Chemical control of the brown planthopper

E. A. Heinrichs

The most commonly practiced method of controlling the brown planthopper (*Nilaparvata lugens* Stål) is through the application of insecticides. Of the various leafhopper and planthopper species that attack rice, the brown planthopper is one of the most difficult to kill. Biotypes with differential responses to various sources of genetic resistance vary in their susceptibility to insecticides. Several methods of applying insecticide have been developed but foliar sprays are still the most commonly used. Proper timing and placement of insecticides are important in achieving effective control. Insect resistance to insecticide, which has occurred in limited cases, is expected to increase with increased use of insecticides in the tropics. Resurgences of the brown planthopper that result in total yield loss occur when certain insecticides are excessively used. Resurgences are more common when insecticides are applied as a foliar canopy spray than when they are broadcast.

CONTROL OF THE BROWN PLANTHOPPER *Nilaparvata lugens* (Stål) has depended primarily on the application of insecticides. In Taiwan, more than 50% of the insecticides applied to rice are directed at the brown planthopper (BPH) (pers. comm. with C. Y. Hsieh, Joint Commission on Rural Reconstruction, Taiwan). The evolution of the chemical control of the BPH is exemplified by the experience in Japan where the insect has had economic significance for many years.

Available records of leafhopper and planthopper outbreaks in Japan begin in the 7th century. The average time interval between recorded outbreaks has decreased from 22.5 years in the old period to 5.6 years in the middle and to 1.4 years in the recent period (Miyashita 1963). Unfortunately, no such data are available for the tropics.

The evolution of chemical control since the later part of the middle period has been recorded by Suenaga and Nakatsuka (1958) and Matsuo (1961). The use of whale oil, found effective in 1670, had spread throughout the country by 1840. Kerosene began to replace whale oil in 1897. DDT dust was the first post-World War II insecticide to replace kerosene and it was soon replaced by

Entomologist, Entomology Department, International Rice Research Institute, Los Baños, Philippines.

BHC. Organophosphorus insecticides were first used in 1952. Diazinon and malathion soon replaced parathion. Since 1964 carbamate insecticides have been used in Japan. A similar evolution is occurring throughout tropical Asia.

The use of insecticides for the control of the BPH is not always effective and can produce undesirable side effects.

This paper discusses some reasons why farmers sometimes find insecticides ineffective in controlling BPH, and some of the solutions research has provided for increasing the effectiveness of chemical control.

INSECTICIDE EVALUATION AND RECOMMENDATIONS

The toxicity of new insecticides to the BPH is first determined in the laboratory. Promising compounds are further tested in the field. Outside of Japan, most of the companies that synthesize and develop insecticides commercially are in Europe and the United States where the BPH does not occur. As a result, most of the basic testing to determine the suitability of the compounds for use against the BPH is conducted not by the manufacturer but by national or regional (state or province) experiment stations in Asian nations.

Insecticides have been extensively tested in Japan and a large number have been identified as effective against the BPH (Iwata 1970). Numerous insecticides were reevaluated in the field in Taiwan (pers. comm. with C. H. Cheng, Chia-yi Agricultural Experiment Station, Chia-yi, Taiwan, and C. C. Chen, Taiwan Plant Protection, Taichung, Taiwan). Carbofuran granules and acephate, BPMC, Hokbal, MIPC, and propoxur sprays were found to be most effective. Field evaluations have been conducted in India (Chelliah and Subramanian 1972), Korea (pers. comm. with J. S. Park, Institute of Agricultural Sciences, Office of Rural Development, Suweon, Republic of Korea) and Malaysia (Lim 1971; MARDI 1976).

Laboratory and field evaluations in the Philippines have identified several insecticides effective against the BPH. Before being field tested, the insecticides are subjected to four laboratory tests at the International Rice Research Institute (IRRI): 1) direct contact toxicity with Potter's spray tower, 2) residual contact toxicity of foliar sprays, 3) paddy-water application, and 4) root-zone application.

Table 1 shows the result of a retest of Philippine recommended insecticides applied as foliar spray. Most of the insecticides are effective at 1 day after treatment, but at 7 days their effectiveness begins to drop, indicating short residual activity, even in the greenhouse. Perthane has the longest residual activity.

Control with foliar sprays is generally poorer in the field than in the laboratory; it varies between 40 and 80% (Table 2). When insect populations are large, 80% control is not sufficient and repeated applications are necessary.

The synthetic pyrethroids are the most recent class of insecticides developed for agricultural use. At low rates they reportedly are active against the lepi-

Table 1. Knockdown and residual effects of Philippine recommended insecticides applied as foliar spray for control of brown planthopper *Nilaparvata lugens* **IRRI greenhouse, 1977.**

Insecticide [a]	Mortality [b] (%)		
	1 DAT	7 DAT	14 DAT
Perthane	100 a	60 a	10 cde
Carbophenothion	100 a	42 abc	10 cde
Metalkamate	100 a	18 c	20 abcd
Azinphos ethyl	98 a	50 ab	37 a
Monocrotophos	98 a	20 c	6 de
Acephate	98 a	18 c	8 de
MIPC	95 a	22 c	18 abcd
Chlorpyrifos	70 b	18 c	23 abcd
BPMC	58 b	22 c	10 cd
MTMC	22 d	28 bc	16 abcd

[a] All insecticides were applied at 0 75 kg a.i./ha, except carbofuran which was applied at 0.25 kg a.i./ha. [b] Mean of four replications, each consisting of 10 Insects caged on a treated plant, adjusted using Abbott's formula DAT = days after insecticide treatment when insects were placed on treated plants. Mortality was determined at 48 hours after caging. For each DAT a fresh group of insects was used. In any column, means followed by the same letter are not significantly different at the 5% level (DMRT).

dopterous species. Greenhouse tests indicated that when applied as foliar spray they are no more effective than carbofuran (Table 3).

Laboratory evaluation of insecticides applied in paddy water indicate that carbofuran, which has the longest residual activity. most effectively controls BPH (Table 4). It is also the most effective when applied to the root zone (Table 5).

