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Effects of manure use on seasonal patterns of arthropods in rice with special reference to modified biological control of whitebacked planthopper, *Sogatella furcifera* Horváth (Homoptera: Delphacidae)

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Abstract Seasonal dynamics of the whitebacked planthopper (WBPH), *Sogatella furcifera*; its major predators (*Cyrtorhinus lividipennis*, *Microvelia horvathi*, *Theridion octomaculatum*, *Oedothorax insecticeps*, and *Pardosa pseudoannulata*) and parasitoids (*Anagrus* spp.); and collembolans and chironomids were investigated in organically manured (OM) plots as well as in chemically fertilized (CF) plots of rice in Hangzhou between June and September 2001. Predation and parasitism of WBPH eggs were also surveyed. Among these arthropods, only the abundances of *M. horvathi* and collembolans were clearly modified due to manure use, with density of the former being significantly decreased around 61 days after transplantation (DAT) and the latter significantly increased 21–28 DAT. Density of WBPH (nymphs and adults) was relatively low before 21 DAT, but it increased rapidly thereafter and peaked between 28 and 35 DAT in both OM and CF plots. Predation on WBPH eggs increased significantly around 47 DAT due to the manure use, and parasitism on eggs also increased persistently between 17 and 47 DAT. These results suggested that biological control of WBPH could be potentially enhanced by manure use in two approaches, i.e., by increasing alternative prey (collembolans) of WBPH predators (particularly spiders) around 21 DAT or earlier when WBPH are scarce and by mediating plant quality in a way that favors natural enemies of WBPH eggs.

Introduction

The whitebacked planthopper (WBPH), *Sogatella furcifera* Horváth, is a major insect pest of rice (*Oryza*

sativa L.) in many Asian countries (Dale 1994). Ovipositional marks and sucking of plant sap by nymphs and adults cause hopperburn or yellowing, browning, and drying of plants. Lower WBPH density has been found more frequently in organically farmed rice fields than in chemically fertilized fields (Kajimura et al. 1993), due to the decreased reproduction and survival of this pest on organically manured plants (Kajimura et al. 1993, 1995a). These reduced population indices have also been observed by Jiang and Cheng (2003) in a greenhouse study.

The significance of alternative prey for predators of rice insect pests, especially during early rice stages when target insects are usually not abundant, has been well described in several studies (Wu et al. 1994; Guo et al. 1995; Settle et al. 1996; Hao et al. 1998; Sigsgaard 2000). Settle et al. (1996) found that, by increasing organic matter in rice fields, the populations of detritivores (such as collembolans and ephydrid flies) and plankton feeders (such as mosquito larvae and chironomid midge larvae) could be boosted, and in turn the abundance of generalist predators could be significantly increased. From this standpoint, it can be anticipated that applying organic manure to rice would probably lead to such an increase in predators, and thus enhance their control of WBPH. Moreover, as compared with chemically fertilized plants, organically manured plants are nutritionally and morphologically different (Kajimura et al. 1995b; Jiang and Cheng, unpublished data), therefore, they would conceivably induce a different top-down (natural enemies) impact on WBPH by influencing predators and parasitoids of this pest in a different way. However, whether these WBPH-targeted impacts could result in practice from manure use and how much their contribution would be to the biological control of WBPH have not been evaluated thoroughly.

In the present study, the seasonal dynamics of WBPH, its major predators, dominant detritivores, and plankton feeders were studied in organically manured rice plots, as well as in those subjected to chemical fer-

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tilization. Numbers of parasitized and predated WBPH eggs were also investigated. Our objectives were to determine the effect of manure use on the abundance of these arthropods, and subsequently to evaluate the potential of this practice in enhancing the biological control of WBPH.

Materials and methods

Experimental field and treatments

The experiment was conducted in an old rice paddy (60×17 m) located at the experimental farm (ca. 22.5 ha) of Zhejiang University between May and September 2001. To the south of this field was a luxuriant grass patch (ca. 2 m wide, >100 m long, dominated by gramineous species); in the other three directions were neighboring rice paddies, with levees (ca. 0.5 m wide, 0.3 m high) standing between them and the experimental field. Within the field, eight plots (14.2×8.0 m each) were established, with irrigating ditches (at least 1 m wide) constructed between neighboring plots.

