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Research Article

Sequential sampling plan for rice planthoppers with incorporation of predator effect

S. RAJNA and SUBHASH CHANDER

Division of Entomology, Indian Agricultural Research Institute, New Delhi 110 012

Corresponding author E-mail: schander@iari.res.in

ABSTRACT: Spatial distribution of rice planthoppers, *Nilaparvata lugens* (Stal) and *Sogatella furcifera* (Horvath) together, and their predators, spiders and mirid bugs was studied on Pusa 1121 rice during rainy season 2010 through Taylor's power law and Iwao's mean crowding regression. Planthoppers as well as their predators followed aggregated distribution in the field. Sequential sampling plans based on Taylor's distribution parameters (a = 0.398, b = 1.614) and economic injury level (10 hoppers/hill) were formulated for rice planthoppers with and without consideration to predation by spiders and mirid bugs. During pre-flowering, sequential plans suggested need for control when two rice hills harboured cumulative planthopper population of 36 hoppers with predators and 27 hoppers without predators. Likewise, during post-flowering phase, control was required if two rice hills had cumulative population of 51 hoppers with predators compared to 27 hoppers without predators. Sequential sampling plans with predator effect thus suggested need for management measures at higher planthopper population. This would be helpful in avoiding unwarranted pesticide application thereby ensuring natural enemy conservation and favourable benefit- cost to farmers.

KEY WORDS: Mirid bugs, planthopper, predator, rice, sequential sampling, spider

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INTRODUCTION

In India, rice is grown on an area of 43.8 million hectares in different agro-climatic regions with a production of 104.32 million tonnes during 2010-2011 (Anonymous, 2012). Insect-pest complex of rice has undergone drastic changes during the last three decades following the green revolution (Chander and Singh, 2003; Mishra and Jena, 2007). Major pests of rice in India are planthoppers, *Nilaparvata lugens* (Stal) and *Sogatella furcifera* (Horvath); stem borer, *Scirpophaga incertulas* (Walker) and leaf folder, *Cnaphalocrocis medinalis* (Guenee). Among the planthopper species found in India, the brown plan-thopper (BPH), *N. lugens* and white backed planthopper (WBPH), *S. furcifera* are the most important (Krishnaiah *et al.*, 2008). Srivastava *et al*. (2009) reported a rapid multiplication and widespread outbreak of brown planthoppers in northern India in 2008 that resulted in heavy yield loss.

With a view to have scientific understanding of the spatio-temporal changes in pest populations, it is necessary to assess pest population in diverse habitats and relate it to abiotic and biotic factors (Southwood and Henderson, 2000). An efficient sampling plan is indispensible to facilitate appropriate pest management decisions. Reliable estimates of pest population can be ensured through unbiased sampling. However, a balance need to be struck between sampling accuracy and cost involved. Commonly used sampling procedures *viz.*, random sampling, stratified sampling and systematic sampling are labour and time intensive (Southwood, 1978). Sequential sampling is one of the most useful methods having been adopted to estimate insect population for quicker management decisions (Krishnaiah *et al.*, 1987). Compared to other sampling techniques, the savings in time and labour usually exceeds 50% with this technique (Kao, 1984; Chander, 1997; Wilson *et al.*, 1989; Parajulee *et al.*, 2006). Sequential sampling plans have been developed for many insect pests including planthoppers (Shepard *et al.*, 1986; Krishnaiah *et al.*, 1987). However, influence of predators on pest population has been ignored in most of the sampling programmes, leading to unwarranted pesticide application. Shepard *et al.* (1988) developed a sequential sampling plan for rice planthoppers by accounting for predator effect, but much has not happened in this area after that. Present study was thus undertaken to develop sequential sampling plan for rice planthoppers with incorporation of predators' effect.

