Biological control of the brown planthopper

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Outbreaks of the brown planthopper *Nilaparvata lugens* Stål are often attributed not only to high plant density, heavy nitrogen fertilization, and continuous cropping, but also to the decreasing populations of natural enemies caused by increased use of insecticides. Because those natural enemies are always present in paddy fields, their actions help reduce the brown planthopper population if they are properly managed.

To date, 79 species of natural enemies of the brown planthopper have been recorded, including 42 species of parasites and pathogens (34 insects, 1 nematode, and 7 pathogens) and 37 species of predators (21 insects and 16 spiders) Some of them have shown great potential for controlling pest populations

This paper presents a general review of the natural enemies of the brown planthopper, and the response of natural enemies to insecticides.

OUTBREAKS OF THE BROWN PLANTHOPPER (BPH) *Nilaparvata lugens* Stål have been reported recently from India, Indonesia, the Solomon Islands, and Sri Lanka. BPH control depends almost solely on the regular application of insecticides. Untreated paddy fields usually suffer heavy hopper infestation and the damage commonly known as hopperburn.

Many natural enemies are almost always present in the paddy fields. Their role in suppressing insect populations has long been considered important. During the last decade, studies of the biological control of the BPH have been conducted in several countries, but they have been generally restricted to the ecology and biology of natural enemies, or to surveys of natural enemies to identify species and estimate the amount of parasitism or predation. However, little practical effectiveness has been demonstrated in the field. Otake (1976b) indicated that the natural enemies of planthoppers on rice have been much less intensively studied than those of the rice stem borer.

Only recently, the effects of insecticides on the natural enemies of insect pests have attracted the attention of entomologists working on control programs.

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The use of selective insecticides and low rates of application to achieve control without destroying natural enemies has been considered. However, no rice insect has ever been consistently controlled solely by natural enemies. Feasibility of using natural enemies as part of integrated control to regulate the BPH must be investigated.

NATURAL ENEMIES

Parasites and pathogens of the BPH have been reported from Taiwan, Japan, Thailand, India, Malaysia, Sri Lanka, Sarawak, Fiji, Philippines, and the Solomon Islands. At least 19 species of hymenopterous insects (Eulophidae, Mymaridae, and Trichogrammatidae) have been identified as egg parasites. Sixteen species belonging to Hymenoptera (Dryinidae), Strepsiptera (Elenchidae), and Diptera (Pipunculidae) were identified as parasites of BPH nymphs and adults. One species of nematode (Mermithidae) and seven species of fungi (Entomophthoraceae and Stilbaceae) were also found in nymphs and adults of BPH (Table 1).

Egg parasites

Mymaridae. Lin (1974) surveyed the BPH parasites obtained from field-collected samples of eggs in Taipei and Pingtung, Taiwan. He found that *Anagrus* sp. was most prevalent among the trichogrammatid and mymarid

Table 1. Egg parasites of *Nilaparvata lugens.*

Parasite	Country of occurrence	Reference
Hymenoptera		
Eulophidae		
Ootetrastichus nr *beatus*	Fiji	Hinckley (1963)
Mymaridae		
Anagrus flaveolus	Japan	Yasumatsu and Watanabe (1965)
A nr flaveolus	Japan	Otake (1970a,b. 1976a,b)
A. optalilis	Thailand	Yasumatsu et al (1975), Nishida et al (1976)
Anagrus sp.	Taiwan, Japan, Malaysia	Lin (1974). Fukuda (1934). Kuno (1973), Heong (pers. comm.)
Anaphes spp.	Solomon island	MacQuillan (1974)
Gonatocerus sp.	Thailand	Yasumatsu et al (1975)
Lymaenon sp.	Taiwan	Lin (1974)
Mymar? indica	Taiwan	Lin (1974), Chiu et al (unpubl.)
M. taprobanicum	Thailand	Yasumatsu et al (1975)
Polynema sp.	Thailand	Yasumatsu et al (1975)
Trichogrammatidae		
Aphelinoidea sp.	Taiwan	Fukuda (1934)
Oligosita sp	Thailand	Yasumatsu et al (1 975)
Oligosita sp. A.	Taiwan	Lin (1974)
Oligosita sp. B.	Taiwan	Lin (1974)
Paracentrobia andoi	Taiwan, Japan	Suenaga (1963), Lin (1974)
P. garuda	Thailand	Yasumatsu et al (1 975)
P. yasumatsui	Thailand	Yasumatsu et al (1975)
Trichogramma sp.	Taiwan	Fukuda (1934)

parasites. It constituted 93% of the egg parasites of the BPH in Taipei paddy fields. Chiu et al (1975) also reported egg parasitism at four sites in northern Taiwan during 1974 and 1975. Most of mymarid parasites appeared in May and June, and from September through November. The parasitism ranged from 11.3 to 29.6% in the first crop and 3.3 to 38.1% in the second crop.

Yasumatsu et al (1975) reported that four mymarid parasites—*Anugrus optubilis, Mymar taprobanicum, Polynema* sp., and *Gonatocerus* sp.—have contributed much to the reduction of the populations of planthoppers and leafhoppers in Thailand. Nishida et al (1976) also indicated that *A. optabilis* was more abundant than *Paracentrobia yasumatsui* (Trichogrammatidae) or a few other unidentified parasites. Parasitism rates ranged from less than 10% to 100%.

