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Polycultural manipulation for better regulation of planthopper populations in irrigated rice-based ecosystems

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ABSTRACT

The frequent outbreaks of rice planthoppers, especially brown planthopper *Nilaparvata lugens* (Stål), in the last ten years in China and other Asian countries have caused serious rice (*Oryza sativa* L.) yield losses. The key problem is possibly due to biodiversity loss in rice ecosystems. We examined the potential of intercrops of soybean (*Glycine max* L.) and corn (*Zea mays* L.), both of which are more profitable than rice and mostly planted in levees, to diversify rice ecosystems and enhance insect pest management. We studied the impacts of such intercrops on planthopper populations and their natural enemies. The results showed significantly lower numbers of rice planthoppers in rice fields with intercrops of corn than in rice monocultures and rice fields with intercrops of soybean. Rice fields with corn intercrops had 26–48% fewer planthoppers than rice monoculture. Rice fields with soybean intercrops had lower rice planthopper abundance compared to rice monoculture in 2008 but higher in 2009. However, neither parasitoid nor predator numbers were significantly affected by intercropping. There were no significant differences in directional movements of planthoppers or natural enemies between crop subplots in the different cropping systems. Moreover, movement of planthoppers was very limited. Our study indicated that soybean and corn intercrops do not greatly enhance the ability of natural enemies to suppress planthoppers. However, rice fields with intercrops of corn had lower abundance of planthoppers and this strategy may be useful as part of an integrated pest management strategy for the sustainable rice production.

1. Introduction

Rice (*Oryza sativa* L.) is widely cultivated throughout the world and serves as a basic food staple for over half the world's population (FAO, 2004). Its sustained production is vital especially for Asian counties (Maclean, 2002). However, recently, two migratory planthoppers, *Nilaparvata lugens* (Stål) (brown planthopper; BPH) and *Sogatella furcifera* (Horváth) (white-backed planthopper; WBPH) and a less migratory species, *Laodelphax striatellus* (Fallén) (small brown planthopper; SBPH), were listed as new threats to sustainable rice production (Heong and Hardy, 2009). These three species of rice planthoppers (RPH) cause damage to rice directly by sucking the phloem sap and indirectly by transmitting viral diseases (Heong and Hardy, 2009). Outbreaks of RPH can completely destroy crops, causing "hopper burn".

Currently, RPH population management depends heavily on insecticides and resistant rice varieties (Heong and Hardy, 2009). However, pesticides are often considered environmentally harmful, and can have detrimental effects on natural enemies (Schoenly et al., 1996), causing resurgence (Chellial and Heinrichs, 1980) and resistance (Nagata, 2002). Additionally, Chen (2009b) has shown that within several generations in the laboratory and several years in the field, the virulence of RPH, especially BPH, can overcome the resistance of certain resistant rice varieties deployed against such pests.

Frequent RPH outbreaks have been recorded since late 1960s in China, and occurrences have worsened since 2000 (Chen, 2009a). Among the reasons explaining these new outbreaks, simplification of the rice ecosystem appears to play the most important role (Chen et al., 2008; Chen, 2009a). Biodiversity loss in modern intensified agriculture may be linked to increasing pest problems (Way and Heong, 1994; Gurr et al., 2003; Altieri and Nicholls, 2004). Biodiversity enhancement of agroecosystems has been promoted under

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integrated pest management and other sustainable management practices. It is considered more sustainable and aims to reduce pesticide use and prolong the effectiveness of resistant rice varieties (Gurr, 2009).

In southern China, rice field borders or marginal areas, especially levees, are usually used for planting more profitable vegetables (e.g. soybean (*Glycine max* L.) and corn (*Zea mays* L.)), which take full advantage of the land and completely coincide with self-sufficiency and small farm economics (Xie and Xia, 1992; Lin, 1996). It was suggested that soybean and corn may be beneficial to parasitoids in rice fields, as they supply nectar and pollen (Lu et al., 1995; Zheng et al., 2003). However, few studies have empirically examined the roles of these intercrops on insect communities, especially parasitoids at the field or landscape level. In this study, we examined the role of soybean or corn intercrops within a rice ecosystem. Our objectives were to (1) assess the effects of intercrops on the abundance of rice planthoppers; (2) examine the roles of soybean and corn in the population increase of natural enemies of planthoppers; and (3) determine whether intercrops can influence insect movement between habitats.

2. Materials and methods

2.1. Study site and experimental design

The experiments were conducted in 2008 and 2009 at the research station of Institute of Applied Ecology, Fujian Agricultural and Forestry University (IAE, FAFU) in Mount Wuyi, Northwest of Fujian province, China (27°39′8.12″N, 117°53′19.38E). This study site is a subtropical ecosystem, subjected to monsoon, an average annual temperature of 16.2 °C, annual precipitation of 2190 mm, 78% relative humidity, and over 120 days of frost-free period.