MATERIALS AND METHODS

Present study was undertaken at the Indian Agricultural Research institute, New Delhi (28°362 363N 77°132 483E) during rainy season 2010 with Pusa Basmati 1 rice. One-month old rice seedlings were transplanted on August, 2010 in each of 20 plots of 4 x 2.5 m, with row and plant spacing of 20 x 15 cm, respectively. Crop was raised in accordance with recommended agronomic practices but without any insecticide application. Weekly observations on cumulative counts of nymphs and adults of planthoppers *viz*., *Nilaparvata lugens* and *Sogatella furcifera* on five randomly selected hills in each plot were initiated at 30 days after transplanting (DAT) and continued until crop maturity. Populations of different spider species and mirid bug were also recorded simultaneously.

Regression models *viz*., Taylor's power law (Taylor, 1961) and Iwao's mean crowding regression (Iwao, 1968) were used to analyze spatial distribution pattern of species during the crop season. Taylor's power law related population variance (S^2) to mean density (X) as:

$$S^2 = a\ x^{\ b}$$

where 'a' is the sampling parameter and 'b' is the aggregation parameter. Values of b=1 indicated a random, b = 1, a regular and b<1, an aggregated distribution.

Iwao's patchiness model related mean crowding (X*) to mean density as:

$$X^* = \acute{a} + \hat{a}\ X$$

where 'á' is the index of basic contagion and 'â' is the density contagiousness coefficient. The values of â = 1 represent random, â < 1, regular and â > 1, aggregated distribution.

The formulation of sequential sampling plan requires information on spatial distribution pattern and economic injury level of the pest on the crop (Kao, 1984; Chander and Singh, 2001).

Sequential sampling plan for planthopper was devised using Taylor's power law according to Ekborm (1985)

$$d = nm_o \pm t\ (\sqrt{n\ a\ m_o^{\ b}})$$

such that, $d_1 = nm_o + t$ ("n $am_o^{\ b}$) and $d_0 = nm_o - t$ ($\sqrt{n\ a\ m_o^{\ b}}$), represented the upper and lower decision lines of sequential sampling, respectively.

d_0= Lower limit of the confidence interval for the cumulative number of planthoppers

d_1 = Upper limit of the confidence interval for the cumulative number of planthoppers

n = Number of sample units observed

m_0 = Economic injury level of planthoppers

t = Student's't' test at 20 per cent probability level

a = Sampling parameter of Taylor's power law

b = Aggregation parameter of Taylor's power law

Economic injury level (EIL) of rice planthoppers was used as 10 hoppers/hill (Yadav and Chander, 2010), while values of 'a' and 'b' were obtained by fitting Taylor's power law to planthopper mean density and variance data. The maximum number of samples that would be required if the cumulative number of planthoppers remained between the upper and lower limits was expressed as:

$$n_{max} = t^2/p^2\ a\ m_o^{\ b}$$

where p = 't.Sx' (t = value of normal deviate and Sx = S.E. of the mean). The SE of 25% of the mean was deemed as acceptable (Southwood and Henderson, 2000) and at 20% probability level, the value of 't' used was 1.28.

For incorporating natural enemy effect, the equation of sequential sampling was modified as

$$d = n\ (m_o + P_e) \pm t\ \sqrt{\ }\ [a\ (m_o + P_e)^{\ b}]$$

P_e refers to predator effect, which in turn depended upon predator density (P_d) and its feeding rate (P_{fr}), such that $P_e = P_d \times P_{fr}$. The P_d was estimated through field studies, while P_{fr} value was taken as five hoppers/predator according to Shepard *et al*. (1988).

Sequential sampling plans were formulated for pre-flowering (30-58 DAT) and post-flowering stage (65-86 DAT) of the crop. Mean pooled population of spiders and mirid bug during these stages was incorporated into decision lines of sequential sampling. Sequential sampling plan for rice planthoppers was tested with field incidence during *kharif* 2012.

RESULTS AND DISCUSSION

Planthoppers, *Nilaparvata lugens* and *Sogatella furcifera* were observed on rice crop during the entire season, while major predators of planthoppers were nine species of spiders and one species of mirid bug. The spider species included *Lycosa pseudoannulata* Boes and Stand, *Oxyopes javanus* Thorell, *O. lineatipes* (C. L. Koch), *Tetragnatha javana* (Thorell), *Phidippus* spp., *Araneus inustus* (C.L. Koch), *Neoscona theisi* Walckenaer, *Thomisus* spp.and *Leucauge* sp., while mirid bug species was *Cyrtorhinus lividipennis* Reuter.