Anagrus species had been reported to be a common parasite of delphacid eggs in paddy fields. It was as abundant as *Laodelphax striatellus* and it often attacked eggs of BPH (Otake 1967). Parasitism could be easily detected through the transparent chorion of the host egg when the parasite larva was at least half grown (Otake 1970b). The parasitism of *Anagrus* reported by Kuno and Hokyo (1970) in Fukuoka ranged from 10 to 15% during the various seasons. Otake (1976b) reported that the parasitization of the BPH by *A.* nr *flaveolus* in Zentuz and Kagawa, Japan, was 44.5% and 66.9% respectively. The parasite was said to influence BPH populations during the early growth stages of the pest (Otake 1976b). The seasonal trends in parasitic and dispersal activities of *A.* nr *flaveolus* parasitizing in *L. striatellus* were studied by Otake (1970a).

Trichogrammatidae. Four genera, including at least eight species of Trichogrammatid parasites, have been reported attacking the BPH, but only 3 species of *Paracentrobia* have been identified (Table 1).

Yasumatsu et al (1975) reported that in addition to the mymarid parasites, *Paracentrobia yasumatsui, P. garuda,* and *Oligosita* sp. were abundant and effectively suppressed the population of leafhoppers or planthoppers in Thailand.

Two species of trichogrammatids were found to attack BPH eggs in Sri Lanka. The parasitism rate was about 80%. However, that rate was not consistent, and the parasites did not appear to have much influence on the host population (Fujimura and Somasunderam, unpubl.).

Paracentrobia andoi and *Oligosita* spp. were reared from eggs of the BPH in Taiwan; the parasitism rate was found to be extremely low (Lin 1974). Chiu et al, in a field-sampling and rearing study during 1974 and 1975, found that the trichogrammatid parasitism rates in the first rice crop ranged from 0.6 to 11.7% in Taipei and 7.5 to 19.5% in Hsinchu. They believed that the actual parasitism rate may be higher if sampling and counting methods are improved.

Eulophidae. A eulophid, *Ootetrastichus* sp. nr *beatus* Perk. was observed parasitizing delphacid eggs in Fiji. However, the parasitism appeared to be rare (Hinckley 1963).

Nymph and adult parasites

Dryinidae. Six species of dryinid parasites of the BPH were reported (Table 2). A few unidentified dryinids were recorded in Thailand, Taiwan, India, Sarawak, and Sri Lanka.

A parasitized nymph or adult carries a sac on its abdomen; a mature larva of the parasite emerges from the sac and spins a cocoon and pupates on the surface of a rice leaf or any surface.

Otake (1976b) indicated that the adult dryinids were often caught in paddy fields in Japan, but did not usually parasitize planthoppers to a great extent.

Dryinid larvae sacs carried by rice planthopper nymphs and adults at Ilu, Solomon Islands, have been seen from time to time. The encyrtid parasites *Echthrogonatopus exitiosus* Perk. and *Chrysopophagus australiae* Perk. were reared from the larval sacs on BPH (MacQuillan 1974).

Otake and Hokyo (1976) also reported the low parasitism of BPH by dryinids in Java. The parasites gave little control of pest populations when the BPH was epidemic.

During 1973 and 1974, the parasitism by dryinids of adult BPH and *Sogatella furcifera* in Maha, Sri Lanka, was found to be 5.5% by rearing and 2.3% by dissection (Santa et al. unpubl.).

Elenchidae. Four species of *Elenchus* attacking the nymphs and adults of BPH were recorded (Table 2). Female planthoppers parasitized by elenchids often had degenerate ovipositors (Otake 1976b) and both sexes of the host were inevitably sterile (Kuno 1973). The parasitized hoppers were generally recognized by the extrusion of male parasite puparia or by the opening made by a female adult parasite (Otake 1976b).

Yasumatsu et al (1975) reported that in northern Thailand, the BPH was frequently parasitized by *Elenchus yasumatsui* Kif. & Hir. They believed that the role of the parasite in controlling BPH was significant. The parasitism by *E. yasumatsui* averaged 30% and reached a maximum of 90% in the first rice crop. Parasitized hoppers were also found in the second rice crop in Thailand (FAO 1975).

Hinckley (1963) reported that the BPH was occasionally parasitized by *Elenchus* (*Liburnelanchus*) *koebelei* (Pier.) in Fiji. Another species, *Elenchus japonicus,* also attacks nymphs and adults of planthoppers in Fukuoka, Japan (Kuno 1973). In Sarawak, where a high degree of natural control of the hopper population occurs, rice leafhoppers and planthoppers with protruding Strepsiptera female adults and pupae frequently occur (Munroe 1975). According to his survey in 1974, adult hoppers of the most common species (including the BPH) attacked by Pipunculidae and Strepsiptera had a parasitism rate of 20 to 30% and occasionally one as high as 65%.

The parasitism of BPH caused by Strepsiptera and dryinid Hymenoptera in some locations in Sri Lanka was generally low (Fernando 1975). The combined parasitism by elenchids and dryinids of *S. furcifera* and the BPH occasionally reached 40% (Otake 1976b).

