USE OF SPIDERS AS NATURAL ENEMIES TO CONTROL RICE PESTS IN KOREA

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ABSTRACT

Spiders play an important role in regulating insect pests in the agricultural ecosystem. There are a large number of species, many of them with high population densities. There are 22 families, 99 genera and 175 species of spiders in Korean rice fields. They limit the availability of habitats open to insect pests of rice by occupying various microhabitats. They have a wide range of prey species, catch significant numbers of prey and use various foraging strategies. Most of the spiders in rice fields seem to evacuate the field after the application of insecticides and move back into the field later. Their predatory capacity can have a synergistic effect in suppressing densities of insect pests when they are used to complement the effect of insecticides.

INTRODUCTION

For many decades, insecticides have been widely used to control rice pests. However, the continuous use of a wide range of pesticides has caused many side effects, including loss of biodiversity, the problem of secondary pests, insecticide resistance, residual toxicity, the resurgence of insect pests, and environmental pollution. Recently, many efforts have been made to combine various non-chemical control methods with insecticides in systems of Integrated Pest Management (IPM). One such effort is the combined use of natural enemies with insecticides. Many uses of parasitic and predatory natural enemies to control agricultural pests have been reported (Van den Bosch *et al.* 1992).

Spiders are carnivorous arthropods. They are classified into 40,000 species, and are found all over the world in almost every kind of habitat. They mainly prey on insects, although they may also feed on various other kinds of prey. The population densities and species abundance of spider communities in agricultural fields can be as high as in natural ecosystems (Turnbull 1973, Tanaka 1989, Riechert 1981).

Spiders consume a large number of prey, and do not damage plants. They can achieve an equilibrium in pest control, after which their own numbers are suppressed by their territoriality and cannibalism. For some time, spiders have been considered important predators which help regulate the population densities of insect pests (Pickett *et al.* 1946, Dondale 1956, Duffey 1962, Kajak *et al.* 1968, Fox and Dondale 1972, Tanaka 1989). In particular, spider communities in areas with a temperate climate achieve equilibrium in the control of agricultural pests (Riechert 1982). In spite of this, they have not usually been treated as an important biological control agent, because there is so little information on the ecological role of spiders in pest control (Turnbull 1973, Riechert and Lockley 1984).

However, research has shown that spiders in rice fields can play an important role as predators in reducing the densities of planthoppers and leafhoppers (Hamamura 1969, Sasaba *et al.* 1973, Gavarra and Raros 1973, Samal and Misra 1975, Kobayashi 1977, Chiu 1979, Holt *et al.* 1987, Tanaka 1989). In Korea, many studies have been carried out to evaluate spiders as a biological control agent. This Bulletin reviews past research into spiders in rice fields in Korea, and presents an effective method of using spiders as a biological control agent.

Keywords: hunters, Korea, pesticides, spiders, rice pests, web builders

STUDIES OF RICE FIELD SPIDERS IN KOREA

Since E. Strand first described *Ganphosa koreae* in 1907, there have been many publications about spiders in Korea. Currently, a total of 46 families, 222 genera and 626 species of spiders are recorded from Korea (Namkung *et al.* 2000).

Up until 1970, most of the research on spiders concentrated on identification. From the early 1970s, researchers began to study the basic ecological and biological characteristics of spiders as biological control agents. Spiders in rice fields have been studied more than spiders on other crops (Park *et al.* 1972, Paik and Kim 1973, Paik *et al.* 1974, Choi and Namkung 1976, Okuma *et al.* 1978, Paik *et al.* 1979, Yun and Namkung 1979, Paik and Namkung 1979, Paik and Namkung 1979, Kim *et al.* 1990, Kim 1992, Lee *et al.* 1993a, 1993b, Song and Lee 1994, Kim and Kim 1995, Kim 1995a, 1995b, Im and Kim 1996, Lee *et al.* 1997, Yun 1997, Yang *et al.* 1998, Kim 1998. Im and Kim 1999). However, most of these studies were limited to the identification of spiders, and to investigating the dominant spider species, their regional distribution, seasonal fluctuations and the effect of insecticides. There were few studies on the spatial distribution of spiders, how this is related to their ecological role, and how many insect pests they consume in rice fields.

RICE FIELD SPIDERS AVAILABLE IN KOREA

The spiders living in rice fields in Korea comprise 27.96% of all Korean spiders, and can be classified into 22 families, 99 genera and 175 species (Table 1). It has been reported that *P. subpiraticus*, *P. clercki* and *G. dentatum* are dominant spider species in rice fields (Paik *et al.* 1979). However, more recent studies have shown that there is no regional pattern in the distribution of rice field spiders, and that *P. subpiraticus* is the overall dominant species in Korea.

Table 1. Overview of spiders in Korean rice fields

Family	No. of genera	No. of species	Life style
1. Titanoecidae	1	1	Web builder
2. Dictynifae	1	1	Web builder
3. Uloboridae	3	3	Web builder
4. Pholcidae	1	1	Web builder
5. Theridiidae	9	16	Web builder
6. Nesticidae	1	1	Web builder
7. Linyphiidae	13	23	Web builder
8. Araneidae	10	22	Web builder
9. Tetragnathidae	6	14	Web builder
10. Agelenidae	3	3	Web builder
11. Hahniidae	1	1	Web builder
12. Pisauridae	2	3	Hunter
13. Lycosidae	6	20	Hunter
14. Oxyopidae	1	4	Hunter
15. Liocranidae	3	3	Hunter
16. Clubionidae	2	6	Hunter
17. Corinnidae	1	1	Hunter
18. Ctenidae	1	1	Hunter
19. Gnaphosidae	8	11	Hunter
20. Thomisidae	8	13	Hunter
21. Philodromidae	2	5	Hunter
22. Salticidae	16	22	Hunter
Total	99	175	

