Studies on Integrated Control of Brown Planthoppers, *Nilaparvata lugens* (Stål) in Taiwan[1]

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ABSTRACT

For improvement in the efficiency of brown planthopper control, the criteria for chemical application basing on the pest population growth model and the economic threshold were determined on the one hand, and the prevelence of major natural enemies were investigated and low toxicity insecticides to the natural agents were evaluated on the other hand. Basing on these information, the hopper can be properly controlled with a half reduction of insecticide applications as compared with conventional control method. In order to further decressing the use of insecticide, the brown planthopper resistant cartivars were developed and the measures for preventing the development of virulent biotypes of the hopper were evaluated during the past decate. Through a series experiments, a simple combination of resistant cartivar and insecticide application basing on timing and economic threshold provided the most reliable way not only for controlling the hopper and the other rice insect pests, but also for preserving the natural enemies. The profit of pest control basing on integrated control tacties were always higher than that basing on insecticides and calendar dating presently.

Introduction

The brown planthopper has been one of the most important insect pests of rice in Taiwan although it had been a sporadic pest before 1960. According to statistics, more than 100,000 hectares of paddy fields in Taiwan have been infested every year by this pest during the last decade. This figure is about one seventh of the total acreage of rice in Taiwan (TPDF, 1981; 1982).

The hopper damages rice plants by sucking plant juices feeding. When the population density is hight, extensive feeding causes a wilting and drying of the crop, which is a condition known as "hopperburn". It was estimated that if chemical control was not made or made improperly the hopper caused about 2,000 kg/ha or more than a 35 percent yield loss in the second crop in central and southern Taiwan (Cheng, 1978). Besides direct damage, the hopper may also transmit virus diseases such as grassy stunt, ragged stunt which can further reduce crop yield (Chen *et al.*, 1978; 1979; Ling, 1977).

The use of insecticides is considered to be the most reliable measures to control this pest at present. The farmers used to apply insecticides from 3 to 6 times for controlling the BPH in the second crop season. However, since the insect

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feed on the base of rice plant, where insecticides often fail to reach, chemical control does not necessary produce a satisfactory effect. Moreover, it has been reported that frequent use of insecticides results in a reduction of natural enemies, an evalution of pest resistance to chemicals and sometimes an increase in the pest population (Kiritani, 1972; Ku *et al.,* 1976; Heinrichs *et al.,* 1982).

The present study is an attempt to establish an integrated management system for BPH control in Taiwan. For this purpose, population growth patterns, economic thresholds, timing of chemical application, natural enemies and host resistance were investigated in separate experiments, respectively. It was expected that an integrated tactics, if properly made, could provide a more effecient and longer lasting control than the sole use of any control method.

Model of Population Growth and Timing for Control

There are two crop seasons in Taiwan. The first rice crop is transplanted from January in south to March in north and harvested from May to June; the second rice crop is transplanted from June to July and harvested from October to November. Both in the first and second rice crop each may be infested by 4 generations of the BPH. The population of the hopper is low during the first crop season, the maximum number of the hopper even in the population peak are usually less than 3 per hill (Fig. 1). Fewer immigrants from the overwintered generation and lower temperatures during the early stage of rice growth are the main factors limiting the population increase in the first crop season.

The growing pattern of BPH populations

Table 1. The Highest Number of the Brown Planthopper Counted During the Nymphal and Adult Stage Each Generation in the First and Seocnd Crop Season, Chiayi, 1981-1983

Place[1]	Year	Date of planting	No. BPH / 10 hills						
				1st. generation		2nd. generation		3rd. generation	
			Immigrant[2]	Nymph	Adult	Nymph	Adult	Nymph	Adult
				1st rice crop					
Chiayi*	1982	Jan. 23	0.13	6.8	0.4	8.4	4.3	1.8	1.2
Suanfu	1982	Jan. 10	0.06	1.9	0.2	6.8	1.6	15.9	2.9
Shiayanchu	1982	Jan. 6	0.06	0.4	0.1	3.9	0.8	13.4	3.4
Chi-ko A	1982	Feb. 5	–	0.1	0.1	0.4	0.5	16.1	3.9
Chi-ko B	1982	Jan. 10	0.13	1.2	0.3	8.2	1.1	15.2	2.6
Chiayi*	1983	Feb. 2	–	0.7	0.9	4.8	3.5	3.1	0.9
Suanfu	1983	Jan. 26	–	0.1	0.1	1.9	3.6	78.2	10.7
Chi-ko*	1983	Jan. 23	–	0.2	0.1	0.3	1.3	4.6	4.3
				2nd rice crop					
Chiayi*	1981	Jul. 24	6.12	37.4	14.4	72.8	76.5	4728.5	65.4
Chiayi*	1982	Aug. 13	3.32	23.4	55.8	474.2	100.3	56.6	6.2
Suanfu	1982	Aug. 1	0.23	4.7	10.5	117.4	103.5	4215.4	11.5
Chi-ko	1982	Jul. 17	0.75	9.9	12.8	384.4	112.6	4924.2	3.9
Chi-ko A	1983	Jul. 14	0.13	2.6	1.0	23.9	24.5	4062.8	402.1
Chi-ko B*	1983	Jul. 25	1.15	22.7	22.8	2448.1	283.0	4168.0	1.7
Chi-ko C*	1983	Aug. 7	0.06	0.1	1.4	228.9	95.5	4428.2	467.9
Chiayi*	1983	Aug. 4	3.00	24.7	58.4	3748.5	528.5	332.6	31.3

1. The appearance of adult population peaks in the investigation field with "star mark" were disting uished basing on the number of BPH caught in the yellow water-pan trap and the hopper counted in the field, whereas for the others were distinguished only basing on the number of BPH counted in the field.
2. Black bar means no clear immigration detected.

