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Impact of Pesticide Treatment on an Arthropod Community in the Korean Rice Ecosystem

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ABSTRACT: An arthropod community in a rice ecosystem was surveyed to determine the impact of two insecticides frequently used in Korean rice ecosystems: carbofuran 3GR, which targets the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae) in the early season and fenobucarb EC, which targets the brown planthopper, *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) in the mid- and late seasons, respectively. Overall, the application of the insecticides reduced density of total arthropods by 48.4% compared to the untreated field, but their impact on each functional group were different. Carbofuran GR treatment on 1 June reduced the *L. oryzophilus* population significantly until mid-season. The population of filter-feeding chironomids was also reduced by 50%, whereas the spider population was less disturbed. Fenobucarb EC treatment on 16 August significantly reduced *N. lugens* and detrivorous entomobryid populations until the late season. Both web-building and wandering spiders were also significantly disturbed by fenobucarb EC although the impact differed according to their behavioral differences. While the population of web-building spiders significantly decreased over time, that of wandering spiders recovered from the disturbance a few weeks later.

Key words: Arthropod guilds, Insecticide application, Rice ecosystems, Trophic interactions

INTRODUCTION

In tropical and temperate rice ecosystems, the trophic relationships among arthropods during the rice-growing season have been explored and interactions among trophic levels have been made rather clear (Settle et al. 1996, Park and Lee 2006). In particular, Park and Lee (2006) provided isotopic evidence that filter feeders and detrivores such as those in the families, Chironomidae (Diptera) and Entomobryidae (Collembola) play an important role in sustaining predators such as spiders in rice ecosystems. Although improving natural or biological control by enhancing natural enemy conservation has been increasingly stressed for sustainable agriculture in rice ecosystems (Matteson 2000, Takahashi 2000), the insect pest control system frequently relies on insecticide treatments that might often disrupt a natural enemy complex as well.

Studies of negative impacts on biological components in rice ecosystems due to insecticide application have been conducted for some of the dominant natural enemies, such as spiders and predaceous bugs (Fabellar and Heinrichs 1984, Kim et al. 1987, Yoo et al. 1993, Choi et al. 1994, Heong and Schoenly 1998). In the laboratory, spiders were particularly susceptible to organo-synthetic insecticides such as carbamates and organophosphates, while fungicides, herbicides, and natural insecticides such as Bt and neem had little or no toxicity for spiders (Stark et al. 1995). However, field studies often failed to lead to consistent conclusions in the determination of the impacts on spiders by synthetic insecticides (Kim et al. 1987, Grigarick et al. 1990, Choi et al. 1994). In addition to direct impacts, some studies emphasized that the effect of insecticide application should be examined by considering how much the prey-predator balance is disturbed during the rice-growing season (Cohen et al. 1994, Settle et al. 1996, Schoenly et al. 1996, Matteson 2000).

Carbofuran granules and fenobucarb emulsions constitute a high proportion of the insecticides used under conventional insect pest control systems in Korea (Anonymous 2005). These insecticides target *L. oryzophilus* in the early season and *N. lugens* in the mid- and late season, respectively. A little is known about pesticide impacts under field conditions on key components of biological communities including target species, natural enemies, and other species. This study was conducted to intensively examine the direct effects of these insecticides on the population dynamics of arthropods and to infer their impacts on trophic interactions.

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MATERIALS AND METHODS

Experimental Design

This study was conducted in the experimental fields of the National Institute of Agricultural Science and Technology (NIAST), Dangsu-dong, Suwon, Gyeonggi-do, Korea in 2001. Two rice paddies (0.1 ha each) were selected for the experiment: one for insecticide treatment and the other serving as a control; and rice seedlings (variety "Chucheong") were transplanted by machine transplanting (3 plants/hill, 30 × 15 cm spacing) on 25 May. Both fields were managed according to standard rice cultural practices except for insecticide treatment. On 21 June, five pairs of *N. lugens*/hill were released on 120 hills randomly selected in each field. Insecticides were applied twice in the treated field. Furadan® (carbofuran 3GR, 3 kg/10a) targeting *L. oryzophilus* was submerged by hand application on 1 June, and Bassa® (fenobucarb 50%EC, 1,000×, 150 L/10a) targeting *N. lugens* was foliar sprayed by a power sprayer (HS-70A, Asia Agricultural Machinery Co., Korea) on 16 August.