The experiments followed a complete randomized block design with three treatments: 1) rice monoculture (RMon), 2) rice fields with intercrops of corn (RC), and 3) rice fields with intercrops of soybean (RS). Four blocks were used in this experiment and were separated from each other by a buffer of at least 3 m. Each block was divided into three plots of 2400 m^2. Each plot (also buffered by 3 m bare soil) was further divided into six subplots of 22 × 5 m planted with one crop (rice or intercrop) in alternating pattern. Each subplot was bordered on all sides by an unplanted 0.5 m-wide earthen walkway. Fig. 1 describes the experimental design as well as the locations of the various traps used to survey insects within and between subplots (see next section for description of surveys). On 23 June 2008 and 20 June 2009, two to four thirty-day-old rice seedlings per hill were transplanted by hand (average 25 × 22.5 cm spacing). Rice (variety: T55YOU627) was harvested on 2 October 2008 and 27 September 2009. Soybean (variety: Wanfeng No.6) was sown on 27 June 2008 and 14 June 2009, and harvested on 27 September 2008 and 12 September 2009. The first crop of corn (variety: Huyunuo No.3) was sown on 29 April 2008 and 5 May 2009, and harvested on 22 July 2008 and 1 August 2009. The second crop of corn was sown on 28 July 2008 and 2 August 2009, and harvested on 20 October 2008 and 26 October 2009. Corn and soybean were both sown before transplanting rice at an average spacing of 140 × 35 cm, except for a delay for soybean in 2008 due to a heavy rain event. The crops were subsequently managed with usual agronomic practices and without any pesticide application.

2.2. Sampling communities

Planthopper species in these communities included species such as BPH, WBPH and SBPH. Natural enemy communities of planthoppers included (1) egg parasitoids: *Anagrus nilaparvatae* Pang *et* Wang, *Anagrus longitubulosus* Pang et Wang, and *Panstenon oxylus* (Walker); (2) nymph or adult parasitoids: *Gonatopus flavifemur* (Esaki et Hashimoto), *G. nigricans* (R. C. L. Perkins), *Haplogonatopus apicalis* R. C. L. Perkins, and *Haplogonatopus oratorius* (Westwood); and (3) egg predators *Microvelia horvathi* Lundblad and *Cyrtorrhinus lividipennis* Reuter). Egg parasitoids are considered to be specialist, nymph and adult parasitoids mainly parasitize rice planthoppers but occasionally parasitize rice leafhopper, and egg predators can also feed on eggs of rice leafhoppers (He and Pang, 1986; He et al., 2004).

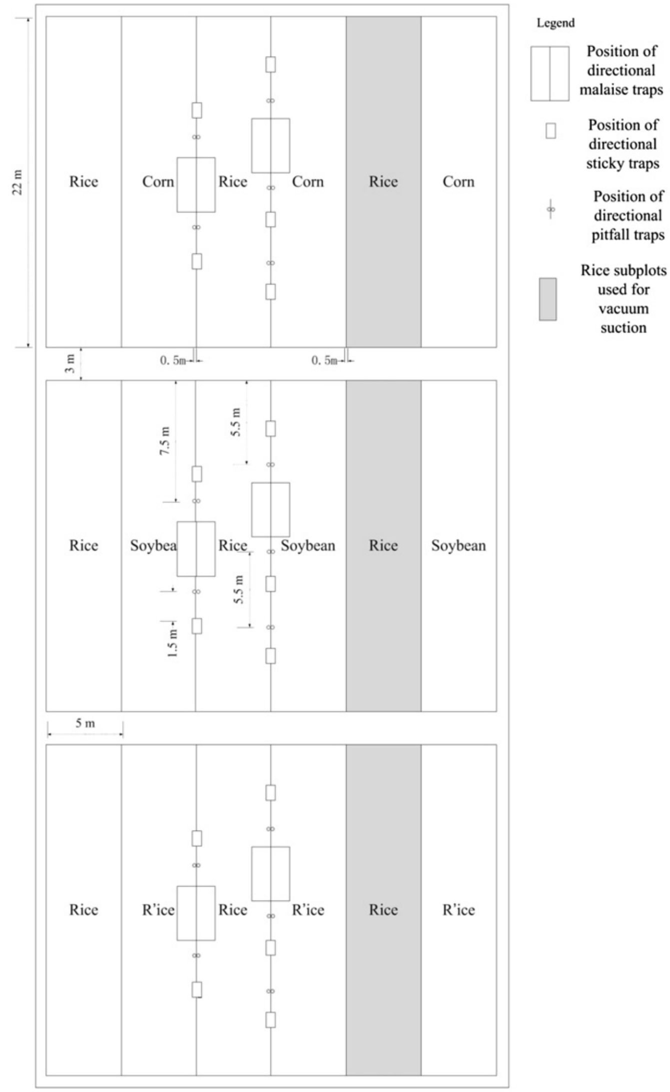

Fig. 1. Layout of one of the experimental blocks and sampling patterns. Three treatments: rice monoculture (RMon); rice fields with intercrops of corn (RC); rice fields with intercrops of soybean (RS). R′, rice subplot on the same side with corn or soybean subplot.