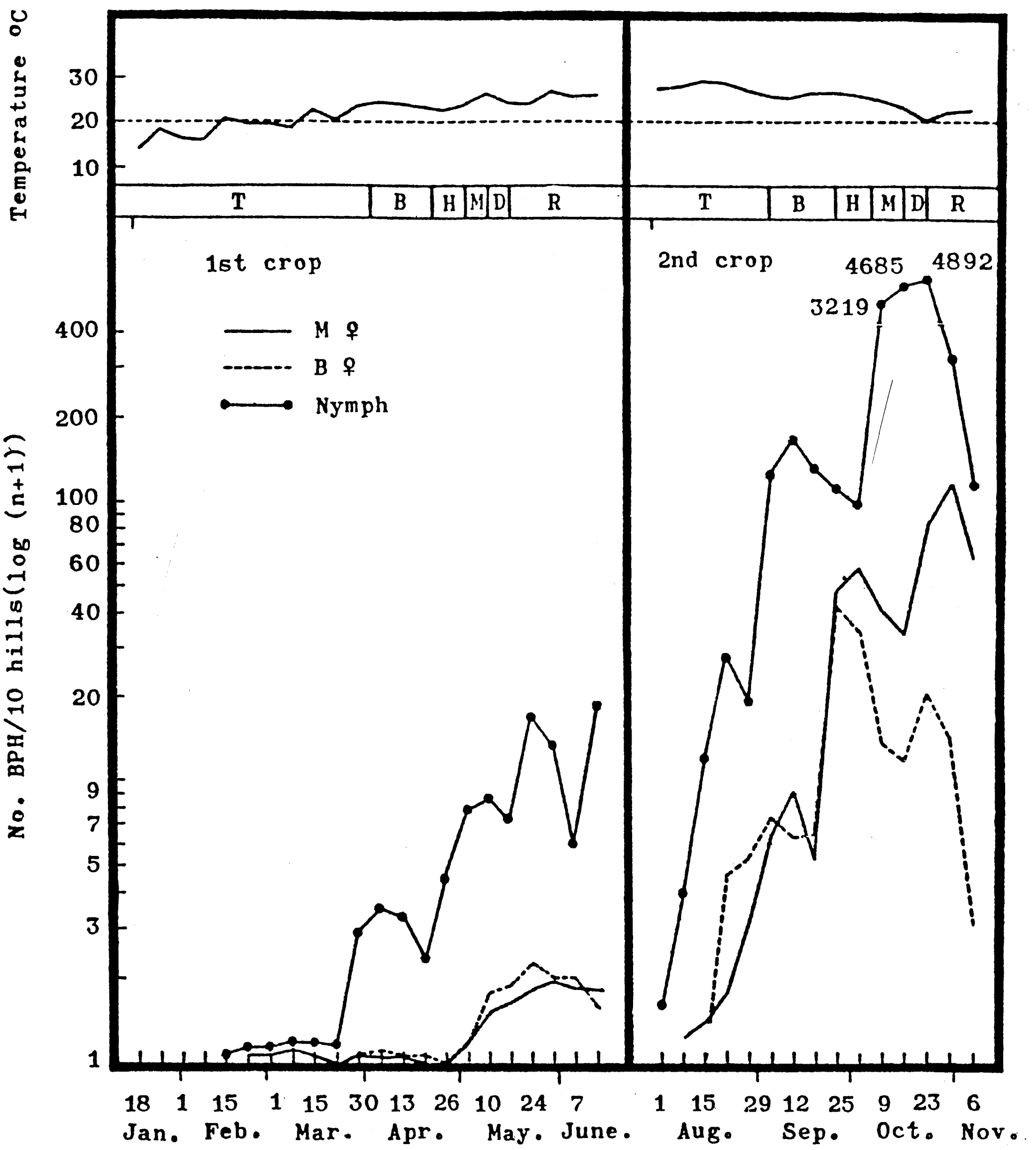

Fig. 1. Seasonal population growth of BPH at Ming-hsiung, Chiayi, 1976. (T: Tillering stage; B: Panicle initiation and booting stages; H: Heading stage; M: Milky stage; D: Soft dough stage; R: Ripening stage)

during the second rice crop in Taiwan is similar to those observed in Japan and the Philippines. Populations starting from a low initial density multiply themselves in two generations and reach a peak after heading of rice (Fig. 1) (Kisimoto, 1977; Dyck *et al.*, 1979). The peak population is usually several hundreds times to more than thousand times as high as the initial population (Table 1). Severe damage commonly called "hopper burn" appears generally in the nymphal stage of the third generation.

A low density of immigrants, heavy rainfall and low temperatures in the late stage of rice seem to be important factors in reducing the population density and damage of BPH in the second rice crop. Fukuda (1934), Tao (1966), and Chiu (1970) reported that high temperatures and continuous cloudy weather without much rain fall in July to October promoted hopper populations to increase. In fact, analysing the hopper collections with a light trap and a net trap during last two years, showed that the collections of the hopper during April to August varied greatly from day to days (Cheng, 1984). High collections correlated closely with some particular weather conditions, such as frond systems approching to the north of Taiwan or the air ciculation inducing either by subtropical high or typhoon and affecting to Taiwan (Cheng, 1984). This indicate that the BPH may immigrate from southeast to this island. However, the role of the immigrants from long distance migration in the population development of the hopper in this island needs further evaluation.

The BPH can overwinter in Taiwan mainly on rice stubbles although their number are low and decrease rapidly with time. From the structure of BPH populations during the winter fallow period suggests that the hoppers can multiply one generation in ratooned stubbles in winter. The emerged adult disperse and some may migrate to the nurserybed of the first rice crop or to the rice fields planted earlier. During the summer fallow period, most of adult of the fourth generation in the first rice crop disperse and some may migrate to the second rice crop. This shows that the hopper can multiply in this island whole year round, and the hopper in each rice crop may became the source of the pest of the other crop each other. However, the role of the native sources of the hopper in each rice crop is in need of further determination.

The main difference in the characteristics of seasonal population changes between Taiwan and temperate region is the BPH may start from native or migrated macropterous adults, while it starts merely from migrated adults in Japan and Korea (Kuno, 1979; Kisimoto, 1977). Accordingly, generations overlap in Taiwan, and the peaks of population representing respective generations are not so clear in Taiwan as in Japan. On the other hand, the rate of macropterous adults of each generations in Taiwan is higher than that in Japan (Table 2). This suggests that the BPH population in Taiwan has higher dispersal ability than that in Japan.

In view of the population growth pattern of BPH in Tiawan, it is proposed that control of BPH in the first rice crop is not necessary, while the maximum nymphal stage of the second generation (generally appearing during 50 to 60 days after transplanting or the maximum booting stage of rice) is the critical time for control of the hopper in the second crop (Cheng, 1977). If the hopper can not be controlled sufficently, another application timing the maximum nymphal stage of the third generation is necessary. One of such experiment shows in figure 2

Table 2. The Ratio of Brachypterous Female of Brown Planthopper in the First and Second Rice Crop in Chiayi Area

Year	Place	Date of Planting	Generation 1st.	2nd.	3rd.
		1st rice crop			
1982	Chi-ko A	1/10	50.0	88.5	15.3
	Chi-ko B	2/5	50.0	23.2	51.1
	Chiayi	1/21	80.6	14.7	11.4
	Suanfu	1/10	31.6	60.7	53.2
	Shiayanchu	1/6	50.0	55.4	16.0
1983	Chi-ko	1/23	–	19.4	8.6
	Suanfu	1/26	–	74.6	5.8
	Chiayi	2/2	–	36.4	17.0
	Mean		52.4	46.6	22.3
		2nd rice crop			
1981	Chiayi	7/24	30.0	14.8	21.4
	Suanfu	7/16	60.6	59.0	40.1
	Tingliao	8/4	40.7	27.3	27.3
1982	Chiayi	8/13	40.7	50.4	12.0
	Suanfu	8/1	95.0	64.6	3.1
	Chi-ko	7/17	88.5	31.5	5.2
1983	Chiayi	8/4	29.4	43.2	9.5
	Chi-ko A	7/14	22.1	85.1	6.1
	Chi-ko B	7/25	88.7	46.3	0.2
	Chi-Ko C	8/7	0	64.0	2.0
	Mean		49.6	48.6	12.7