Table 6 summarizes the results of experiments at IRRI to determine the suitability of insecticides for use as direct contact spray, as foliar spray, and

Table 2. Field evaluation of insecticides for the control of the brown planthopper. IRRI, 1976 wet season.

Insecticide [a]	Brown planthoppers [b]					
	Before 1st insecticide application (no.)	Four days after 1st insecticide application (no.)	Control (%)	Two days after 2nd insecticide application (no.)	Control (%)	Average control (%)
Metalkamate	2678	304	89	67	78	84
Monocrotophos	3502	659	81	192	70	76
Carbofuran	2914	835	71	431	48	59
Carbophenothion	2892	1785	38	375	79	59
BPMC	3182	1644	48	353	79	59
Acephate	3091	1414	54	588	58	56
MIPC	2318	1124	52	571	49	51
Methyl parathion	2991	2153	28	737	66	47
Endosulfan	2903	1935	33	1059	45	39
Control	2481	6183		5129	–	–

[a] All insecticides were applied at 0.75 kg a.i./ha, except carbofuran which was applied at 0.25 kg a.i./ha. A total volume of 1,022 liters of water plus insecticide was sprayed per hectare. The nozzle was held 5–7.5cm from the water surface. [b] Collected with a D-Vac suction machine. Second application was 5 days after the first. Percentage of control was based on population count 4 days after first application.

Table 3. Knockdown and residual effects of insecticides applied as foliar spray at low rates against the brown planthopper. IRRI greenhouse, 1976.

Insecticide[a]	Formulation[b]	Concentration[c] (%)	Brown planthopper mortality[d] (%)		
			1 DAT	7 DAT	14 DAT
Carbofuran	20 F	0.02	100 a	100 a	100 a
		0.004	100 a	82 b	21 b
		0.0002	47 b	6 def	18 bc
NRDC 149	10 EC	0.02	100 a	26 cd	18 bc
		0.004	30 bcd	11 cdef	13 bcd
		0.0002	9 ef	11 cdef	5 cde
WL 41 706	30 EC	0.02	97 a	30 c	13 bcd
		0.004	20 cde	9 cdef	3 de
		0.0002	15 def	8 def	7 bcd
NRDC 161 (Decis)	2.5 EC	0 02	92 a	14 cde	16 cde
		0.004	12 def	11 cdef	20 b
		0.0002	5 fg	8 def	14 bcd
WL 43775	30 EC	0.02	48 b	14 cde	11 bcd
		0.004	10 ef	8 def	7 bcd
		0.0002	12 def	0 f	12 bcd
Perthane	45 EC	0.02	38 bc	7 def	5 cde
		0.004	12 def	5 def	5 cde
		0.0002	10 ef	5 def	8 cde

[a] Applied at the rate of 12.5 ml solution per 45-day-old plant. [b] F = flowable, EC = emulsifiable concentrate. [c] 0.02 = 0.4 kg a.i./ha; 0.004 = 0.08 kg a.i./ha, 0.0002 = 0.004 kg a.i./ha. Carbofuran is a carbamate, perthane an organophosphate, and the others pyrethroids. [d] Mean of 4 replications, each consisting of 15 insects caged on plants; adjusted using Abbott's formula. In a column means followed by a common letter are not significantly different at the 5% level. DAT = days after treatment, when insects were placed on treated plants

Table 4. Effect of paddy water application of insecticides at 1 kg a.i./ha on control of the brown planthopper. IRRI greenhouse, 1976.

Insecticide	Formulation[a]	Brown planthopper mortality[b] (%)		
		1 DAT	7 DAT	14 DAT
Carbofuran	3 G	100 a	92 a	26 b
Metalkamate	3 G	100 a	48 c	26 b
Disulfoton	5 G	100 a	31 c	—[c]
FMC 27289	5 G	100 a	5 d	19 b
Diazinon	10 G	66 bc	13 cd	8 c
BPMC	4 G	62 bcd	32 c	30 b
MTMC	5 G	59 bcd	13 cd	0 d
Aldicarb	10 G	59 bcd	0 d	17 b
Padan	10 G	56 cde	0 d	—[c]
Dyfonate	5 G	48 bcde	26 c	0 d
Chlorfenvinphos	10 G	14 efgh	0 d	11 c
Triazophos	5 G	14 efgh	0 d	0 d
Chlordimeform	5 G	10 fgh	0 d	—[c]
Perthane	5 G	10 fgh	0 d	0 d

[a] G = granules. [b] Means of three replications; each consisting of 10 insects caged on a treated TN1 plant; adjusted using Abbott's formula. DAT = days after treatment, when insects were caged on treated plants. Mortality was determined at 48 hours after caging. In a column, means followed by a common letter are not significantly different at the 5% level. [c] Plants were hopperburned.

Table 5. Evaluation of insecticides applied in the root zone at 1 kg a.i./ha for control of brown planthopper. IRRI greenhouse. 1976.

Insecticide	Formulation[a]	Brown planthopper mortality[b] (%)			
		1 DAT	12 DAT	26 DAT	32 DAT
Carbofuran	20F	100a	73a	16a	24a
FMC27289	48EC	100a	60a	27a	24a
Methamidophos	50EC	50 b	13 bcd	29a	–[c]
AC64475	5G	43 bc	60a	13a	15a
Methomyl	20EC	23 cd	20 bc	13a	–[c]
Carbofuran	3G	13 d	60a	29a	32a
Acephate	75SP	10 de	8 bcd	22a	–[c]
Methomyl	50DP	5 de	5 cd	15a	13ab
Metalkamate	3G	0 e	12 b	11a	8ab

[a] F = flowable, EC = emulsiflable concentrate, G = granules, SP = soluble powder, DP = dispersible powder. Flowable and emulsifiable concentrates were injected into the root zone with a syringe, and granules were placed in gelatin capsules and injected by hand. [b] Mean of four replcations, each consisting of 10 Insects caged on a treated TN1 plant; adjusted using Abbott's formula Mortality was determined at 48 hours after caging. DAT = days after treatment, when Insects were caged on treated plants. In a column, means followed by a common letter are not significantly different at the 5% level. [c] Plants dead due to brown planthopper burn.

as applied to the paddy water or to the root zone (E. A. Heinrichs, and S. L. Valencia, unpubl. data). Insecticide activity varies with the type of application. Few insecticides are effective when applied to paddy water or the root zone. Carbofuran's effectiveness in all four tests, however, indicates its versatility against rice pests. Many insecticides are ineffective as a direct contact spray in Potter's spray tower but are effective as a residual contact foliar spray. The pyrethroids are all highly effective as contact poisons.

