested by Jaccard (1908) and Magurran (1988).

$$C_j = \frac{j}{(a+b-j)}$$

Where, aN is the number of individuals in sample A; bN is the number of individuals in sample B; ani is the number of individuals in the i^{th} taxon in sample A; and bni is the number of individuals in the i^{th} taxon in sample B

$$C_m h_w = \frac{2\sum (ani \times bni)}{(da + db)\ aN \times bN}$$

Where, j is the number of taxa occuring in both samples A and B; a is the number of taxa in sample A; and b is the number of taxa in sample B.

$C_m h_w$ index of similarity. The similarity statistics between protected and unprotected canopy were calculated for taxa and numbers of individuals (Morisita, 1959; Wolda, 1981).

$$da = \frac{\sum ani^2}{aN^2} \text{ and}$$

$$db = \frac{\sum bni^2}{bN^2} \text{ and}$$

Community turnover of taxa. On each date after the first sample, the estimates of succession rates in protected and unprotected faunas are expressed as a modification of Sorensen's index of similarity (Diamond, 1969).

$$\%\ To\ (t) = 100\ [(a + b) / (c + d - e)]$$

Where, a is the number of taxa in the 1st sample but not in sample t; b is the number of taxa in the sample t but not in 1st sample; c is the number of taxa present in the 1st sample; d is the number of taxa present in sample t; and e is the number of joint taxa occurring in both samples.

Rank abundance values. For studying the species dominance of coccinellids throughout the crop period, rank abundance values were worked out by taking the sum of individual species found throughout the crop period and ranks were given based on the dominance of coccinellid species.

Results

Occurrence of predatory coccinellids in different agro-ecosystems

A total of nine species of predatory coccinellids were found associated with 15 homopteran prey insects in cereals, pulses and vegetables (Table 1) during September 2004-January 2005. Maximum number of coccinellids was observed during the tillering, flowering, fruit setting and pod development stages of the crop.

Relative abundance of coccinellid

Rice. The total number of species collected was seven in Madurai and six in Alagarkovil. Species richness was more in Madurai recording 3.29 and less in Alagarkovil (3.11), while the species evenness and species diversity were more in Alagarkovil recording the values of 1.06 and 0.89, respectively as compared to Madurai (0.90 and 0.76) (Table 2).

Cowpea. Six species were recorded in both the localities. Alagarkovil showed higher species richness (2.74). The species evenness and diversity was also higher in Alagarkovil recording the values of 0.99 and 0.77, respectively and the overall measure of diversity of coccinellids was higher than Madurai with reduced species richness and unequal relative abundance (Table 2).

Blackgram. Five species were recorded in both the localities. Species richness was higher at Alagarkovil (2.45). However, there was more equitable representation of species in Madurai with higher species evenness and diversity (1.14 and 0.79) as compared to Alagarkovil (0.98 and 0.68) (Table 2).

Table 1. Diversity of predatory coccinellids and their associated prey in cereals, pulses and vegetables during September 2004-January 2005