Table 2. Nymph and adult parasites of *Nilaparvata lugens*

Parasite	Country of occurrence	Reference
Hymenoptera		
Dryinidae		
Echthrodelphax bicolor	Japan	Esaki and Hashimoto (1936)
E. fairchildi	India	Rai (pers. comm).
Haplogonatopus japonicus	Japan	Esaki and Hashimoto (1931), Sakai (1932), Esaki and Mochizuki (1941)
Haplogonatopus sp.	India	Rai (pers comm)
	Sri Lanka	Santa et al (unpubl.)
Pseudogonatopus flavifemur	Japan	Esaki and Hashimoto (1 933, 1936), Esaki (1932), Sakai (1 932)
P. hospes	Thailand	Napompeth (unpubl.)
Encyrtidae (Hyperparasites of Dryinidae)		
Chrysopophagus australiae	Solomon Island	MacQuillan (1974)
Echthrogonatopus exitiosus	Solomon Island	MacQuillan (1974)
Strepsiptera		
Elenchidae		
Elenchus laponicus	Japan	Esaki and Hashimoto (1932), Esaki (1932), Sakai (1932), Mochida and Okada (1973), Kuno (1973)
E. koebelei	Fiji	Hinckley (1963)
E. yasumatsui	Thailand	Kifune and Hirashima (1975), Yasumatsu et al (1975), Otake (1976b)
Elenchus sp.	Sri Lanka	Santa et al (unpubl.)
Diptera		
Pipunculidae		
Dorylas sp.	Sri Lanka	Santa et al (unpubl.)
Pipunculus javanensis	Taiwan	Chiui et al (unpubl.)
Tomosvaryella oryzaetora	Taiwan	Chiui et al (unpubl.)
T. epichalca	Taiwan	Chiui et al (unpubl.)
T. subvirescens	Taiwan, Thailand	Chiui et al (unpubl.), Yasumatsu et al (1975)
Nematoda		
Mermithidae		
Agamermis unka	Japan	Esaki and Hashimoto (1933), Esaki (1932), Imamura (1932), Kaburaki and Imamura (1932), Kuno (1973)
Pathogen		
Entomophthoraceae		
Entomophthora nr *coronata*	Japan	Okada (1971)
E. nr *apiculata* var. *major*	Fiji	Hinckley (1 963)
E. coronata	Philippines	IRRI (1973), Gabriel (1968)
E. delphacis	Japan	Esaki and Hashimoto (1936, 1937), Sakai (1932), Shimazu (1976), Aoki (1957)
Stilbaceae		
Isaria farmosa	Japan	Aoki (1 957)
Hirsutella sp.	Philippines	IRRI (1973), Gabriel (1968, 1970)
H. citriformis	Solomon Island	MacQuillan (1974)

Pipunculidae. Five species of pipunculid parasites were recorded in BPH nymphs and adults in Sri Lanka, Thailand, Taiwan (Table 2), and Sarawak (unidentified). The degree of parasitism was not high. Yasumatsu et al (1975) reported that *Tomosvaryella subvirescens* Loew was the most important parasite of leafhoppers or planthoppers in Thailand. However, its population was not as high as in temperate countries.

Chiu et al (1974) found four species of pipunculids (Table 2) were also attacking BPH nymphs and adults in Taiwan but with very low parasitism rates.

Nematodes

Nematode parasites of the BPH have been reported from Japan, Sri Lanka, and the Solomon Islands, but only one species, *Agamermis unka* Cobb. (Mermithidae), was identified. Sakai (1932) reported that *Agamermis* usually occurred from June to December, but was most abundant from August through October in Japan. *Agamermis* left its hosts for the soil, where it matured during winter. Mating took place in mid-May. Eggs were laid from late June to early autumn. Larvae appeared in the rice field, swimming until they reached rice plants where the insect hosts were located. After a 2- or 3-week parasitic period, *Agamermis* left its host again. In general, one or two *Agamermis* were found in one host. If parasitism by fungi, bacteria, sporozoa, etc. can be prevented, the nematode is able to breed in the soil under optimum temperature and moisture conditions. Parasitized hoppers had swollen abdomens and were inactive; they could also be distinguished by their dark-brown color (Kaburaki and Imamura 1932). Nematode parasitism of BPH collected from rice fields occasionally reached 38.1% to 41.3% (Sakai 1932; Esaki and Hashimoto 1930). If an artificial rearing technique can be developed *Agamermis* might be able to play an important role in BPH control.

Otake et al (1976) observed in BPH an unidentified nematode parasite whose parasitism rate sometimes reached 20%.

Pathogens

Seven species of entomophagous fungi were found to infect BPH (Table 2), but only a few caused high mortality. *Entomophthora* fungi are considered the most important pathogens for control.

Fungal infestation of *E. delphacis* Hori. was low, but high from August through November in Japan (Sakai 1932). Okada (1971) isolated *E.* nr *coronata* Srin. & Thir. from adult BPH and reported that the infestation of the fungus produced by spraying a conidia suspension was also low. *E.* nr *apiculata* var. *major* was a more important agent for reducing BPH populations in Fiji, especially in densely planted rice. Its infestation rates of adult and nymphal hoppers occasionally exceeded 10% under humid conditions, but never reached an epidemic level (Hinckley 1963). Occasionally *Hirsutella citriformis* Spea. was responsible for some mortality of *S. furcifera* and BPH at Ilu, Solomon Islands (MacQuillan 1974).

The fungi *E. coronata* and *Hirsutella* sp., which usually occurred near the end of a rice crop, periodically killed BPH in paddy fields at the International Rice Research Institute (IRRI). Padua and Gabriel (1975) isolated *E. coronata* and successfully grew it in artificial media. They tested a medium of coconut milk and water for mass production. *Hirsutella* sp. was prevalent from October to November in IRRI experimental fields (Gabriel 1970), but it has not been successfully cultured.

Isaria farinosa also seldom infested BPH in paddy fields (Aoki 1957).