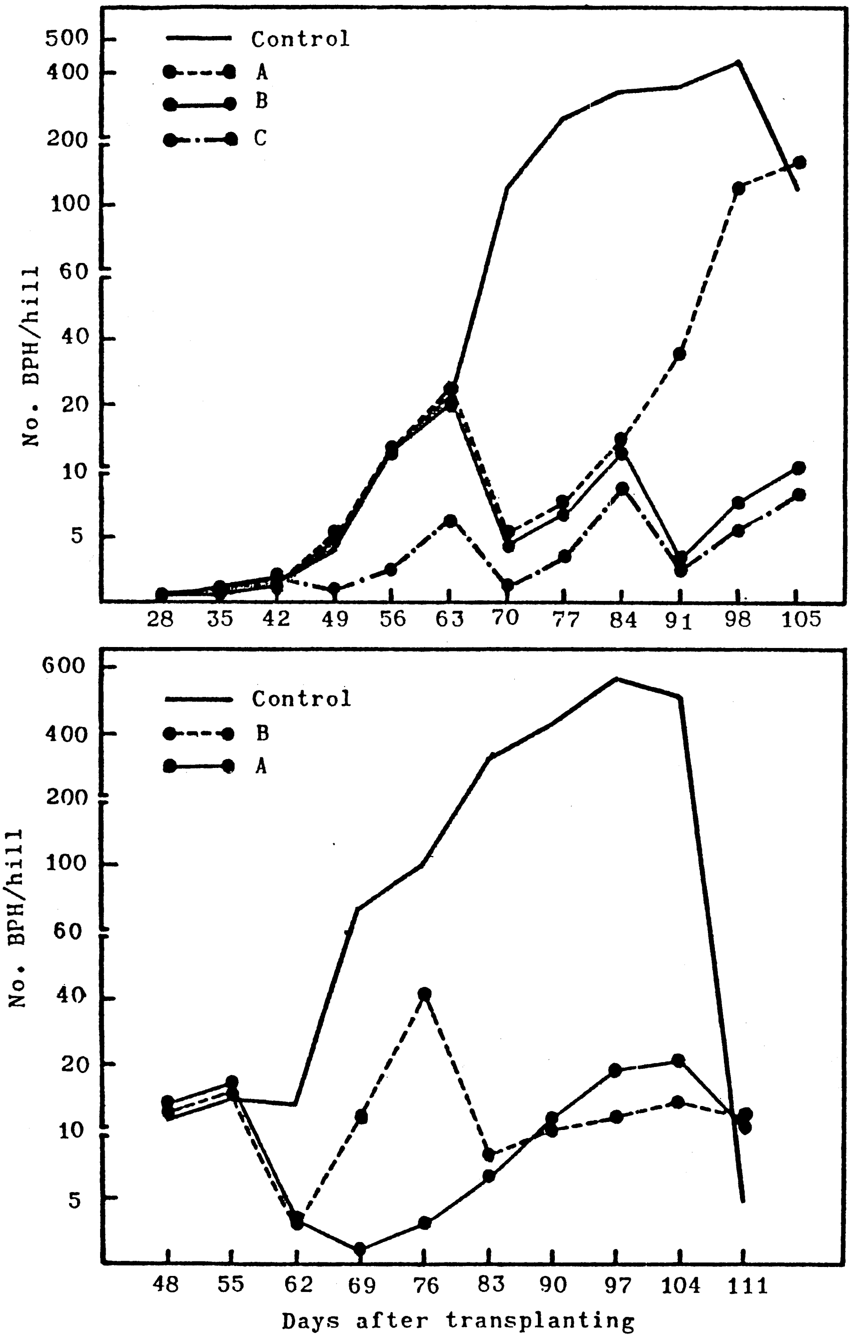

Fig. 2. Effect of Hokbal spray at the nymphal stage of different generations on the population of BPH. (Upper fig., A: Spray at the maximum nymphal stage of the 2nd generation, B: Spray at the maximum nymphal stage of the 2nd and 3rd generations, C: Spray at the maximum nymphal stages of the 1st, 2nd and 3rd generations; lower fig., A: Two sprays during the nymphal stage of the 2nd generation with an interval of 7 days, B: One Spray at the maximum nymphal stage of each of the 2nd and 3rd generation.

(Cheng, 1984). It showed that one spray at the maximum nymphal stage of the second generation was not adequate to suppress the population of BPH through out the crop season. Two sprays with one at the nymphal stage of the second generation and the another at the nymphal stage of third generation obtained almost equal control to that with three sprays timing separately at the nymphal stage of the first, second and third generations. On the other hand, two sprays during the nymphal stage of the second generation with 7 days interval suppressed the population of the hopper better than that sprayed separately at the numphal stage of the second and third generation. This proposal was also assented by Liu and Chang (1978, 1980) and by the IRRI (IRRI, 1978).

Determination of the Economic Threshold Level and Prediction of the Population to Reach the Level

Determination of economic threshold and prediction of the population growth are important in establishing a procedure of pest management. At present, the control of BPH remains solely dependent on insecticide application. Because of the lack of criteria upon which control measures can be justified, insecticides are often applied more frequently than is really necessary. In order to set up a criterion as a basis for control of BPH in Taiwan, loss of rice yield due to different population levels of BPH was studied both in a wire house and field to determine economic threshould levels. The result showed that rice plants at different ages differed in sensitively to BPH. The relationship between the population level of the insect and yield reduction followed an exponential curve at different stages of the rice, respectively (Table 3). It showed that the initial tillering and booting stages of rice were more sensitive to BPH than other stages, these were followed by milky, maximum tillering and dough stages.

Table 3. Relationships Between the BPH Population Level (X) and Percentage of Yield Reduction (Y) in Tainan 5

Stage of rice	Equation	r^2 Value
Maximum tillering stage	$Y=1.7120\ X^{0.6110}$	0.8919**
Initial booting stage	$Y=1.6717\ X^{0.7000}$	0.9292**
Maximum booting stage	$Y=1.9416\ X^{0.6636}$	0.8681**
Milky stage	$Y=1.7785\ X^{0.6582}$	0.8955**
Soft dough stage	$Y=1.5993\ X^{0.5730}$	0.9056**

Based on the damage potential of the BPH at different stages of rice, Tainan 5, and some other variables, the economic threshold of BPH on rice was calculated by using the model proposed by Chiang (1979). The values calculated for different stages of rice ranged from 4.6 to 12.3 hoppers per hill (Table 4), which is further simplified to be 5-10 hoppers per hill for ease of handling by farmers.

The proposed economic threshold values were further evaluated in different field conditions with different insecticides. The results showed that the highest profit was gained only by the control done when the BPH population reached the predicted economic threshold (Cheng, 1978; 1979). This indicate that the values estimated in the present study may be considered feasible in Taiwan.

From the economic threshold, it is expected that 1 to 4 applications are needed to protect a rice crop from economic damage depending on the abundance of the insect and effectiveness of insecticides used (Cheng, 1978). However, another studies as shown in figure 2 indicated that the hopper could be controlled effectively with two insecticide applications per crop if applied at the appropriate time. Thus, the concept of economic threshold and on-time appliation can greatly reduce spraying frequency for BPH control in Taiwan.

As the above mentioned, the nymphal stage of the second generation is the critical time for controlling the BPH. In order to set up a control program before the pest reaches its economic threshold, the relationship between the number of female adults of the first generation and the nymph density of the following generation was evaluated by using cage-method and field investigation. It is concluded that if the density of the first-generation female adults exceeds 25 per 100 hills in the first rice crop, or 12 females per 100 hills in the second crop season, the population at the maximum nymphal stage of second generation is expected to reach or exceed the economic threshold (Fig. 3). Then, insecticide application is need. This method is suitable for an individual farmer to predict the time of BPH control at his own field.

Table 4. Economic Threshold of BPH at Different Stages of Rice[1]

Sites of test	Stage of rice					
	Init. tillering	Max. tillering	Init. booting	Max. booting	Milky	Doughy
Potted plants	6.4-9.6	6.0- 9.0	5.4-8.1	4.6-6.9	5.2- 7.3	7.4-11.1
Field plants	6.4-9.6	7.6-11.4	–	5.6-8.4	7.1-10.2	8.2-12.3

1. Calculation based on the model proposed by Chiang (1979)
   ET= Cost of control/efficiency of control x yield x price of crop x survival coefficiency x yield reduction resulting from a given population density.
   Rice price: 8 (NT$)/kg, Cost of control: 1080 (NT$)/ha/time, Yield: 4000 kg/ha, Control efficiency: 80%, Survival rate: 50%, Sampling error: 20%.