Crop	Coccinellid species	Prey
Cereals		
Rice	*Brumoides suturalis* Mulsant	*Cofana spectra* (Dist.), *Sogatella furcifera* (Horv.), *Nephotettix nigropictus* (Stal.), *Nephotettix cincticeps* (Stal.), *Nephotettix virescens* (Dist.), *Nilaparvatha lugens* (Stal.)
	Coccinella transversalis Fabricius	*N. nigropictus, N. virescens, N. cincticeps, C. spectra, S. furcifera*
	Chilocorus nigrita *Fabricius*	N. lugens, N. nigropictus, N. virescens, N. cincticeps, C. spectra
	Menochilus sexmaculatus Fabricius	*S. furcifera, N. lugens, N. nigropictus, N. virescens, N.cincticeps*
	Micraspis sp.	S. furcifera, N. lugens, N. nigropictus, N. virescens, N. cincticeps, C. spectra,
	Propylea dissecta Mulsant	*N. nigropictus, N. virescens, N. cincticeps, N. lugens,*
	Propylea japonica Thunberg	
	Scymnus nubilus Mulsant, *Scymnus sp.*	
Maize	*C. transversalis, M. sexmaculatus*	*Melanaphis sacchari* (Cock.), *Rhopalosiphum maidis* (Fitch), *Pyrilla persusilla* (Wlk.)
	Scymnus coccivora Ayyar, *M. discolor*	*M. sacchari, R. maidis*
Sorghum	*B. suturalis, C. transversalis*	*R. maidis, M. sacchari*
	M. sexmaculatus, S. coccivora	
Pearl millet	*C. transversalis, M. sexmaculatus*	*R. maidis*
Pulses		
Cowpea	*B. suturalis C. transversalis*	*Aphis craccivora* (Koch), *Empoasca kerri* (Pruthi),
	M. sexmaculatus, M. Discolor	*Empoasca binotata* (Pruthi)
	C. ingrata	*E. kerri, E. binotata*
	S. castaneus, S. Coccivora	A. craccivora
Blackgram	*B. suturalis, C. Transversalis,*	*A. craccivora, E. kerri, E. binotata*
	M. sexmaculatus	
Redgram	*B. suturalis, C. transversalis,*	*A. craccivora*
	M. sexmaculatus, S. coccivora, S. nubilus	
Lablab	*B. suturalis, M. sexmaculatus, Scymnus sp.*	*A. craccivora, E. kerri, E. binotata*
Vegetables		
Tomato	*B. suturalis, C. transversalisC. nigrita*	*A. gossypii, Bemisia tabaci* (Genn.), *Myzus persicae* (Sulz.) *Ferrisia virgata* (Ckll.)
	M. sexmaculatus	*A. gossypii, F. virgata, B. tabaci, M. persicae,*
Chillies	*B. suturalis*	*A. gossypii, B. tabaci, F. virgata*
	C. transversalis	*A. gossypii, Amrasca biguttula biguttula* (Ishida), *B. tabaci, F. virgata*
	C. nigrita	A. biguttula biguttula, F. virgata
	M. sexmaculatus	A. biguttula biguttula, A. gossypii, B. tabaci
	Scymnus spp.	A. gossypii, B. tabaci
Bhendi	*B. suturalis*	*A. gossypii, B. tabaci, F. virgata*
	C. transversalis	A. gossypii, , A. biguttula biguttula, B. tabaci
	C. nigrita	A. biguttula biguttula, B. tabaci, F. virgata
	M. sexmaculatus	A. gossypii, A. biguttula biguttula, B. tabaci,
	Scymnus spp.	A. gossypii, B. tabaci
Bittergourd	*C. transversalis, M. sexmaculatus*	*A. gossypii, B. tabaci*
	Scymnus spp.	
Brinjal	*B. suturalis, C. nigrita*	*C. insolitus*
	M. sexmaculatus, C. transversalis	A. gossypii

Tomato. The number of species recorded was six and five at Madurai and Alagarkovil, respectively. Madurai showed more of species heterogeneity with richness (3.27) and more of species evenness and diversity as well showing the values of 1.23 and 0.96, respectively (Table 2).

Bhendi. The number of species recorded from Madurai and Alagarkovil were seven and six, respectively. However, both the communities showed similar values of relative abundance of coccinellid and showed homogeneity with comparatively higher diversity in Madurai recording the value of 0.79 as compared to 0.73

Table 2. Comparison of abundance, diversity and richness of coccinellids on crops during September–December 2004

Crop / location	No. of species (S)	Total no. of individuals in all species	Species evenness* (J)	Species diversity* (H)	Species richness*	Simpson's Index D*	1 – D*	1 / D *
Rice								
Madurai	7	66	0.90	0.76	3.29	0.26	0.74	3.84
Alagarkovil	6	87	1.06	0.89	3.11	0.29	0.75	3.44
Cowpea								
Madurai	6	98	0.97	0.75	2.51	0.21	0.79	4.75
Alagarkovil	6	66	0.99	0.77	2.74	0.21	0.79	4.73
Blackgram								
Madurai	5	72	1.14	0.79	2.15	0.25	0.75	3.94
Alagarkovil	5	43	0.98	0.68	2.44	0.21	0.79	4.78
Tomato								
Madurai	6	63	1.23	0.96	3.27	0.24	0.76	4.18
Alagarkovil	5	58	1.14	0.80	2.77	0.22	0.79	4.10
Bhendi								
Madurai	7	101	0.93	0.79	2.99	0.23	0.87	4.87
Alagarkovil	6	58	0.94	0.72	2.83	0.23	0.77	4.28
Chillies								
Madurai	5	65	0.96	0.67	2.21	0.226	0.77	4.43
Alagarkovil	5	43	0.93	0.64	2.44	0.22	0.75	3.93
Bitter gourd								
Madurai	4	52	1.09	0.65	1.75	0.20	0.80	4.90
Alagarkovil	4	34	0.99	0.60	1.99	0.25	0.75	3.97