Table 2. Important spider predators of rice pests

Family	Species	Habitat
Theridiidae	*Enoplognatha transversifoveata* (Bösenberg et Strand, 1906)	Paddy field
	Theridion subpallens Bösenberg et Strand, 1906	Paddy field and levee
Linyphiidae	*Gnathonarium dentatum* (Wider, 1834)	Paddy field
	Ummeliata insecticeps (Bösenberg et Strand, 1906)	Paddy field
Araneidae	*Argiope bruennichi* (Scopoli, 1772)	Paddy field
	Lariniodes cornutus (Clerck, 1757)	Paddy field
Tetragnathidae	*Pachygnatha clercki* Sundevall, 1823	Paddy field
	Tetragnatha maxillosa Thorell, 1895	Paddy field
Pisauridae	*Dolomedes sulfureus* L. Koch, 1877	Paddy field and levee
Lycosidae	*Arctosa ebicha* Yaginuma, 1960	Paddy field and levee
	Arctosa subamylacea (Bösenberg et Strand, 1906	Paddy field and levee
	Pardosa astrigera L. Loch, 1878	Levee
	Pardosa laura Karsch, 1879	Levee
	Pirata subpiraticus (Bösenberg et Strand, 1906	Paddy field and levee
Clubionidae	*Clubiona kurilensis* Bösenberg et Strand, 1906	Paddy field
Salticidae	*Marpissa magister* (Karsch, 1879)	Paddy field and levee

SEASONAL OCCURRENCE OF SPIDERS IN KOREAN RICE FIELDS

Seasonal fluctuations of spiders in rice fields in Korea have been reported to follow an "M" shaped curve (Im and Kim 1996, Choi and Namkung 1976, Hokyo *et al.* 1976, Kim *et al.* 1990, Paik *et al.* 1979, Yang *et al.* 1998). Other surveys which began at a different time and covered a different period have reported that fluctuations in the density of spider communities followed a curve shaped like a "W" (Choi and Namkung 1976, Yun and Namkung 1979).

During the rice growing period in Korea, rice field spiders generally show two peaks. One is when spiders which have overwintered nearby migrate into the paddy, and the other is when the second generation of the year appears. However, annual fluctuations in numbers of rice field spiders showed several peaks when overwintering periods are included (Fig. 1).

Spiders in rice fields in Korea start to build up their populations in the middle of July, 40 - 45 days after transplanting, (Kim 1992, Yun 1997). The same pattern is seen in Japan, which has a similar agricultural environment (Kobayashi and Shibata 1973). Hamamura (1969) has reported that the density of spiders in rice fields in Japan is always low when transplanting is taking place. Lee *et al.* (1997) suggested that the different time taken by different spider species to immigrate from levees into paddy fields is the cause of the low initial population densities, in spite of the abundance of prey. However, Kim (1998) showed that the immigration rate of overwintering spiders from levees into paddy fields was low. He suggested that most of the dominant spider species immigrated from outside areas into the rice fields by ballooning (Note: "Ballooning" is the term used to describe the habit of young spiders of sailing through the air borne by silk strands on wind currents).

He also suggested that the immigration of the spiders was delayed after transplanting because the young rice plants are too small to provide a suitable habitat for either hunters or web builders.

Even though web builders were more numerous than hunters in some areas (Choi and Namkung 1976, Yun and Namkung 1979, Lee *et al.* 1993a, 1993b, Kim and Kim 1995), seasonal fluctuations in rice field spiders in Korea are thought to depend mainly on the density and species composition of hunting species of spider (Table 3, Park *et al.* 1972, Paik and Kim 1973, Paik *et al.* 1974, Okuma *et al.* 1978, Paik *et al.* 1979, Paik and Namkung 1979, Kim 1992, Song and Lee 1994, Kim and Kim 1995, Im and Kim 1996, Yang *et al.* 1998, Im and Kim 1999). Kim (1998) pointed out that if spiders are being used as biological control agents, it is very important to understand their life styles. Both web builders and hunters follow a foraging strategy. Song and Lee (1994) suggested that web builders such as *P. clercki* were better able to suppress insect pests than hunters such as *P. subpiraticus*. However, hunters are usually active predators which follow a "pursue and kill" foraging strategy, while web builders follow a passive "sit and wait" strategy (Enders 1974). Furthermore, the webbing sites of web builders are easily affected by environmental factors. In addition, when the web spaces overlap, there is competition with and between species of web builders. Therefore, hunters probably are more effective predators than web builders.

SUPPRESSION OF RICE BROWN PLANTHOPPERS BY SPIDERS

All the organisms in a rice field, as in other kinds of ecosystem, are involved in interactions within and between species, including prey-predator and host-parasite relationships (Hijii 1984). In particular, the interaction of prey and predator show a constant numerical interaction. Information about these relationships is fundamental to biological control.

Yamano (1977) suggested that spiders are the most important biological control agents regulating insect populations in rice fields, including insect

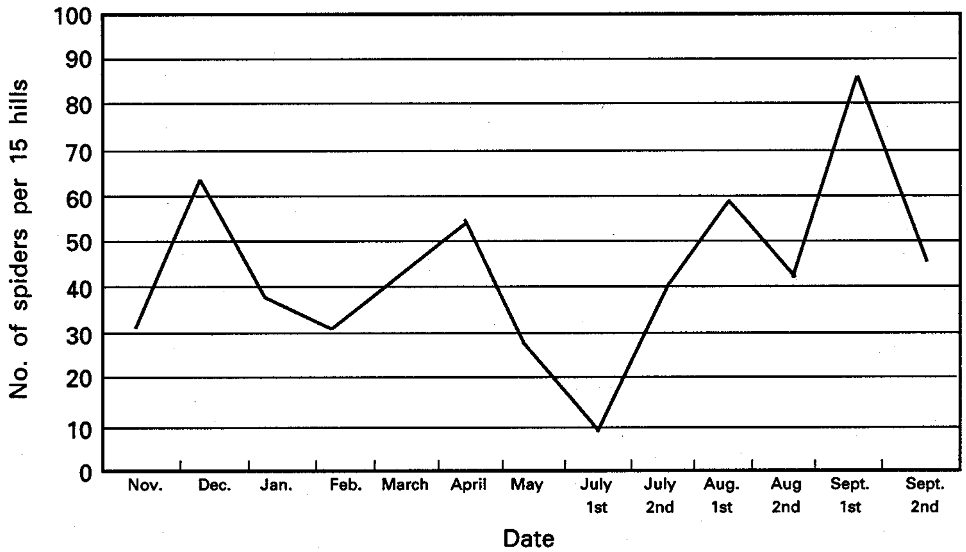

Fig. 1. Seasonal fluctuations in the mean density of spider populations in Yoju, Korea, 1994-1997