Results of insecticide evaluation programs have been used as a guide in developing control recommendations for BPH in various Asian countries. At least 31 different insecticides are recommended throughout Asia, not only because of their effectiveness but also because of their commercial availability and safety. BPMC, carbaryl, carbofuran, and diazinon are the most widely recommended. Carbamates are primarily recommended in Japan where insects have been found resistant to the phosphates.

SELECTIVE TOXICITY

Species

The BPH generally is more difficult to kill with insecticides than are other hoppers in rice fields. In both laboratory and field tests at IRRI, the green leafhopper *Nephotettis virescens* Distant was much more sensitive to insecticides than the BPH. Choi and Lee (1976) and Fukuda and Nagata (1969), who studied the toxicity of several insecticides to the BPH, the whitebacked planthopper *Sogatella furcifera* Horvath, and the small BPH *Laoddphax striatellus* Fallen, found the BPH to be the least susceptible.

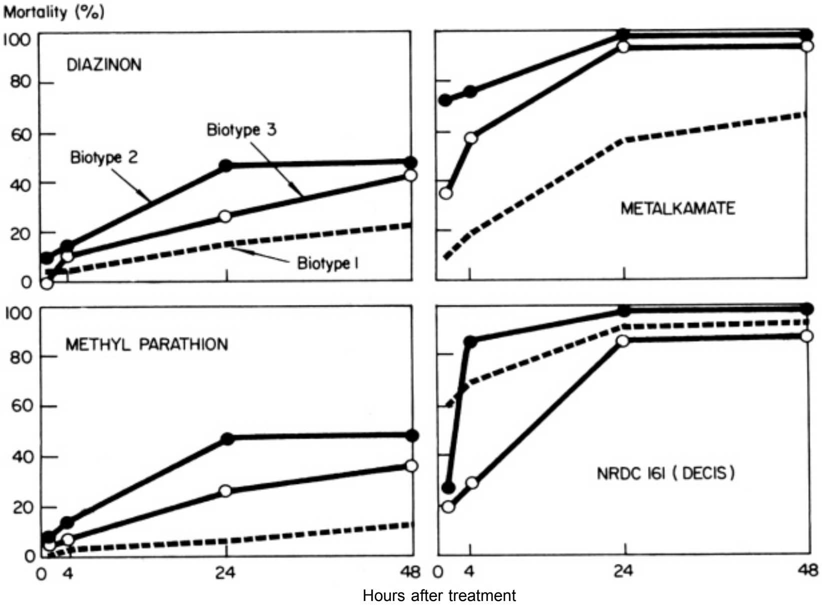
Table 6. Activity of insecticides against the brown planthopper as tested by four application methods. IRRI laboratory. (E. A. Heinrichs and S. Valencia, unpubl.)

Insecticide [a]	Activity [b]			
	Contact toxicity	Foliar spray	Paddy water	Root zone
Carbamates				
BPMC	+	+	-	-
Carbaryl	-	+	+	-
Carbofuran	+	+	+	+
Metalkamate	+	+	+	-
Methomyl	+	-	+	-
MIPC	+	+	+	-
MTMC	+	+	-	-
Padan	-	-	-	-
Organophosphates				
Acephate	-	+	+	-
Azniphos ethyl	-	+	-	-
Carbophenothion	-	+	-	-
Chlorfenvinphos	-	-	-	-
Chlorpyrifos	-	+	-	-
Diazinon	-	+	-	-
Methyl parathion	-	-	+	-
Monocrotophos	+	+	-	-
Vamidothion	-	+	-	-
Organochlorines				
Endosulfan	-	+	-	-
Perthane	-	+	-	-
Pyrethroids				
NRDC 149	+	+	-	-
NRDC 161	+	+	-	-
WL 43467	+	+	-	-
Permethrin	+	+	-	-

[a] Applied as a 0.01% spray in the contact toxicity test in Potter's spray tower, 0.04% spray equal to 0.75 kg a.i./ha in the foliar spray test, and at 1.0 kg a.i./ha in the paddy water and root-zone tests. [b] + = effective; mortality counts of 80% or higher; - = not effective. Mortality readings in the contact toxicity experiments taken at 48 hours after treatment. Readings in the foliar spray, paddy water, and root-zone experiments were at 1, 7, and 14 days, respectively, after brown planthoppers were caged on treated plants.

Stage and sex

The age of adult insects influences their sensitivity to insecticides (Sugimoto and Yamazaki 1970). The susceptibility of adults was studied at 1 to 13 days after emergence. The mortality of females at 3 hours after treatment was lowest—15% at 4–5 days; it was 67% at 1 day and 94% at 13 days. Uebayashi and Osaki (1968) studied the susceptibility to several insecticides of the BPH at various stages; they ranked the adult male to be more susceptible than the adult female, which was more susceptible than nymphs of the 4th or 5th instars. Studies by Fukuda and Nagata (1969) indicated no difference between males and females.



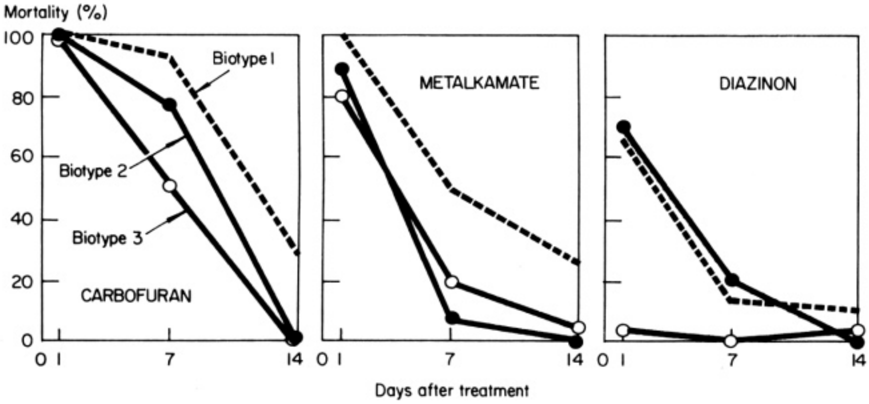
1. Mortality of three brown planthopper biotypes treated with 0.04% contact spray in a Potter's spray tower at indicated hours after treatment. IRRI, 1977 (E. A. Heinrichs and S. Valencia, unpubl. data).