* Values in the columns are indices

in Alagarkovil. Species richness and evenness values were 2.99 and 0.93, respectively in Madurai, while 2.84 and 0.94 in Alagarkovil (Table 2).

Chillies. Five species of coccinellils were recorded both at Madurai and Alagarkoil. However, Alagarkovil showed higher species richness (2.45) than at Madurai. The relative abundance of coccinellids was more in Madurai as measured by high species evenness and diversity (0.96 and 0.67) than Alagarkovil (0.93 and 0.64) (Table 2).

Bitter gourd. Only four species were recorded in both the localities. Alagarkovil showed higher species richness (1.99), while higher values of species evenness and diversity of 1.09 and 0.65, respectively, were recorded in Madurai showing more relative diversity of coccinellids (Table 2).

Simpson's diversity index. Simpson's diversity index revealed that the probability of two randomly selected individuals in a locality belonging to different species (1-D) was the highest for bhendi ecosystem in Madurai (0.87) as compared to chillies (0.77), cowpea (0.79) and bitter gourd (0.80), while rice (0.75), tomato (0.79) and black gram (0.79) had higher values of probability in Alagarkovil (Table 2).

Taxonomic similarity and community turn over of coccinellid species in weeded and partially weeded rice and cowpea ecosystems

The similarity values were expressed from zero (no similarity) to 1.00 (perfect similarity). Increased diversity showed less similarity values. Taxonomic similarity (Jaccard) index in rice ecosystem revealed that the coccinellids exhibited perfect similarity value of 1.00 in the 1st week of crop growth followed by 2nd and 12th week of crop with similarity value of 0.85 and 0.83, respectively (Table 3). Coccinellids registered less similarity values (greater diversity) of 0.40, 0.28 and 0.33 in the 5th, 6th and 7th week of crop growth, respectively. In cowpea ecosystem, the occurrence of coccinellid was absent in the 1st week and perfect similarity of coccinellid was recorded in the 3rd and 6th week of crop. Coccinellids showed less similarity indices ranging from 0.16, 0.20 and 0.16 in the 9th, 10th and 11th week of crop, respectively.

The Morisita index of taxonomic similarity indicated that coccinellids showed the perfect similarity value of 1.00 during the 1st week of crop in rice ecosystem (Table 3). Similarity values steadily decreased from 0.95 in 2nd week of crop to 0.33 in 8th week of crop growth. Coccinellids registered greater similarity of 0.95 and 0.98 in the 11th and 12th week of crop, respectively. In cowpea ecosystem, coccinellids exhibited perfect similarity in the 1st and 12th week of crop growth. The coccinellid registered less similarity value of 0.41, 0.65 in the 5th and 7th week of crop, respectively. Similarity values steadily increased from 0.65 to 1.00 from 7th to 12th week of the crop.

The rate of community turn over, in weeded

Table 3. Taxonomic similarity and community turn over of coccinellids in weeded and partially weeded ecosystems of rice and cowpea during December 2004-February 2005