Table 3. Comparison of population levels and occupancy ratio of web builders and hunters in Yoju, Korea, 1994-1997

Season	Survey period	Site	Mean no.			Mean occupancy rate (%)	
			Total spiders	Web builders	Hunters	Web builders	Hunters
Production of rice crop	July - Sept. 1994-1996	Paddy field	274	108	166	39.4	60.6
		Levee	136	42	166	30.6	69.4
Hibernation	Nov. - May 1994-1997	Levee	285	70	94	31.6	68.4

pests. Predators tend to cluster in stable sites where many species of prey are maintained at a high density (Schmitt 1987). Seasonal fluctuations in the numbers of spiders in rice fields showed a constant numerical interaction with those of other arthropods, including insect pests.

The brown planthopper (*Nilaparvata lugens* Stål) is a pest which feeds only on rice plants (Otake and Hokyo 1976). Insecticides have been widely used to control brown planthoppers in Asian countries, including Korea (Nagata 1985). Integrated pest management programs to control this pest have been proposed, using natural enemies of planthoppers. Studies have reported numerous parasitic and predatory natural enemies of planthoppers. For predators alone, there are 14 species belonging to 13 genera in Korea (Okuma 1958, Suenaga 1963, Gavarra and Raros 1973, Samal and Misra 1975, Hamamura 1971, Chiu 1979, Kuno and Dick 1984, Shepard *et al.* 1987, Chua and Mikil 1989, Tanaka 1989, Kim *et al.* 1991, Choi *et al.* 1992, Choi and Lee 1990, Shepard and Ooi 1991, Ooi and Shepard 1994, Choi *et al.* 1996).

For effective control of brown planthoppers, predators should inhabit the same part of the rice plant, to reduce the time spent searching for prey. Brown planthoppers prefer to live on rice plants about 10 cm above the surface of the irrigation water (Lin 1970). This part of the plant is usually shaded, and has a high relative humidity and a relatively low temperature, both of which are favorable for reproduction of the pest. Leasar and Umzicker (1978) showed that humidity and temperature are the most important factors affecting the distribution of spiders. Most of the dominant species of spiders in Korean rice fields live on the lower 20 cm of rice plants (Table 5).

Spiders represent more than 90% of the natural enemies of brown planthoppers living in paddy fields in Korea (Lee *et al.* 1997). Because of this fact, most of the studies related to biological control of planthoppers have focused on spiders. Table 6 shows the mean number of brown planthoppers consumed each day by major species of rice field spiders. Subadults of *P. subpiraticus* consumed the greatest number, although the total numbers consumed by *C. kurilensis* and *G. dentatum* were as high. Spiders belonging to the species *P. subpiraticus* showed the greatest variation in daily consumption, while the number of planthoppers consumed each day by *C. kurilensis* and *G. dentatum* varied by only 0-4 planthoppers.

It appears that the difference in the numbers of planthoppers consumed by hunters and by web builders is the result of differences in the efficiency of their foraging strategies. Generally, female spiders consumed more prey than males, except in the case

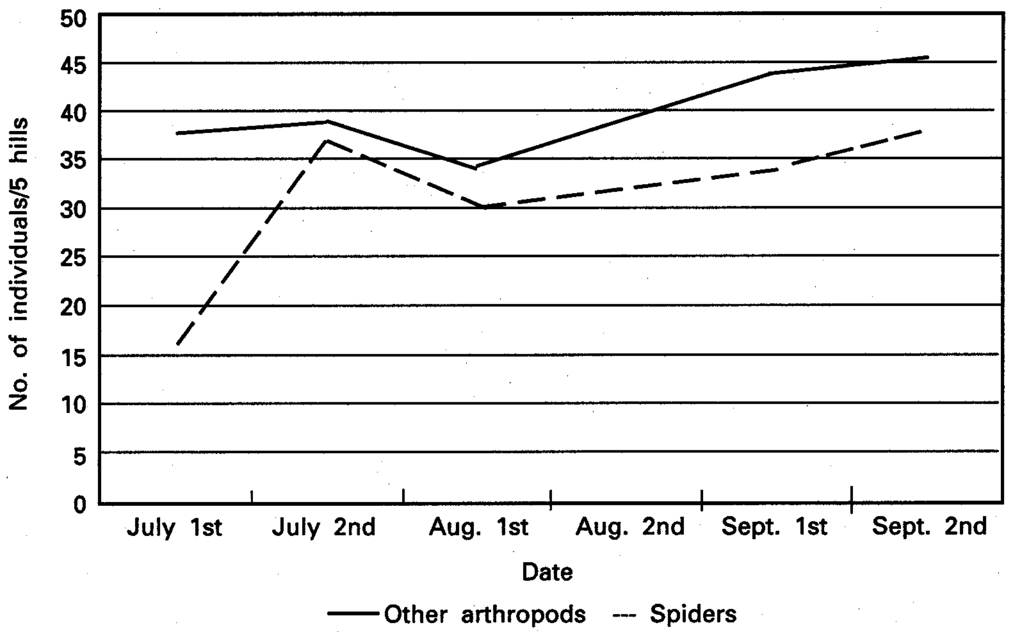

Fig. 2. No. of spiders in rice fields, and numerical response of other arthropods, in Yoju, Korea, 1996.