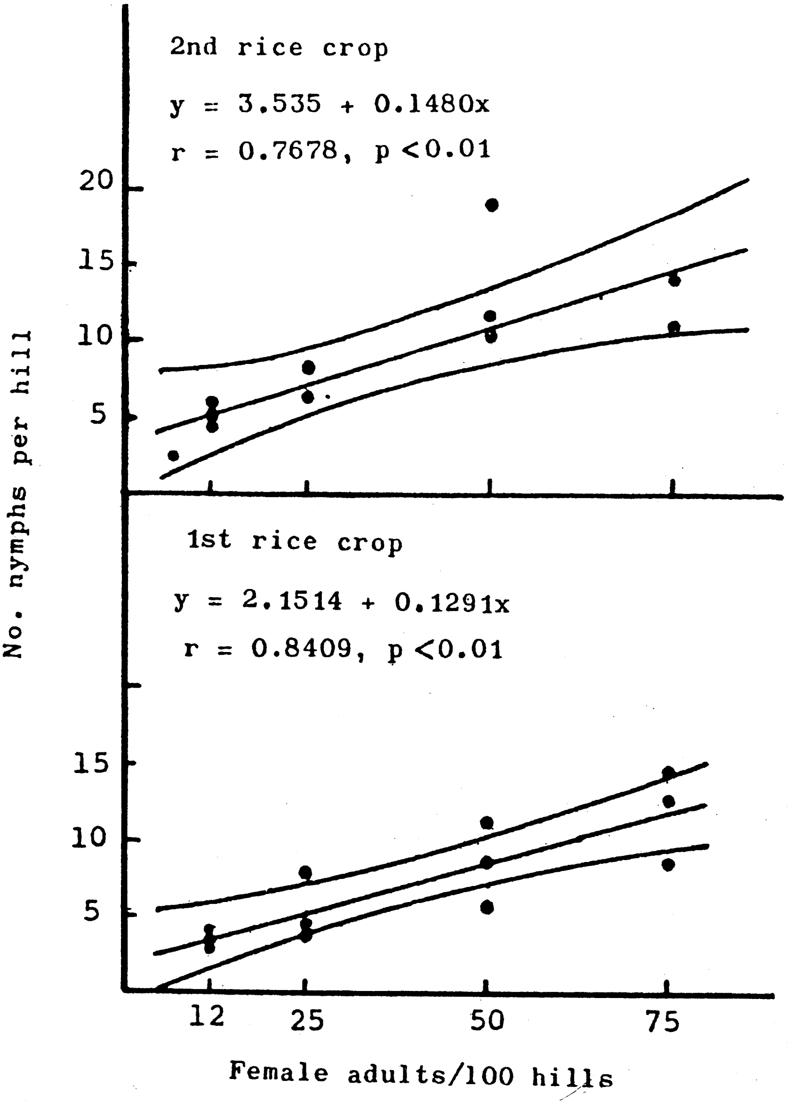

Fig. 3. Correlation of the number of brachypterous females caged on rice plants at panicle initiation stage and the number of nymphs appeared in following generation at the end of booting stage of rice, CAES, 1981.

Preservation of Natural Enemies for Biological Control

Although a series of parasites and predators against the BPH have been recorded in Taiwan as well as in other Asian countries (Otake, 1977; Chiu, 1979), the role of natural enemies in controlling BPH population is not fully understood. Generally, it has recognized that the BPH has a too high rate of population growth to be effectively suppressed by natural enemies (Otake, 1977; Chen, 1978; Kuno, 1979). However, without the regulation of natural enemies, the plants may suffer from more severe damage much earlier. Therefore, to understand the role of natural enemies on the control of BPH and searching the way to improve their fuctions are important for developing an integrated control program.

From a survey of population changes of natural enemy species conducted in the experimental field of the Chiayi Agricultural Experiment Station in 1974 and 1981 showed that *Lycosa pseudoannulata, Tetragnata japonica, Oedothorax insecticeps, Cyrtorhinus lividipennis, Anagrus optabilis* and *Paracentrobia andio* were the most abundant.

The invasion of spiders into paddy field started within a few days after transplanting. Two to three population peaks could be recognized for different species of spiders in a crop season. The highest population density of important spiders averaged about 2 per hill (Fig. 4). On the other hand, the density of *Cyrtorhinus lividipennis* was quite low during the early stage of rice. It increased rapidly following the population growth of the BPH. An average density of 30 bugs per hill was recorded during the dough to ripening stage of rice in the second crop season.

The parasitism rates of the BPH egg tended to increase with the development of the rice canopy. The percentage of parasitism observed 15 days after transplanting was less than 10 percent, 35 to 56 days after transplanting was about 30 percent, and varied from 40 to 70 percent thereafter (Fig. 5).

Observations of seasonal changes in the abundance of these natural enemies showed that the predator *Cyrtorhinus lividipennis* and egg-parasites were closely associated with the population growth of the BPH, but the spiders were not evidently associated. Based on the feeding capability of the predators and eggs-parasitization, the combined effect of the natural enemies could cause about 90 percent mortality of the BPH in the late stage of rice, yet the rice crop in the field was hopper-burned before harvest. This reveals that the natural enemies alone are not strong enough to suppress the population growth of the BPH below the level of economic injury.

Analysing the incapability of natural enemies in check the population of BPH suffeciently were mainly due to the low population of predators and egg parasitism in the early stage of rice and the polyphagous behavior of the predators (Yasumatsu, 1981; Pathak and Saha, 1976). The BPH population is in many cases low in the initial generation and needs two to three generation to increase to a high enough density to cause severe damage of the rice crop. Therefore, increasing the number of species and the activity of various natural enemies in the early stage of rice would be most important in controlling the BPH. The weedy leaves and ditchs around the rice fields serve as a shelter for natural enemies during the fallow period of the rice field. The management of those surrounding needs more consideration. On the other hand, an intensive use of broad-spectrum insecticides is one of important factors destructing the population increase of natural enemies. Therefore, searching for an insecticide that is relatively safe to natural enemies is also an important subject in pest management program.

According to the evaluation of the toxicity of insecticides on natural enemies of the BPH both in the laboratory and fields, the result showed that the adverse effect of insecticides to the predators and parasites varied greatly according to the species. Besides conduct toxicity, the insecticides also killed the prodators through the food-chain (Chiu and Cheng, 1976). Among the predators, *Cyrtorhinus lividipennis* was the most sensitive to insecticides. Carborfuran, BHC, Meltakamate and Fensulfothion were high toxic to the predators, whereas Acephate was considered a relative safe insecticide to them. The adverse effect of insecticides on egg parasites is not so strong as that on predator. BHC, Parathion and Carbofuran reduced parasitism for about two weeks, but the other

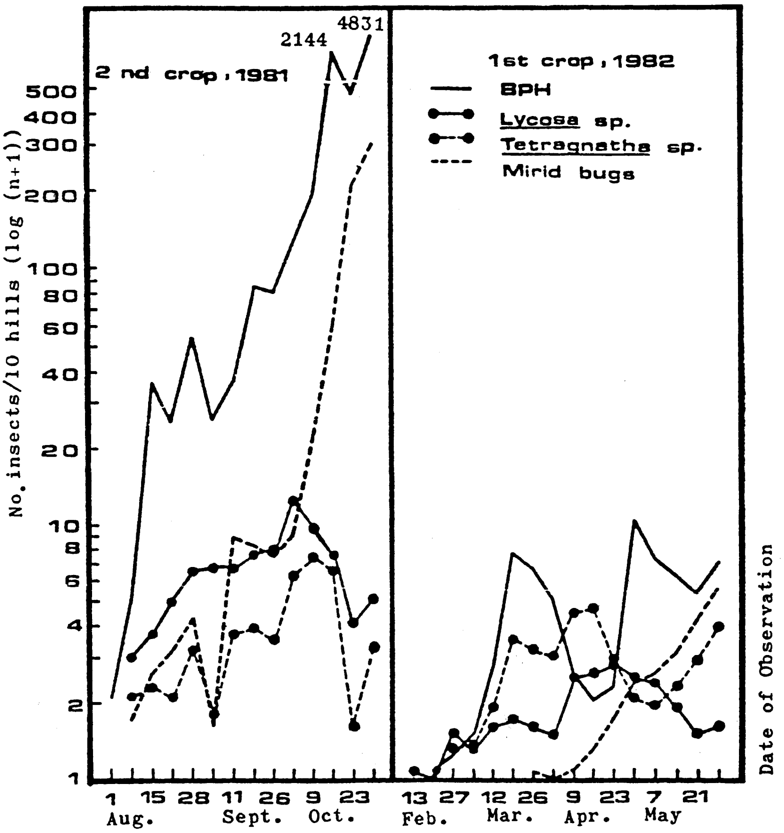

Fig. 4. Seasonal population changes in predacious spiders and mirid bug (*C. lividipennis*) in relation to the population growth of BPH, CAES, 2nd crop 1981 and 1st crop 1982.

insecticides commonly used for control of BPH had little affect on parasitism. This is probably due to the advantage of their short life-cycle, particular reproductive behavior and higher despersing ability than predators (Otake, 1977; Chandra, 1980). Therefore, the populations of the parasites may recover quickly from destruction by insecticide.