2.2.1. Subplot surveys

Communities of rice planthoppers and their natural enemies were surveyed using the suction equipment used by Lin et al. (2010). In this case, arthropods in nine rice hills (ca. 0.25 m^2) were collected as one of five sub-samples per plot. Those five sub-samples were randomly sampled (Chen et al., 2007) in subplots not used for monitoring the movement of insects (Fig. 1). Sampling was conducted in the morning, on average every 15 days starting one week after transplantation and continued until the rice was fully grown (for a total of 6 surveys). Samples were kept at least 0.8 m from the edge and at least 2 m from each other. All collected arthropods were stored in 75–80% ethanol for sorting and counting in the laboratory. All insects including nymph of rice planthoppers were identified to species (Zhejiang Agricultural University, 1982; Gong et al., 1985; He and Pang, 1986; He et al., 2004).

2.2.2. Directional movement of insects between subplots

Directional pitfall traps modified from those described by Yu et al. (1999) were used. Transparent plastic sheets (60 × 30 cm) were installed approximately 5 cm deep into the ground in the middle of the ridge between two subplots with the long side parallel with the ridge. On each side of the middle of each sheet, a plastic container (300 ml) was buried with its rim flush with the soil surface. The set up was protected from rain by a sheet of 30 × 15 cm. Five traps were installed on the two transects adjacent to a rice subplot. Pitfall traps were filled with 250 ml of a water solution of Diaopai® washing powder (5 g washing powder per L water). Traps were placed in the afternoon after suction sampling and remained in place for 24 h.

Directional sticky traps were used to survey the movement of flying insects between subplots in 2008. Five systems of pairs of transparent plastic sheets (20 cm in height and 30 cm in width) were installed on stakes along the levees in between the pitfall traps (1.5 m apart). Pairs of traps were added over time with the increase in height of the rice during the growing season, i.e. at 25, 65 and 95 cm above ground (to ensure that the traps were always higher than the height of the rice) (Chen et al., 2006). Machine oil was brushed evenly on the sheets in the morning and traps remained in place for 24 h. The sheets were then taken back to the laboratory, and the insects were scraped off with the soapy solution used in the pitfall traps. Insects were then washed from the oil and passed through a fine-mesh strainer to be sorted, identified, and counted.

To survey insects moving between subplots while discounting wind effect, a directional malaise trap, similar to the one described by Hossain et al. (2002), was installed in 2009. Malaise trap collection bottles were filled with 350 ml 95% ethanol and changed every seven to nine days. Malaise traps continuously monitored the movement of insects from July 16 to September 16. All malaise trap samples were passed through a fine-mesh strainer and specimens were sorted, identified and counted. Samples collected by malaise trap were summed over the entire growing season. Samples from the various traps were collected on average 5–8 times each year (Table 1).

2.3. Data analysis

In order to better fulfill the assumptions of ANOVA, the data were log- or log $(x+1)$ transformed before analysis. Data were separated by year and analyses were performed on the plot means.

Table 1
Sampling procedures and days after transplantation of rice seedling or sowing of corn and soybean in 2008 and 2009.

Year	Sampling method	Sampling date (mm-dd)	Days after transplantation or sowing (*d*)		
			Rice[a]	Corn[b]	Soybean[b]
2008	Suction trap	07-01	8	63	4
		07-15	22	77	18
		08-02	40	5 (second crop)	36
		08-17	55	20	51
		09-01	70	35	66
		09-15	84	49	80
	Pitfall trap	07-02–07-03	10–11	65–66	6–8
		07-15–07-16	22–23	77–78	18–19
		08-02–08-03	40–41	5–6 (second crop)	36–37
		08-17–08-18	55–56	20–21	51–52
		09-01–09-02	70–71	35–36	66–67
		09-15–09-16	84–85	49–50	80–81
	Sticky trap	07-17–07-18	24–25	79–80	20–21
		08-04–08-05	42–43	7–8 (second crop)	38–39
		08-19–08-20	57–58	22–23	53–54
		09-02–09-03	71–72	36–37	67–68
		09-16–09-17	85–86	50–51	81–82
2009	Suction trap	06-27	7	53	13
		07-12	22	68	28
		07-27	37	83	43
		08-11	52	8 (second crop)	58
		08-26	67	23	73
		09-10	82	38	88
	Pitfall trap	06-27–06-28	7–8	53–54	13–14
		07-15–07-16	25–26	71–72	31–32
		07-29–07-30	39–40	85–86	45–46
		08-12–08-13	53–54	9–10 (second crop)	59–60
		08-27–08-28	68–69	24–25	74–75
		09-11–09-12	83–84	39–40	89–90
	Malaise trap	07-16–07-24	26–34	72–80	32–40
		07-24–07-31	34–41	80–87	40–47
		07-31–08-07	41–48	87–89 0–4 (second crop)	47–54
		08-07–08-14	48–55	4–11	54–61
		08-14–08-22	55–63	11–19	61–69
		08-22–08-31	63–72	19–28	69–78
		08-31–09-07	72–79	28–35	78–85
		09-07–09-16	79–88	35–44	85–94

[a] Days after transplantation.
[b] Days after sowing.