Table 4. Important arthropod predators of brown planthopper *(Nilaparvata lugens)* in paddy fields in Korea

Predatory species	Stage of BPH attacked
Paederus fuscipes (Coleoptera: Staphylinidae)	Nymph, adult
Microvelia douglasi (Hemiptera: Veliidae)	Nymph, adult
Mesovelia vittigera (Hemiptera: Mesoveliidae)	Adult
Gerris lacustris (Hemiptera: Gerridae)	Adult
Aquaris paludum (Hemiptera: Gerridae)	Adult
Cyrtorhinus lividipennis (Hemiptera: Miridae)	Egg, nymph
Tytthus chinensis (Hemiptera: Miridae)	Egg
Staccia diluta (Hemiptera: Reduviidae)	Nymph
Oncocephalus sp. (Hemiptera: Reduviidae)	Nymph
Hydrometra sp. (Hemiptera: Hydrometridae)	Adult
Sepedon sp. (Diptera: Sciomizidae)	Adult
Pardosa pseudoannulata (Araneae: Lycosidae)	Nymph, adult
Pirata subpiraticus (Araneae: Lycosidae)	Nymph, adult
Ummeliata insecticeps (Araneae: Linyphiidae)	Nymph adult

Table 5. Vertical distribution of important species of spider on rice plants in Korea

Vertical division	*Pirata subpiraticus*	*C. kurilensis*	*G. dentatum*	*U. insecticeps*	*T. praedonia*	*E. japonica*
(Above water/soil surface)						
< 20 cm	+++	++	+++	++	+	
20-40cm	+	++	++	++	+	++
40-60cm					++	++
60-80cm		++			+++	±
> 80 cm		±			+	

±: Very rare, +: Usually present, ++: Fairly common, +++: Abundant

of *G. dentatum.* It is thought that females usually need more energy for oviposition and brood care, while males need only the essential energy for survival. Subadults had a higher consumption rate than adults, which implies that the energy needs for growth are higher than those needed for reproduction.

COMPATIBILITY OF SPIDERS AND INSECTICIDES

Most studies of the effect of insecticides on natural enemies in the paddy field have focused on spiders. As we might expect, the results have shown that insecticides have a negative effect on the population densities of rice field spiders (Kuno 1968, Kuno and Hokyo 1970, Kawahara *et al.* 1971, Choi *et al.* 1978, Paik *et al.* 1979, Jang 1981, Ryu *et al.* 1984, Kim *et al.* 1984, Paik and Hwang 1990, Lee *et al.* 1993b, Bae *et al.* 1994).

The relative toxicity to spiders of various insecticides used against the brown planthopper was tested in the laboratory (Table 7). Carbofuran, which is widely used in rice fields, is very toxic to spiders (Bae *et al.* 1994). Choi *et al.* (1978) have suggested that the root zone placement of Carbofuran reduces the density of spiders in rice fields by direct lethal action, and by poisoning their food chain.

All the insecticides which were most lethal to spiders were dust or granule types. Many of those tested, such as sprays and wettable powders, were selective, in that *P. subpiraticus* had a higher survival rate after a longer period of exposure. This was

Table 6. Predation by major rice field spiders in Korea on brown planthoppers

Species	No. of planthopper	Subadults[1] ♀	Subadults[1] ♂	Range	Mean	Adults ♀	Adults ♂	Range[2]	Mean[2]
Pirata subpiraticus	15	4.5	2.7	0-12	3.6	3.4	2.3	0-9	2.8
Clubiona kurilensis	15	2.2	1.9	0-4	2.1	2.0	1.6	0-4	1.8
Gnathonarium dentatum	15	1.7	1.3	0-3	1.5	1.1	2.2	0-4	1.7
Ummeliata insecticeps	15	3.3	1.9	1-5	2.6	2.2	2.1	0-6	2.2

Rice was planted in a pot (12 cm in diameter) and covered with net (20 mesh). It was kept at 24°C, RH 70%. The experiment was replicated five times.

1 Instar around maturity

2 Mean and range for 7 days

Table 7. Relative toxicity of insecticides to the spider *Pirata subpiraticus*, and the brown planthoppers, *Nilaparvata lugens*

Insecticide	Formulation	No. tested	Mortality (%) *P. subpiraticus** (A)	Mortality (%) *N. lugens*** (B)	Relative toxicity (A/B)*
BPMC	Emulsion	60	86.7	100	0.867
BPMC	Dust	60	100	100	1
Carbofuran	Granules	60	100	100	1
Tebufenozide + BPMC	Wettable powder	60	70	100	0.7
Imidacloprid	Spray	60	16.7	100	0.167
Bufrofezine + BPMC	Wettable powder	60	10	100	0.1
Bufrofezin + isoprocarb	Wettable powder	60	90	100	0.9
Pyridaphenthio + metolcarb	Dust	60	100	100	1
Deltamethrin	Emulsion	60	96.7	100	0.967
Tebufenozide + bufrofezin	Wettable powder	60	23.3	46.7	0.499

† 24°C, RH 60%

‡ In a pot (7cm in diameter) in which rice was planted, and covered with a glass lid

✿ A/B < 1: Effective to *N. lugens*

A/B > 1: Damage to *P. subpiraticus*

A/B = 1: Effective to both

* Subadult (7th to 9th instar)

** Adult

probably because of the active behavior of this species. It is recommended that if there is no difference in the effect of different types of insecticides on brown planthoppers, the use of dust or granule type insecticides should be avoided.

Several studies have shown that the application of insecticides reduces the population density of spiders in rice fields (Park *et al.* 1972, Kawahara *et al.* 1971, Paik *et al.* 1979, Kim 1992, Yun 1997). They have a negative effect, not only on numbers, but also on species diversity (Lee *et al.* 1993a, 1993b). Even insecticides which generally protect natural enemies often have a negative effect on spiders (Clausen 1990). Hunting species tend to suffer more damage than web builders (Specht and Dondale 1960, Legner and Oatman 1964, Bostanian *et al.* 1984), while active hunters suffer more than less active ones (Bostanian *et al.* 1984).

