Evaluating augmentative releases of the mirid bug *Cyrtorhinus lividipennis* to suppress brown planthopper *Nilaparvata lugens* in open paddy fields

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Augmentative releases of natural enemies are a widely used method of controlling many pests, mainly in greenhouse vegetables (Van Driesche and Bellows 1996). In open rice fields, however, few attempts have been made to manage insect pests by releasing natural enemies. The mirid bug *Cyrtorhinus lividipennis* Reuter is the egg predator of the brown planthopper *Nilaparvata lugens* (Stål) and the whitebacked planthopper *Sogatella furcifera* (Horváth), the two major pests of rice throughout Asia (Chiu 1979). Although the potential growth rate of *C. lividipennis* is very high (Suzuki and Tanaka 1996, Matsumura and Suzuki 1999), the initial population density of *C. lividipennis* in Japan is usually low (Teramoto et al 1996). This is because *C. lividipennis* is not able to overwinter successfully in Japan, and colonization occurs annually following long-distance migration from southern China. Thus, we evaluated the effectiveness of augmentative releases of *C. lividipennis* to suppress *N. lugens* in open paddy fields.

Materials and methods

Mass rearing of *C. lividipennis*

As no mass-rearing technique for *C. lividipennis* using an artificial diet has been established, we developed a simple method for mass rearing of *C. lividipennis* on rice seedlings using *N. lugens* eggs as food. To calculate the reproductive efficiency of *C. lividipennis*, 25 or 50 pairs of adult *C. lividipennis* were introduced into plastic cages (30 × 25 × 28 cm) containing 5–6-day-old rice seedlings infested with 50 gravid females of *N. lugens*. After 2 weeks, new rice seedlings were introduced into the plastic cages and the old rice seedlings were removed after all the insects had moved to the new ones. Thereafter, the rice seedlings were renewed at 7-day intervals. After 5 weeks, the number of adult offspring was counted. The experiments were conducted in the laboratory at a temperature of 25 ± 1 °C and a photoperiod of 16L:8D.

Augmentative release experiment

In 1999-2001, *C. lividipennis* adults (1-week-old adults produced in the laboratory) were augmentatively released at predator:prey (*C. lividipennis* adult:*N. lugens* adult) ratios of 0:1 (nonrelease control), 1:1, and 1:2 (only in 1999) into replicated experimental blocks (7 × 7 m) in open paddy fields. The release was done at the start of the immigrant generation of *N. lugens* (early July). Because the density of *N. lugens* immigrants was quite low in those three years, *N. lugens* adults were also released at a rate of 0.2 individual per hill prior to the release of *C. lividipennis*. In 2001, the effect of an additional release of *C. lividipennis* at the start of the second generation (early August) was also evaluated.

A routine population census for the two planthoppers (released *N. lugens* and naturally-occurring *S. furcifera*) and *C. lividipennis* was conducted using a FARMCOP suction sampler (Cariño et al 1979). A plastic cylinder (30 cm in diameter and 70 cm in height) was used to cover a rice hill. All arthropods inside the cylinder were collected with the sampler, stored in 70% alcohol, and counted in the laboratory under a binocular microscope. The number of rice plants sampled was 15 per experimental block per sampling date. Censuses were made at intervals of 5–10 days from late July to late September (in 1999) or early October (in 2000 and 2001).

Generation boundaries and mean population density of the two planthoppers and *C. lividipennis* for each successive generation were calculated based on Kuno's (1968) method. All analyses were conducted using a 3-year data set of mean population densities. The effect of the natural enemy release on population dynamics of *N. lugens* was determined by Yamamura's (1999) key-factor/key-stage analysis. All statistical analyses were performed with the JMP version 5 Statistical Package.

Results and discussion

Mass rearing of *C. lividipennis*

Five weeks after the introduction of *C. lividipennis* adults into the plastic cage, 286.8 ± 15.7 and 436.4 ± 30.3 individual adult offspring were obtained from 25 and 50 *C. lividipennis* adults, respectively. The population growth rate of *C. lividipennis* was 5.7 and 4.4 per generation for the 25- and 50-adult treatments, respectively.

The present method of mass rearing of *C. lividipennis* is high enough for stock maintenance and use in release experiments. For practical and commercial uses of *C. lividipennis* as a biological control agent, however, there is a need to establish a mass-rearing technique using an artificial diet.