Insecticide classes

Studies in Japan (Fukuda and Nagata 1969) indicated that carbamates are the most toxic of the compounds tested, while the organophosphate and chlorinated hydrocarbon insecticides are the least. In general, organophosphates have more selective toxicity to the various hopper species; carbamates and chlorinated hydrocarbon insecticides are not selective. Choi and Lee (1976) reported similar results.

Biotypes

Three BPH biotypes with differential reactions to genetic resistance from various sources have been selected in the greenhouse at IRRI (1976). Studies in 1976 indicated that the biotypes vary biologically (IRRI 1977). Their responses to insecticides differ, depending on the method of application and the insecticide. Biotypes 2 and 3 are generally more susceptible than biotype 1 to insecticides sprayed directly on the planthoppers as a contact poison in a Potter's spray tower (Fig. 1). When insecticide granules are applied to paddy water, biotype 3 is distinctly less susceptible than biotype 1 to the carbamate insecticides carbofuran and metalkamate, and to the phosphate insecticide diazinon (Fig. 2).



2. Knockdown and residual activity against three brown planthopper biotypes of insecticide applied as granules at 1 kg a.i./ha. IRRI laboratory, 1977 (E. A. Heinrichs and S. Valencia, unpubl. data).

FIELD APPLICATION

Application methods

To make chemical control of BPH more economical, application methods have been refined. Foliar sprays have been most commonly used in the tropics, and dusts most commonly used in Japan. Sprays and dusts are readily washed off the plants by the frequent monsoon rains in the tropics; thus, they have been replaced to some extent by easy-to-apply granules. Because of their effectiveness and wide-spectrum activity, systemic granular insecticides have gained popularity in recent years. New approaches to the use of chemicals against the BPH are being developed.

Seed treatment. Treatment of seeds with insecticides was first tested at IRRI in 1968 in a direct-seeded crop (IRRI 1968). It was further tested in 1971 in the greenhouse, in an upland field, and in a lowland field (IRRI 1972). Carbofuran at 1 kg a.i./ha provided protection against BPH caged for 3 weeks on treated plants in the greenhouse and in the upland field test, but it was ineffective in the lowland field. Soaking seeds in a carbofuran solution for 12 hours before planting was ineffective even at 5,000 ppm, which is equivalent to 4 kg a.i./100 kg seed. Seed treatment thus has not proven to be an effective means of control except, possibly, for short periods in the nursery.

Placement in furrows. An alternative to seed treatment was placing the insecticides 2 to 3 cm below the seed in upland rice before planting (IRRI 1974). Carbofuran or lindane + MTMC, so applied, followed by a side-dressing at 55 days after seeding (DS), each at 2 kg a.i. ha, controlled BPH up to 58 DS. Hopperburn in the carbofuran-treated plot was 1%; in the plot with lindane + MTMC it was 4%; the untreated control was 93% hopperburned at 66 DS.

Seedling soak and root coat. Soaking seedlings in a 1,300 ppm carbofuran solution for 24 hours before transplanting provided almost 100% control for up to 40 days in an air-conditioned insectary; in the field, however, such treatment was ineffective (IRRI 1972). In field studies in 1972 (IRRI 1973) some control of BPH for less than a week was obtained when seedlings were soaked 24 hours in a 1,000 ppm carbofuran solution. Adding 29, methyl cellulose in the solution as an adhesive increased mortality, but was not enough to provide more than 5 days of control.

Foliar sprays. For BPH control in the tropics insecticides are most commonly applied as foliar spray. Because the insect feeds at the base of the plant near the water level, and outbreaks generally occur after a dense canopy has been formed, control with a canopy spray is difficult. In Malaysia, the BPH was completely controlled at 3 days after spraying when the spray pattern was directed toward the plant bases; control was only 57% when the spray was directed to the canopy (Heong 1975). Studies at IRRI in 1977 (E. A. Heinrichs and G. B. Aquino, unpubl.) indicate that insecticides vary in effectiveness depending on place of application. Control by metalkamate increased by 20% and that by Perthane by 30% when the insecticides were applied to the plant bases instead of on the canopy. For monocrotophos, there was no such difference. In previous studies (IRRI 1968) the effectiveness of monocrotophos sprays in controlling the BPH was attributed partly to the systemic action of the insecticide. Movement of a systemic insecticide down to the leaf sheath would make application of sprays to the base of the plant less necessary.

Phosphamidon and dichlorvos were applied as high-volume ground sprays, and ultra low-volume aerial sprays to a 70-day-old rice crop in Indonesia in 1970 (Singh 1975). Both insecticides were effective against BPH when applied as ground sprays, but only dichlorvos was effective when applied as aerial spray. The lack of effectiveness of the phosphamidon aerial treatment was attributed to the failure of the spray to reach the bases of the plants. Because of the fumigant action of dichlorvos, its placement at the plant bases was not essential.

It is laborious and time consuming to spray the base of every plant with a single-nozzle sprayer. To shorten application time, IRRI developed a six-row sprayer with drop nozzles (Fig. 3). Its use provides more effective control than does the use of canopy sprays.

Granular broadcast. Broadcasting of granules has become a popular method of BPH control. It has several advantages over foliar sprays and dusts. It is less laborious and more rapid than foliar sprays and requires no equipment. Granules penetrate the dense canopy and reach the area where the planthoppers feed; they have longer residual activity (Takai 1971).

Granules were first used in Japan about 15 years ago (Okamoto 1970). Early work at IRRI (Pathak et al 1967) with a granular combination of carbaryl and gamma-BHC applied at the rate of 3 kg a.i. ha controlled the BPH and produced yields twice those of treatments with a 0.04% endrin foliar spray.

