Recent Progress in the Pest Management for Rice in Japan

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Introduction

Paddy fields constitute 70% (2.7 million ha) of the total arable land of Japan and produce some 12 million tons of husked rice annually. The advent of synthetic pesticides has enabled not only heavy manuring, but also early planting of rice by mediating pest problems. The use of vinyl polyethylene film alleviated low temperature damage during the nursery period. During the last 20 years, the average yield of husked rice has increased from 3 tons/ha to 4.8 tons/ha.

Rice plants of *japonica* type are grown mostly under irrigated conditions during April to October. After harvest, paddy fields are either left as fallow or utilized for winter crops. Insecticides are applied 3–4 times on an average during the 4 months of cultivation, although the frequency of appliactions has begun to decrease recently.

The arthropod fauna of paddy fields including natural enemies is mostly composed of endemic species. Only two species of planthoppers, *Nilaparvata lugens* and *Sogatella furcifera*, are migrants from distant overseas areas in association with the frontal system in the rainy season (Kishimoto 1971). In addition, some species including grass leaf roller, *Cnaphatocrocis medinalis*, are considered to be long distant migrant species.

The endemic type of rice pest fauna and cropping *japonica* rice once a year to irrigated fields have to be taken into account to develop any integrated pest management system.

Pest management system of key pests

A list of insect pests arranged in the decreasing order of importance is shown in Table 1. The importance was evaluated in view of their numerical abundance, economic damage and the intensity of control currently practiced against them.

Forecasting of insect pests and diseases is being made by the nation-wide network of prefectural agricultural experiment stations and district plant protection service stations. About 700 full-time staffs are engaged in forecasting and controlling pests. A great bulk of information thus obtained on seasonal and annual changes of prevalence and of infestation has assisted developing strategies of pest management.

1) The rice stem borer, Chilo suppressalis

Control of *C. suppressalis* by parathion and BHC had widely been practiced until 1969 and 1971, respectively, when they were completely banned. In spite of the intensive chemical control, the 2nd brood moths caught by light traps almost invariably increased in many localities at least during 1951–7 compared with those for 1933–42 (Miyashita 1963). One of the factors inducing this increase was considered to be the destruction of natural enemies, especially egg parasites (Nozato and Kiritani 1976).

Since 1960–65, an appreciable reduction both in the percentage of stalks infested and in light-trap catches has been observed every-

Table 1. Relative importance of rice pests in Japan

Southern Japan

Importance in decres-ing order	Species	No. genera-tion/year	Note
1	*Nephoetettix cincticeps*	4–5	vectors of rice dwarf and yellow dwarf diseases
2	*Nilaparvata lugens*	3–4	migrant from overseas and hopperburn
3	*Chilo suppressalis*	2–3	stalk borer
4	*Laodelphax striatellus*	4–5	vector of rice stripe virus
5	Heteropterous plant bugs	1–multi.	injure grain by sucking

Northern Japan

1	*Chilo suppressalis*	1–2	stalk borer
2	*Oulema oryzae*	1	leaf eater } only injurious at young rice
	Agromyza oryzae	2–3	leaf miner } only injurious at young rice
3	*Chlorops oryzae*	2–3	injure leaf and ear
4	*Nephotettix cincticeps*	3–4	injure ear by sucking
5	Heteropterous plant bugs	1–multi.	injure grain by sucking

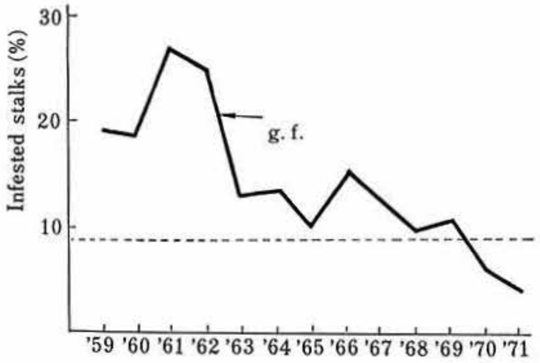

Fig. 1. Annual changes in percentage of stalks infested by 2nd generation larvae of *Chilo suppressalis*, in Japan

where in Japan (Fig. 1). Factors considered to be responsible for this decline are various cultural practices introduced recently. As shown in Table 2, a great change in rice cultivation occurred during the 1960's. These new cultural practices, except for the use of granular BHC, have no direct bearing with control of *C. suppressalis*.