Composted barnyard manure (54% water) was collected from a piggery at the experimental farm. Concentrations of soluble nitrogen (N), phosphorus (P), and potassium (K) in the manure were measured as 12.9, 14.9, and 6.2 g/kg dried manure, respectively (Institute of Soil and Fertilizer, Zhejiang Academy of Agricultural Sciences, Hangzhou). Four days before rice transplantation, the manure was applied to four plots of the field at the rate of 5.25 t (fresh weight) per ha. As a control, the chemical fertilizers urea (46% N), calcium superphosphate (15.5% P₂O₅), and potassium chloride (60% K₂O) were applied at the rates of 67, 300, and 29 kg/ha, respectively, to the other four plots. Between the two treatments, NPK rates were approximately the same, i.e., 31 kg N, 36 kg P, and 15 kg K per ha.

An *indica* hybrid rice cultivar, Shanyou 63, which is sensitive to WBPH (Liu et al. 1998), was used. Seeds were sown (150 kg/ha) in a paddy neighboring the experimental field on 15 May 2001; urea was applied to the seedlings at the three-leaf stage and 1 week before transplantation at the rate of 45 and 60 kg N/ha, respectively. Plants were transplanted (18×18 cm spacing) to the experimental field on 13 June, and urea was applied to each plot 10 days after transplantation at the rate of 60 kg N/ha. Water in all plots was maintained at a depth of 1–3 cm for 60 days after transplantation, and managed following standard tactics thereafter. Hand weeding was carried out and no pesticides were used during plant growth.

Arthropod sampling and identification

A square sampling frame (0.5×0.5×0.9 m) made of Mylar sheets to enclose six hills was placed randomly in the field. All fauna (on plants and above water surface) inside the enclosure were sucked up using a vacuum-suction device and gathered at the bottom of a sock-shaped interceptor attached to the suction pipe. The interceptors were then labeled and brought to the laboratory, where arthropods were transferred to vials of 70% alcohol solution for later sorting and identification. Such a sampling procedure was used by Z.C. Liu et al. (2002) to estimate the abundance and diversity of arthropods in transgenic-Bt rice paddies. Sampling was carried out on 12 dates between 20 June and 10 September, approximately at weekly intervals. On each date, sampling was replicated three times in each plot, and a total of 12 samples was obtained in each of the two treatments.

From the collected arthropods, major predators of WBPH were identified to the species level, parasitoids of WBPH to the level of genera, dominant detritivores and plankton feeders to orders or families, and the others to orders. Their abundance was presented as mean number per sample unit (0.25 m²).

Density of WBPH eggs was investigated on eight dates between 30 June and 31 August. On each date, ten tillers were randomly selected from five hills of plants (two tillers per hill) in each plot, and a total of 40 tillers was sampled in each treatment. The sampled tillers were cut at the base, brought to the laboratory, and dissected under a binocular microscope to determine the number of WBPH eggs deposited. The density was presented as mean number per tiller.

Survey of predated and parasitized WBPH eggs

During the survey of WBPH egg density described above, eggs attacked by predators were counted; such eggs have a shriveled chorion with their contents being absolutely or partially consumed (Sivapragasam et al. 1985). All eggs were transferred to glass tubes (8 cm long, 1.7 cm diameter) with moist filter paper and incubated at 26±1 °C and 16L:8D hours. They were checked daily for color change due to parasitism, and the number of adult parasitoids that emerged was recorded. Eggs that died after the egg pigmentation stage without any sign of color change were regarded as non-parasitized eggs (Watanabe et al. 1992). The number of predated and parasitized eggs on the ten tillers sampled from each plot was calculated.

Data analyses

The data analyses were performed using SPSS 11.5 for Windows (SPSS Inc, 2002). Means were compared between the manure and chemical fertilization treatments, using an independent t-test at the level $P=0.05$. Data were $\log(x+1)$ transformed before being subjected to analysis.

Results and discussion

A total of 20,986 and 22,132 arthropods were collected from the organically manured (OM) and chemically fertilized (CF) plots, respectively. Both OM and CF plots were dominated by WBPH, which accounted for 40.0 and 42.8% of the total arthropods, respectively. The subdominant taxon was cicadellids, followed by collembolans, araneae, and chironomids in this order (Fig. 1). To achieve the objectives of this study, the seasonal dynamics of eight taxa in addition to the WBPH were analyzed, including five predator species, one parasitoid complex (*Anagrus* spp.), and two detritivore/plankton-feeder complexes (collembola and chironomids) (Table 1). These predators and parasitoids are important natural enemies of WBPH and other rice hoppers (Chiu 1979; Li and He 1991; Döbel and Denno 1994; Ooi and Shepard 1994; Zhao 2003), and the detritivores/plankton feeders can potentially serve as important alternative prey for WBPH predators (Guo et al. 1995; Settle et al. 1996; Y.F. Liu et al. 2002).