3. Six-row sprayer for applying insecticide to the base of the rice plants. IRRI, 1977.

which failed to reach the feeding site. Gamma-BHC, however, was more effective against the stem borers than against the BPH. With the development of diazinon granules, simultaneous control of stem borers, leafhoppers, and BPH was achieved (Bae and Pathak 1969). Diazinon is still widely recommended. In certain countries carbofuran granules are more popular than diazinon because their residual and systemic activity makes them effective against most rice pests (IRRI 1975).

The action of granular insecticides in paddy fields has been described by Koyama and Tsurumachi (1968), Toyoda (1970), and Koyama and Tsurumachi (1971). Koyama (1971) classified the mode of action of granules into three groups: 1) a fumigation effect as insecticide vapor rises from the paddy water, 2) a systemic effect caused insecticides taken up by the roots to be moved through the stem to the leaves, and 3) a direct systemic effect through the stem and leaves that come in contact with the insecticide. The fumigation vapors act as a contact poison; the systemics kill the insect when it sucks the plant sap. Insecticides in the first group have a high vapor pressure, those in the third group have high water-solubility, and those in the second have intermediate characterisitics. Toyoda (1970) applied BPMC, MIPC, and diazinon in a paddy with no standing water and achieved a quick knockdown of the BPH. The result indicates that certain granular insecticides might be effective under upland conditions because of the fumigation effect.

Microgranules that readily stick to the leaves were developed to act as insecticides of the third group. Koyama (1971) reported that microgranules are more effective than ordinary granules, but tests at IRRI indicated that they have no advantage over ordinary granules (IRRI 1974). Both effectively controlled BPH nymphs. but neither controlled the grassy stunt virus vectored by the BPH.

Root-zone application. Because microbes and chemicals rapidly degrade the insecticide in the paddy water and rains wash it off the rice plants, three or four applications are generally required to provide season-long control of rice pests. Thus the concept of root-zone application in which the insecticide is placed in a protected area near the roots was developed.

In field tests, carbofuran, which was most effective in the root zone, controlled the BPH for up to 40 days when applied as 1 capsule/hill at the rate of 1 kg a.i./ha at transplanting (Pathak et al 1974). Plant residues, determined by gas chromatography, were much higher when carbofuran in gelatin capsules was applied in the root zone than when it was broadcast (Aquino and Pathak 1976). In Korea, Choi et al (1975) tested the effectiveness of root-zone application 3 days after transplanting (DT) and found that carbofuran and BPMC controlled the BPH for up to 80 days after treatment. Tests in Indonesia (Sama and van Halteran 1976) have also indicated that carbofuran and BPMC provide control but for a shorter period than in Korea. Because hand placement of encapsulated insecticide is laborious, IRRI engineers have designed equipment for root-zone application. A liquid band applicator was compared with the capsules for BPH control. At 45 DT, the two methods gave similar control (Table 7).

Soil incorporation. Incorporation of insecticide into the soil is a modified type of root-zone application, but it is not quite as effective as placing the insecticide in each hill. However, the method is much easier. A farmer only needs to spread the granules and incorporate them at the last harrowing. BPH generally build up slowly in a crop and reach their peak near harvest time. One root-zone application is not expected to provide control until harvest. One application at transplanting may prevent insect buildup to damaging levels, but it has not controlled late-season migrations from adjacent hopperburned areas in IRRI tests. Root-zone application appears to be most useful in locations

Table 7. Brown planthopper populations after carbofuran had been applied in gelatin capsules or with a liquid band applicator to the root zone of the rice variety IR20. IRRI, 1976 wet season.

Treatment [a]	Rate (kg a.i./ha)	Brown planthopper (no./10 sweeps)[b]	
		36 DT	45 DT
Capsule	2	9 a	1 a
Liquid applicator	2	8 a	6 a
Capsule	0.5	13 ab	34 b
Liquid applicator	0.5	32 b	71 b
Control		59 c	302 c

[a] 3% granules were used in the capsule treatment and 20% flowable in the liquid application. Insecticide was applied once at 5 days after transplanting (DT). [b] In a column, means followed by a common letter are not significantly different at the 5% level.

where BPH infestations begin early in the crop season and migration from adjacent fields does not occur.

TIMING

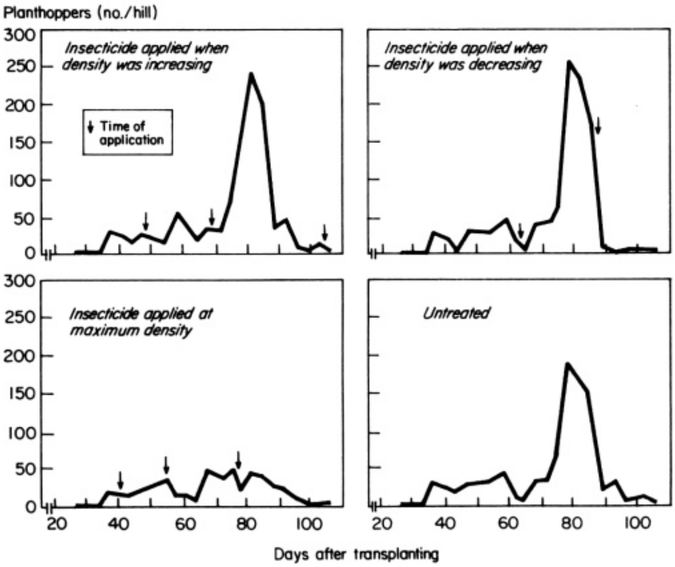
Proper timing of insecticide application can minimize costs. In the tropics where planthoppers are active throughout the year, generations usually overlap. The presence at the same time of several stages of the insect complicates control. Eggs inside the plant are difficult to kill, and most insecticides lack sufficient residual activity to kill the nymphs that hatch from eggs several days after application and whose population often increases thereafter.