Early harvesting, mechanical harvesting, burning straw after threshing, and the use of straw for manure in vinyl-house culture, all contribute to the reduction of overwintering population of *C. suppressalis*. Application of slag increases SiO_2 content in the straw, resulting in the reduced survival rate of larvae (Sasamoto 1958).

The slender stalks of panicle number type varieties also cause a retarded development and low survival of *Chilo* larvae. Not all of the factors mentioned above are operative in a given locality, but trigger factors seems to be different according to the locality.

It should be noted that no natural enemies seem to be responsible for this decline of *C. suppressalis* population. Because, for instance, in Hiroshima Prefecture, the egg parasitism by trichogrammatid parasites has been less than 10% since early 1960's, while it was around a level of 60–80% until the late 1950's or before an intensive use of insecticides (Nozato and Kiritani 1976).

In spite of the decrease in abundance of *C. suppressalis*, this borer is still one of the most important potential pest for rice growers. With regard to the threshold of chemical control, it was elucidated that an increase in yield of rice through chemical control could be expected only when stems were infested more than 5–6% by each of the 1st and 2nd broods

Table 2. Factors responsible for the change in pest status of *Chilo suppressalis*

Factor	Stage affected	Since around
Factors contributed to decrease		
1. Cultivation of early planted rice	adults of 2nd brood	1955
2. Cultivation of panicle number type with more tillers of slender, stiff and short stalks	growing larvae	1955
3. Use of BHC granules	larvae	1960
4. Increase in acreage of vinyl-house culture which requires a great deal of stalks for manure	overwintering larvae	1960
5. Early harvest of middle season rice by 2–3 weeks	overwintering larvae	1960
6. Increase in amount of slag ($CaSiO_3$) by 2–3 times	growing larvae	1965
7. Introduction of combined harvester	overwintering larvae	1965
Factors contributed to increase		
1. Increase in amount of nitrogenous fertilizer	growing larvae	1945
2. Decimation of natural enemies	eggs and larvae	1960–65

of *C. suppressalis* (Kobayashi et al. 1971; Koyama 1973, 1975). The percentage of infested stems by the 1st brood or that of dead hearts (Y) could be predicted 2 weeks before by the percentage of injured leaf-sheaths (X) utilizing the following equation: $Y=0.41X+0.23$ ($R^2=0.89$) (Koyama 1975). Thus the control threshold index for the infestation by the 1st brood larvae is 11–12% in terms of the perecntage of injured leaf-sheaths.

It is urged that the rice yield is affected more by the infestation of the 2nd brood larvae than by the 1st brood ones. Prediction of the percentage of infested stems by the 2nd brood is, therefore, urgently needed for the timely chemical application and for the saving of applications. Koyama (1976) found that 50–100 ppm emulsion (1/10–1/5 of the conventional concentration) and 0.2–0.5% dust and fine granules (1/10–1/4 of the conventional content of a.i.) of chlorphenamidine can be utilized in the practical control of *C. suppressalis* and that the former formulation was better than the later two in minimizing the deleterious effects on spiders.

Our experience strongly suggests that cultural practices should be a nucleus in implementing the pest management system for rice borers. It must be mentioned that unless these practices are carried out in a sufficiently large acreage, their effectiveness would be minimized as experienced in the pre-War period. It is suggested tentatively that an acreage covered with a radius of 25 km or about 200,000 ha would be the minimum size of area. Twenty-five km is one half of the maximum distance of population displacement observed on the occasion of the centrifugal extension of *Chilo* outbreaks in Kyushu Island in 1953 (Kiritani and Oho 1962).