The mean planthopper population varied from 4.6 to 33.2 hoppers/ hill during the crop season with population peak having been recorded at 72 DAT (Table 1). Planthopper population variance increased with increase in its density with the highest variance having been recorded at the highest density.

Taylor's power law equation was:

$$\log S^2 = 1.614 \log X - 0.004 \ (R^2 = 0.91)$$

In $S^2 = a X^b$ form, this could be expressed as $S^2 = 0.398\ X^{1.613}$. Aggregation parameter (b = 1.614) revealed the aggregated distribution of planthoppers on the crop (Table 2).

Iwao's mean crowding and mean density relationship was:

$$X^* = 1.113\ X + 0.229 \ (R^2 = 0.95)$$

Density contagiousness coefficient (â = 1.113) depicted aggregated distribution of planthoppers (Table 2). The positive value of the index of basic contagion (á) revealed an attractive tendency among the individuals and also indicated that the basic component of distribution was a group of planthoppers and not a single one.

The regression models revealed the most dominant type of distribution behaviour based on population counts of the entire season. Although at commencement of incidence, planthopper alates were scattered in the field, on multiplication colony formation took place and the population became aggregated. Earlier field distribution of rice planthoppers was found to be aggregated through of Taylor's power law (Kusmayadi *et al.*, 1990; Reddy *et al.*, 1993).

Table 1. Variance-mean (S^2/X) for rice planthoppers and their predators, spiders and mirid bug

Crop stage (DAT)*	Planthoppers			Spiders			Mirid bug		
	Mean (X)	Variance (S^2)	S^2/X	X	S^2	S^2/X	X	S^2	S^2/X
30	4.6	3.93	0.86	0.62	0.86	1.38	0	0	0
37	6.9	12.18	1.77	0.64	0.96	1.5	0	0	0
44	14.7	25.51	1.74	0.91	1.32	1.44	0	0	0
51	7.5	13.36	1.79	0.99	1.79	1.81	0.15	0.39	1.21
58	8.5	14.37	1.69	1.3	1.34	1.03	0.61	1.51	1.56
65	8.7	19.87	2.28	1.39	6.08	4.37	1.54	2.41	1.34
72	33.2	112.23	3.38	1.13	1.27	1.12	3.25	3.97	1.17
79	11.5	15.26	1.33	1.5	1.50	1.00	24.48	79.20	3.15
86	5.8	4.13	0.712	1.04	1.23	1.18	11.41	19.72	1.67

*DAT – Days after Transplanting

Table 2. Parameters of Taylor's power law and Iwao's mean crowding regression for planthoppers and predators

Pest/ Predator	No. of samples	Taylor's power law			Iwao's mean crowding regression		
		Sampling parameter (a)	Aggregation Parameter (b)	Coefficient of determination (R^2)	Index of basic contagion (á)	Density contagiousness coefficient (â)	Coefficient of determination (R^2)
Planthoppers	9	0.398 (t = –2.03, p = 0.08)	1.614 (t = 8.18, p < 0.0001)	0.91	1.694 (t = 0.17, p = 0.87)	1.113 (t = 11.58, p < 0.0001)	0.95
Spiders	9	0.902 (t = –0.18, p = 0.87)	1.473 (t = 1.83, p = 0.11)	0.32	–0.234 (t = 0.17, p = 0.87)	1.837 (t = 1.70, p = 0.19)	0.24
Mirid bug	6	1.115 (t = 0.64, p = 0.56)	1.239 (t = 13.33, p = 0.0002)	0.98 (t = 2.26, p = 0.09)	0.86 (t = 30.48, p < 0.0001)	1.041	0.99

Taylor's power law for pooled population of nine spider species was found to be

$$\log S^2 = 1.473\ X - 0.044 \quad (R^2 = 0.32)$$

Likewise, Iwao's mean crowding regression was

$$X^* = 1.837\ X - 0.235\ (R^2 = 0.24)$$

Low R^2 values indicated that spider population mean and variance data did not fit well to Taylor' power law and Iwao's mean crowding regression (Table 2). However, the variance- mean ratio of spider population to be > 1.0 in all the samples indicated aggregated distribution (Table 1).