Miridae

Cyrtorhinus lividipennis Reuter is widely distributed in Southeast Asia, Australia, and the Pacific Islands (Table 3). It preys on the eggs, nymphs, and adults of rice leafhoppers and planthoppers and has been considered an effective predator of the BPH and the green leafhopper *Nephotettix virescens* (Hinckley 1963; IRRI 1973; Lim 1974; Stapley 1976; pers. comm. with C.S. Li).

Table 3. Predators of *Nilaparvata lugens.*

Predator	Country of occurrence	Reference
Hemiptera		
Nabidae		
Nabis sp.	Japan	Kuno (1973)
Miridae		
Cyrtorhinus lividipennis	Japan, Sarawak, Solomon Island, Philippines, India, Indonesia, Sri Lanka, Thailand, Malaysia, Taiwan, Australia	Suenaga and Takeuchi (1952), Suenaga (1963), Wan (1972), Bae and Pathak (1966, 1968), MacQuillan (1968), Stapley (1975, 1976), Pawar (1975), Yasumatsu et al (1975), Lim (1974), Chiu and Lung (1975), Li (pers, comm.), Otake et al (1976), Fernando (pers comm.)
C. lividipennis vitiensis	Fiji	Hinckley (1963)
Tytthus chinensis	Fiji, Japan, Solomon Island	Kobayashi (1961), Hinckley (1963). MacQuillan (1968, 1974), Stapley (1976)
T. mundulus	Taiwan, Fiji	Chiu and Lung (1975), Hinckley (1963)
T. parviceps	India	Pathak and Saha (1976)
Hymenoptera		
Formicidae		
Tetramorium guineense	Taiwan	Fukuda (1934)
Coleoptera		
Carabidae		
Acupalpus inornatus	Taiwan	Chiu et al (unpubl.)
Bembidion semilunium	Taiwan	Chiu et al (unpubl.)
Casnoidea cyanocephala	Malaysia	Lim (1974)
C. infersititrialis	Sri Lanka, Malaysia	Lim (1974), Fernando (1975), Otake et al (1976)
Ophionea indica	———	Otake (1976b)

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Table 3 continued

Predator	Country of occurrence	Reference
Staphylinidae		
Paederus fuscipes	Japan, Malaysia Taiwan, Thailand	Lim (1974), Otake (1976b), Chiu et al (unpubl.), Yasumatsu et al (1975)
Stenus cicindelloides	Taiwan	Chiu et al (unpubl.)
Coccinellidae		
Coccinella arcuata	Australia India, Fiji, New Guinea, Papua	Israel and Prakasa Rao (1968), Abraham et al (1973), Otake (1976b), Hinckley (1963), Li (pers. comm.)
C. repanda transversalis	Fiji	Hinckley (1963)
Harmonia sp.	Philippines	Dyck and Orlido (unpubl.)
Hippodamia tredacimpunctata	Mainland China	Lei and Wang (1958)
Micrapis discolor	Thailand, Malaysia, Indonesia	Otake (1976b)
M. vincta	Thailand	Otake (1976b)
Verania sp.	Philippines	Dyck and Orlido (unpubl.)
Araneae		
Argiopidae		
Neoscona doenitzi	Japan	Kayashima (1960)
Araneus inustus	Taiwan	Chiu et al (unpubl.)
Lycosidae		
Lycosa pseudoannulata	Japan, Taiwan, Philippines	Kiritani et al (1971, 1972), Chu and Wang (1972, 1973), Sasaba et al (1970, (1973), IRRI (1974), Otake (1976b)
Pardosa T-insignita	Korea	Choi and Lee (unpubl.)
Pirata subpiraticus	Korea	Choi and Lee (unpubl.)
Micryphantidae		
Oedothorax insecticeps	Japan, Taiwan, Korea	Sasaba et al (1970), Kiritani et al (1972), Chiu et al (1974), Otake (1976b), Kobayashi (1961), Paik et al (1974)
Salticidae		
Plexippus paykulli	Japan	Sakai (1932)
Icius magister	Japan	Sakai (1932)
Theridiidae		
Enoploynatha japonica	Japan	Kiritani et al (1972), Kuno (1973), Otake (1976b)
Theridion spp.	Philippines	IRRI (1972)
T. octomaculatum	Taiwan	Chiu et al (unpubl.)
Tetragnathidae		
Tetraynatha spp.	Japan	Kiritani et al (1973), Kuno (1973), Otake (1976b)
T. Japonica	Taiwan	Chiu et al (unpubl.)
T. mandibulata	Taiwan	Chiu et al (unpubl.)
T. nitens	Taiwan	Chiu et al (unpubl.)
Linyphiidae		
Notioscopus pallidulus	Japan	Sakai (1932)

Many workers have observed the predatory activity of *C. lividipennis* against rice hoppers. Bae and Pathak (1966) considered it an active predator against BPH in the greenhouse. IRRI entomologists determined its predation rate at the equivalent of a kill of 0.6 or more planthoppers per day by each predator. It usually killed more nymphs than adults, especially the young nymphs. In the field, the most damaging period probably was when young nymphs were abundant. The predation of *Cyrtorhinus* on BPH was 79% in a 1 : 1 ratio per day while 23% died in a 1 : 20 ratio. Bae and Pathak also showed that the mirid appeared to be an effective predator against both, but more destructive to the green leafhopper than to BPH (IRRI 1973, 1974).

In the Solomon Islands, the maintenance of *C. 1ividipennis* populations on grass appeared to be important in the control of rice planthoppers. Whether the predators entered a rice field depended on the adjacent grass, especially *Digitaria.* A 6-week fallow period for a rice field at the beginning of the year may also help reduce the hopper population. Weeds in the fallow field allow the mirid to multiply. Stapley (1976) suggested that the ratio of prey to predator should be 20: 1.