2) *The brown planthopper, Nilaparvata lugens*

The transoceanic migration of *N. lugens* and *S. furcifera*, which have not been proved to overwinter in the northern temperate Asia, has recently been shown to be important (Kishimoto 1971). The mass immigration of these planthopers occurs every year during late June to middle July. *N. lugens* and to a lesser extent *S. furcifera* often cause serious damage to the rice production in Japan (Fig. 2). The long-winged immigrants give rise to offsprings with a gerater proportion of short-winged adults due to low population density and favorable food ocnditions. Short-winged females concentrate their eggs on the limited number of rice plants because of their low mobility. Then, a typical round-shaped hopper burn develops after 2–3 generations. It is now possible to predict the degree of infestation by *N. lugens* in a given locality based on the information on the trajectory of depressions which carry planthoppers and

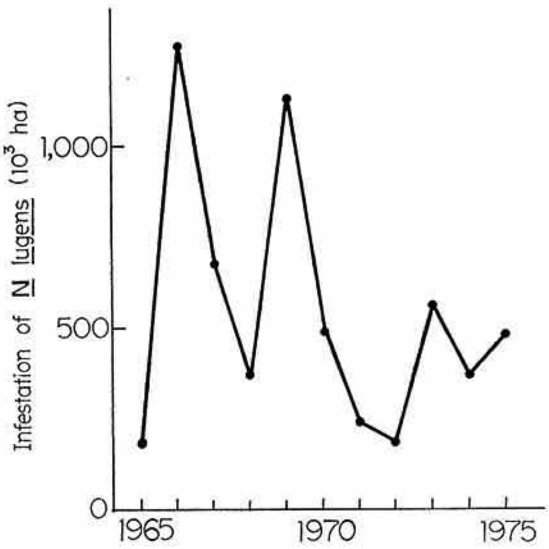

Fig. 2. Annual fluctuation in the acreage of paddy fields infested by *N. lugens* in Japan.

on the number of insects caught by a yellow pan trap (Kishimoto unpublished). Chemical control of individual paddy fields can be decided by using the key index shown in Fig. 3, and the damage could be controlled at most by two applications.

According to Kishimoto (unpublished), the rate of population increase is greatest (10–20 times) on rice plants during the one month period starting from one month after transplanting. Before and after this period, the rate suddenly decreases. Therefore, in the year when mass immigration of *N. lugens* took place unusually late, severe hopper burns are likely to develop because two generations could reproduce successively at the favorable stage of rice plants. The formation of hopper burn is accelerated by high temperatures during August and September. It is shown that a rise in the mean temperature by 1.5°C makes the formation of hopper burn a fortnight earlier. The yield loss caused by the hopper burn is greatest or almost 100% when it occurs on around 30 days after heading and becomes smaller as time elapses after heading. It can be said, therefore, that damage caused by *N. lugens* is related to the temperature during August and September on the one hand, and to the time of immigration on the other hand.

Currently, the control of *N. lugens* depends entirely on insecticides. The dosage at which practical control can be done is 0.15–0.3 kg a.i./ha before the heading stage, but after this stage even the dosage of 0.8 kg a.i./ha is not sufficient to control *N. lugens* which locates at the lower part of rice hills (Nakasuji and Kiritani 1974). All varieties of *japonica* type are believed to be susceptible to *N. lugens*

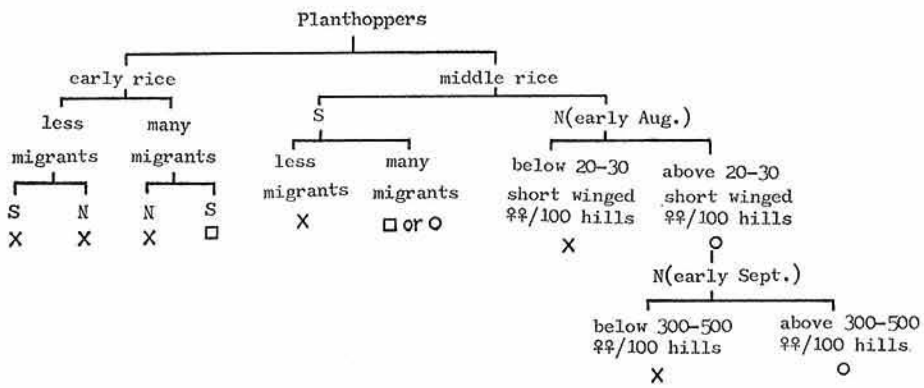

Fig. 3. Key index for control thresholds of migratory planthoppers

Legent.