Standard week	Crop week	Taxonomic similarity				Per cent community turn over of coccinellid			
		Jaccard Index		Morisita Index		Rice		Cowpea	
		Rice	Cowpea	Rice	Cowpea	Weeded	Partially weeded	Weeded	Partially weeded
49	1	1.00	0.00	1.00	1.00	-	-	-	-
50	2	0.85	0.50	0.95	0.83	33.34	50.00	50.00	50.00
51	3	0.66	1.00	0.91	0.78	33.34	75.00	50.00	50.00
52	4	0.50	0.75	0.66	0.71	50.00	83.34	66.66	60.00
1	5	0.40	0.60	0.64	0.41	60.00	85.71	66.66	83.33
2	6	0.28	1.00	0.56	0.78	66.66	85.71	83.33	83.33
3	7	0.33	0.80	0.43	0.65	75.00	87.50	83.33	83.33
4	8	0.50	0.52	0.33	0.89	80.00	85.71	83.33	83.33
5	9	0.66	0.16	0.64	0.86	80.00	87.50	33.33	60.00
6	10	0.50	0.20	0.80	0.96	80.00	80.00	50.00	85.71
7	11	0.66	0.16	0.95	0.90	75.00	85.70	50.00	85.71
8	12	0.83	0.50	0.98	1.00	75.00	83.33	66.66	60.00

rice ecosystem, after the first week of crop increased slowly over the growing season (Table 3). The community turnover of coccinellids was 33.34 per cent in the 1st and 2nd week of crop and the highest turn over of 80 per cent was recorded from 8th to 10th week of crop. There was a decline of turn over recording 75 per cent in 10th and 11th week of crop growth. In partially weeded rice ecosystem, the percent turn over of coccinellid in the 2nd week of crop was 50, which was higher than weeded ecosystem. The community turnover of coccinellids was maintained steadily thereafter (75-87.5 per cent) from 3rd to 9th week of crop and there was decline in the 10th week of crop. The data presented in the Table 3 also revealed that the community turn over of coccinellid ranged from 50 to 83.33 per cent from 2nd to 7th week of crop in both the ecosystems. There was decline (33.33 per cent) of turn over in the 9th week of crop in weeded cowpea ecosystem; whereas the partially weeded cowpea ecosystem had 60 per cent of turn over and increased thereafter.

Rank abundance values for coccinellids in weeded and partially weeded ecosystem

Rice. A total of seven taxa of coccinellids were recorded in weeded and partially weeded ecosystem (Table 4). Among them, *Micraspis discolor* was the dominant taxa in weeded ecosystem which had the maximum mean abundance of 0.43 followed by *Coccinella transversalis* (0.40) and *Brumoides suturalis* (0.36). In partially weeded rice ecosystem, *C. transversalis* showed maximum mean value of 0.57 followed by *M. discolor* and *B. suturalis* with a mean values of 0.50 and 0.49, respectively.

Cowpea. A total of six taxa of coccinellids were recorded in weeded and partially weeded cowpea ecosystem (Table 4). *Menochilus sexmaculatus* dominated with maximum mean abundance value of 0.53 and 0.86 in weeded and partially weeded ecosystems, respectively. This was followed by *C. transversalis* in both the ecosystems with mean abundance value of 0.31 and 0.75. *Scymnus coccivora* (0.16) ranked 3rd in weeded ecosystem, while *B. suturalis* (0.33) in the partially weeded ecosystem.

Table 4. Rank abundance values for coccinellids in weeded and partially weeded rice and cowpea ecosystems during December 2004-February 2005

Coccinellids	Rice				Cowpea			
	Weeded		Partially weeded		Weeded		Partially weeded	
	Mean population / week*	Rank**	Mean population / week*	Rank**	Mean population / week*	Rank**	Mean population / week*	Rank**
Brumoides suturalis	0.36	3	0.49	3	0.11	5	0.33	3
Coccinella transversalis	0.40	2	0.57	1	0.31	2	0.75	2
Menochilus sexmaculatus	0.08	5	0.43	5	0.53	1	0.86	1
Micraspis discolor	0.43	1	0.50	2	0.12	4	0.13	5
Propylea dissecta	0.11	4	0.44	4	-	-	-	-
Propylea japonica	0.06	6	0.17	7	-	-	-	-
Scymnus nubilus	0.08	5	0.24	6	-	-	-	-
Scymnus coccivora	-	-	-	-	0.16	3	0.30	4
Scymnus castaenus	-	-	-	-	0.02	6	0.08	6