In our study, when insecticides were applied to rice fields, the number of many arthropods, including insect pests, fell immediately afterwards. However, the population density of spiders was not affected (Fig. 3). This implies that many of the insecticides used in rice fields have some level of selectivity, and also that rice field spiders may have acquired insecticide resistance, as other arthropods have done. Therefore, the reduction of spider populations in rice fields after insecticide

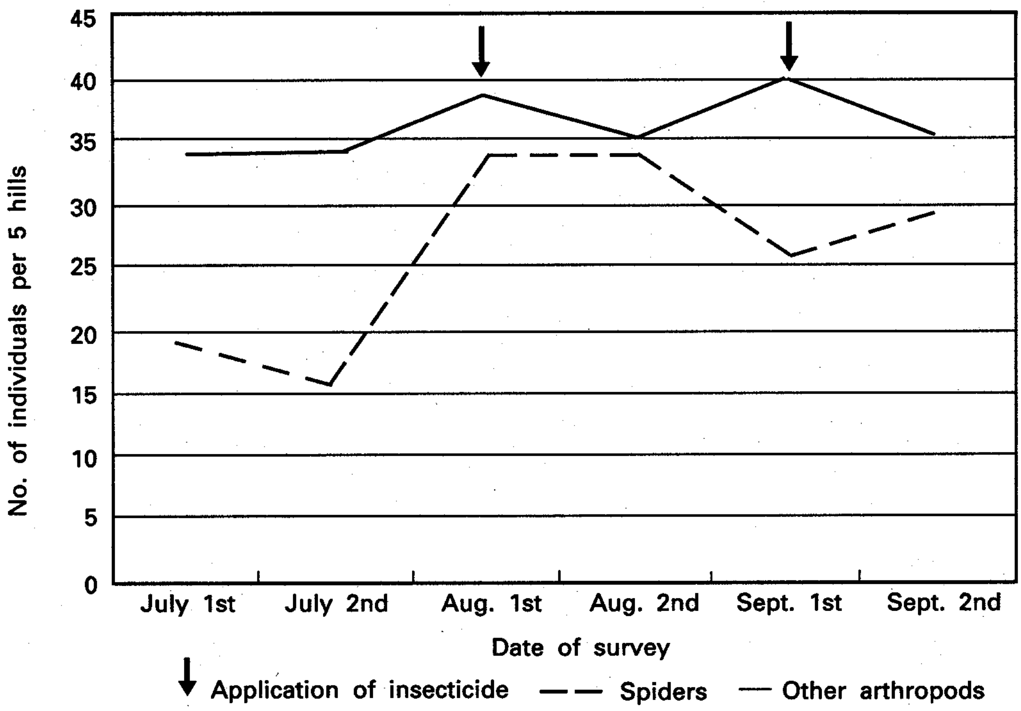

Fig. 3. Seasonal fluctuations in rice field spiders and other arthropods after insecticide applications in Yoju, Korea, 1996

applications shown in previous studies was perhaps not because the spiders were killed by the insecticides, but because their prey were killed. Lee *et al.* (1993a) showed that the density of hunters was higher than that of web builders in the period after insecticides were applied. They suggested that during the recovery period, the active hunters played an important role in rebuilding spider densities at this time.

Factors which produce mortality in brown planthoppers include high temperatures, predation and parasitism by natural enemies, nutritional deficiencies, and the maturity of crops (Cheng and Holt 1990). Table 8 shows the result of various combinations of insecticides, brown planthoppers and *P. subpiraticus*. The combination of an insecticide and *P. subpiraticus* gave the highest control value (66.8%). When insecticide was used alone, the control value was 63.4%, while *P. subpiraticus* used alone gave 51.6% control. This result suggests that there is a positive relationship between insecticide applications and control by *P. subpiraticus.*

When 16 individuals of *P. subpiraticus* were inoculated, the control effect was 4.5% higher than when 8 individuals were inoculated. This implies that if the population density of spiders is high enough, their control of brown planthopper can be as effective as that of insecticides, or even more effective.

The control effect of *P. subpiraticus* varied according to when it was introduced. When brown planthoppers were introduced first, the control value of *P. subpiraticus* was 51.6%. If *P. subpiraticus* was introduced before the planthoppers, the control value was 53.3%. Therefore, if the density of rice field spiders is high enough before the immigration of brown planthoppers, the spiders can control the planthoppers effectively and the number and quantity of insecticide applications can be reduced.

CONCLUSION

Large numbers of a wide range of spider species inhabit agricultural fields. Their presence limits the habitats open to insect pests. Spiders threaten insect pests with various foraging strategies. As well as consuming large numbers of insect pests as prey, they have the trait of killing all insects living in their territory. For this reason, spiders are a favorable biological control agent in the agricultural ecosystem.

Table 8. Control of brown planthopper (BPH) (*Nilaparvata lugens*) after different treatments

Treatment	Inoculation density		Mean density of BPH after harvest/8 hills (Mean ± SD)	Control value (%)[1]
	BPH	*P. subpiraticus*		
BPH (control)	16	0	128.6 ± 8.9	0a
BPH + insecticide	16	0	47.1 ± 3.4	63.4c
BPH + spiders + insecticide[2]	16	8	42.7 ± 2.8	66.8d
BPH + spiders (preinoculation of BPH)	16	8	62.3 ± 6.0	51.6b
BPH + spiders (preinoculation of BPH)	16	16	56.4 ± 3.9	56.1bc
BPH + spiders (preinoculation of spiders)	16	8	60.1 ± 7.2	53.3c

1 Percentage of control value followed by different letters are significantly different ($P < 0.05$) according to Duncan's multiple range test
2 Bufrofezin + BPMC

Fagan *et al.* (1998) indicated that treatments which combine the augmentation of natural enemies with insecticide applications may be counterproductive. However, spiders still play an important role in reducing the numbers of insect pests in agricultural fields, even when insecticides are used. In fact, spiders may be responsible for a significant proportion of insect deaths which were thought to be from insecticide applications (Carter and Brown 1973). A quantitative analysis of the capacity of spiders to suppress insect pests, including the spatial distribution of major species of spiders and pests, should be carried out in the field on a large scale, so that spiders can be successfully used as biological control agents.