In both OM and CF plots, the density of WBPH increased rapidly beginning 21 days after transplantation (DAT) and peaked between 28 and 35 DAT (Fig. 2). WBPH were less abundant in OM plots than in CF plots on most sampling dates, but a statistically significant difference between the two treatments occurred only at 42 and 49 DAT for adults ($t=-2.210$, $df=22$, $P=0.038$, and $t=-5.921$, $df=22$, $P<0.001$),

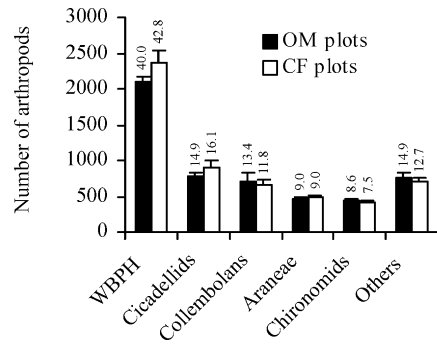


Fig. 1 The number (mean + SE, per sample unit) of arthropods of major taxa that were collected from organically manured (OM) and chemically fertilized (CF) rice plots on 12 dates between 20 June and 10 September 2001. Values above bars are corresponding percentages of total arthropods collected. WBPH is the white-backed planthopper; others refers to the taxa each comprising less than 5%. Sample unit = 0.25 m²

and at 75 DAT for nymphs ($t=3.049$, $df=22$, $P=0.008$). That is, manure use did not lead to a markedly lower WBPH density compared to chemical fertilization. This result differs to that reported by Kajimura et al. (1993), who observed a significantly lower WBPH density in an organically farmed field.

Each of the five predator species showed a similar pattern of change in the OM and CF treatments throughout the season (Fig. 3a, b). A significant difference was observed for the veliid bug (VB), *Microvelia horvathi*, at 61 DAT, when its density was significantly lower in OM plots (0.6 per 0.25 m²) than in CF plots (2.5 per 0.25 m²) ($t=-2.712$, $df=22$, $P=0.017$). This difference appeared to have extended to 67 and 75 DAT, though it was not significant statistically on either date (Fig. 3a).

The greater abundance of *M. horvathi* in CF plots described above might be related to rice plants, because it is now generally accepted that interactions between plants and natural enemies are relatively commonplace (Forkner and Hunter 2000; Denno et al. 2002). According to Kajimura et al. (1995b), rice plants in poultry-manured fields had lower levels of nitrogen than those in chemically fertilized fields, particularly during later stages. In the present study, we found that more tillers and leaves were produced by plants in CF plots

than in OM plots (unpublished data). This nutritional and growth superiority in chemically fertilized plants might have provided a more suitable habitat for *M. horvathi*, and thus attracted and supported a greater number of this bug there.

The small difference in the densities of the mirid bug (MB), *Cyrtorhinus lividipennis*, between the OM and CF treatments is consistent with the results reported by Lou and Cheng (2003). They found that neither *C. lividipennis*'s preference for brown planthoppers (*Nilaparvata lugens* Stål) nor its response to volatiles from rice plants were significantly affected by levels of nitrogen fertilizer. To our surprise, however, their predation on WBPH eggs appeared to be higher in OM plots than in CF plots, as indicated by the number of predated eggs observed at 47 and 53 DAT (Fig. 5). Therefore, whether the *C. lividipennis*–WBPH system could be modified by fertilization is to be further studied.

The density of both collembolans (nymphs and adults) and chironomids (adults) began to increase markedly at 14 DAT, peaking at 28 and 35 DAT, respectively, and thereafter both declined to a relatively low density within 1–2 weeks (Fig. 4). The abundance of adult chironomids increased only slightly by the manure use. The OM treatment, however, greatly favored the increase in collembolans, as indicated by the significantly higher collembolan density in OM plots than in CF plots at 21 and 28 DAT ($t=2.222$, $df=22$, $P=0.037$, and $t=2.642$, $df=22$, $P=0.015$). After 35 DAT, little difference was found in collembolan density between the treatments (except at 89 DAT). Therefore, it was only before 35 DAT, particularly during the fourth week, that the number of detritivores (collembolans) could be greatly increased by manure use.