Arthropod Sampling

Sampling was conducted from 14 June to 13 September in weekly intervals. A sample (three or four hills depending on the rice growing stage) was randomly selected and enclosed by a round plastic cage (50 cm diameter, 90 cm height) in the field. All arthropods above the water surface inside the cage were sucked up by a suction device (D.C. 12V, Bioquip Co.). Ten samples were taken in each field on each sampling occasion. Arthropods from each sample were kept in a vial of 70% ethyl alcohol. Then arthropods were counted and identified to the species or genus level under a dissecting microscope (10～40×) in the laboratory.

Data Analysis

Arthropods were divided into five functional groups: herbivores, parasitoids, predaceous insects, spiders, and filter feeders/detrivores, based on Heong et al. (1991) and Park and Lee (2006). Spiders were further divided into wandering spiders such as *Pirata subpiraticus* (Bösenberg et Strand) (Lycosidae), *Pachygnatha clerki* Sundevall (Tetragnathidae), *Clubiona* sp. (Clubionidae), *Marpissa* sp. (Salticidae), and *Xysticus* sp. (Thomicidae), and web-building spiders such as Erigoninae spp. (Linyphiidae), *Enoplognatha* sp. (Theridiidae), *Tetragnatha* sp. (Tetragnathidae), and *Araneus* sp. (Araneidae). Spiders were also sorted according to their developmental stages, such as adult and immature.

To quantitatively compare the arthropod community composition between fields untreated and treated with insecticides, the Kendall-tau similarity index, which is a nonparametric measure of association based on the number of concordances and discordances in paired observations, was used (Knight 1966). The density of arthropods was transformed into log (x+1) and was analyzed by a pooled or paired *t*-test. All statistical analyses were conducted using SAS (SAS Institute 1999).

RESULTS

Arthropod Community

Forty taxa, which are represented by five functional groups, were collected during the study period (Table 1). Compared to arthropod density in the untreated field, density in the treated field was reduced by 48.4% for total arthropods, by 55.2% for filter feeders/detrivores, by 44.0% for herbivores, and by 39.7% for spiders. Among the herbivores, densities of *L. oryzophilus* and *N. lugens,* which were target insect pests of carbofuran GR and fenobucarb EC, respectively, were remarkably reduced. Among non-target groups, the density difference between the two treatments was little for parasitoids and predaceous insects, but was great for some species of spiders and filter feeders/detrivores.

Table 1. Total density of arthropods in rice fields (insecticide treated or untreated) in Dangsu-dong, Suwon, Korea, during the rice-growing season in 2001

Guilds and Taxa	Untreated	Treated
Herbivores		
Aphididae	8.0	3.0
Nilaparvata lugens (Stål)	238.6	125.5
Sogatella furcifera (Horvarth)	2.9	4.9
Laodelphax striatellus (Fallen)	19.5	17.7
Nephotettix cincticeps (Uhler)	1.8	1.5
Oxya sp.	0.1	0.0
Rhopalus maculates (Fieber)	0.1	0.0
Trigonotylus coelestialium (Kirkaldy)	0.1	0.0
Pachygrontha antennata (Uhler)	0.0	0.3
Thysanoptera	0.2	0.2
Lissorhoptrus oryzophilus Kuschel	3.8	0.2
Chlorops oryzae Matsumura	1.6	1.4
Mythimna separata Walker	0.0	0.3
Sub-total	276.7	155.0
Parasitoids		
Mymaridae	0.6	0.6
Braconidae	2.1	1.8
Sub-total	2.7	2.4