Other ecological and biological characteristics of spiders also need to be understood. Chiu (1979) suggested that it takes longer for spiders to rebuild their population densities after the application of insecticides than planthoppers and leafhoppers, because spiders have a longer generation interval. Also, the development of selective insecticides, the effect of insecticides on spiders, and appropriate timing and quantities of insecticide applications, should all be considered.

REFERENCES

Bae, Y.H., J.H. Lee, and J.S. Hyun. 1994. A Systematic Application of Insecticides to Manage Early Season Insect Pests and Migratory Planthoppers on Rice. *Kor. Jour. Appl. Entomol.* 33, 4: 207-215.

Bostanian N.J., Dondale, C.D., Binns, M.R. and D. Pitre. 1984. Effects of Pesticide on Spiders (Araneae) in Quebec Apple Orchards. *Canadian Entomologist* 116: 663-675.

Cheng, J.A. and J. Holt. 1990. A system analysis approach to brown planthopper control on rice in Zhejiang Province, China. I. Simulation of Outbreaks. *Jour. Appl. Ecol.* 27: 85-99.

Chiu, S.C. 1979. Biological control of the brown planthopper. In: *Brown Plant-hopper, Threat to Rice Production in Asia.* International Rice Research Institute, Los Baños, Laguna, Philippines, pp. 335-355.

Choi, B.R., K.L. Heong, J.O. Lee, J.K. Yoo and C.G. Park. 1996. Effects of Sublethal Doses of Insecticides on the Brown Planthopper, *Nilaparvata lugens* Stål (Homoptera: Delphacidae) and Mirid predator, *Cyrtorhinus lividipennis* Reuter (Hemiptera: Miridae). *Kor. Jour. Appl. Entomol.* 35, 1:52-57.

Choi, J.S., H.G. Goh, K.B. Uhm, K.M. Choi and C.Y. Hwang. 1992. Life cycle of the Mirid predator, *Cyrtorhinus lividipennis* Reuter (Hemiptera: Miridae). *Kor. Jour. Appl. Entomol.* 31, 4: 329-337.

Choi, K.M. and M.H. Lee. 1990. Use of Natural Enemies to Control Agricultural Pests in Korea. In: *Use of Natural Enemies to Control Agricultural Pests*. Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei, Taiwan, ROC pp. 40-50.

Choi, S.S. and J. Namkung. 1976. Survey on the Spiders of the Rice Paddy Field (I). *Kor. Jour. Plant Protection* 15, 2: 89-93.

Choi, S.Y., H.R. Lee and J.K. Ryu. 1978. Effects of Carbofuran Root-zone Placement on the Spider Populations in the Paddy Fields. *Kor. Jour. Plant Protection* 17, 2: 99-103.

Chua, T.H. and E. Mikil. 1989. Effects of prey number and stage on the biology of *Cyrtorhinus lividipennis* (Hemiptera: Miridae): A predator of *Nilaparvata lugens* (Homoptera: Delphacidae). *Environ. Entomol.* 18: 251-255.

Clausen, I.H.S. 1990. Design of research work based on a pilot study dealing with the effect of pesticides on spiders in a sugar-beet field. *Acta Zool. Fennica* 190: 69-74.

Dondale, C.D. 1956. Annotated list of spiders (Araneae) in Nova Scotia apple orchards. *Canadian Entomologist* 88: 697-700.

Enders, F.A. 1974. Vertical stratification in orb web spiders (Araneae: Araneidae) and a consideration of other methods of coexistence. *Ecology* 55: 317-328.

Fagan, W.F., A.L. Hakim, H. Ariawan, and S. Yuliyantiningsih. 1998. Interactions between Biological Control Efforts and Insecticide Applications in Tropical Rice Agroecosystems: The Potential Role of Intraguild Predation. *Biological Control* 13: 121-126.

Fox, C.J.S. and C.D. Dondale. 1972. Annotated list of spiders (Araneae) from hayfields and their margins in Nova Scotia. *Canadian Entomologist* 104: 1911-1915.

Gavarra, M. and R.S. Raros. 1973. Studies on the biology of the predator wolf spider, *Lycosa pseudoannulata* Bös. st Str. (Araneae: Lycosidae). *Philippine Entomologist* 2, 6: 427.

Hamamura, T. 1969. Seasonal fluctuation of spider populations in paddy fields. *Acta Arachnol.* 22, 2: 40-50.

Hamamura, T. 1971. Ecological studies of *Pirata subpiraticus* (Bös. st Str. 1906) (Araneae: Lycosidae) I. *Acta Arachnol.* 23: 29-36.

Hamamura, T. 1977. Ecological studies of *Pirata subpiraticus* (Bös. st Str. 1096) (Araneae: Lycosidae) II. *Acta Arachnol.* 27 (Special number): 229-238.

Hijii, N. 1984. Arboreal Arthropod Fauna in a Forest. II. Presumed Community Structures based on Biomass and Number of Arthropods in a Chamaecyparis Obtusa Plantation. *Jap. Jour. Ecol.* 34: 187-193.

Holt, J., A.J. Cook, T.J. Perfect and G.A. Norton. 1987. Simulation analysis of brown planthopper (*Nilaparvata Lugens*) population dynamics on rice in the Philippines. *Jour. Applied Ecology* 24: 87-102.