S : *Sogatella furcifera*, N : *Nilaparvata lugens*.

× : control is unnecessary, □ : control has to be done when necessary.

○ : insecticide treatment is necessary.

Early rice : planting in late April, harvest in early August.

Middle rice : planting in early June, harvest in late September.

Table 3. Varietal resistance of japonica type as compared with indica type

(Kiritani 1973)

Pest species & insect borne-virus	Growth type		Source
	japonica	indica	
Chilo suppressalis	S–M	S–R	Pathak 1971
Nephotettix cincticeps	S	S–R	Koshihara 1971
Rice dwarf virus			
wet paddy	S–R	S–R	Ishii et al. 1969
dry paddy	S	—	
Laodelphax striatellus			
wet paddy	S	R	Sakurai & Ezuka 1964
dry paddy	R	—	
Rice stripe virus	S–R	S–R	Sakurai & Ezuka 1964
Nilaparvata lugens	S	S–R	Pathak 1971
Chlorops oryzae	S–R	—	Munakata & Okamoto 1967

S: susceptible; M: medium; R: resistant.

(Kiritani 1972) (Table 3). However, there is no possibility of developing new biotypes under natural conditions in Japan when BPH resistant varieties are used, because continuity of life cycle of *N. lugens* is intercepted by the winter during which all populations die out.

The green rice leafhopper, *Nephotettix cincticeps*

1) Pest status as the key pest

In the pre-War period, outbreaks of rice dwarf virus (RDV) transmitted by *N. cincticeps* occurred only sporadically, lasting at most one or two years. Since around 1955, this disease has begun to extend its distribution northwards.

The RDV epidemic is considered to have resulted from the following factors (Nakasuji 1974): (1) Increased cultivation of early sown rice which provides a favorable host for the 1st generation which otherwise develops on graminaceous weeds in the fallow paddy field. (2) Increase in the acreage of fallow paddy fields due to a decreased cultivation of winter crops such as wheat and barley. This provides overwintering nymphs of *N. cincticeps* with a large quantity of winter hosts. (3) Decimation of natural enemies of *N. cincticeps* by the use of insecticides with a broad spectrum as BHC, parathion etc. to control *C. suppressalis*. Specifically, BHC was so toxic to spiders that even the granular formulation of BHC affected wolf spiders, *Lycosa pseudoannulata*, through the foodchain toxicity (Kiritani and Kawahara 1973). (4) The development of a high level of insecticide resistance to various kinds of organophosphates and carbamates.

With regard to (1), it has been confirmed that the rate of population increase can be 10 to 20 times on early sown rice compared with less than 1 on the wild graminaceous hosts in fallow paddy fields (Kiritani et al. 1970; Hokyo 1976). In addition, simultaneous presence of early and middle season rice in a locality results in an increased proportion of RDV-infected insects through transmission/acquisition processes of the virus (Nakasuji and Kiritani 1971).

In controlling plant- and leafhoppers, insecticides were applied 4–7 times annually in the southern Japan during 1969–71 in contrast to 1–2 applications around 1965 (Fig. 4). Development of resistance to malathion in *N. cincticeps* was first recorded in 1957 in Kochi after 3 years of use (Kiritani 1972). Later, the resistance to other organophosphates was found, and then the resistance