Table 1. Continued

Predaceous insects		
Aquarius sp.	0.3	0.3
Microvelia sp.	0.8	2.1
Orius sp.	1.3	1.5
Cercyon aptus Sharp	0.4	0.9
Stenus sp.	5.1	2.0
Paederus parallelus Weise	0.7	0.2
Scymnus hoffmanni Weise	0.7	0.9
S. tsushimaensis Sasaji	0.1	0.2
Hippodamia tredecimpunctata (Linné)	0.4	0.6
Platynus daimio (Bates)	0.1	0.8
Conocephalus sp.	0.0	0.1
Gryllidae	0.3	0.4
Dermaptera	0.1	0.0
Sub-total	10.3	10.0
Spiders		
Pirata subpiraticus (Bösenberg et Strand)	24.1	17.3
Pachygnatha clerki Sundevall	6.3	6.4
Clubiona sp.	16.5	7.3
Marpissa sp.	0.3	0.4
Xysticus sp.	1.2	0.7
Erigoninae spp.	62.8	36.4
Enoplognatha sp.	13.8	6.5
Tetragnatha sp.	0.7	0.9
Araneus sp.	0.3	0.1
Sub-total	126.0	76.0
Filter feeders/Detrivores		
Chironomidae	163.4	94.9
Ephydridae	0.0	2.4
Entomobryidae	260.9	92.7
Sub-total	424.3	190.0
Total	840.0	433.5

Samples were collected on 13 occasions from 14 June to 13 September. Densities are total of mean number per each occasion.

The similarity in arthropod community composition between untreated and treated rice fields fluctuated during the rice-growing season (Fig. 1). The similarity was high when insecticide activity seemed to disappear. The disturbance impact on the arthropod community by carbofuran GR in the early season appeared rather late, but increased as time went on. The similarity increased when carbofuran seemed to become ineffective. Fenobucarb EC treatment in the mid-season also decreased the similarity but its effect lasted a much shorter time than that of carbofuran GR.

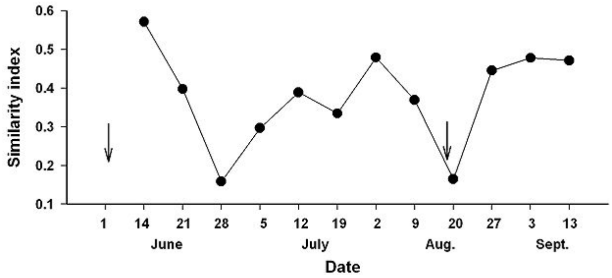

Fig. 1. Changes in the similarity index values of arthropod composition between untreated and treated rice fields, Dangsu-dong, Suwon, Gyeonggi-do in 2001. Arrows indicate dates of insecticide applications.

Target Insect Pest Populations

The density of *L. oryzophilus* was low in both fields (Fig. 2a). The application of carbofuran GR on 1 June kept the *L. oryzophilus* population very low in the treated field. In the untreated field, on the other hand, adult *L. oryzophilus* emerged for a short time in mid-July. *N. lugens* populations increased noticeably on 12 July (Fig. 2b). On 12 and 19 July the density of *N. lugens* was higher in the untreated field, but statistical significance was found only on 12 July (*t*-test, $df = 15$, $p = 0.0294$; $df = 18$, $p = 0.1486$, respectively).

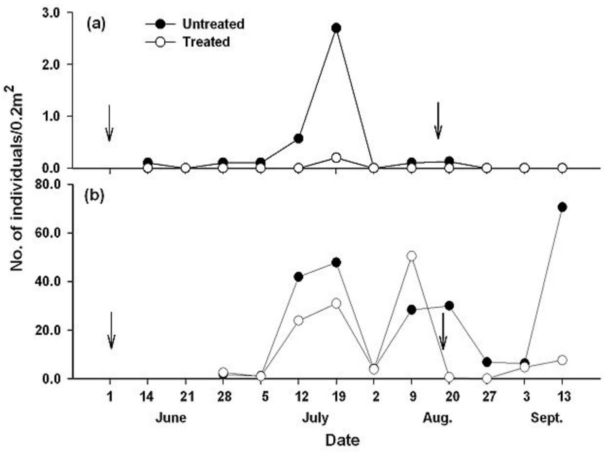

Fig. 2. Population patterns of *L. oryzophilus* (a) and *N. lugens* (b) in insecticide untreated and treated rice fields, Dangsu-dong, Suwon, Gyeonggi-do in 2001. Arrows indicate dates of insecticide applications.