Augmentative release experiment

The population density of the first-generation *N. lugens* (late July to early August) was significantly suppressed when *C. lividipennis* was released at predator:prey ratios of 1:1 (high-ratio release) (ANOVA, $F = 8.38$, $P<0.05$) (Fig. 1). Yamamura's (1999) key-factor/key-stage analysis revealed that the effect of the natural enemy release at the start of the first generation

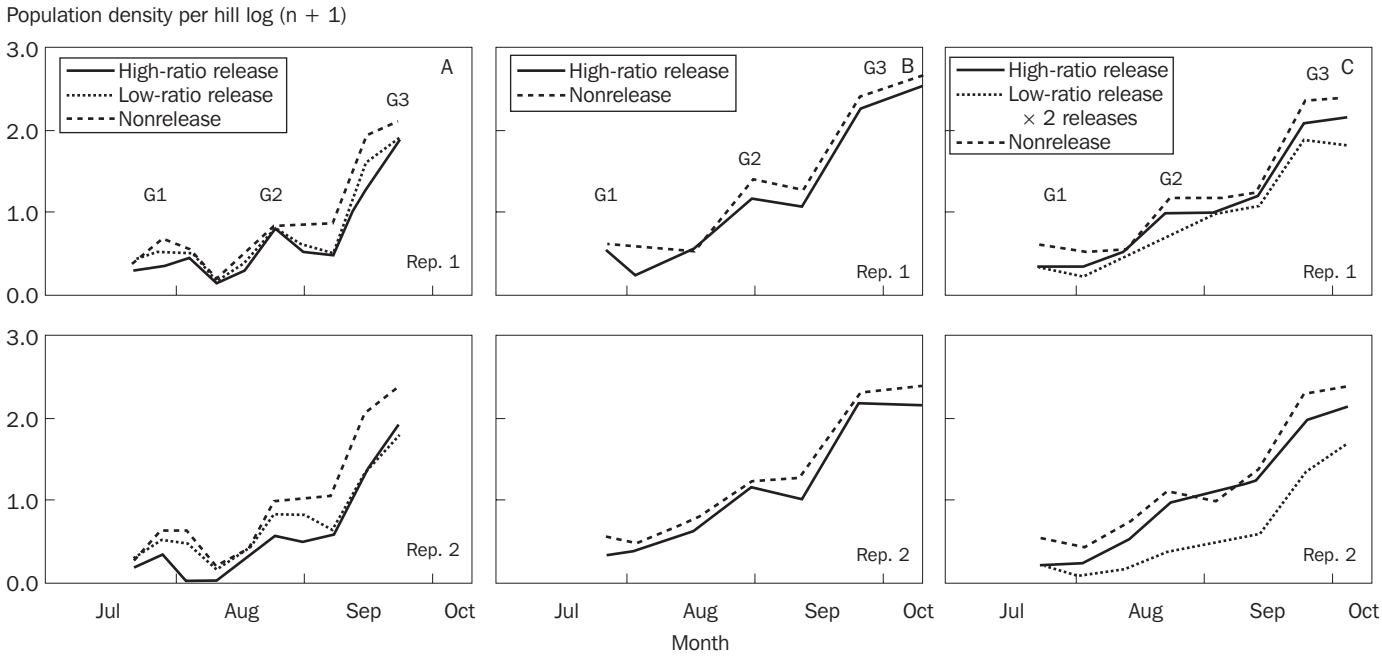

Fig. 1. Population trends of *Nilaparvata lugens* in each replicated block (replication 1 and 2) following augmentative releases of *Cyrtorhinus lividipennis* in open paddy fields. (A) *C. lividipennis* adults were released in early July at predator:prey (*C. lividipennis* adult:*N. lugens* adult) ratios of 0:1 (nonrelease), 1:1 (high-ratio release), and 1:2 (low-ratio release) in 1999, (B) at ratios of 0:1 and 1:1 in 2000, and (C) at ratios of 0:1 and 1:1, and an additional release in early August (high ratio × 2 releases) in 2001. G1, G2, and G3 indicate the first, second, and third generation, respectively.

Table 1. Key-factor/key-stage table for the population density of the third generation in *Nilaparvata lugens*.