Values of mean of 12 weeks; ** Numbers in the columns are rank abundance values

Temporal trends of coccinellids in weeded and partially weeded canopy

Rice. The data presented in Table 5 revealed that the temporal abundance of coccinellids was more in partially weeded plot when compared to weeded plots. At the initial stage of the crop, the number of taxa and individuals were low. Taxonomic richness of coccinellids increased during the growing season; particularly from the 5^{th} week of crop both in weeded and partially weeded plots. Abundance of coccinellids was high in 5^{th}, 6^{th} and 7^{th} week of crop growth in weeded (24-28), while in the 8^{th} and 9^{th} week of crop in the partially weeded (50 and 51) ecosystem. Abundance of coccinellids in weeded plot ranged between 18 and 28 during 5^{th} to 10^{th} week of crop with peak occurrence of coccinellids. In partially weeded plot coccinellid abundance was between 30 and 51 during 4^{th} to 11^{th} week of crop with peak activity.

Cowpea. Coccinellids dominated in partially weeded plots throughout the crop period (Table 5). In the initial stage of crop growth, the number of taxa and species abundance (individuals) was low and the abundance of coccinellids increased during the growing season. Peak occurrence of coccinellids was recorded from 7^{th} and 8th week of crop in weeded canopy with highest individuals in 8^{th} week of crop (20). The population of coccinellids in partially weeded canopy showed higher values in the 8^{th} week of crop (35) and peak occurrence of coccinellids was recorded during 7^{th} to 11^{th} week of crop ranging between 25 and 35.

Coccinellids guild in weeded and partially weeded canopy fauna

Rice. The guild of *M. discolor* was 31.42 per cent followed by *C. transversalis* (27.36) and *B. suturalis* (21.05) in weeded ecosystem and the other species of coccinellids recorded in weeded canopy provided less contribution (3.26-7.36 per cent). In partially weeded canopy, *C. transversalis* was the dominant guild (29.17 per cent) followed by *M. discolor* (26.22 per cent) and *B. suturalis* (21.18). Other species of coccinellids recorded in partially weeded ecosystem provided less contribution (6.14-7.20 per cent) in partially weeded plots when compared to weeded plots (Table 6).

Cowpea. The guild of *M. sexmaculata* and *C. transversalis* dominated in both the ecosystems. The guild of *M. sexmaculata* was high in both the ecosystems with values of 45.68 and 37.92 per cent in weeded and partially weeded canopy, respectively. This was followed by the domination of *C. transversalis* in both the ecosystems (30.16 and 26.15 per cent). The guild of *S. coccivora* provided certain contribution (10.34 and 13.38 per cent) in weeded and partially weeded ecosystem, respectively. *M. discolor* and *S. castaneus* exhibited poor contribution (4.15 and 3.85 per cent) in partially weeded plots however slightly better than in weeded condition (Table 6).

Discussion

Coccinellids are cosmopolitan in distribution and are found in abundance wherever the associated prey species were present. Both the adults and grubs are found feeding on wide variety of small insect pests infesting crops of economic value. The prey range included homopterans, to a greater extent, *viz*., aphids (Aphididae), whiteflies (Aleyrodidae), leafhoppers (Cicadellidae) and planthoppers (Delphacidae) (Agarwala *et al*., 1988; Omkar and Bind, 1993; 1998; Omkar and Srivastava, 1999). In this study, a total of nine species of predatory coccinellids were recorded from cereals, pulses and vegetable ecosystems in this study. Of these species, the most abundant coccinellids occurring in field and vegetable crops were; *C. transversalis, M. sexmaculatus, Brumoides suturalis* and *Chilocorus nigrita* while the abundance of *Micraspis discolor, S. coccivora*, *S. castaneus* and *Scymnus nubilus* were present low abundance. Few species of coccinellids were found to be crop specific. *Propylea dissecta* and *Propylea japonica* showed perfect specificity with rice crop (Tadashi Tahizawa *et al*., 2000) and *S. castaneus* and *S. nubilis* with cowpea.