Taylor's power law equation for mirid bug was:

$$\log S^2 = 1.239\ X + 0.047\ (R^2 = 0.98)$$

In $S^2 = a\ X^b$ form, this was expressed as $S^2 = 1.115\ X^{1.239}$. The bugs followed aggregated distribution ($b = 1.239$) on the crop (Table 2).

Iwao's regression equation for mirid bug was:

$$X^* = 1.041\ X + 0.86\ (R^2 = 0.99)$$

The value of the density contagiousness coefficient, ($\hat{a} = 1.041$) revealed aggregated distribution of the predator population (Table 2). Positive value of index of basic contagion ($\acute{a} = 0.86$) indicated an attractive tendency among mirid bugs and suggested that the basic component of spatial distribution was a group of mirid bugs and not a single individual.

Information on the spatial distribution of predators along with the pest population could be useful to develop IPM strategies for the pest species. Studies on spatial distribution of pest and predators have been undertaken by many workers (Kamal *et al*., 1995; Wang *et al*., 2004). In present investigation through Taylor's power law and Iwao's regression did not provide good fit to spider population data, but they pointed towards its aggregative behaviour, which was also indicated by variance – mean ratio (Table 2). On the other hand, mirid bug distribution was revealed to be aggregated by both the regression models. As spiders and mirid bug, *Cyrtorhinus lividipennis* are important predators of planthoppers (Ooi and Shepard, 1994; Sigsgaard, 2000; Zhong-Xian *et al*., 2006), their aggregation in response to planthopper aggregation is logical. Present study showed that pest distribution pattern influenced distribution of their predators like Tomanovic *et al*. (2008) observed aggregated distribution of cereal aphids and their parasitic wasp.

Based on the Taylor's power law spatial distribution parameters *viz.* aggregation parameter ($b = 1.614$) and sampling parameter ($a = 0.398$), economic injury level (EIL) as 10 planthoppers / hill, and tolerable error in decisions as 20% ($t = 1.28$), the decision lines of sequential sampling for planthoppers without predator effect were determined to be:

$$d = 10n \pm 5.174\ \sqrt{n}$$

Lower decision line : $d_0 = 10n - 5.174\ \sqrt{n}$

Upper decision line : $d_1 = 10n + 5.174\ \sqrt{n}$

Corresponding to two sample units *i.e.* two hills in the field, lower and upper decision lines showed cumulative planthopper population of 13 and 27 hoppers, respectively (Table 3; Fig. 1A). These lines would be executed in the following manner. After observing

Table 3. Sequential sampling plan for treatment decisions against planthopper population with and without predator effect

Number of Sample (n)	Lower decision line $d_1 = 10n - 5.174\ \sqrt{n}$	Upper decision line $d_0 = 10n + 5.174\ \sqrt{n}$	Lower decision line $d_1 = 13.2n - 6.473\ \sqrt{n}$	Upper decision line $d_0 = 13.2n + 6.473\ \sqrt{n}$	Lower decision $d_1 = 19.15n - 8.74\ \sqrt{n}$	Upper decision $d_0 = 19.15n - 8.74\ \sqrt{n}$
	Without predator effect		With predator effect – pre-flowering		With predator effect – post flowering	
1	5	15	7	20	10	28
2	13	27	17	36	26	51
3	21	39	28	51	42	72
4	30	50	40	66	59	94
5	38	62	52	81	76	115
6	47	73	63	95	94	136
7	56	84	75	110	111	157
8	65	95	87	124	129	117
9	75	106	99	138	146	199
10	84	116	112	153	164	219