We analyzed the effect of different cropping systems and sampling dates on the abundance of all rice planthoppers (RPH) and of the three main species (WBPH, BPH and SBPH), parasitoids and egg predators with repeated measure ANOVA (SAS Proc Mixed; SAS Institute, Inc., Cary, NC, USA), using treatment as fixed factor, block as random factor, date as the repeated measure and an interaction term (treatment × date). Two sets of time-series-type covariance structures were tested, including one for equally spaced sampling (i.e. compound symmetry (CS), variance components (VC), first-order autoregressive (AR(1)) and Toeplitz (TOPE)) and another for unequally spaced sampling (i.e. CS, VC, and spatial power (SP(POW)(time)) (Littell et al., 2006). The model with the most appropriate covariance structure was determined with Akaike's Information Criterion (AIC). The adjusted denominator degrees of freedom were calculated with the Kenward-Roger method (Littell et al., 2006).

The movement of insects sampled by pitfall traps and sticky traps were analyzed separately by repeated measures ANOVA in a mixed model using treatment as fixed factor, block as random factor, date as the repeated measure and an interaction term (treatment × date). Unequally spaced sampling covariance structures were evaluated and the model with the smallest AIC was selected. Insects sampled by sticky traps at different heights on each sampling date were summed. Prior to analysis, data were log $(x+1)$ transformed.

The number of insects sampled by malaise trap, summed over year, were analyzed by two-way ANOVA (SAS Proc GLM; SAS Institute, Inc., Cary, NC, USA), with treatment as fixed factor and block as random factor. When a significant treatment effect was found, *post-hoc* pairwise comparisons, using Tukey's test, were performed.

3. Results

3.1. Planthoppers

3.1.1. Within rice subplots

In both 2008 and 2009, there were significant differences of abundance of RPHs, WBPHs and BPHs between treatments (Table 2). The abundance of RPHs, WBPHs and BPHs were significantly lower in rice fields with intercrops of corn (RC) than in rice monocultures (RMon) and rice fields with intercrops of soybean (RS), except for BPHs in 2008 when there was no significant difference between RC and RS (Table 3). Overall, RC reduced planthopper populations by an average of 48% and 26% in 2008 and 2009, respectively. RS did not reduce RPH density.

For all insects, differences of abundance between treatments did not significantly vary across sampling dates except for BPHs and SBPHs in 2009 (Table 2, Figs. 2 and 3). For RPHs, WBPHs and BPHs, the number of individuals was almost always lower in RC than in RS and RM through the sampling dates. Abundance varied significantly between sampling dates (Table 2).

3.1.2. Directional movement between subplots

The majority of planthoppers caught in pitfall traps were nymphs, while those caught on sticky traps and in malaise traps were dominated by adults. There was no significant difference of directional movement of planthoppers between adjacent subplots in different cropping systems sampled by the three trap types (Table 4). The number of moving planthoppers in 2008 was too small for analysis.

3.2. Natural enemies

There were no effects of treatments or of the treatment × date interaction on the abundance of parasitoids or predators (Table 2, Fig. 4). There were no significant differences of directional movement of parasitoids in either year (Table 4). The number of moving predators in the two years was too small for analysis (Table 4).

4. Discussion

In our study, higher vegetation diversity did not necessarily result in lower rice planthopper abundance. Only rice fields with intercrops of corn resulted in 26–48% lower abundance of planthoppers. Results varied between years, with planthopper abundance in rice fields with intercrops of soybean lower in 2008 but

Table 2
Results of the effects of different cropping system (Treatment), sampling dates (Date) and the interaction item (Treatment × Date) on the abundance of rice planthoppers and their natural enemies. The d.f. column gives both the nominator (first) and denominator degrees of freedom (second). The adjusted denominator degrees of freedom were calculated with the Kenward–Roger method. Bold values indicate that there exist statistically significant difference between treatments.