Species diversity or biodiversity means the distribution and number of species in a given

Table 5. Temporal trends of coccinellids in weekly intervals in weeded and partially weeded rice and cowpea ecosystem

Coccinellid species	Crop	No. of coccinellids / week*																							
		Weeded												Partially weeded											
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Brumoides suturalis	Rice	0	2	3	2	4	3	3	2	1	2	0	0	0	0	1	4	8	11	10	13	8	8	6	5
	Cowpea	0	0	0	0	0	0	3	3	2	2	2	1	0	0	0	1	3	2	2	4	2	3	3	1
Coccinella transversalis	Rice	0	0	0	4	5	5	3	3	4	3	2	3	0	2	4	4	4	5	7	8	5	3	5	2
	Cowpea	0	0	3	2	2	2	3	3	2	0	1	0	0	3	5	7	5	3	3	4	2	1	0	1
Menochilus sexmaculatus	*Rice*	*0*	*0*	*3*	*3*	*3*	*5*	*4*	*2*	*6*	*7*	*2*	*1*	*0*	*2*	*3*	*6*	*7*	*10*	*8*	*0*	*12*	*17*	*6*	*4*
	Cowpea	0	0	1	2	5	6	7	9	5	3	2	4	0	0	1	1	2	5	9	15	18	14	12	9
Micraspis discolor	*Rice*	*0*	*2*	*4*	*3*	*5*	*8*	*7*	*8*	*5*	*6*	*5*	*5*	*0*	*3*	*4*	*6*	*5*	*8*	*9*	*10*	*14*	*9*	*4*	*7*
	Cowpea	0	0	1	2	5	6	7	9	5	3	2	4	0	0	1	1	2	5	9	15	18	14	12	9
Propylea dissecta	Rice	0	0	0	0	2	2	2	1	1	1	0	0	0	0	1	2	2	3	2	1	1	0	0	0
	Cowpea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Propylea japonica	Rice	0	0	0	1	1	3	2	1	1	1	0	0	0	0	0	0	1	2	1	2	2	0	1	1
	Cowpea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scymnus castaneus	*Rice*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cowpea	0	0	0	0	2	3	2	3	2	1	1	2	0	1	2	1	4	3	5	3	2	6	5	5
Scymnus coccivora	Rice	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Cowpea	0	0	0	1	3	1	2	2	1	1	1	0	0	0	0	0	2	5	4	8	5	7	5	4
Scymnus nubilus	Rice	0	0	0	0	2	2	3	1	1	2	2	1	0	0	3	4	8	11	10	8	9	6	7	4
	Cowpea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total No. coccinellids in rice		0	4	10	13	25	28	24	18	19	22	11	10	0	7	16	26	35	40	48	50	51	43	30	23
Total No. coccinellids in cowpea		0	0	0	1	3	1	2	2	1	1	1	0	0	0	0	0	2	5	4	8	5	7	5	4

area, habitat, or community under prevailing environmental conditions. It seeks to characterize the diversity in a locality with reference to other localities. Heterogeneity of taxa in a locality is measured by its richness and evenness in a locality. Species richness is the most popular approach to evaluate species diversity in a locality and to compare habitats or species assemblages with other locality having different weather conditions (Humphiries *et al*., 1996). In the present study, high coccinellid species richness was recorded in Madurai locality for crops *viz*., rice, tomato and bhendi and in Alagarkovil crops *viz*., chillies, cowpea, blackgram and bitter gourd. High species evenness was recorded in Madurai locality for crops *viz*., tomato, chillies, blackgram and bittergourd and in Alagarkovil for crops *viz*., rice, bhendi and cowpea.

Simpson's diversity index is a measure for both richness and proportion of each species in a locality. Thus, indicating the probability of two randomly selected individuals belonging to different taxa. The present study indicated the probability value (1-D) as high in Madurai for crops *viz*., bhendi, chillies, and cowpea while Alagarkovil crops *viz*., rice, tomato and blackgram. This is in accordance with the findings of Hayek (1994) that higher probability for two randomly selected individuals in a locality, for such crops, being less equitable and the selected individuals belong to different taxa. The higher index values for such crops in a locality was due to the vegetation found surrounding the field, which provided prey insects and other alternate resources.