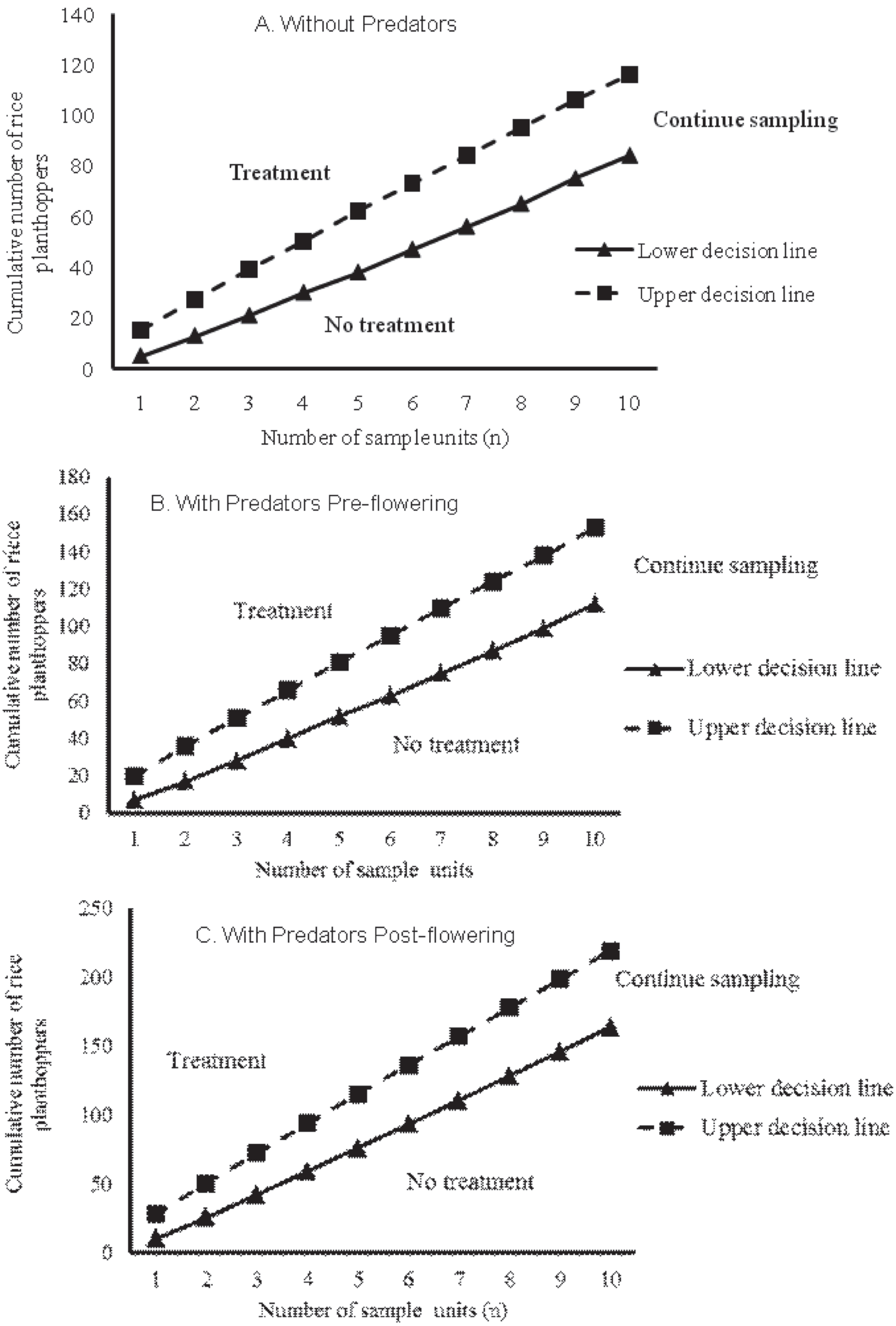

Fig. 1. Sequential sampling plan for planthoppers (A) without predators, (B) with predators during pre-flowering crop phase and (C) with predators during post-flowering crop phase

two rice hills, cumulative pest population below 13 and above 27 would indicate decision not to spray and to spray, respectively, but population level between 13-27 would demand observation on third sampling unit. Maximum of three sample units needed to be observed in case of indecisiveness. If decision would not be reached even after 3 sample units, sampling would be then suspended and resumed after 4-5 days interval.