Im, M.S. and S.T. Kim. 1996. Study on the ecology of the spiders as natural enemy on insect pest of main crops I, the fauna and population structure of the spiders at rice paddy field and levee. *Jour. Life Sciences, Konkuk Univ.* 3: 37-72.

Im, M.S. and S.T. Kim. 1999. Studies on the ecological characteristics of the spiders as natural enemy for rice insect pest at rice paddy field in Koesan area, Chungcheongbuk-do. *Journal of Development of Agricultural Resources, Konkuk Univ.* 21: 57-66.

Jang, Y.D. 1981. Studies on the protection and utilization of the natural enemy against rice insect pests. *Res. Reports, Agri. Tech., Chungnam Nat. Univ.* 8,1: 19-29.

Kajak, A., L. Andrzejeuska and Z. Wojcik. 1968. The role of spiders in the decrease of damages caused by Acridoidea on meadows — Experimental investigations. *Ekol. pol.* (A)16: 755-764.

Kawahara, S., K. Kiritani and T. Sasaba. 1971. The selective activity of rice-pest insecticides against the green leafhopper and spiders. *Botyu-Kagaku* 36: 121-128.

Kim, H.S. 1992. Suppressive Effects of Wolf Spider, *Pirata subpiraticus* (Araneae: Lycosidae) on the Population Density of Brown Planthopper (*Nilaparvata lugens Stål*). Unpublished Ph.D. Thesis, Dongkuk Univ, Seoul, Korea. 69pp.

Kim, H.S., Y.I. Lee and H.P. Lee. 1990.

Influence on the levee-burning on the fauna of insect pests and their natural enemies. *Kor. Jour. Appl. Entomol.* 29,3: 209-215.

Kim, H.S., D.J. Im, D.R. Choi and H.K. Ko. 1991. In: *Encyclopedia of Identification of Natural Enemy*. Rural Development Administration, Suweon, Korea, pp. 25-52.

Kim, J.B., D.J. Cho, C.H. Kim, K.B. Uhm and S.D. Chang. 1984. Studies on the seasonal fluctuation and the timing of control for the brown planthopper (*Nilaparvata lugens* Stål) and white-backed planthopper (*Sogatella furcifera* Horvath) in southern rice cultural area. Res. Reports, ORD (Office of Rural Development, Korea) 26-2 (S.P.M.U): 16-20.

Kim, J.P. 1995a. Studies of spiders in paddy fields and collecting methods. *Kor. Arachnol.* 11,2: 115-122.

Kim, J.P. 1995b. A list of Korean spiders in paddy fields. *Kor. Arachnol.* 11,2: 123-133.

Kim, J.P. and J.C. Kim. 1995. Influence of the levee and paddy burning on the fauna of overwintering spider. *Kor. Arachnol.* 11,2: 59-71.

Kim, S.T. 1998. Studies on the Ecological Characteristics of the Spider Community at Paddy Field and Utilization of the *Pirata subpiraticus* (Araneae: Lycosidae) for Control of *Nilaparvata lugens* (Homoptera: Delphacidae). Unpublished Ph.D. Thesis, Konkuk Univ., Seoul, Korea, 90 pp.

Kobayashi, S. 1977. Changes in population density of spiders in paddy field during winter. *Acta Arachnol.* 27 (special number): 247-251.

Kobayashi, S. and H. Shibata. 1973. Seasonal changes in population density of spiders in paddy fields, with reference to the ecological control of the rice insect pests. *Jap. Jour. Applied Ent. Zool.* 17,4: 193-202.

Kuno, E. 1968. Studies on the population dynamics of rice leafhopper in a paddy field. *Bull. Kyushu Agri. Exp. Stn.* 14,2: 131-246.

Kuno, E. and V.A. Dyck. 1984. Dynamics of Philippines and Japanese populations of the brown planthopper: Comparison of basic characteristics. In: *Proceedings, ROC-Japan Seminar on the Ecology and the Control of the Brown Planthopper*. National Science Council, Rep. of China, pp. 1-9.

Kuno, E. and N. Hokyo. 1970. Comparative analysis of the population dynamics of rice leafhopper, *Nephotettix cincticeps* Uhler and *Nilaparvata lugens* Stål, with special reference to natural regulation of their numbers. *Res. Popul. Ecol.* 12: 154-184.

Leasar, C.D. and J.D. Umzicker. 1978. Life history, habits and prey preferences of *Tetragnatha laboriosa* (Araneae: Tetragnathidae). *Environ. Entomol.* 7: 879-884.

Lee, H. P., J.P. Kim, and J.R. Jun. 1993a. Utilization of insect natural enemies and spiders for the biological control in rice paddy field, community structure of insect pest and spiders, suppress effect on insect pest by natural enemies, and their overwintering habitats in rice paddy field. *RDA Jour. Agri. Sci. (Agri. Inst. Coop.)* 35: 261-274.

Lee, H.P., J.P. Kim, and J.R. Jun. 1993b. Influences of the insecticidal application on the natural enemies and spider community. *Jour. Indus. Tech. Grad. Sch. Dongguk Univ.* 1: 295-307.

Lee, J.H., K.H. Kim and U.T. Lim. 1997. Arthropod community in small rice fields associated with different planting methods in Suwon and Icheon. *Kor. Jour. Appl. Entomol.* 36, 1: 55-66.

Legner, E. F. and E.R. Oatman. 1964. Spiders on apple in Wisconsin and their abundance in a natural and two artificial environments. *Canadian Entomologist* 96: 1202-1207.

Lin, K.S. 1970. Studies on the microclimatic factors in relation to the occurrence of the rice planthopper. *Plant Protection Bulletin* (Taiwan) 12,4: 184-189.

Nagata, T. 1985. Chemical control of the brown planthopper in Japan. *Jap. Agri. Res. Quart.* 18: 176-181.

Namkung, J, S.T. Kim and J.H. Lee. 2000. Revision of the Fauna of Korean Spiders. *Insecta Koreana* 17,4: 303-343.