Hinckly (1963) indicated that mirid bugs preying on eggs were a very important cause of rice hopper mortality in Fiji. *Cyrtorhinus* was the most common, but its populations did not increase rapidly enough to prevent a heavy infestation of BPH in transplanted rice. The mirids were less effective in seedbeds except in grassy areas. It also appeared that *Cyrtorhinus* prevented the increase of pest populations in drilled rice fields, but was less effective in transplanted rice.

Lim (1974) witnessed large numbers of *C. lividipennis* in Malaysian fields and an associated reduction of leafhopper populations. Such observations clearly indicate the significance and potential of the predator.

In Taiwan, two species of mirids, *C. lividipennis* and *Tytthus mundulus,* attacked BPH and green leafhoppers in paddy fields. *T. mundulus* (Bred.) was formerly recognized as an egg predator of the sugarcane leafhopper *Perkinsiella saccharicida.* Its presence was also reported in Australia, Java, Fiji, Philippines, and Hawaii (Chan and Ju 1951). Chiu and Lung in 1975 first observed that it also fed on BPH nymphs. Its appearance, life history, and habitat are similar to those of *C. lividipennis.* It differed in color pattern and a few morphological characteristics. *T. mundulus* was prevalent in May or June while *C. lividipennis* occurred in October and November. There were about 10 generations in a year. Nymph or adult mirids can kill the BPH at every developmental stage. One adult mirid usually preyed on 1 to 20 eggs at one feeding. Nymphal mirids consumed fewer eggs. Mortality rate of the BPH was about 73% when equal numbers of third instar mirids and second instar BPH were caged for 24 hours. It would appear that the mirid plays an important role in BPH control (Chiu and Lung, unpubl.).

Swezey (1936) stated that because it feeds on both parasitized and nonparasitized eggs of leafhoppers, *Cyrtorhinus* reduces the effectiveness of egg parasites.

Other mirid predators preying on the eggs of planthoppers were *T parviceps* (Lin.) and *T. chinensis* (Stål) (Pathak and Saha 1976; Stapley 1976; Kobayashi 1961).

Coccinellidae

Coccinellid beetles are important members of arthropod communities in paddy fields where they play a valuable role in the biological control of insect pests of rice. Sasaji (1968) studied the fauna of oriental coccinellids in paddy fields, and 33 species were recorded, seven of which were recognized as predators of the BPH (Table 3). Yasumatsu et al (1975) reported six species of coccinellids common in the rice fields of Thailand. Among them, *Micrapis discolor* Fabr. and *M. vincta* Gorh. were abundant. *M. discolor* was also dominant in Malaysia (Otake and Hokyo 1976). It is believed that planthoppers are a part of their diet.

Coccinella arcuata has been known as the most common and important coccinellid predators of BPH and *S. furcifera* in India, Fiji, Australia, and Papua, New Guinea (Table 3). In Cuttack, India, the increase of planthopper populations (including the BPH) in rice fields was closely followed by a rapid multiplication of *C. arcuata* from mid-August until late September. Then the hopper population gradually decreased until late October. Because of its feeding habit *C. arcuata* may prove to be an effective predator of rice hoppers (Israel and Prakasa Rao 1968).

IRRI entomologists caged coccinellid predators with BPH preys in a ratio of 1:4 on potted rice plants in a greenhouse. The mortality of BPH caused by *Harmonia* adults was 77% for nymphs and 91% for adults by *Verania* adults was 52% for nymphs and 93% for adults (V. A. Dyck and G. Orlido, unpubl.).

Other common carnivorous beetles found in paddy fields include carabids and staphylinids (Table 3). Staphylinid beetles, particularly *Paederus fuscipes* Curt., are probably significant in the control of insect pests in rice. They usually migrate to the young rice plants shortly after transplanting. In Taiwan, Chiu et a1 (1974) also found that *P. ,fuscipes* and *Stenus cicindlloides* were the most common staphylinid species in paddy fields.

Fukuda (1934) reported that an ant, *Tetranorium guineense* Fabr., preyed on eggs and attacked nymphs and adults of planthoppers during molting or emergence. V. A. Dyck and M. Orlido (unpubl.) also observed that some species of ants attacked the BPH.

Other predators that may be found preying on rice planthoppers in rice fields include Odonata, nabids, anthocorids. reduvids, hebrids, hydrometrids, ochterids, pleids, salids, and veliids; empidids and asilids, sphecids, nyssonids, stizids, and pemphtedonids ; birds ; frogs ; and a giant toad (*Bufo marinus*) (Habu 1958; Kobayashi 1961; Hinckley 1963; Asahina et al 1972; FAO 1975; Yasumatsu et al 1975).