In Japan and Korea, where the BPH annually immigrates, early generations have little overlap and control is rather easy. But if treatment is delayed until late in the season, repeated applications are necessary. Studies in Japan by Nagata et al (1973) indicated that when the insecticide was applied at the proper time, only one application per crop was necessary. MIPC granules broadcast on 7 August to control adult brachypterous females of the second generation, or on 3 September to control females of the third generation, reduced the planthopper population to an extremely low level, and kept it at that low level throughout the crop period. However, application on 15 August during the oviposition period, or on 27 August before nymphal hatch was complete, increased the BPH population and caused hopperburn in early October.

In Korea, BPH immigration dates are used to determine time of insecticide application. Studies in Korea (pers. comm. with J. O. Lee, Institute of Agricultural Sciences, Office of Rural Development, Suweon, Republic of Korea) indicate that the BPH population increases rapidly about 5 weeks after migration, and insecticide application is scheduled just before the increase. Lee also studied the relationship between stage of plant growth at the time of initial infestation and yield losses. One pair of BPH per hill beginning on 1 July caused 100% loss; infestation beginning on 15 August caused only 3% loss.

In the tropics, where continuous and staggered plantings are common, timing is much more difficult. When insect populations are high in mature crops, the insects may migrate to the nursery at harvest. Heavy populations can inflict severe damage on young plants, and cause transmission of the grassy stunt virus. When a migratory population is absent in the Philippines, buildup within a crop is gradual and hopperburn generally occurs near harvest.

In an experiment at IRRI, MIPC was applied as foliar spray 1) during hatching when nymphal density was increasing, 2) at peak nymphal density when third instar nymphs were predominant, 3) and when nymphal density was rapidly decreasing and the adult population was increasing (IRRI 1973). Only the application at maximum nymphal density in each generation provided control (Fig. 4). Thus, three applications were required. Control in the first treatment was poor because eggs that had not been killed hatched and the insecticide did not remain effective long enough to kill the newly hatching



4. Density of brown planthopper nymphs on IR20 in relation to timing of insecticide (MIPC at 0.04%) application. IRRI, 1972 wet season.

nymphs. In the third treatment, the insect population increased because oviposition took place before the treatment and nymphs hatched after the insecticide was no longer active.

From tests in Taiwan conducted by C. H. Cheng, Chia-yi Agricultural Experiment Station, Chia-yi, one application of carbofuran granules at 64 DT provided control and gave a yield equal to that obtained with three applications and double that in the control plots (pers. comm. with C. Hsieh, Joint Commission on Rural Reconstruction, Taipei, Taiwan). That one application coincided with the maximum nymphal population stage of the second generation.

NOVEL MEANS OF CHEMICAL CONTROL

Insecticides are commonly known to kill insects by their action as a contact or stomach poison, or by fumigation. Research in recent years has identified some novel approaches to BPH control that are of great interest. Chemicals that act as feeding and oviposition inhibitors, ovicides and as insectistatic compounds have been identified.

Feeding inhibition

Sogawa (1971) evaluated more than 50 amino acid derivatives to determine their ability to inhibit BPH feeding. Several aromatic amines occurring in plants suppressed BPH feeding. Further studies by Kurata and Sogawa (1976) indicated that solutions containing 100 ppm of phenethylamine hydrochloride, tyramine hydrochloride, or hordenine sulfate inhibited feeding by 55, 73, and 73%, respectively.

Chlordimeform, whose chemical structure is similar to that of aromatic amines, suppressed feeding by the BPH at 10 ppm and above (Hirata and Sogawa 1976). Mortality at 10 ppm was similar to that of starved planthoppers.

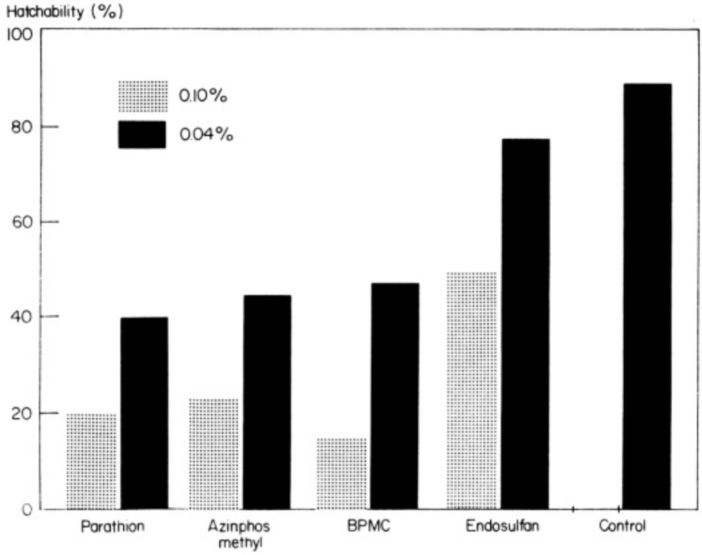
Inhibition of oviposition, and ovicides. Chlordimeform granules applied to paddy water suppress oviposition (Moriya 1976). Wettable powder applied to the paddy water at 18 ppm decreased oviposition by 90%. Nagata and Moriya (1975) found that contact and oral toxicity of chlordimeform were negligible, but that dipping roots in a chlordimeform solution inhibited oviposition.

Nagata and Moriya (1975) also found that dipping roots in a 10 ppm chlordimeform solution reduced hatching by 50%. Hatching nymphs escaped from the plants and starved to death. Ito and Saito (1973) tested the ovicidal activity of several systemic insecticides applied as root dips. Paraoxon, the most toxic, caused 88% egg mortality at 4 ppm. Studies by Toyoda (1968) and Israel et a1 (1968) indicated that insecticides were selectively toxic to BPH, whitebacked planthopper, and green leafhoppers, and that their selectivity differed. Toyoda found propoxur, MIPC, and MPMC applied to paddy water to be the most effective ovicidal agents against the BPH. Lethal doses were similar to those used in normal farming practices.

Preedasuvan and Pura (1973) sprayed several insecticides at rates of 0.08, 0.04, and 0.10% on plants containing BPH eggs. Egg mortality increased with insecticide concentration. Among the most effective ovicides were BPMC, azinphos methyl, and parathion (Fig. 5). Laboratory studies have indicated the potential of certain insecticides as BPH ovicides. The effectiveness of such ovicides in the field has not been determined.