On 9 August, the *N. lugens* density was higher in the treated field but statistical significance was not shown ($df = 18$, $p = 0.1471$). After fenobucarb EC treatment against *N. lugens*, the *N. lugens* density remained low in the treated field, whereas it increased remarkably in the untreated field on 13 September (*t*-test; $df = 18$, $p = 0.0001$) (Fig. 2b).

Spiders

Fig. 3 shows the spider population dynamics in the two fields during the study period. Spider populations gradually increased toward the late season in the untreated field. However, spider populations in the treated field decreased immediately following the application of fenobucarb EC on 16 August, and then started to recover somewhat a few weeks later.

Fig. 4 shows that the impact of the carbofuran GR treatment on spider abundance, which was determined by averaging the density of five successive samplings taken in one-week intervals from 14 June to 12 July, seemed non-existent. The densities of total, adult, and immature wandering spiders (paired *t*-test; $df = 4$, $p = 0.3098$, $p = 0.61361$, $p = 0.3814$, respectively) and web-building spiders ($df = 4$, $p = 0.6327$, $p = 0.7577$, $p = 0.6589$, respectively) did not differ significantly between the two fields (Fig. 4).

However, the fenobucarb EC treatment affected spider abundances significantly (Fig. 5). Before treatment, spider abundances were similar between the two fields. Four days after treatment (DAT), total spider abundances had decreased significantly in the treated field (*t*-test; $df = 14$, $p = 0.0001$). The abundance of wandering spiders in the treated field significantly decreased in all developmental stages ($df = 14$; $p = 0.0009$, $p = 0.0009$, $p = 0.0001$ for immature, adult, and total, respectively). For web-building spiders, adults were not significantly affected ($df = 14$, $p = 0.21$), but immature spiders were significantly affected ($df = 14$, $p = 0.028$). Eleven DAT in the treated field, the density of adult wandering spiders had recovered ($df = 18$, $p = 0.57$), but the densities of total and immature wandering spiders remained significantly low ($df = 18$; $p = 0.006$, $p = 0.002$, respectively). The abundance of web-building spiders (total and immature) appeared lower in the treated field, although no statistical significance was obtained ($df = 18$; $p = 0.0745$, $p = 0.0701$, respectively). The density of adult web-building spiders was not different ($df = 18$, $p = 0.25$). On 18 and 28 DAT, the densities of total, adult, and immature wandering spiders were not significantly different between the two fields ($df = 18$, $p = 0.35$, $p = 0.37$, $p = 0.72$ for 18 DAT; $p = 0.35$, $p = 0.79$, $p = 0.27$ for 28 DAT). In contrast, the density of immature web-building spiders had not recovered, and the densities of total and immature web-building spi-

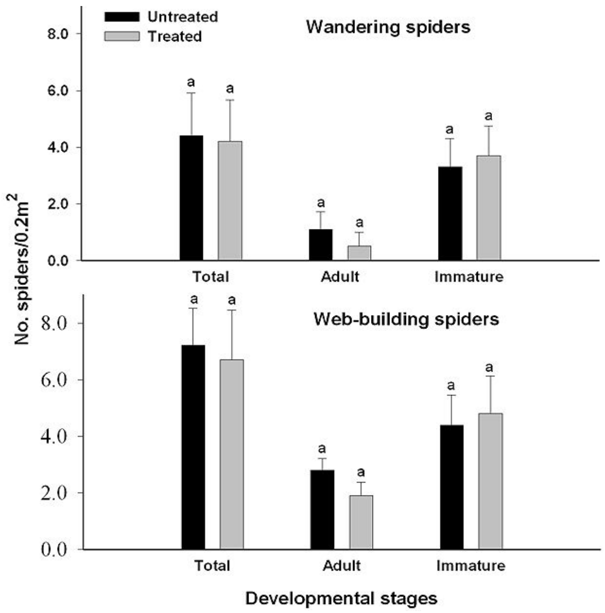

Fig. 4. Comparison of spider abundances by guild and developmental stages between insecticide untreated and treated plots after the carbofuran GR treatment (1 June) in the rice fields, Dangsu-dong, Suwon, Gyeonggi-do in 2001. The spider abundance was determined by averaging five successive samplings taken in one-week intervals from 14 June to 12 July. Statistical analysis was conducted using log (x+1) transformed data