Form the above studies, it shows that timely application with a relatively selective and non-persistant insecticide like Acephate seems to be most reliable method for reducing the adverse effect to natural enemies at present. This concept was proved in a field experiment in 1975 as Acephate and a broad-spectrum insecticide, Carbofuran were tested for controlling the BPH. It showed that both Acephate and Carbofuran suppressed the population of BPH to a level below the economic threshold for more than 30 days and produced equal grain yield, but Carbofuran reduced the population of predators more severly and for a longer period than Acephate (Cheng, 1983) (Fig. 6).

Breeding for Varietal Resistance and Searching Measures for Coping With Virulent Biotypes

Varietal resistance to insect pests has long been considered as a major element of integrated pest management programs. Host resistance provided a built in insurance against pest damage at a low cost for the growers and reduces the problem associated with the use of insecticides.

In Taiwan, all native cartivars are susceptible to BPH. In order to develop resistant variety, a research program for breeding BPH resistant variety has been initiated since 1969. Most of resistant sources were introduced from the International Rice Research Institute. The hybrids from the breeding program were screened for their resistance by using seedling bulk test

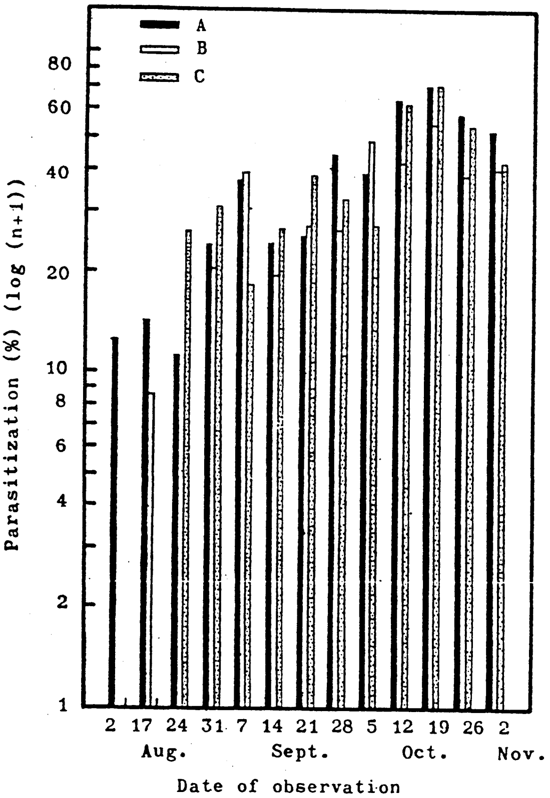

Fig. 5. Seasonal changes in parasitization of BPH eggs by parasites, 2nd crop, 1973 and 1974 (A: Potted plants bearing BPH eggs were exposed to parasites in paddy field; B: From field collected rice plants, 1973; C: From field collected rice plants, 1974).

method (Pathak *et al.*, 1969) and the advance lines were evaluated with seedlings at a screenning house and adult plants in the field (Cheng and Chang, 1979).

During last 13 years, seven resistant varieties, including 5 Indicas and 2 Japanicas have been named and released for commercial cultivation in Taiwan through the effort of the entomologists and breeders. The effectiveness of planting resistant varieties suppressing BPH infestation has been demonstrated in many experiments. In many cases, the BPH population on resistant varieties were less than 10 per hill throughout the crop season, insecticide application for controlling the BPH was not necessary. Whereas on susceptible varieties, several hundred hoppers per hill were recorded after heading stage, and hopper-burn occurred before maturity (Fig. 7). The BPH was responsible for more than 30 percent yield losses in susceptible varieties, but was negligible in resistant varieties. In addition, the resistant varieties did not reduce the natural enemies of the pest inhabiting them. The predatory spiders were almost equally abundant on resistant and susceptible cultivars; the ratio of the *Cyrtorhinus lividipennis* to the BPH in the resistant variety was even higher than that on susceptible varieties (Cheng, 1977). These data reveal that the use of a resistant variety may be a principal method of BPH control.

A threat to the stability of varietal resistance is the development of biotypes capable of surviving and multiplying on resistant varieties. The first commercial resistant variety IR 26 (with the *Bph*-1 genes) developing by IRRI was attacked by virulent biotypes two to three years after its extension in the Philippines, Indonesia, Solomon

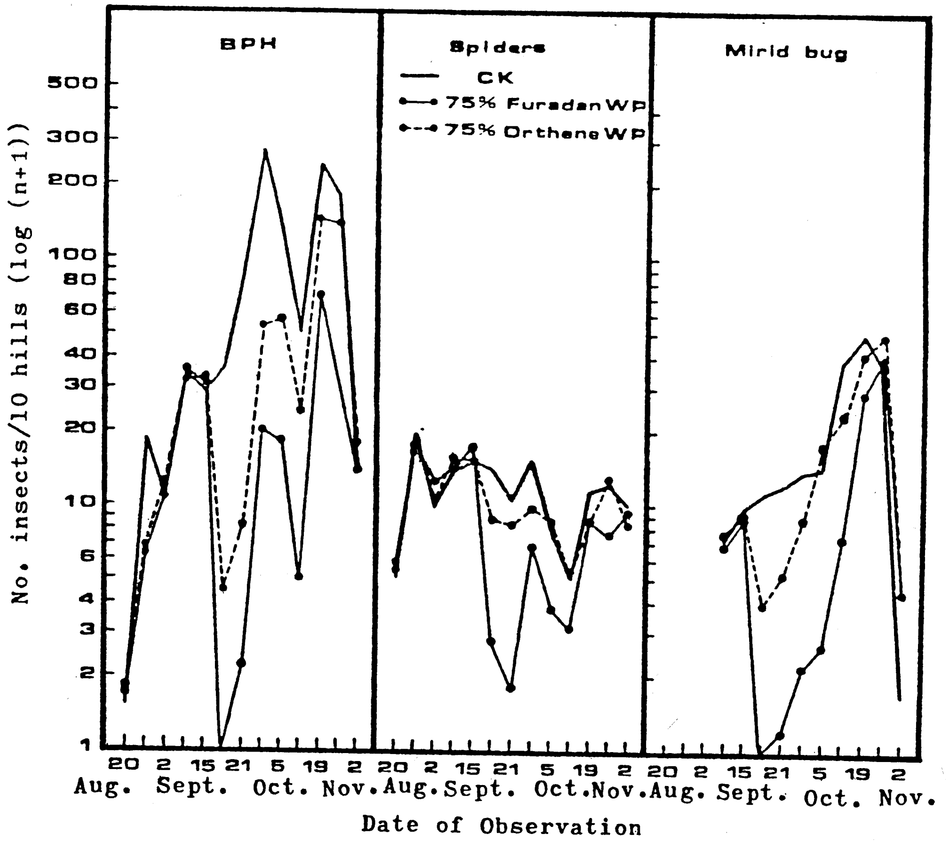

Fig. 6. The effectiveness of Acephate (Orthene) and Carbofuran (Furadan) on BPHs and their predators: spiders and mirid bug (*C. lividipennis*) in a field experiment, 2nd crop, 1975 (Grain yield for treatment of Carbofuan was 4601 kg/ha. For Acephate was 4492 kg/ha and for no treatment was 4140 kg/ha).