Factor	df	Generation				*F*	*P*
		G1/G0	G2/G1	G3/G2	Total		
Natural enemy release	1	3.129	–0.199	0.798	3.728	11.0	0.002
Replication	1	0.295	–0.055	–0.026	0.215	1.9	0.201
Year	2	0.872	3.491	–0.407	3.957	17.6	0.001
Unknown variability	7	0.445	0.339	0.229	1.014		
Total	11	4.742	3.576	0.595	8.913		

was the most significant factor suppressing the density of the third-generation *N. lugens* (Table 1). One-time release of *C. lividipennis* was insufficient to suppress the density of third-generation *N. lugens* (Fig. 1C). However, an additional release of *C. lividipennis* at the second generation (early August) successfully regulated the mean population density of the third-generation *N. lugens* to 13.6–36.1 individuals per hill (1.13–1.56 in log scale), which is lower than the density at which "hopper-burn" damage occurs (Fig. 1C).

Stepwise multiregression analysis revealed that the most important factor decreasing the population growth rate from the initial to the first generation of *N. lugens* was the density of released *C. lividipennis* ($P<0.001$, $r^2 = 0.628$). In contrast, the most important factor decreasing the population growth rate from the first to the second generation of *N. lugens* was not the density of the first generation of *C. lividipennis* but the population density of naturally-occurring first-generation *S. furcifera* ($P<0.05$, $r^2 = 0.645$). This negative effect of *S. furcifera* on the population growth of *N. lugens* is the first field evidence of interspecific interactions between *N. lugens* and *S. furcifera*, which had been suggested in laboratory experiments (Matsumura and Suzuki 2003).

The population density of *C. lividipennis* increased at the next generation (early August) of natural enemy release, but it decreased thereafter (data not shown). The population density of *C. lividipennis* increased again in mid-September, when the density of *N. lugens* increased (data not shown). The number of *C. lividipennis* was positively correlated with the sum of the number of *S. furcifera* and *N. lugens* ($P<0.001$, $r^2 = 0.967$). Because *S. furcifera* density peaks earlier in the season than does *N. lugens*, the present results suggest that the

population increase of *C. lividipennis* depends on *S. furcifera* early in the season and on *N. lugens* later in the season.

Our field experiment suggests that the augmentative release of *C. lividipennis* is highly promising for regulating *N. lugens* density to levels low enough to prevent "hopper-burn" damage in open paddy fields. To further enhance the effect of the released natural enemy, additional techniques such as a banker plant system (Van Lenteren 1995) should be worthwhile to evaluate. For open rice fields, eggs of the delphacid planthopper *Sogatella vibix* (Haupt) (a nonpest species of rice plants) found on the Japanese barnyard millet *Echinochloa utilis* Ohwi et Yabuno could serve as a noncrop plant reservoir for food and reproduction of *C. lividipennis*. The evaluation of this system is now in progress (Matsumura M and Urano S, unpublished data).

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Notes

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Developing a rice production system for sustainable pest management

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The development and cultivation of shorter-duration and agronomically well-adapted varieties has fed half of the world's total population of about six billion people, mostly in Asia. This not only allowed intensification of the rice crop in time and space, which reduced the demand for land to grow it to meet this population pressure, but it also accounts for 30% to 50% of agricultural production and 50–90% of the calories consumed by these people (Hossain and Fischer 1995). While there is a need to achieve greater rice productivity, intensification also makes the rice crop more vulnerable to attack by rice pests and diseases (Mew et al 2004).

Pests and diseases are a moving target. Genetic elasticity allows them to readjust their population to adapt to new environments and on new resistant varieties bred by plant breeders. It is not uncommon that the scenario of pest and disease profiles shifts as production systems change. Accompanying this intensification is the use of genetically uniform varieties that reduce the buffering capacity in the rice-cropping system. This situation creates some concerns regarding modern rice production in relation to pest outbreaks. Below, we outline some of these concerns and propose that scientists working on pest management should consider sustainable rice production systems as a means to manage pests and diseases as an important option for another doubly green revolution in agriculture.

The first concern is the deployment of a few high-yielding varieties over large areas, leading to a decline in cultivar diversity. The general landscape of rice production in intensive rice ecosystems is characterized as a monoculture system. A reduction in cultivar diversity is a concern of rice intensification because maintaining adequate diversity and resilience is important in the humid tropics of Asia, where pressure