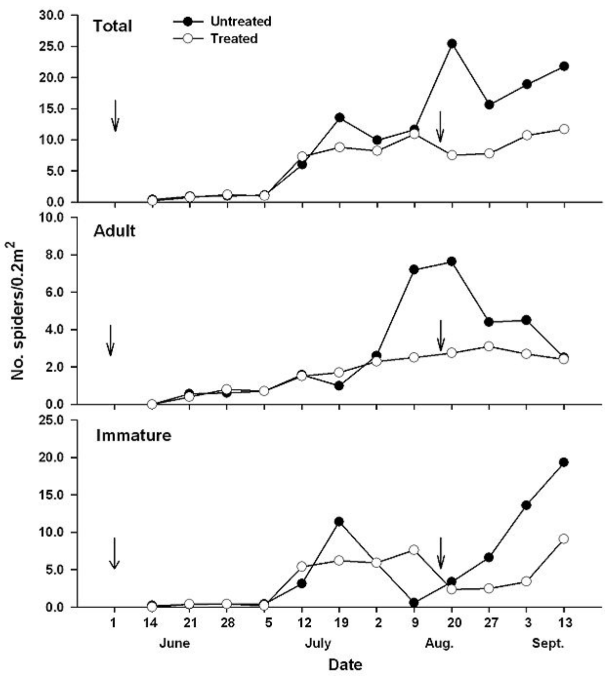

Fig. 3. Population patterns of total, adult, and immature spiders in insecticide untreated and treated rice fields, Dangsu-dong, Suwon, Gyeonggi-do in 2001. Arrows indicate dates of insecticide applications.

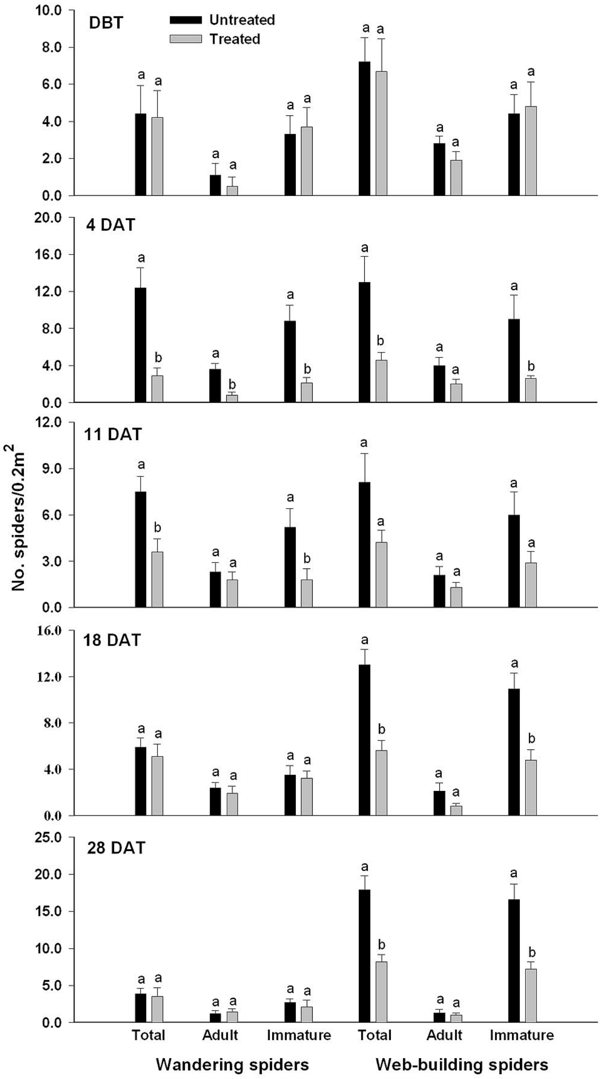

Fig. 5. Comparison of spider abundance by guild and developmental stages between insecticide untreated and treated plots before and after the fenobucarb EC treatment (16 August) in the rice fields, Dangsu-dong, Suwon, Gyeonggi-do in 2001. DBT and DAT indicate days before treatment and days after treatment, respectively.