Insects	Factors	2008			2009		
		d.f.	*F*	*P*	d.f.	*F*	*P*
RPH	Treatment	2, 6	38.00	**0.0004**	2, 6	77.50	**<.0001**
	Date	5, 45	22.32	**<.0001**	5, 45	153.77	**<.0001**
	Treatment × Date	10, 45	0.26	0.9872	10, 45	1.20	0.3191
WBPH	Treatment	2, 6	14.78	**0.0048**	2, 6.41	13.05	**0.0055**
	Date	5, 45	27.67	**<.0001**	5, 20.1	204.08	**<.0001**
	Treatment × Date	10, 45	0.29	0.9812	10, 22.5	1.12	0.3890
BPH	Treatment	2, 6	11.77	**0.0084**	2, 42	8.22	**0.0010**
	Date	4, 36	22.80	**<.0001**	4, 42	94.34	**<.0001**
	Treatment × Date	8, 36	0.42	0.9012	8, 42	2.38	0.0324
SBPH	Treatment	2, 6	4.44	0.0655	2, 42	1.38	0.2623
	Date	4, 36	5.59	**0.0013**	4, 42	5.66	**0.0010**
	Treatment × Date	8, 36	0.57	0.7981	8, 42	3.56	**0.0031**
Parasitoids	Treatment	2, 6	2.07	0.2066	2, 51	2.86	0.0666
	Date	5, 45	21.96	**<.0001**	5, 51	57.77	**<.0001**
	Treatment × Date	10, 45	0.25	0.9881	10, 51	0.45	0.9142
Predators	Treatment	2, 54	0.47	0.6275	2, 51	0.38	0.6864
	Date	5, 54	8.71	**<.0001**	5, 51	31.63	**<.0001**
	Treatment × Date	10, 54	1.60	0.1303	10, 51	0.35	0.9608

Table 3
The overall abundance (Mean ± SE) of rice planthoppers (RPHs), WBPHs, BPHs, SBPHs and their natural enemies within rice subplots in rice monocultural (RMon) and dicultural (rice fields with intercrops of corn, RC; rice fields with intercrops of soybean, RS) systems sampled by suction traps in 2008 and 2009.[a]

	2008			2009		
	RMon	RC	RS	RMon	RC	RS
RPHs	73.54 ± 19.12a[b]	40.42 ± 8.85c	56.83 ± 15.19b	107.04 ± 19.40a	78.83 ± 16.06b	122.50 ± 22.55a
WBPHs	28.96 ± 10.21a	15.67 ± 3.88b	30.08 ± 9.64a	63.96 ± 18.00a	55.13 ± 16.28b	80.13 ± 23.40a
BPHs	48.65 ± 13.91a	21.45 ± 5.25b	27.85 ± 8.08b	48.50 ± 15.13a	25.35 ± 8.86b	47.25 ± 14.56a
SBPHs	4.85 ± 1.32a	8.25 ± 2.16a	4.25 ± 1.01a	4.30 ± 0.97a	3.10 ± 0.58a	3.60 ± 1.19a
Parasitoids	16.67 ± 4.94a	12.96 ± 4.02a	16.71 ± 6.46a	18.17 ± 3.09a	12.50 ± 2.53a	17.75 ± 3.57a
Predators	10.63 ± 4.30a	6.79 ± 2.48a	7.50 ± 2.97a	50.49 ± 13.75a	41.08 ± 9.50a	37.79 ± 11.84a

[a] Means were compared by repeated measure ANOVA. $n = 24$ for RPHs, WBPHs, parasitoids and predators; $n = 20$ for BPHs and SBPHs.
[b] Values of abundance for each insect followed by same letter indicate there is no significant difference ($\alpha = 0.05$) within year.

higher in 2009. For parasitoids and predators of rice planthoppers, abundances did not differ significantly between treatments.

Earlier laboratory work has shown that soybean nectar and corn pollen extend longevity and increase parasitic activity of *A. nilaparvatae* (Zheng et al., 2003). Our results do not reflect such an effect, because neither the abundance of parasitoids nor the number of moving parasitoids were significantly different between treatments. It may be that, in the field, flowering of soybean (ca. 30 d) and corn (ca. 10 d) do not last long enough to supply enough nectar and pollen to parasitoids. In addition, the timing of flowering did not coincide with the peak abundance of the parasitoids. Soybean flowered later (especially in 2008) than the peak abundance of parasitoids. The spatial location of the intercrops in relation to the rice may have also affected the results. Corn not only flowered too early but the flowers were also likely too high off the ground (ca. 1.8 m–2.0 m) to be available for parasitoids, which are most active near the ground. Other studies have shown that spatial arrangement of fields may impact pest incidence. Parsa et al. (2011) found that the Andean potato weevil (*Premnotrypes* spp.) decreased with the expansion of monoculture, suggesting that host plant patch arrangement had an impact on insect communities. Finally, in the field, parasitoids have numerous requirements other than food sources (e.g., prey finding, competition and predation).

For planthopper egg predators (*M. horvathi* and *C. lividipennis*) and nymph/adult generalist predators (spiders, carabids and staphylinids; unpublished data), numbers were not significantly different between treatments, implying equal predatory pressure on planthoppers. Therefore, the intercropping systems used in this experiment did not favor biological control, and our results do not support the enemy hypothesis (Root, 1973).