Island, and Vietnam (Varca and Fuer, 1976; Mochida et al., 1977; Huynh and Xuan, 1981; Stapley, 1979). In order to cope with the evolution of new virulent biotypes, the biological characteristics of biotypes, the possible response of BPH to different resistant genes of rice and the evolutionary dynamics of occurrence of specific virulent biotype have been investigated at Chiayi Agricultural Experiment Station during past few years (Cheng, 1983).

At present, the BPHs collected from different localities in Taiwan shows similar reactions to resistant varieties, and a majority of the insect appear to belong to the so-colled biotype I. However, when the collected hoppers were reared on resistant varieties, there were few nymphs which survived on the resistant varieties and became adults. When surviving nymphs on a particular resistant variety were reared for more than 6 generations, most of the hoppers could survive and kill the plants of the resistant variety. By this selection technique, five biotypes were developed in the laboratory. The biotypes could be distinguished from each other only by their responses to differential varieties (Table 5).

The behavioral and physiological responses of a biotype to rice varieties having the same resistant gene on which the biotype was developed resemble the responses to susceptible varieties. For instance, biotype II was able to feed, develop, and reproduce on varieties with *Bph*-1 as well as on susceptible varieties. Among the five biotypes, biotypes II and IV were more virulent to different varieties than biotypes I and III. On the other hand, basing on the survival rate of biotypes on varieties with different resistant

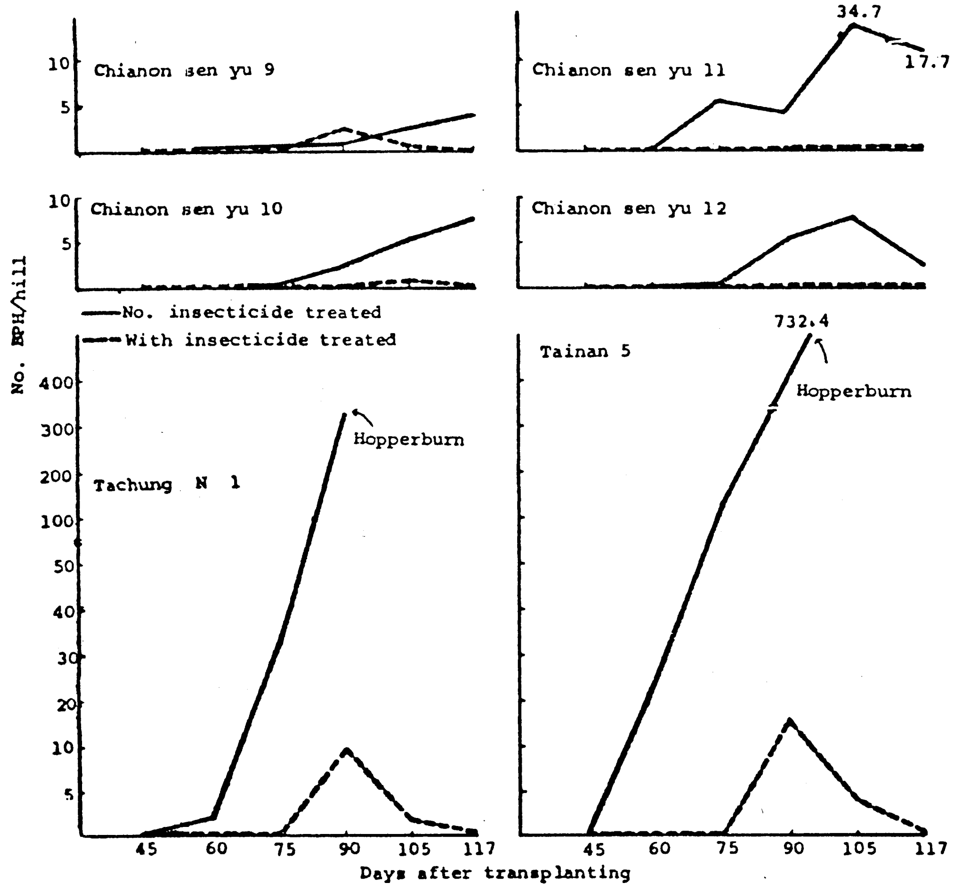

Fig. 7. Differences in BPH population development on some rice selections between insecticide treated and untreated plots, 2nd crop, 1972.

genes, it showed that varieties with *Bph*-2 genes had a week antibiotic factor, whereas, the varieties with *Bph*-1, *Bph*-3 and *Bph*-4 genes posses a strong antibiotic agent to the insect. It was reported that varieties having a strong antibiotic factor were readily capable of developing new biotype or races as compared with these having weaker antibiotic factor (Gallun, 1972).

Table 5. Interactions Between Biotypes of BPH and Resistance Genes of Rice

Resistance genes	Biotypes				
	I	II	III	IV	V
Susceptible varieties	S	S	S	S	S
Bph-1	R	S	R	R	R
bph-2	MR	MR-MS	S	MR-MS	MR-MS
Bph-3	R	R	R	MS	R
bph-4	R	R	R	R	MS

R: Resistant MR: Moderately resistant
S: Susceptible MS: Moderately susceptible

Studies on the feeding behavior of biotypes on varieties with different resistant genes showed that the hoppers put on unsuitable host plants were restless and changed their feeding site frequently (Table 6). An anatomical examination of the feeding sites showed that no mechanical barrier was involved in the resistance (Chang, 1983). However, any biotype fed less from resistant varieties (Fig. 8). This strongly suggested that differences in the response of biotypes to different resistant genes was likely to be due to different gustatory thresholds of the biotypes to the concentration of feeding inhibitory or stimulating factors controlled by resistant genes.

Table 6. Feeding Punctures Made by Biotypes of BPH on Rice Varieties with Different Resistance Genes at 30°C (March 1981)

Varieties[1]		Punctures/female/24 hrs				
		Biotypes				
		I	II	III	IV	V
Taichung N 1	(S)	28.7^{b}	30.2^{c}	26.6^{b}	27.4^{b}	25.1^{b}
Mudgo	(*Bph*-1)	53.7^{a}	32.2^{bc}	67.9^{a}	56.0^{a}	54.6^{a}
ASD7	(*bph*-2)	32.6^{b}	34.6^{bc}	28.5^{b}	31.1^{b}	29.0^{b}
Rathuheenati	(*Bph*-3)	56.2^{a}	65.3^{a}	71.2^{a}	43.2^{ab}	56.5^{a}
Babawee	(*bph*-4)	51.2^{a}	48.4^{ab}	53.2^{a}	56.8^{a}	38.5^{ab}

1 15-day-old seedlings.

a. b, ect. show ranks differing at 5% level of significance.