During pre-flowering period, with predator density to be 0.64 predator /hill and feeding rate as 5 hoppers/ day/ predator, the sequential decision lines were:

$$d = 13.2n \pm 6.473\sqrt{n}$$

Lower decision line – $d_0 = 13.2n - 6.473\sqrt{n}$

Upper decision line – $d_1 = 13.2n + 6.473\sqrt{n}$

After inspecting two sample units in the field, lower and upper decision lines depicted cumulative planthopper population to be 17 and 36, respectively (Table 3; Fig. 1B).

During post-flowering stage, the predator density was higher (1.8 predators/ hill) than pre-flowering stage and based on their feeding rate as 5 hoppers/ day/ predator, the sequential decision lines were derived as:

$$- d = 19.15n \pm 8.74\sqrt{n}$$

Lower decision line – $d_0 = 19.15n - 8.74\sqrt{n}$

Upper decision line – $d_1 = 19.15n + 8.74\sqrt{n}$

Corresponding to two sample units, lower and upper decision lines had cumulative planthopper population of 25 and 51, respectively (Table 3; Fig. 1C).

Comparison of sequential sampling lines with and without predators' effect (Table 3) during pre-flowering crop phase revealed that after two sample units, control was needed at cumulative planthopper population of 36 and 27 hoppers with and without consideration to predators, respectively. Likewise, during post-flowering phase, control was required when two sample units had cumulative planthopper population of 51 with predators compared to 27 hoppers without predators. As predators' population increased, level of planthopper population that required control also increased. Sequential sampling plans with predator effect suggested need for management measures at higher population levels thus helping to defer pesticide application.

Data on testing of sequential sampling plan of rice planthoppers during *kharif* 2012 are presented in Table 4. Cumulative planthopper counts 65 and 80 DAT on different sample units were lower than the corresponding counts under upper decision line in Table 3, indicating that pesticide application was not warranted. However, pesticide application was made on one set of plots to compare yield in untreated and treated crop. The yield in treated and untreated crop under prevalent planthopper population levels did not differ significantly, which was logical because planthopper populations were below ETL level. The sequential

Table 4. Testing of sequential sampling plan for rice planthoppers during *kharif* 2012

No. of sample (n)	Cumulative population			
	65 DAT*		80 DAT	
	Planthoppers	Predators	Planthoppers	Predators
1	8	0	4	2
2	10	0	12	4
3	10	1	17	4
4	16	2	20	4
5	24	3	24	5
6	24	3	29	7
7	27	4	36	7
8	31	6	36	7
9	33	8	41	8
10	36	9	53	9

*DAT= Days after transplanting

sampling plan will again be tested under high planthopper incidence to ascertain role of predators in deferring pesticide application.

Effect of predators was accounted for separately during the pre-flowering and post-flowering crop growth stages because pest as well as predator populations differed during the two crop stages. During pre-flowering, planthopper population ranged between 4.6-14.9 hoppers/hill with mean pooled density of spiders and mirid bug being 0.64 predator/hill, though spiders dominated over mirid bug. During post-flowering period, planthopper population was higher (5.8 – 33.2 hoppers/hill) than pre-flowering stage with mean pooled predator density being 1.8 predators/hill. In present study, spiders and mirid bug exhibited some sort of planthopper population regulation.

Predator population usually builds up following the pest population and there exists a correlation between pest and the predator abundance (Gangurde, 2007). Sequential sampling plans have been developed for many insect pests including planthoppers (Shepard *et al*., 1986; Krishnaiah *et al*., 1987). Shepard *et al*. (1988) developed a sequential sampling plan for planthoppers with incorporation of natural enemy effect.

Sequential sampling plan with predator effect would help in avoiding unwarranted pesticide application, thereby facilitating conservation of natural enemies. This would also help in averting environmental contamination and cost of cultivation, thus increasing benefit-cost ratio to the farmers.

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