Although the area of rice planted was greater in the monoculture, the area of planted rice was the same between intercropped systems. Furthermore, the predominant BPH and WBPH rice planthoppers are both monophagous feeders of rice (Teng et al., 1994). Reducing the area of planted rice did not necessarily lead to lower densities of planthoppers. This is contrary to Cronin

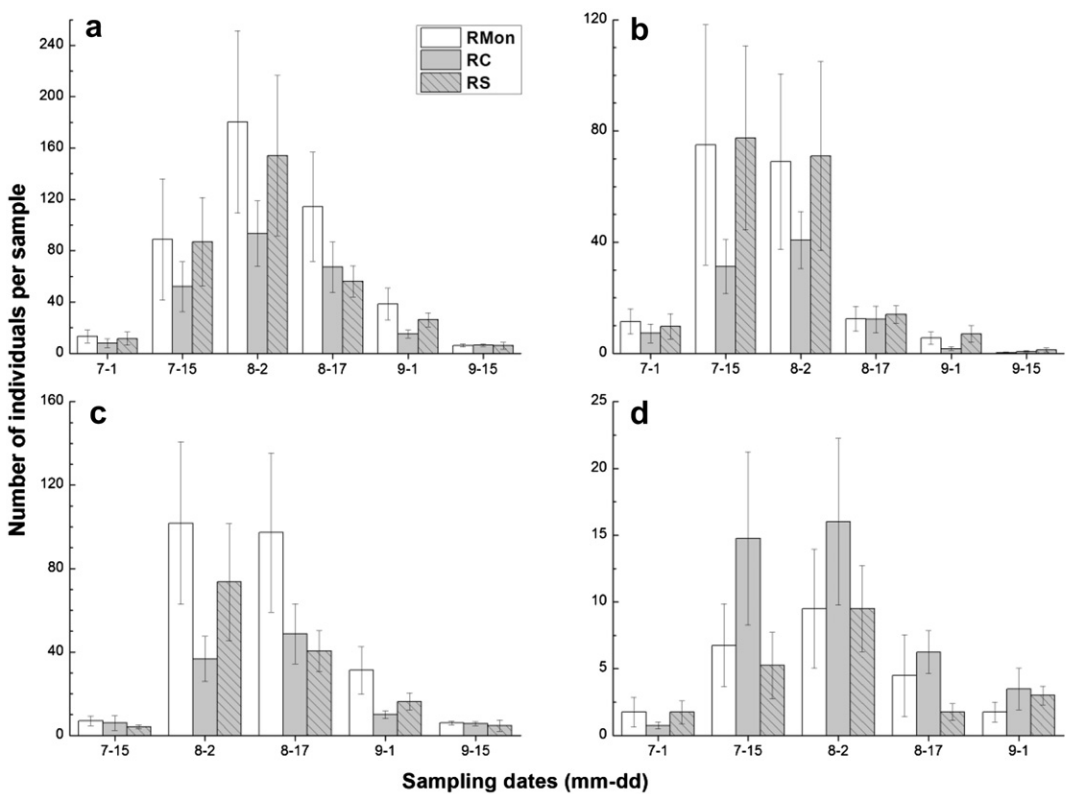

Fig. 2. Seasonal Dynamics of RPHs (a), WBPHs (b), BPHs (c) and SBPHs (d) in different cropping systems (RMon: rice monoculture; RC: rice fields with intercrops of corn; RS: rice fields with intercrops of soybean) in 2008. Data shown as mean ± standard error ($n = 4$).