The contribution of increased collembolans to predators, however, would be largely based upon the density of WBPH. For example, at 21 DAT, when the density of WBPH was relatively low (16 and 27 adults and nymphs per 0.25 m² in OM and CF plots, respectively; Fig. 2), collembolans are probably the preferred prey (especially of spiders). However, at 28 DAT, when WBPH nymphs were very abundant in both OM and CF plots (Fig. 2), the presence of large number of collembolans at this time (Fig. 4) would probably decrease the predation on WBPH. Collembolans are preferred by spiders to WBPH (Pang et al. 1998; Zhao 2003).

Table 1 The taxa potentially having strong trophic relations with WBPH

Guild	Order	Family	Species	Stage of WBPH attacked
Predators	Hemiptera	Miridae	<i>Cyrtorhinus lividipennis</i> Reuter	Egg and young nymph
		Veliidae	<i>Microvelia horvathi</i> Lundblad	Young nymph
	Araneae	Theridiidae	<i>Theridion octomaculatum</i> Boese. & Str.	Nymph and adult
		Linyphiidae	<i>Oedothorax insecticeps</i> Boese. & Str.	Nymph and adult
Parasitoids	Hymenoptera	Lycosidae	<i>Pardosa pseudoannulata</i> Boese. & Str.	Nymph and adult
		Mymaridae	<i>Anagrus</i> spp.	Egg
Detritivores/plankton feeders	Collembola	-	-	-
	Diptera	Chironomidae	-	-

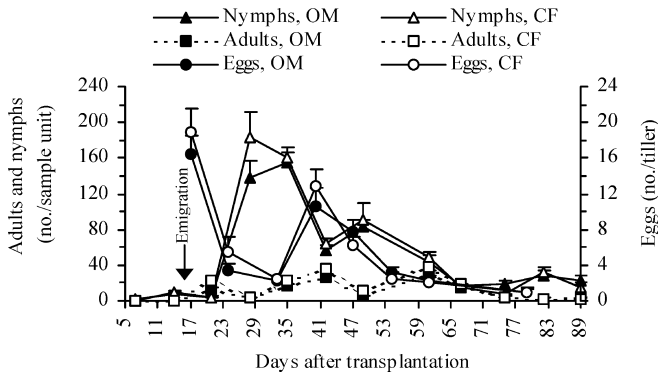


Fig. 2 Seasonal changes in the number of WBPH adults, nymphs (mean + SE, per sample unit) and eggs (mean + SE, per tiller) in organically manured (OM) and chemically fertilized (CF) rice plots. Downward arrow indicates estimated dates of WBPH emigration

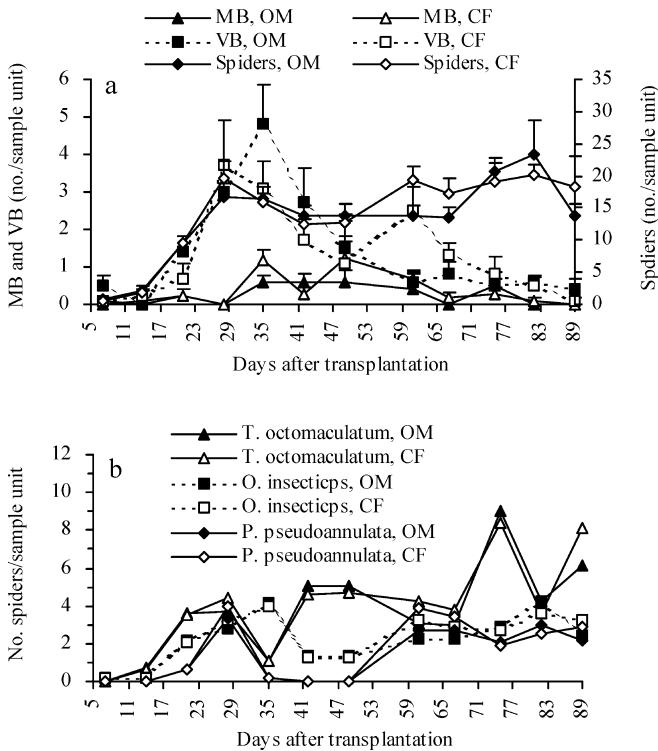


Fig. 3a, b Seasonal changes in the number (mean + SE, per sample unit) of WBPH predators: mirid bug (MB) *Cyrtorhinus lividipennis*, veliid bug (VB) *Microvelia horvathi*, and spider complex (a), and dominant spider species, *Theridion octomaculatum*, *Oedothorax insecticeps* and *Pardosa pseudoannulata* (b, +SE marks were omitted), in organically manured (OM) and chemically fertilized (CF) rice plots