Spiders

The spider fauna in paddy fields in Korea, Japan, Taiwan, and Thailand has been investigated (Table 4). About 16 species of spiders are recorded as preying on BPH (Table 3). *Lycosa pseudoannulata, Pirata subpiraticus, Pardosa T-insignita, Oedothorax insecticeps, Tetragnatha niten, T. japonica, Enoplognatha*

Table 4. Spider-families in paddy fields in Korea, Japan, Taiwan, and Thailand.[a]

Family	Spider species and genera (no.)							
	Korea		Japan		Taiwan		Thailand	
	Genera	Species	Genera	Species	Genera	Species	Genera	Species
Agelenidae	1	1	1	1				
Argiopidae[b]	5	8	8	12	6	12	9	16
Clubionidae	3	5	2	5	2	3	2	3
Ctenidae	2	2	1	1				
Dictynidae					1	1		
Hahniidae	1	1			1	2		
Heteropodidae			2	2	1	1		
Linyphiidae	1	1	2	2	3	3	1	1
Lycosidae	5	8	6	11	3	5	5	5
Micryphantidae	4	8	5	5	4	4	3	3
Oonopidae					1	1		
Oxyopidae	1	1	1	1	1	4	1	2
Pisaundae	1	3	1	3		[c]	2	3
Salticidae	5	6	9	10		(ca.5)		(ca. 10)
Tetragnathidae	3	8	4	11	4	11	4	13
Theridiidae	3	3	5	8	3	5	5	8
Thomisidae	5	9	8	11	7	8	4	4
Uloboridae			2	2			1	1
Total	37	64	57	85	37	62	37	59

[a] Data obtained from Okuma (1968), Okuma and Wongsiri (1973), Chu and Okuma (1970), and pers. comm. with J. S Park, Head, Ent. Dep., Inst. Agric. Sci., Korea. [b] Spiders confirmed to be predators of the brown planthopper, *Nilaparvata lugens.* [c] Including a few very young specimens not determined.

japonica, and *Theridion octomaculatus* were the major species. In India about 20 species of spiders were observed preying on BPH. It was believed these spiders could play an important role in keeping down BPH populations (Samal and Misra 1975).

Lycosa pseudeannulata Boes. et Str. *Lycosa pseudeannulata* a wolf spider, is one of the predominant spiders in paddy fields (Kobayashi 1961 ; Kawahara et al 1969; Sasaba et al 1970; Chu and Okuma 1970; Mochida and Dyck 1976). It has been considered an effective predator of rice hoppers in Taiwan, Japan, and the Philippines. Of the species preyed upon by the spider. 80% were the green leafhopper and BPH (Sasaba et al 1973; Kiritani et al 1972). The mean indices of food preference of adult female spiders assessed in the laboratory were 0.49 and 0.60 for BPH and *Nephotettix cincticeps,* respectively (Sasaba et al 1973). Kiritani et al (1972) also indicated that the ratio of prey taken by the spider was 5 green leafhoppers : 2 BPH in Japan between 1968 and 1970.

Lycosa inhabits the lower part of rice plants in the daytime but moves toward the middle and upper sections at night. The fact that leafhoppers tend to inhabit the middle and upper parts of rice plants while planthoppers inhabit the lower part might explain why *Lycosa* preys on more leafhoppers at night and on more BPH during the day (Sasaba et al 1973).

In the Philippines, *L. pseudeannulata* was common in IRRI rice fields. In spite of its relatively low field density, *Lycosa,* because of its high predation rate, was regarded by IRRI entomologists as the most important predator of BPH. IRRI entomologists caged *Lycosa* with different numbers of BPH adults and nymphs to determine its daily feeding capacity in relation to prey density during 3 consecutive days. Greater prey density occasionally increased the feeding rate of the spider. The spider generally showed no preference for nymphs over adults or vice versa. When 50 or 100 hoppers were available a spider killed an average of at least 14 BPH nymphs or 8 or more adults daily (IRRI 1975).

At IRRI (1976) it was also found that in a 14-day period each spider killed an average of 17 BPH nymphs/day. A similar experiment gave an average of 24 nymphs/day in 9 days. It was found in India that *Lycosa* could kill about 15 to 20 adult BPH/day (Samal and Misra 1975). In another experiment, when green leafhoppers and BPH were caged together with *Lycosa* for over 12 days, the spiders killed three times as many BPH as green leafhoppers. *Lycosa's* apparent preference for BPH over leafhoppers supports the contention that *Lycosa* is a greater predator of BPH than is *C. lividipennis.*

In Taiwan, *L. pseudoannulata* is the dominant spider in rice fields, particularly in the second rice crop. Predation rates observed in the laboratory were 3.08 and 4.28 adult BPH for the second and the fourth instar spider nymphs and 13.32 and 11.48 adult BPH for adult female and adult male spiders, respectively (Chiu et al, unpubl.).

Chu and Wang (1973) studied the feeding habit of the spider and found that leafhoppers and planthoppers were its preferred prey. They found that the daily predation rate of female spiders was apparently greater than that of males. The predation rate for females during their maternal care of their young was low and increased as the young spiders began to disperse. Cannibalism often occurred among the spiders when the food supply was inadequate.

Oedothorax insecticeps Boes. et Str. *Oedothorax insecticeps,* a micryphantid or dwarf spider, was also found to be an effective predator in Taiwan, Japan, and Korea. *Oedothorax,* a small species, prefers to prey on nymphs and adults of hoppers. In the laboratory Chiu et al (1974) observed that the daily predation rates averaged 1.84 and 3.00 adult BPH for second and fourth instar spider nymphs and 3.20 and 2.03 BPH for adult females and adult male spiders, respectively. The spider took prey more often under warmer conditions. The average number of BPH preyed on by each adult female was about 1.5 times that preyed on by a male. Cannibalism occurred when the prey population was low.

Oedothorax had 4 or 5 generations in northern Taiwan. Adults usually situated themselves near the paddy level above the roots, but frequently migrated by skating on the water surface or hanging on a silk that was transported by wind. They could tolerate about 20 days of starvation. The spider spun very thin, irregular webs which were difficult to see and efficient in catching prey. Ensnared victims usually died within 2 days, even if not fed upon.