ders remained significantly lower in the treated field ($df = 18$, $p = 0.0002$, $p = 0.002$ for 18 DAT, respectively; $p = 0.00012$, $p = 0.0004$ for 28 DAT, respectively) although the density of adults was not significantly different ($df = 18$; $p = 0.12$, $p = 0.95$ for 18 DAT and 28 DAT, respectively).

Filter Feeders/Detrivores

Fig. 6 shows the dynamics of chironomid and entomobryid populations, which are representative filter feeders/detrivores in rice fields. Carbofuran GR treatment on 1 June in the treated field reduced the chiromomid population by 50% compared to that of the untreated field in the early season. The impact of carbofuran was not apparent on 14 June (*t*-test; $df = 18$, $p = 0.918$), but became apparent on 21 and 28 June ($df = 17$, $p = 0.0001$; $df = 18$, $p = 0.0071$, respectively). The impact on entomobryid populations by fenobucarb EC was also very significant. Before the treatment, the entomobryid population was significantly higher in the treated field ($df = 18$, $p = 0.0347$), but after treatment, the density became significantly lower in the treated field ($df = 16$, $p = 0.001$) and was kept much lower than that in the untreated field until the late season.

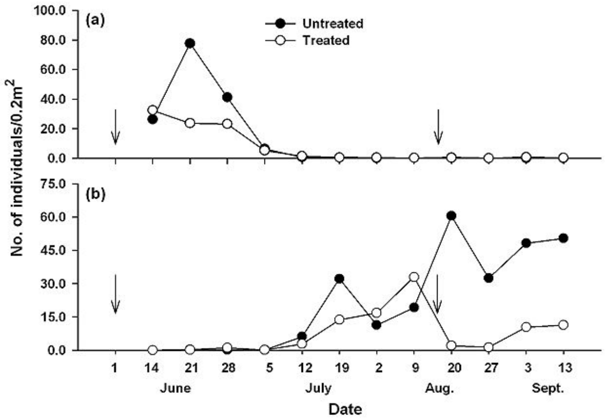

Fig. 6. Abundance pattern of chironomid (a) and entomobryid (b) populations in insecticide untreated and treated plots in the rice fields, Dangsu-dong, Suwon, Gyeonggi-do in 2001. Arrows indicate dates of insecticide application.

DISCUSSION

The abundance of arthropods in rice ecosystems changes according to insecticide treatments, seeding or planting methods, and the pollution of irrigation water (Lee et al. 1997, Park and Lee 1997, Yun 1997, Lee et al. 1998, Schoenly et al. 1998). Of these factors, the most significant decline in arthropod density was found in the fields where broad-spectrum insecticides were applied (Yun 1997). The present study also shows that conventional insecticide treatments can considerably decrease the densities of spiders and filter feeders/detrivores (Table 1).

In Korea, conventional practices for insecticide treatment have usually targeted two major insect pests: *L. oryzophilus* in early June and *N. lugens* in early and mid-August. Currently, carbofuran GR is the leading insecticide to control rice insect pests in the early season (Anonymous 2005). In this study, application of carbofuran GR by the submerged method on 1 June increasingly disturbed the formation of the normal arthropod community in the early season (Fig. 1). The chironomid population decreased continuously after treatment (Fig. 6a), and this impact on non-target organisms by carbofuran treatment was also reported by Simpson et al. (1994). The chironomid populations in the Korean rice ecosystems typically show high peak density in June and July, and sharply decrease thereafter (Kim et al. 2001). They are the secondary consumers in the aquatic food web (Yoshioka et al. 1994) and are valuable prey as the primary carbon source supporting the predators such as spiders in rice fields during the early season (Park and Lee 2006). Although the chironomid population was not completely destroyed in the treated field, the lower density might have a negative impact on arthropod community development, considering their importance as food of the predators in the early season in rice fields.