Therefore, the potential of manure use in enhancing biological control of WBPH by increasing alternative prey (collembolans) should be carefully evaluated, especially during the periods when abundant collembolans co-occur with WBPH. In Zhejiang, China, WBPH emigration generally begins in late May and peaks in

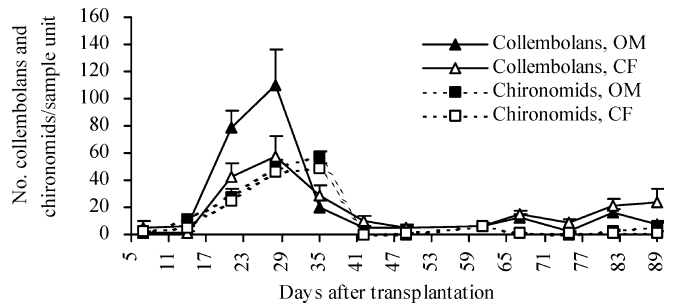


Fig. 4 Seasonal changes in the number (mean + SE, per sample unit) of collembolans and adult chironomids in organically manured (OM) and chemically fertilized (CF) rice plots

mid- and late June (Feng et al. 1997); rice transplantation is carried out during early May and early August, depending upon the rice cropping system areawide and the growth period of rice varieties used. Undoubtedly, each of these aspects can have great influence on the relative density of collembolans versus WBPH in fields, and thus should be taken into account when evaluating the impacts of manure use. We imagine that the later the WBPH emigration occurs and the earlier the rice cultivation is, the higher the potential manure use would have in enhancing the biological control of WBPH.

To our surprise, for each of the three spider predators of WBPH, *Theridion octomaculatum*, *Oedothorax insecticeps* and *Pardosa pseudoannulata*, no higher abundance resulted from the manure use (Fig. 3b). This suggests that, in the present study, the colonization or reproduction of these spiders has not been increased by manure use. Their growth or survival, however, might have been improved by such a treatment, due to the increased density of collembolans around 21 DAT or earlier when WBPH nymphs or adults were scarce as described above, and thus their predation capacity on WBPH might have been elevated during a later period (such as around 28 DAT). In future studies, monoclonal antibodies of WBPH and collembolans (Pang et al. 2001; Zhao 2003) are to be used to quantify the predation capacity of these spiders in both OM and CF fields.

Relatively few individuals of *Anagrus* spp. were collected. The major reason might be that these insects were too tiny to be retained by the interceptor of the suction device. Slightly more WBPH eggs were parasitized by these parasitoids in OM plots than in CF plots between 17 and 47 DAT (Fig. 5). This difference, though not significant statistically, was fairly persistent, and thus was probably related to the treatments assigned. Modification of the *Anagrus*-planthopper system by fertilization has been reported by Moon and Stiling (2000). They found that fertilization significantly increased the percentage of eggs of a salt marsh planthopper (*Pissonotus quadripustulatus*) that were parasitized by *Anagrus* sp. nr. *armatus*, and that the softer stems of fertilized *Borrichia frutescens* (host plants), which were much easier to penetrate by the parasitoid, were responsible for this impact.

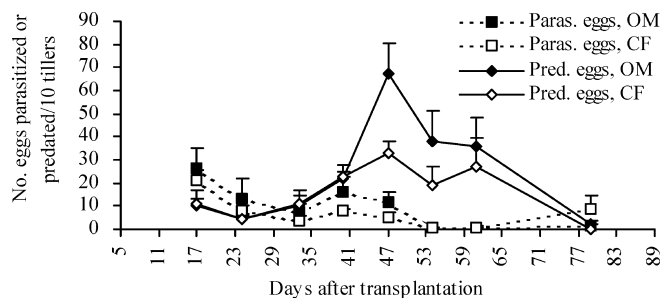


Fig. 5 Seasonal changes in the number (mean + SE, per ten tillers sampled) of parasitized or predated WBPH eggs in organically manured (OM) and chemically fertilized (CF) rice plots

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