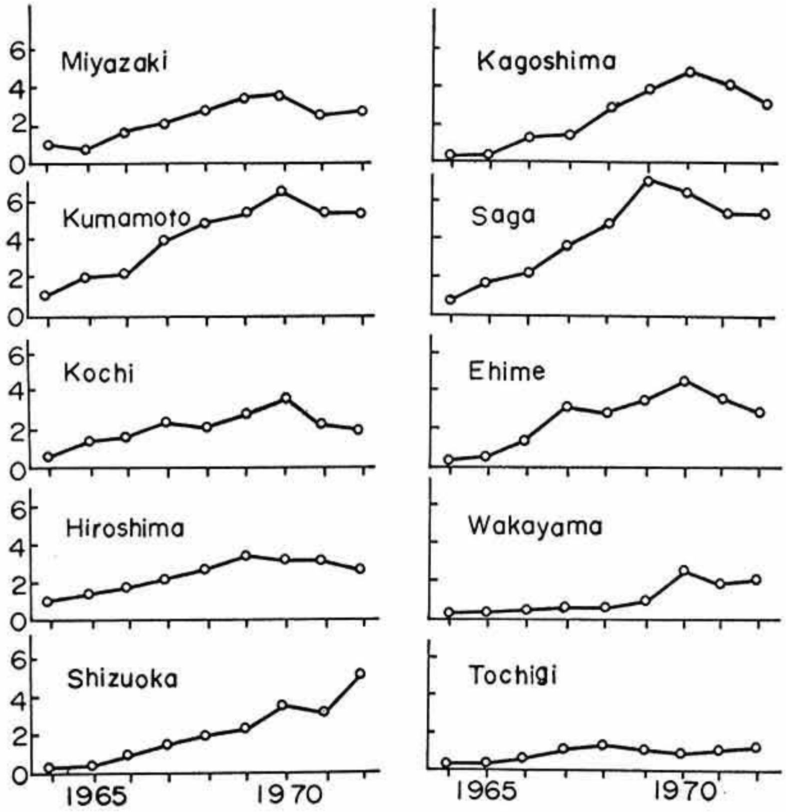

Fig. 4. Frequency of insecticide applications for control of leaf- and planthoppers in some prefectures, Japan

to carbamates which took the place of organophosphates was developed (Fig. 5). Presently, it is found that only some mixtures of organophosphates and carbamates are effective to the resistant strains. Thus, the control of *N. cincticeps* becomes a principal target of pest management system of rice in southern Japan.

2) Objectives of the pest management system of N. cincticeps

The damage caused by RDV differs greatly with stages of rice plants. Early infection induces entire dwarfing of plants and a total loss of rice yield. Consequently, control of RDV is composed of two different aspects. First, the prophylactic insecticide application against *N. cincticeps* to prevent the transmission of RDV to rice plants either in nurseries or immediately after transplanting. Secondly, the overall suppression of the population density of *N. cincticeps* in a given locality by the management of its life system.

An infection level of 15% of RDV-infected hills, including early and late infection, is considered to cause some yield loss (Sugino 1975). The level is determined by the proportion of infective insects in the population, the number of hills infected by an infective adult during its life span, the number of adults per hill that immigrated into the rice field and the mean longevity of adults under natural conditions (Kiritani and Nakasuji, unpublished). It is calculated that one adult per 10 hills per day, when the proportion of RDV-infective individuals is 0.05, will result in a 15% RDV-

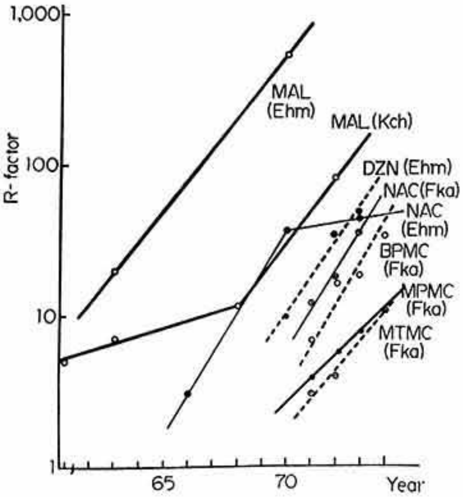

Fig. 5. Rates of development of insecticide resistance in *N. cincticeps* in southern Japan.
MAL: malathion; DZN: diazinon; NAC: carbaryl
Ehm: Ehime; Kch: Kochi; Fka: Fukuoka

Table 4. Difference in characteristics between leafhopper and planthopper in Japan

	leafhopper	planthopper
movement	non-migratory	migratory
reproductivity	low	high
population stability	high	low
tolerance to crowding	low	high
population regulation works at	a low density	a high density
overwintering in Japan	yes	no (impossible)
virus vector	yes	no

infected hills. Such a low density as the *control threshold* impose difficulty in controlling RDV infection, requiring heavy use of the insecticide.