Other spiders often occurred in paddy fields; *Tertragnathus* was a dominant species in Thailand, Malaysia, and Indonesia (Otake 1976b); *T. nitens* was common in Taiwan. *Gnathonarium dentatum* (Wider) and *Pirata subpiraticus* (Boes. et Str.) were major species in Korea (pers. comm. with J. S. Park,) and *Enoplognatha japonica* (Boes. et Str.) was a major species in Japan (Kiritani et a1 1972). *Theridion octomaculatum* (Boes. et Str.) often occurred in northern Taiwan from May through August; its webs were built on the lower part of rice plants under the rice canopy, situated well for predation on BPH.

RESPONSE OF NATURAL ENEMIES TO INSECTICIDES

Because the mortality of natural enemies was high when insecticides were applied, the response of natural enemies of arthropods to insecticides in rice fields was generally observed qualitatively rather than quantitatively. A number of entomologists have recently suggested that one reason for the presence of many rice hoppers could be the destruction of their natural enemies by intensive application of broad spectrum insecticides (Kobayashi 1961; Miyashita 1963; Kiritani 1972, 1975; Kiritani et a1 1971). The disturbance by insecticides of the balance between pests and natural enemies has contributed to the development and application of the concepts of integrated control and pest management, and has prompted studies of insecticide selectivity in relation to natural enemies (Croft and Brown 1975).

Lycosa and *Oedothorax,* two dominant spider species in Taiwan paddy fields, have been considered effective against rice hoppers. Unfortunately, they are very susceptible to the insecticides commonly used for rice-pest control.

Direct toxicity of insecticides to natural enemies

The reduction in numbers of natural enemies or the degree of parasitism or predation rate after insecticide application has been well documented.

Chu et al (1976b, c) used a dipping method to evaluate the susceptibility of *N. cincticeps, N. lugens,* and *L. pseudoannulata* to various insecticides. They found that the degree of susceptibility of the *Lycosa* spider to different chemical compounds varied greatly. Leptophos, dicrotophos, monocrophos were less toxic to the spiders than were CPMC, bufencad, fenthion, and PM. Fenthion was much more toxic to *Lycosa* than were fenitrothion and methyl parathion, which were commonly used for rice stem borer control.

In a laboratory study of contact toxicity of insecticides currently recommended for rice insect control, Chiu and Cheng (1976) found that *Lycosa* was generally more susceptible to the insecticides than was *Oedothorax* (Table 5). The carbamates tested were as toxic or more toxic than organophosphates. Of all insecticides tested, Hokbal EC., bufencarb, and carbofuran showed highest contact toxicity to the spiders. Compounds with lower toxicity were acephate, monocrotophos, MTMC EC., and sevin WP. All insecticides tested,

Table 5. The contact toxicity of insecticides on predators of the brown planthopper[a] (Chiu and Cheng 1976).

Insecticides	Concn (%)	Corrected mortality (%)		
		Lycosa Pseudoannulata	*Oedothorax insecticeps*	*Cyrtorhinus lividipennis*
		Organophosphates		
50% Fenthion EC	0.05	30	37	100
47% Parathion EC	0.047	30	25	100
40% Vamidothion S	0.05	35	21	85
50% Phosmet WP	0.05	30	20	100
50% Fenthion EC	0.05	15	26	100
75% Acephate SP	0.05	10	15	80
60% Monocrotophos	0.03	5	21	95
5% Disulfoton G	36 kg/ha.	25	8	–
5% Disulfoton G	18 kg/ha.	15	3	–
		Carbamates		
40% Bufencorb EC	0.05	90	21	100
25% Metalvariate 2 EC	0.027	80	25	100
30% MTMC EC	0.038	10	0	100
40% BPMC WP	0.05	35	65	100
50% MPMC WP	0.025	45	15	90
50% MIPC WP	0.025	35	15	100
50% Promecarb WP	0.05	30	5	85
50% Propoxus	0.05	25	20	100
50% CPMC WP	0.025	20	20	85
85% Sevin WP	0.05	15	10	100
50% MTMC WP	0.025	20	0	90
90% Methomy 1 WP	0.05	5	26	80
3% Carbofuran G	60 kg/ha.	95	35	–

[a] Twenty spiders or 40 mirids for each treatment with 2 replications. The spiders were forced to crawl over a chemical-solution film in a large petri dish for 10 minutes then were transferred individually to glass tube and fed with second or third instar nymphs of the brown planthopper. Mortality corrected by Abbott's formula.

except acephate and methomyl, were highly toxic to the mirid hopper predator, *C. lividipennis.*

Cheng et al (1973–75 unpubl.) estimated the rice yield loss caused by insect pests at 12 sites in Taiwan and the effect of frequency of insecticide application on natural enemies. Their results showed more predacious spiders and more egg parasitism in unprotected plots than in plots where insecticides were applied as needed, and fewer spiders and less parasitism in plots where insecticides were applied at 15-day intervals. Frequent insecticide applications apparently reduced the population density of natural enemies of rice crop pests. Similar results were obtained by Chiu et al (Table 6).

Indirect effects of insecticides on predators

Early advocates of integrated control of crop pests stressed the usefulness of compounds that act as systemic insecticides toxic to plant-feeding pests but not appreciably affecting their natural enemies; many experiments have demonstrated the selectivity of systemic toxicants. However, significant mortality of predators, not only from direct toxicity but also from the ingestion of prey

Table 6. Effect of insecticide thru treatments[a] on population densities of brown planthopper and two predacious spiders in paddy fields (1974–1975) (Chiu et al, unpubl.).