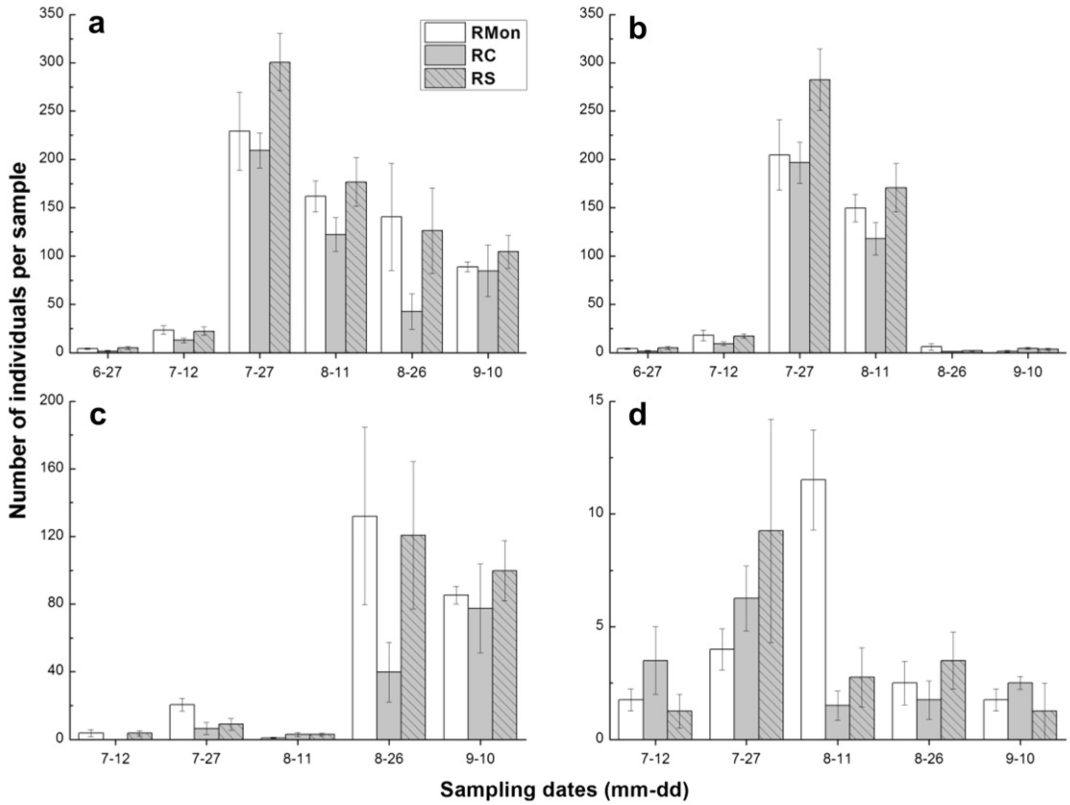

Fig. 3. Seasonal dynamics of RPHs (a), WBPHs (b), BPHs (c) and SBPHs (d) in different cropping systems (RMon: rice monoculture; RC: rice fields with intercrops of corn; RS: rice fields with intercrops of soybean) in 2009. Data shown as mean ± standard error ($n = 4$).

(2003) who found that population densities and patch occupancy rates of a prairie planthopper, *Prokelisia crocea* (Van Duzee), were positively correlated with patch size. However, relationships of patch size and population density may be organism-dependent and determined by landscape configuration (Grez and González, 1995; Parsa et al., 2011). Grez and González (1995) found that high herbivorous insect densities persisted in patches with only four host plants.

No significant differences in the number of the movement of rice planthoppers between adjacent subplots were found in our study. This suggests that different chemical environments, particularly olfactory, may not be a reason leading planthopper populations being higher in RS but lower in RC. Contrary to expectation, insects mobility appeared not affected by intercropping as no significant difference in number of moving insects between cropping systems was found. Similarly, the lack of significant difference between immigration and emigration in RC indicated that corn may not have had the expected shading effect that could have pushed rice planthoppers out of the fields.

Björkman et al. (2010) proposed that heterogeneous habitats may increase the mortality of mobile insects or disrupt oviposition. In our experiment, while we believe that intercropping constituted a more heterogeneous system than monoculture, the results do not support this hypothesis. Even the shading effect of corn appeared to have no impact on the abundance of planthoppers. Lin et al. (2010) suggested that microclimate conditions created by the irrigated and upland mixed systems may not be suitable for planthoppers.

Table 4
The directional movement of rice planthoppers and their natural enemies between subplots.

Movement of insects	Factors	2008			2009		
		d.f.	*F*	*P*	d.f.	*F*	*P*
Directional movement of RPHs[a]	Treatment	Not tested			5, 87	1.93	0.0980
	Date				4, 87	5.66	**0.0004**
	Treatment × Date				20, 87	1.30	0.2032
Directional movement of RPHs[b]	Treatment	5, 87	1.55	0.1835	5, 15	2.10	0.1221
	Date	4, 87	2.15	0.0814	Not tested		
	Treatment × Date	20, 87	0.66	0.8507	Not tested		
Directional movement of parasitoids[b]	Treatment	5, 87	0.37	0.8708	5, 15	2.68	0.0638
	Date	4, 87	25.85	**<.0001**	Not tested		
	Treatment × Date	20, 87	0.91	0.5780	Not tested		
Directional movement of predators[a]		Not tested			Not tested		

[a] Sampled by pitfall traps.
[b] Sampled by sticky traps in 2008 and malaise traps in 2009.