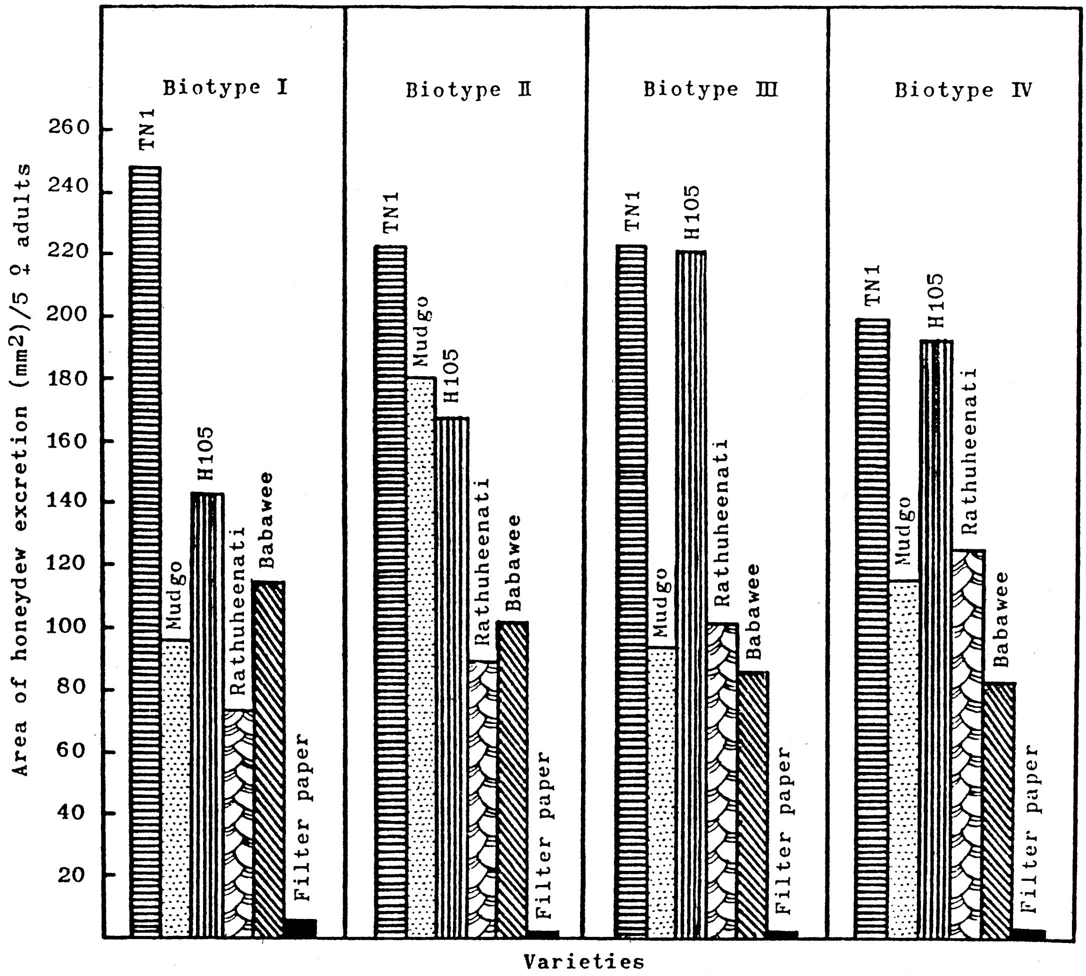

Fig. 8. Honeydew excretion of female adult of different biotypes on rice varieties with different resistance genes (May 1981).

Table 7. Mean Survival Rate of BPH Progenies from Reciprocal Crosses Between Biotypes, I, II and III, Reared on Mudgo (I x II and II x III) or H105 (I x III)

Crosses between:	Generation	No. of replicates	% Survival mean	Standard error
I and II	P1	10	14.0	5.39
	P2	10	89.0	2.83
	F1	20	18.0	3.87
	F2	40	41.3	4.12
	BC1	40	22.8	3.61
	BC2	40	43.0	4.00
II and III	P1	10	82.0	3.32
	P2	10	27.0	5.74
	F1	20	23.0	3.87
	F2	40	65.3	3.74
	BC1	40	47.8	3.61
	BC2	40	52.5	4.12
I and III	P1	10	42.0	2.83
	P2	10	95.0	2.24
	F1	20	60.5	3.00
	F2	80	59.0	1.00
	BC1	40	52.0	1.73
	BC2	40	58.8	2.00

Data from reciprocal crosses were pooled since they differed only slightly. Each replication consisted of 10 nymphs of the first instar, reared on two 10-day-old seedlings in a test-tube.

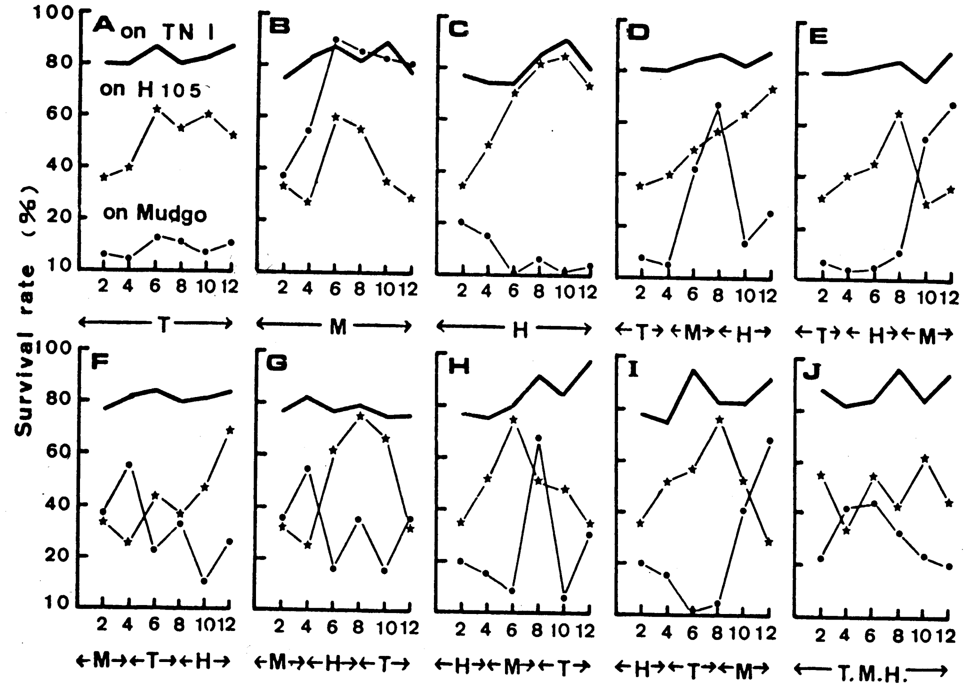

Fig. 9. Survival rate of brown planthopper on resistant varieties (Mudgo, abr. as M; and H 105, abr. as H) and susceptible TN 1 (abr. as T) when they were reared on a variety continously (Fig. A-C), on varieties having different resistance genes in rotation with on variety for four generations (D-I), or on a mixture of resistant and susceptible varieties (J).

The genetic studies on the ability of biotypes I, II, and III to survive on resistant varieties Mudgo (with *Bph*-1 genes) and H105 (with *bph*-2 genes) showed that the virulence of the BPH would not controlled simply by major genes, as was accounted for by models of polygenic inheritance (Table 7). The degree of dominance as estimated by Mather and Jinks (1971) formula indicated that the inability of biotype I to survive on mudgo was partly dominant to the ability of biotype II, while the inability of biotype III was overdominant to the ability of biotype II; the inability of biotype I to survive on H105 was partly dominent over the ability of biotype III. Further analysis of the data of mean survival rates of BPH progenies by Hayman and Mather (1955) equations showed that dominance effects were the most important factor in determining the inability of biotypes to survive on resistant varieties in all three crosses (Cheng, 1983). In addition, interactions between additive, additive and dominance, and dominance gene effects were found to control the virulance of biotypes. These results indicated that the virulence of biotype was controlled by many genes.