Table 6. Coccinellid guild in weeded and partially weeded rice and cowpea ecosystems during December 2004 – February 2005

Coccinellid fauna	Mean percentage of coccinellids *			
	Rice		Cowpea	
	Weeded	Partially weeded	Weeded	Partially weeded
Brumoides suturalis	21.05 ± 0.21	21.18 ± 0.30	8.64 ± 0.08	14.38 ± 0.14
Coccinella transversalis	27.36 ± 0.21	29.17 ± 0.22	30.16 ± 0.15	26.15 ± 0.32
Menochilus sexmaculatus	5.26 ± 0.10	7.20 ± 0.19	45.68 ± 0.48	37.92 ± 0.42
Micraspis discolor	31.42 ± 0.16	26.22 ± 0.20	3.78 ± 0.00	4.15 ± 0.10
Propylea dissecta	7.36 ± 0.17	5.77 ± 0.11	-	-
Propylea japonica	4.21 ± 0.14	4.26 ± 0.15	-	-
Scymnus castaneus	-	-	1.40 ± 0.00	3.85 ± 0.10
Scymnus coccivora	-	-	10.34 ± 0.16	13.38 ± 0.26
Scymnus nubilus	3.26 ± 0.10	6.14 ± 0.16	-	-

* Values in the columns are mean percentage of 20 sweeps

Taxonomic similarity for the coccinellids in weeded and partially weeded rice and cowpea ecosystems were adjudged by Jaccard index and Morisita index in this study. In rice ecosystem, the coccinellids exhibited greater diversity at tillering and panicle initiation stages of the crop. The reason was due to the presence of host insects like brown planthopper, green leafhopper and other homopteran-sucking pests during tillering stage and also due to the availability of pollen and nectar during flowering stage. This statement is in consonance with the view of Southwood (1961) who stated that resource concentration hypothesis predicts plant resource to support the herbivore abundance and resulting in higher density of natural enemies. Also, in the present study, the coccinellids showed perfect similarity in the initial and maturity stage of rice crop, which was possibly due to the presence of common species of coccinellids (*C. transversalis* and *M. discolor*) in both the ecosystems. This is supported by the view of Pimental (1961) that plant associations supposedly supply more favourable conditions for predators reducing the possibility that they will become extinct. Afun *et al*. (1999) stated that different groups of predators may obtain resources from weeds in the cropped area. In cowpea ecosystem, coccinellids were absent in the first week; this may be attributed to the absence of prey insects during first week of the crop. During successional stage of the crop coccinellids showed less similarity. This is supported with the fact that soybean crop during growth stage had low abundance of host insects of aphids and hoppers and alternative resources such as pollen and nectar and hence the diversity of coccinellid was low (Lawton, 1983). During flowering stage of the crop the diversity of coccinellids was found to be more when the main crop and weed plants provided more pollen and nectar for the survival of coccinellid. This is in conformity with the observations of Kandibane (2003) that the plant resource could support the herbivore abundance and their predator density. Another possibility is the availability of adult food in the form of pollen and nectar from the crop and weed hosts (Henricke *et al*., 1992; Kandibane *et al*., 2005).

Community turn over in rice ecosystem was less in weeded ecosystem than in partially weeded ecosystem in first and second week of the crop growth. The reason was due the availability of prey insects and alternate food resources from weeds in the partially weeded ecosystem. Coccinellid species colonies increase with successional growth stage of the crop. This was in conformity with studies conducted by Heong *et al*. (1991). Also, in this study, the rate of turn over increased steadily from 35 days after transplanting in both the ecosystems but at a higher rate in the partially weeded plots. Lawton (1983) stated that weed free ecosystem had its coccinellid turn over after a long period of establishment. There was a decline of coccinellid turn over in both the ecosystems. The reason may be attributed due to the absence of colonization by a new species at this stage of the crop (Myster and Rickett, 1994). In cowpea ecosystem also a similar trend of coccinellid turn over was observed. A decline of turn over was noticed in weeded cowpea ecosystem due to absence of colonization by new coccinellid species. The coccinellid had steady turn over in partially weeded ecosystem. The reason is supported by the view of Ohgushi (1992) and Kandibane (2003) who stated that the diversified ecosystem has continuous availability of resources like pollen and nectar from weed plants and cowpea plants which contributed in maintaining the turn over of coccinellids.