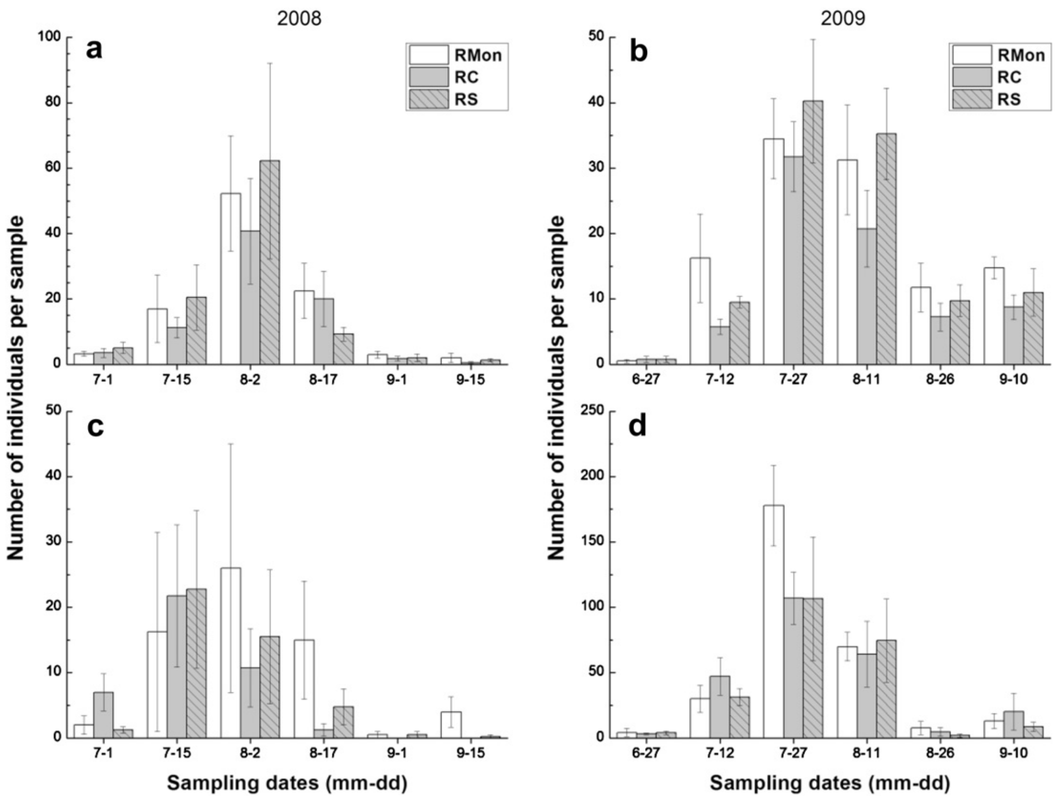

Fig. 4. Seasonal dynamics of parasitoids (a, b) and predators (c, d) of rice planthopper in different cropping systems (RMon: rice monoculture; RC: rice fields with intercrops of corn; RS: rice fields with intercrops of soybean) in 2008 and 2009. Data shown as mean ± standard error ($n = 4$).

The number of moving planthoppers was extremely low compared to their abundance in the rice subplots, indicating a low rate of horizontal movement. This was also observed by Chen et al. (2003, 2006), although the number of planthoppers sampled by sticky traps and malaise traps in our experiments was lower. The entry of planthoppers into rice fields should occur mostly from above rather than through lateral movement at ground level. Migration of planthoppers is usually enhanced by descending air streams and heavy rainfall (Bao et al., 2007; Hu et al., 2007). In our area, predominant meteorological conditions were conducive to planthopper drop-down, but the landing process may not have been completely random and passive. Evidence has shown that BPH can land under slight ascending air streams, reflecting their active flying capability (Tan et al., 1984). We hypothesize that planthoppers can navigate to some extent to land on preferred plants and habitats, especially if there is no heavy rainfall. Complex structures linked with morphological contrast of the three crops might have affected the landing selection of the migratory planthoppers. In our experiments, corn was sowed at least 40 days earlier than rice transplanting and soybean sowing. Before the harvest of the first crop, the corn was much higher (1.8–2.1 m) and denser than rice and soybean (both shorter than 0.7 m). We did catch fewer planthoppers on the first sampling date in RC in 2008 (Fig. 2a) and 2009 (Fig. 3a), and no BPH were sampled in RC while they were found in the other two treatments (Fig. 3c) in 2009.

Several studies have proposed that non-rice habitats surrounding rice fields are important to control by natural enemy communities (Way and Heong, 1994; Yu et al., 1996; Mao et al., 1999, 2002; Gurr et al., 2011). Unfortunately supporting field data are limited (Way and Heong, 1994; Gurr et al., 2011). Most research has focused on the ecological role of weeds, rather than on profitable and native plants like soybean and corn. Our research attempted to fill this knowledge gap but we failed to find a role of soybean or corn as effective enhancements of biological control by natural enemies of planthoppers in rice. Our results do suggest that intercrops of corn with rice reduce the abundance of planthoppers. However, rice yield between treatments did not significantly differ (unpublished data) and the reason might be the moderate infestation of rice planthoppers in 2008 and 2009. More studies will be required to confirm that such an intercropping strategy could be integrated into IPM to better regulate planthoppers. In the light of this study, we suggest that the potential role of short vs. tall intercrops acting as physical and/or visual barriers to reduce pest infestations should be further examined.

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