Insectistatic compounds

Agents that diminish insect populations by suppressing growth and reproduction rather than by causing rapid mortality (as do conventional insecticides) are called insectistatics (Levinson 1975). In Japan, isoprothiolane, a fungicide recently developed to control blast, reportedly has insectistatic properties against the BPH (Miyake 1975). Newly hatched nymphs placed on plants growing in water treated with isoprothiolane slowly died between the third- and fifth-instar stages. Most were dead within 2 weeks of hatching. When third-instar nymphs were reared on treated plants, adults that emerged had short life spans and low oviposition rates. Both adults and nymphs had low probing frequency on treated plants. Isoprothiolane, however, is not promising as a compound for control of BPH when population densities are high (pers. comm. with J. Hirao, Kyushu National Agricultural Experiment Station, Japan). Additional field research will indicate the applicability of insectistatic compounds for BPH control.



5. Effect of two concentrations of insecticides sprayed on infested plants on the hatchability of brown planthopper eggs. Laboratory study (Preedasuvan and Pura 1973).

RESISTANCE TO INSECTICIDES

Most data on the resistance of BPH to insecticides have come from Japan where insecticides have been extensively used for many years. Benzene hexachloride (BHC) has been widely used since 1949 (pers. comm. with K. Ozaki, Kogawa Prefectural Experiment Station, Takamatsu, Kogawa, Japan).

In 1967, planthoppers collected from locations within the Hiroshima prefecture had a maximum of ninefold resistance (Kimura et al 1973). In 1967, poor field control with BHC dusts in Kyushu prefecture was linked to resistance (Nagata and Moriya 1969). Topical doses of BHC in the laboratory increased resistance sevenfold in only five generations.

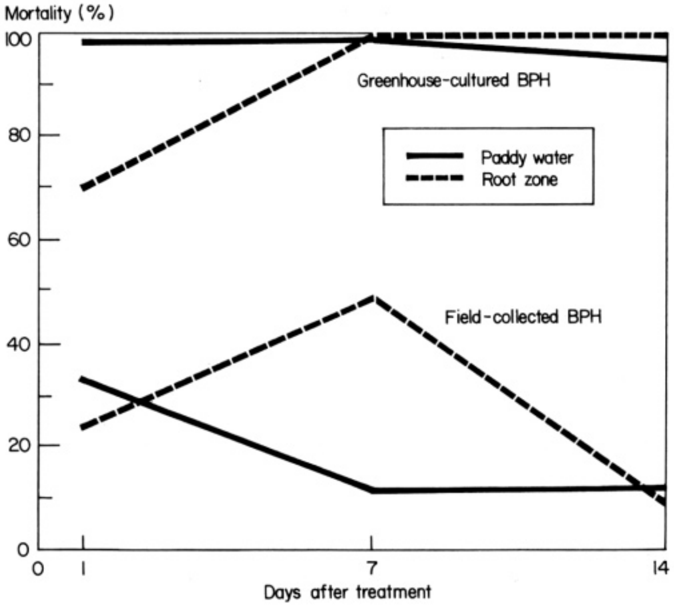
Studies on the seasonal fluctuation of resistance to gamma-BHC in Fukuda prefecture indicated that the third generation had 14 times greater resistance than the migrant population, and the fourth generation had 19 times more resistance (Nagata and Moriya 1974). The fluctuation was considered due to the alternating effects of the selective pressure of BHC and the replacement of resistant populations, which could not overwinter with susceptible populations migrating from distant areas where insecticide resistance did not occur. Cross resistance to dieldrin and fenitrothion was observed in the BHC-resistant strain.

In Japan, organophosphorus insecticides are said to have provided poorer field control in 1967 than in previous years (pers. comm. with K. Ozaki). Studies by Ozaki indicated that the BPH had developed resistance to fenthion, fenitrothion, diazinon, and malathion. Hence, the use of organophosphate insecticides has decreased throughout Japan. K. Ozaki (pers. comm.) also reported an increase in tolerance for the carbamate insecticides carbaryl and MPMC. Asakawa (1975) reported that carbamates are still effective and will continue to be so because of the annual migration of susceptible BPH.

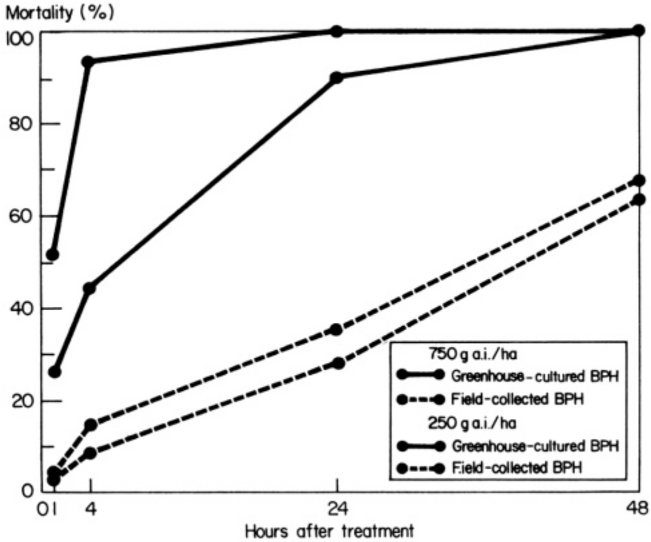
Reports of BPH resistance to insecticides in the tropics are rare, most likely because of the low level of insecticide use. At IRRI, the effectiveness of diazinon markedly declined in 1969 (IRRI 1970) after it had been used continuously for 10 successive crop seasons (about 3 years). Studies indicated that the loss of effectiveness was due to increase in resistance to the insecticide and to microbial degradation (IRRI 1971).

About 50 BPH generations had been exposed to diazinon at IRRI. The IRRI population was the only one with resistance that was five times greater than that of populations from other locations in the Philippines (IRRI 1972). The progeny of field-collected resistant planthoppers lost their resistance after several generations without exposure to diazinon.