Carbofuran was one of the most toxic chemicals to dominant spiders such as *P. subpiraticus* and *Gnathonarium dentatum* in laboratory tests (Yoo et al. 1993). Yoo et al. (1984) reported that the dust formulation was more toxic than wettable powders or emulsions. In this study, the application of carbofuran GR did not disturb the build-up of spider populations in the early season (Figs. 3, 4). The application of carbofuran to the soil also did not reduce the spider population in the early season (Bae 1992). These results suggest that it is desirable to consider not only toxicity itself, but also the formulation type, as well as the method and timing of insecticide applications to evaluate the negative impact of insecticides on spider populations in field conditions. In the Korean rice ecosystem, during the early season (mid-May to early July), the initial spider population remains low and spiders colonize actively into rice fields during the season (Lee et al. 1997, Yun 1997, Park et al. 2005). Therefore, the application of granular insecticides in the early season may not directly reduce the spider population. In tropical rice fields, several foliar sprays in the early season resulted in the destruction of predators and outbreaks of insect pests (Cohen et al. 1994, Settle et al. 1996).

Fenobucarb EC is one of the leading insecticides to control rice insect pests in the mid- and late season (Anonymous 2005). Fenobucarb EC effectively reduced the *N. lugens* population by approximately 99% (Fig. 2b). It also reduced entomobryid (Collembola) populations by 70% (Fig. 6b). In rice fields, Collembola species were very abundant during the mid- and late seasons (Lee et al. 1997, Park and Lee 1997, Yun 1997). Settle et al. (1996) and Takahashi (2000) suggested that Collembola, such as entomobryids, would be one of the important preys of general predators such as spiders and microvellids. Considering stable isotope values of entomobryids, they served as alternative preys supporting the predator complex in rice fields during the mid- and late seasons (Park and Lee 2006). Reduction of the entomobryid population might negatively affect predators in the mid- and late seasons.

Fenobucarb EC also disturbed the spider community (Fig. 5), although of the insecticides commercially available to control *N. lugens*, it is known as one of the least toxic to natural enemies (Fabellar and Heinrichs 1984, Yoo et al. 1993). Reduction of the spider populations by fenobucarb EC was high in both wandering and web-building spiders and immature spiders were more affected than adult spiders (Fig. 5). It is known that younger spiders were more severely affected than older ones by pesticides (Heimbach et al. 1998). Also, it appears that impact of fenobucarb EC on spiders differed according to their behavioral differences. Web-building spiders remained low over time while wandering spiders recovered a few weeks later (Fig. 5). Wandering spiders might escape the field rapidly responding to insecticide treatment and re-colonize the field later while web-building spiders could not.

The *N. lugens* population sharply increased in the untreated field in mid-September (Fig. 2b), which is a typical population increase pattern when hopperburn occurs in rice fields in Korea. The natural enemy complex seemed to fail to effectively suppress the *N. lugens* population in the untreated field. However, in this study, the high density of *N. lugens* in late July (50 individuals/0.2 m^2, Fig. 2b) was apparently due to the high release density in mid-late June (5 pairs of *N. lugens*/hill on 120 hills). The artificial infestation density was much higher than typical real infestation densities of *N. lugens* in the rice fields during a similar period in Korea. In field conditions, we experienced frequent failures in the buildup of the *N. lugens* population with low initial infestation levels. Similarly, in the case of the small brown planthopper, *L. striatellus*, Seo et al. (2005) tried to build up the population by releasing *L. striatellus* at six different levels (0 to 40 adults/m^2) in rice fields in the early season, but failed. When released in greenhouse conditions, the *L. striatellus* population showed a 200-fold increase within two months. Thus, when infestation levels of insect pests are low, the natural enemies should play an important role to suppress them effectively.

Our study showed the significant disturbance impact of insecticide treatment on the arthropod community, especially on spiders and filterfeeders/detrivores in rice fields. We suggest that the pesticides and application methods used in controlling rice pests should be selected carefully to increase the compatibility between pesticide treatments and biological resources in the rice ecosystem, and that this approach would be very helpful in developing a higher-level IPM strategy.

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