N. cincticeps is greatly different from *N. lugens* and *S. furcifera* in its ecological traits as indicated in Table 4. The population density of *N. cincticeps* is sensitively self-regulated particularly at the adult stage (Kuno 1968; Kiritani et al. 1970; Hokyo 1972). Accordingly, the total number of mature nymps and adults per hill rarely exceeds 20 insects even at the time of maximum population which comes after the successive reproduction on rice plants for 2 consecutive generations. Hence, the overall density of prehibernating nymphal populations is considered to be almost constant irrespective of the abundance in the preceding period. This suggests that the success of pest management of *N. cincticeps* depends to a greater extent on the magnitude of the winter mortality of nymphs and on the rate of population increase of their filial generation in spring.

3) Pest management system of N. cincticeps

(1) First step: integrated use of insecticides, cultural practices and natural enemies

It is estimated that mechanized transplanting is done on 45% of the total paddy fields in 1974 and is expected to reach 70% in 1985. Mechanical planting is associated with insecticidal application to seedlings in the nursery box. By this method not only the area treated by the insecticide is reduced by 1/300, but also the amount of insecticides as well as the frequency of applications can be reduced to 1/2 that of conventional control. By this method the percentage of RDV-infected hills can be reduced to 1/2–1/3 that in conventional control and the effect on spiders can be kept to a minimum (Kiritani 1976) (Table 4).

Ploughing fallow paddy fields during the winter, when this is operated on a large scale (300 ha), suppressed RDV epidemic almost completely within two years (Nakasuji and Kiritani 1976) (Fig. 6), due to the destruction of hosts for overwintering nymphs of *N. cincticeps*. Unfortunately, this practice is not widely operated due to the labor shortage and growers still depend largely on chemical control.

It took 4 and 6 years for a full recovery of an egg parasite (*Paracontrolia andoi*) and of the wolf spider (*L. pseudoannulata*), respectively, in a paddy field where no insecticide was applied since 1966 (Fig. 7). On the other hand, the egg density of *N. cincticeps* was reduced to one-half during the corresponding

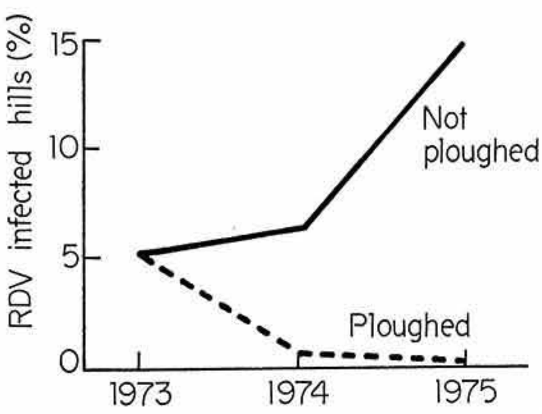

Fig. 6. The effect of winter ploughing on the RDV epidemic.

period, suggesting that natural enemies alone are not able to control RDV infection to an acceptable level. Indeed, a field experiment showed that a reduction of *N. cincticeps* population to 1/10 reduced the percentage of RDV-infected hills only to 1/3 (Kiritani unpublished). It should be emphasized, however, that the effectiveness of free living predators, which prey on nymphs and adults of leaf-hoppers, depends on the density of host eggs as well as their mortality. In other words, the lower the egg density and the higher the egg mortality, the more is the effectiveness of predators.