Okuma, C. 1958. Some observations on the habits of *Oedothorax insecticeps* Bösengerg et Strand (Araneae). *Acta* *arachnol.* 15: 21-23.

Okuma, C., M.H. Lee and N. Hokyo. 1978. Fauna of spiders in a paddy field in Suweon, Korea. *Esakia* 11: 81-88.

Ooi, P.A.C. and B.M. Shepard. 1994. Predators and Parasitoids of Rice Insect Pests. In: *Biology and Management of Rice Insects*. E.A. Heinrichs, (ed.). Wiley, New Delhi, India, pp. 585-612.

Otake, A. and N. Hokyo. 1976. *Rice Plant and Leafhopper Incidence in Malaysia and Indonesia. Report of a Research Tour January to March 1976*. Shiryo No. 33, Tropical Agriculture Research Center, Tokyo. 64 pp.

Paik, J.C. and J.Y. Hwang. 1990. Preliminary survey of Natural Enemies of Rice Pests for the Development of Integrated Control Programs. *Res. Report RDA*. 33: 153-171.

Paik J.C., Y.B. Lee, H.R. Lee and K.M. Choi. 1979. Studies on the physiology, ecology and control of the rice insect pests. *Res. Report R.D.A.*: 341-367.

Paik, K.Y. and J.S. Kim. 1973. Survey on the spider-fauna and their seasonal fluctuation in paddy fields of Taegu, Korea. *Kor. Jour. Plant Protection* 12.3: 125-130.

Paik, W.H. and J. Namkung. 1979. *Studies on the Rice Paddy Spiders from Korea*. Seoul National University, Korea 101 pp.

Paik, W.H., J. Namkung and H.K. Kim. 1974. A list of spiders collected in the rice paddy at Milyang. *Kor. Jour. Plant Protection* 13,1: 24.

Park, J.S., S.C. Lee, B.H. Lee, Y.I. Kim, K.T. Park and K.J. Ahn. 1972. Influences of the insecticides on the rice insect pests. *Res. Report R.D.A.*: 146-169.

Pickett, A.D., N.A. Patterson, H.T. Stultz and F.T. Lord. 1946. The influence of spray programs on the fauna of apple orchards in Nova Scotia: I. An appraisal of the problem and a method of approach. *Scient. Agric.* 26: 590-600.

Riechert, S.E. 1981. The consquences of being territorial: Spiders, a case study. *Amer. Nat.* 117: 871-892.

Riechert, S.E. and T. Lockley. 1984. Spiders as biological control agents. *Annual Rev. Entomol.* 29: 299-320.

Ryu, J.K., S.Y. Choi, H.R. Lee and Y.H. Song. 1977. Root-zone placement of carbofuran for control of rice insect pests. *Kor. Jour. Plant Protection* 16,4: 217-220.

Samal, P. and B.c. Misra. 1975. Spiders: The most effective natural enemies of the brown planthoppers in rice. *Rice Entomol. Newsletter* 3: 31.

Sasaba, T., K. Kiritani and S. Kawahara. 1973. Food preference of *Lycosa* in paddy fields. *Bull. Kochi Inst. Agr. For. Sci.* 5: 61-63.

Schmitt, R.J. 1987. Indirect interactions between prey: apparent competition, predator aggregation and habitat segregation. *Ecology* 68: 1887-1897.

Shepard B.M. and P.A.C. Ooi. 1991. Techniques for evaluating predators and parasitoids in rice. In: *Rice Insects: Management Strategies*, E.A. Heinrichs and T.A. Miller (Eds.). Springer-Verlag, Germany, pp. 197-214.

Shepard, B.M., A.T. Barrion and J.A. Litsinger. 1987. *Helpful Insects, Spiders, and Pathogens*. International Rice Research Institute, Los Baños, Philippines. 127 pp.

Song, Y.H. and Y.G. Lee. 1994. Studies on the spider fauna in the paddy fields of Chinju and Namhae areas. *Korean Jour. Environ. Agric.* 13,1: 98-110.

Specht, H.B. and C.D. Dondale. 1960. Spider populations in New Jersey apple orchards. *Jour. Econ. Ent.* 53: 810-814.

Strand, E. 1907. Süd und ostasiatische Spinnen. *Abh. Naturf. Ges. Gölitz.* 25: 107-215.

Suenaga, H. 1963. Analytical studies on the ecology of two species of planthoppers, the white-backed planthopper, (*Sogata furcifera Horvath*) and the brown planthopper (*Nilaparvata lugens*), with special reference to their outbreaks. *Bull. Kyushu Agric. Expt. Stn.* 8, 1: 1-152.

Tanaka, K. 1989. Movement of the spiders in arable land. *Plant Protection* 43, 1: 34-39.

Turnbull, A.L. 1973. Ecology of the true spiders (Araneomorphae). *Ann. Rev. Entomol.* 18: 305-348.

Van den Bosch, R., Messenger, P.S. and A. P. Gutierrez. 1982. *An Introduction to Biological Control*. Plenum Press, New York, USA. 247 pp.

Yamano, T. 1977. Seasonal fluctuation of population density of spiders in paddy field in Kyoto City. *Acta Arachnol.* 27 (Special Number): 253-260.

Yang, K.J., M.S. Im. and S.T. Kim. 1998. Studies on the ecology of spiders as natural enemy for rice insect pest at rice paddy field in Keumsan area, Chungcheongnam-do. *The Research Bulletin of Agricultural Life Resource Science Institute Joongbu Univ.* 6: 46-56.

Yoon, J.C. 1997. Arthropod Community Structure and Changing Patterns in Rice Ecosystems of Korea. Unpublished Ph.D. Thesis, Seoul National University, Seoul, Korea, 105 pp.

Yoon, J.K. and J. Namkung. 1979. Distribution of spiders on paddy fields in the suburbs of Kwangju City. *Kor. Jour. Plant Protection* 18, 3: 137-141.