Rank abundance values revealed that higher individuals of coccinellid species were found in partially weeded plots than weeded plots. Common taxa of coccinellid were more persistent and abundant in all sampling dates due to availability of alternate resources. In rice ecosystem, the common species like *C. transversalis*, *M. discolor* and *B. suturalis* showed higher abundance in both the ecosystems. Schoenly *et al*. (1998) reported that common taxa of predators were persistent and abundant due to locally availabile food resources. *M. discolor* dominated the weeded rice canopy, while the *C. transversalis* in partially weeded rice canopy, and these species preferred prevailing food resources and also microclimates in the existing canopy for their survival. These studies were in consonance with the earlier reports of Schoenly *et al*. (1996). Rare species like *P. dissecta*, *P. japonica*, *M. sexmaculata* and *S. nubilus* had less contribution in the predator fauna. In cowpea ecosystem, *M. sexmaculatus* and *C. transversalis* showed higher abundance in partially weeded plots, followed by *B. suturalis* and *S. coccivora*. The number of predatory coccinellids on weed hosts was higher possibly due to the availability of alternate resources like pollen, nectar and honeydew. Andow (1988) indicated that the presence of weeds might actually increase predator populations by providing food or other resources. In weeded ecosystem, the abundance of *M. sexmaculata* and *C. transversalis* was also greater but with less abundance values as compared to partially weeded cowpea ecosystem. The coccinellid species like *B. suturalis*, *S. coccivora*, *S. castaneus* and *M. discolor* contributed to lesser extent. This is in view of Odum (1971) who stated that the common species with larger number of individuals associated with many rare species with few individuals is a characteristic feature of community structure.

Temporal trends of coccinellid predators showed increased abundance in the middle and later stages of crop growth, their abundance at this stage may be due to the simultaneous presence of herbivores as suggested by Heinrichs (1979). Abundance and diversity of coccinellids was found to be higher in partially weeded condition in both the rice and cowpea ecosystems. The resource abundance hypothesis predicts that plants, which offer more resources, have the potential to support more species and greater abundances of insect predators (Hunter and Wilmer, 1989). In this study, diversity of coccinellids was greater in partially weeded plots due to diversified plant species, which is in conformity with plant size hypothesis. It can be surmised that the population of natural enemies was more in partially weeded plots where the herbivores were found to be high at initial stages. Later there was a reduction in herbivore population due to their consumption by presence of large number of natural enemies in partially weeded plots. After the depletion of prey insects the natural enemies were tended to move towards the weeded plots. Hence, natural control can be achieved without much use of insecticides and it is suggested to have some weed population on the bunds or in the main fileds (say 10 weeds per sq. m area), which will not affect the yield of crop.

Predatory coccinellids dominated in partially weeded plots than weeded plots from the first week to the last week of sampling in this study. In rice ecosystem, *M. discolor* was the dominant guild in weeded condition, which had different species of sucking insects throughout the season. This is in conformity with the report of Heong *et al*. (1991), who stated that common species mostly prefer protected ecosystem for their establishment. *C. transversalis* preferred diversified ecosystem and contributed more abundance. This was due to the availability of favourable (required) environmental condition (Schoenly *et al*., 1998). In cowpea ecosystem, *M. sexmaculata* and *C. transversalis* exhibited a strong guild in both the ecosystem. The remaining species (*B. suturalis*, *M. discolor*, *S. coccivora* and *S. castaneus*) contributed comparatively more percentage in partially weeded plots than weeded. The rare species preferred diversified ecosystem for their survival, reproduction and establishment, possibly due to the presence of alternate weed hosts (Bentur *et al*., 1985).

In conclusion, *Coccinella transversalis, Menochilus sexmaculata* and *Brumoides suturalis* were the common coccinellid species found in cereals, pulses and vegetable crops. The diversity of coccinellids was found to be greater in partially weeded plots than in weeded plots, both in rice and cowpea ecosystems, particularly during the successional stage of crop growth and recorded less diversity during early vegetative stage and also before harvesting. This study suggests that partially weeded rice or cowpea ecosystem could be a better choice for conserving the coccinellid fauna instead of complete weeding, which would play a vital role in the natural suppression of insect pests.

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