Since the biotypes are differentiated by polygenic changes, field populations must be heterogenous and variable, and initial low virulence of a population to a resistant variety may rapidly be improved by gene recombination. In order to prevent or retard an rapid evolution of new biotypes, an experiment conducted in a greenhouse showed that rotation or mixed planting of plants with different resistant genes were effective in lowering the rate of evolution of virulent biotypes (Fig. 9). This suggest that to increase genetic diversity in the field is an effective means in prevalence of virulent biotypes. In fact, since virulent biotypes, are generally recessive genetically, they may not persist in nature unless the populations are isolated and subjected to a high selection pressure imposed by the host resistant gene. From these results. It is concluded that resistant varieties remain useful for a considerable period in establishing an integrated control of the BPH, if the varieties with different resistant genes can properly be rotated or planted in mixture in the fields.

Integrated Use of Host Resistance, Natural Enemies and Insecticides

Based on all the available data obtained from the foregoing studies, several pilot experiments have been carried out in Chiayi Agricultural Experiment Station in an attempt to establish an integrated control program for the BPH and other insect pests of rice. The results of one of such experiment shows in **Table** 8, 9 and 10 (Cheng, 1983). The major insect pests and diseases found in the experment field were BPH, whorl maggot, leaffolder and bacterial leaf blight. The degree of damage caused by the whorl maggot and leaffolder in the test varieties did not differ significantly, but the BPH populations on resistant and susceptible varieties differed remarkably. The bacterial leaf blight infected Indicas only. In this case, when susceptible varieties are grown, two applications of insecticides properly formulated and timed, based on the economic threshold, are enough to protect the crop from economic injury by insect pests (Table 8). As to the net return profit, the integrated control plots produced a 1.5 percent higher profit than the profit treated with 5 applications according to ordinary schedule (Table 9). This demonstrated that if the effectiveness of insecticide control is assesed not in terms of percentage killed, but in terms of net return profit, the frequency of insecticide application can be reduced to a minimum.

When BPH-resistant varieties were adopted in the control program, one application of a relatively selective insecticide at a proper time was sufficient to suppress rice insect pests in a crop. In fact, the population of the BPH was reduced to a level below the economic threshold, and insecticide application was necessary only for controlling the insect pests to which the varieties were not resistant. As a result, a four to seven percent higher net profit could be obtained from the plots of integrated control than those receiving prophylactic protection. This shows that when varietal resistant is involved in an integrated control program, the insecticide application can be futher reduced, thus realizing a more favorable condition for the activities of their natural enemies than pest control based on the economic threshold with susceptible varieties (Table 10).

Table 8. Pest Population, Damage and Grain Yield of Resistant and Susceptible Varieties with Different Levels of Pest Control (2nd Crop, 1977)

Varieties	Levels of Protection	Damage of whorl maggot (%)		BPH/hill			Damage of leaf folder (%)	Damage levels of	Grain yield
		40 DAT	60 DAT	75 DAT	90 DAT	105 DAT	90 DAT	BLB[4]	(kg/ha)
Taichung shen 10	No insecticide	21.4	0.9	0.6	4.3	6.4	32.3	1	4901.3^{b}
	Economic protection[1]	16.7	0.9	0.7	1.2	4.3	6.5	1	5240.5^{ab}
	Maximum protection[3]	4.5	0	0.2	0.2	0.4	2.4	1	5564.4^{a}
Tainan 5	No insecticide	26.5	4.3	22.4	75.5	215.4	28.7	0	2237.6^{b}
	Economic protection[2]	25.3	3.9	14.3	6.4	5.3	4.7	0	4665.5^{a}
	Maximum protection[3]	6.5	2.6	10.2	7.3	6.1	2.9	0	4937.1^{a}

1 75% Acephate sp. 0.6 kg ai/ha at 80 DAT for controlling leaffolder.
2 75% Acephate sp. 0.6 kg ai/ha at 60 and 80 DAT for controlling brown planthopper and leaffolder.
3 75% Acephate sp. 0.6 kg ai/ha at 20, 40, 60, 80 and 100 DAT for controlling whorl maggot, brown planthopper and leaffolder.
4 Bacterial leaf blight, 0: no visible damage; 1: slight damage; 2: moderate damage; 3: severe damage.
DAT: Days after transplanting.
a, b, etc. show ranks differing at 5% level of significance.

Table 9. Comparison of the Economy of 3 Levels of Insect Control in Two Rice Varieties (2nd crop, 1977)

Levels of protection	Money of account (in thousand NT$)					
	Yield (kg/ha)	Gross profit[4]	Cost of control[5]	Net return[6]	Gain from insecticide[7]	Benefit/cost
Taichung shen 10						
No insecticide	4901.3^{b}	51.46	0	51.46	0	–
Economic protection[1]	5240.5^{ab}	55.03	1.25	53.78	2.32	1.86
Maximum protection[3]	5564.4^{a}	58.43	6.25	52.18	0.72	0.11
Tainan 5						
No insecticide	2237.6^{b}	25.73	0	25.73	0	–
Economic protection[2]	4665.5^{a}	53.65	2.5	51.15	25.42	10.17
Maximum protection[3]	4947.1^{a}	56.78	6.25	50.33	24.80	3.97

1, 2, 3: Refer to table 8., 4. Rice price: NT$10.5/kg for Taichung shen 10 and NT$11.5/kg for Tainan 5, 5. Cost for one application: NT$1,250 (labour cost: 450 + insecticide: 800), 6. Net return = Gross pofit-cost of control, 7. Net return of treatment-Net return of no insecticidal treatment.
a, b, ect. show ranks differing at 5% level of significance.

Discussion and Conclusion

Since the BPH is the important insect pest limiting rice production in Taiwan. For protection rice from the damage of BPH, three to six applications of insecticides in the second crop season are usually practiced. Accordingly, if the BPH can be controlled by other measures than that of insecticide application, the use of insecticide can be reduced greatly. This in turn will contribute not only to the slowdown of the evolution of insecticide resistance of various pest species, but also open the way to manage the pests by the power of the natural enemies in a revived ecosystem.

Recently, different systems of integrated control have been suggested for various crop pests. In developing a practical integrated system whether or not the components and techniques involved in it are acceptable to the farmers must be considered. In Taiwan, because of the small size of farms and the shortage of labor, what is needed is a simple combination of a few components which are inexpensive and easily employed. To meet this requirement, a combination of insecticide application, varietal resistance and protection by natural enemies offers the best possibility controlling BPH as well as other rice pests. By using this control tactics as a pilot experiment has shown, insecticidal treatment is needed only against the pest to which the varieties are not resistant. In addition, as mentioned, either spacial or temporal mixing of varieties with different resistance genes was useful in slowing down the rate of evolution of new virulent biotypes, so as to control the vulnerability of resistant varieties. On the basis of present studies. It is assumed that sufficient technology now exists to implement rice insect pest management programs in Taiwan. A successful implementation of this control tactics in a large area, however, is in need of a group action of farmers, extension workers, scientist and the government administrators.

Table 10. Populations of Natural Enemies of BPH in Resistant and Susceptible Varieties with Different Levels of Pest Control (2nd Crop, 1977)

Varieties and levels of protection	Predators / hill[4]								
	Lycosa spider			C. lividipennis			Egg parasitism (%)[5]		
	Days after transplanting								
	30	60	90	30	60	90	30	60	90
Taichung shen 10									
No insecticide	0.6	0.9	0.6	0.4	2.4	32.3	25	46	61
Economic protection[1]	0.5	0.8	0.6	0.3	2.6	21.4	35	52	62
Maximum protection[2]	0.4	0.6	0.5	0.1	0.6	8.6	28	43	58
Tainan 5									
No insecticide	0.4	0.9	0.7	0.5	2.6	32.3	33	52	74
Economic protection[2]	0.5	0.7	0.5	0.4	2.3	16.2	18	48	68
Maximum protection[3]	0.3	0.5	0.4	0.1	1.3	9.5	21	46	64

1. 2. 3: Refer to table 8., 4. Recorded from 40 hills each plot, 5. Recorded from 40 tillers each plot.

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