(2) Second step: systems approach

Efforts are being made to develop models of the life system of *N. cinctícesp* (Sasaba et al. 1973; Sasaba and Kiritani 1975), of RDV epidemiology (Nakasuji and Kiritani 1972, Nakasuji et al. 1975), and of predator-prey system (Sasaba 1974, Kiritani and Kakiya 1975, Kiritani in press).

Simulation by the RDV model showed that a reduction to 1/10 in the overwintering nymphal population or a reduction to 1/3 in the adult population invading nurseries was necessary to keep the yield loss less than 10% (Nakasuji and Kiritani 1972). Another simu-

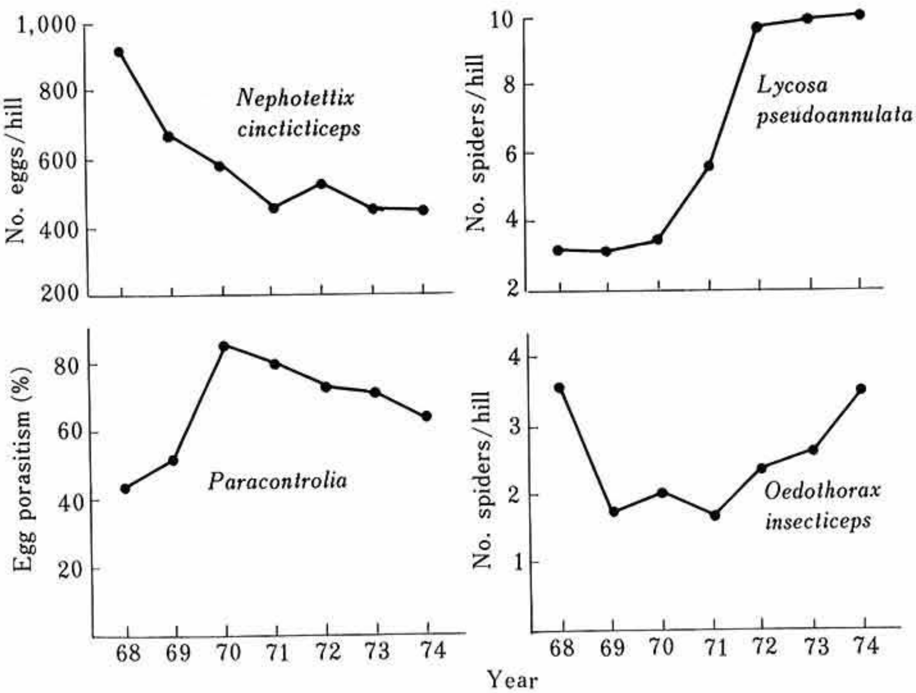

Fig. 7. Annual changes in the maximum density or parasitism of *N. cincticeps*, egg parasite (*Paracontrolia andoi*), and predators (two species of spiders) in an insecticide-free paddy field.

lation indicated that utilization of varietal resistance to RDV infection is most promising (Nakasuji et al. 1975).

The model for spider-leafhopper interaction system is also of use for various preliminary simulation exercises of pest management. The range of density combinations, where effective biological control of *N. cincticeps* can be achieved by lycosid spiders, can be determined by this model (Kiritani in press). Another simulation suggests that a moderate degree of resistance to *N. cincticeps*, about 40% suppression of its reproduction, is sufficient to control *N. cincticeps* with the association of lycosid spiders (Kiritani in press). This simulation suggests that more effort should be made to breed resistant *japonica* varieties in the management of *N. cincticeps*.

Conclusion

The rate of the dissemination of this new endeavour among growers will depend on their concern about environmental quality including development of insecticidal resistance, side-effects on wild life, residue problems etc. Unlike insecticide application, most of the control measures available for pest management will give effects to or will be influenced by neighboring farms. Sometimes their effect can be fully realized only when they are used over an extended area. In an extreme case, some growers have to leave their farms free from insecticide either to secure the persistence or to propagate natural enemies in a locality concerned. Therefore, the pest management program will call for a new type of cooperative organization of growers.

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