Insect	Insects[b] (no /hill)											
	First crop						Second crop					
	1974			1975			1974			1975		
	A	B	C	A	B	C	A	B	C	A	B	C
						Taipei						
BPH	1.0	1.4	2.6	0.3	0.4	1.2	1.7	2.4	11.5	0.8	4.4	3.3
Spider	1.0	1.4	1.7	0.6	0.9	1.1	0.7	0.9	1.5	0.4	0.7	1.2
						Hsinchu						
BPH	0.9	1.0	1.2	1.2	0.4	1.9	0.2	1.1	1.9	0.4	3.5	9.6
Spider	1.1	1.1	1.3	0.6	0.8	1.1	1.1	1.7	2.4	0.3	0.8	1.0

[a] A = insecticides applied on a schedule at 15–20 days intervals, 5-6 applications per crop, B = insecticides were applied as needed, C = no insecticide. [b] Numbers per hill of brown planthopper and predacious spiders, *Lycosa* and *Oedothorax,* shown are averages of 5 samplings at 20-day Intervals.

that had taken up the insecticides in more recent studies, was observed (Kiritani and Kawahara 1973; Chiu and Cheng 1976).

Although predators may be killed by secondary poisoning from contaminated prey, little is known about the fate of some toxicants inside the body of the prey and the factors that determine subsequent toxicity to predators. Kiritani and Kawahara (1973) studied in detail the fate and effect of BHC passing through a food-chain from irrigated soil to rice plants, then to rice hoppers, and finally to *Lycosa* spiders.

Chiu and Cheng (1976) reported the toxicity of insecticides commonly used for rice-insect control to the predators of planthoppers. Their data indicated that carbofuran G and fensulfothion G were more toxic than lindane G to *Lycosa* ; other insecticides—acephate, disulfoton, and fenthion—had low toxicity to spiders through their prey (Table 7). Chu et al (1976a) studied the insecticidal effects of BPMC and propoxur on the predatory ability of *Lycosa.* The results showed that the amount of predation carried out in 6 days by *Lycosa* that survived after feeding on BPMC and propoxur treated hoppers was about 85% of the predation of spiders fed on unpoisoned hoppers. That indicated that BPMC and propoxur had only slight effect on *Lycosa* through its prey.

CONCLUSION

Parasitism has been generally recognized as causing less planthopper mortality than predation. Most parasitism of brown planthopper is low and appears to have limited value for checking hopper populations. However, such a limitation may be overcome by the combined effect of several parasites that attack sequentially during the development of pest insect outbreaks. Various parasites predominate at different times during a crop-growing season, and

Table 7. Effect through the food-chain of granular insecticides on predacious spiders[a] (Chiu and Cheng 1976).

Insecticide	Rate (kg a.i./ha)	Mortality[b] (%)			
		L. pseudoannulata		*O. insecticeps*	
		in 24 h	in 72 h	in 24 h	in 72 h
Acephate G	1.8	0	5	0	15
Disulfuton G	1.8	0	5	5	10
Fenthion G	1.8	5	10	5	15
Propoxar G	1.8	10	20	5	10
Bufencarb G	1.8	25	30	5	10
Lindane G	2.1	20	70	10	35
Fensulfothion G	1.5	40	90	20	25
Carbofuran G	1.8	100	100	25	50

[a]Each treatment consisted of 20 spiders and was replicated twice. The insecticide was applied to irrigation water Twenty second to third instar brown planthopper nymphs and one spider were caged on a potted rice plant 5 days after insecticide application. [b]Corrected by Abbott's formula.

attack the BPH at different developmental stages. Combined egg-parasitism rates exceeded 90% or approached 100% in many localities in Thailand (Nishida et a1 1976). The combined egg-parasitism rate of BPH was also recorded as about 80.1% in Taiwan (Lin 1974) and 79.4% in Sri Lanka (Fujimura and Somasunderam, unpubl.). Otake (1976b) also pointed out that natural parasitism may have been underestimated because sampling and calculating techniques were inadequate. It is suggested that even if parasitism is not consistently high throughout a crop season, it may be more important for biological control of brown planthopper than has been thought in the past.

Predation is considered to be more important than parasitism for controlling brown planthopper population; the idea is supported by the abundant fauna of spiders and the existence of other predators. However, a current problem is how to conserve and augment natural enemies. Stapley (1975) indicated that the activity of *C. lividipennis* was increased where the grass *Digitaria* was grown. Fallowed paddy fields were also favorable for the multiplication of the predator. An important recommended practice is the maintenance of the natural population of predators through use of selective insecticides for rice insect pest control.

A better understanding of the responses of natural enemies of BPH to insecticides could eventually lead to better prognosis and better use of natural enemies in management of the insect pest. Experience has indicated that when chemical control is overemphasized, it can disrupt the balance between natural enemies and hoppers, causing heavy losses of the natural enemies and quick resurgence of the pest. When a rice pest management program is established, it would be desirable to apply insecticide less frequently and more critically than usually has been done. The use of selective insecticides and low application rates for brown planthopper control is one way to minimize the detrimental side effects on the environment, including the destruction of natural enemies.

Kiritani (1975) advocated that the effectiveness of insecticide control be assessed, not in terms of percentage killed, but in terms of degree to which the injury or damage caused by insect pests is decreased as measured by yield or crop quality. We must begin applying insecticides on the basis of necessity, and do away with routinary regularly scheduled treatments.

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