Sethunathan and Pathak (1971) found diazinon to be inactivated by microbial degradation in 3 to 5 days of incubation with water from a rice field that had received several diazinon applications. Degradation in water from an untreated



6. Mortality of the greenhouse-cultured and field-collected brown planthopper as affected by paddy-water and root-zone applications of carbofuran at 1 kg a.i./ha. IRRI greenhouse, 1976.



7. Mortality of greenhouse-cultured and field-collected brown planthoppers as affected by carbofuran applied as a direct-contact spray with the Potter's spray tower. IRRI Laboratory, 1977. (E. A. Heinrichs and S. Valencia, unpubl.)

rice field was nonsignificant. Further research, however, indicated that the occurrence of diazinon-resistant strains was more important than microbial degradation in rendering diazinon ineffective against the BPH. In studies in Taiwan (T. Y. Ku, Plant Protection Center, Taichung, Taiwan, unpubl.), found that the BPH in the Taichung area developed a 13-fold resistance to ethyl parathion and 4-fold resistance to BPMC. No resistance to monocrotophos, acephate, vamidothion, or carbofuran was observed.

In 1976, after several years of use, carbofuran's effectiveness against the BPH at IRRI declined. Applications of 2 kg a.i./ha at 14-day intervals failed to control the insect. The responses of field-collected insects to paddy-water and to root-zone applications of carbofuran at 1 kg a.i./ha were compared with the response of a susceptible greenhouse culture. The field-collected planthoppers showed an extremely low mortality (Fig. 6). To determine whether the resistance was genetic, further studies were conducted after rearing the field-collected insects for four or five generations. In the test for direct contact toxicity the field population was still distinctly more resistant to carbofuran than the susceptible greenhouse culture (Fig. 7). Probit analysis indicated a sevenfold resistance.

The BPH can develop resistance to insecticides within a relatively short time. With increase in continuous cropping and in use of insecticides in the tropics, BPH resistance to insecticides poses a real threat to rice production.

BROWN PLANTHOPPER RESURGENCE

In insecticide trials on experiment stations and in farmers' fields, hopperburn commonly occurs in treated plots while untreated areas remain relatively free of infestation. The phenomenon is most common when foliar sprays are applied but can occur in plots where granules have been broadcast.

Foliar sprays

BPH resurgence after treatment with foliar spray has been reported at IRRI (IRRI 1968, 1971, 1973, 1974, 1975, 1977). In seven experiments, the average hopperburned area in the most severely damaged treated plots was 94%, while that in the control plots was 18%.

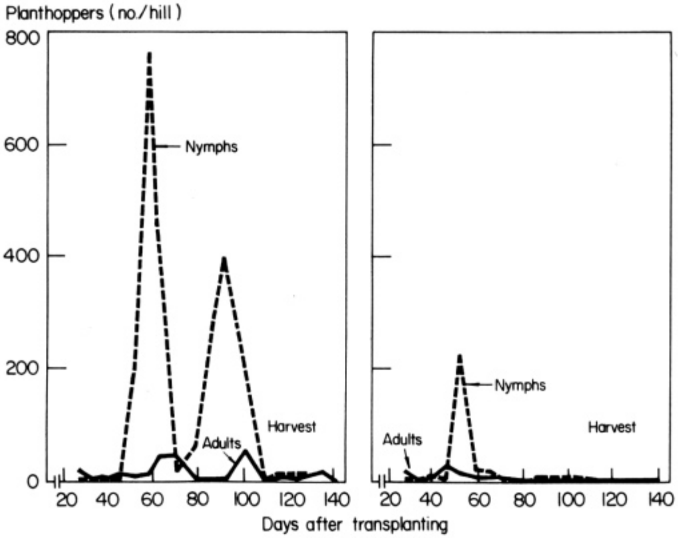
When carbofuran was applied as a foliar spray, by soil incorporation before transplanting, as broadcast granules, and by root-zone application, BPH resurgence was most common with foliar sprays (E. A. Heinrichs and G. B. Aquino, IRRI, unpubl.). Insecticides vary in resurgence activity (R. S. Rejesus and F. O. Cariño, IRRI, unpubl.). Methyl parathion has consistently caused planthopper resurgences; acephate, BPMC, metalkamate, and Perthane have not.

BPH outbreaks in upland fields are rare, but resurgences occur when certain insecticides are applied as foliar sprays. In 1976 (IRRI 1977) hopperburn occurred on a poor-tillering, upland rice variety with inadequate nitrogen where a synthetic pyrethroid, NRDC 161 (Decis), methyl parathion, or diazinon was applied (Table 8).

Table 8. Effect of foliar sprays on brown planthopper populations and damage in upland rice variety Kinanda.[a] IRRI, 1976 wet season.

Insecticide[b]	Brown planthopper (no./11-m row)[c]		Hopperburn (%)
	94 DS	Resurgence ratio	117 DS
NRDC 161 (Decis)	6,733 ef	16.40	100 d
Methyl parathion	2,468 ef	6.00	75 c
Diazinon	1,919 def	4.67	55 b
Azinphos ethyl	718 cde	1.75	4 a
Monocrotophos	374 bcd	.91	1 a
Carbaryl	336 bc	.82	3 a
Methomyl	164 abc	.40	1 a
BPMC	178 bc	.43	0 a
Acephate	156 abc	.38	1 a
Endosulfan	157 abc	.38	0 a
MIPC	133 abc	.32	0 a
Vamidothion	55 ab	.13	3 a
Perthane	29 a	.07	0 a
Control	411 bcd	–	4 a

[a] In a column, means followed by a common letter are not significantly different at the 5% level. [b] All insecticides were sprayed at 0.75 kg a.i./ha. Plots received 3 applications at 49, 77, and 94 days after seeding (DS). [c] Collected with a D-Vac suction machine. Resurgence ratio = number of planthoppers after two insecticide applications at 94 DS divided by the number in the untreated control.



8. Change in brown planthopper populations in plots of IR20 treated with diazinon granules (2 kg a.i./ha) at 18, 38, 56, 76, 97, and 118 days after transplanting (left) and in untreated plots (right). IRRI, 1971 dry season.

Granules

IRRI Annual Reports (IRRI 1970, 1971, 1972, 1975, 1976) describe numerous resurgences after the broadcast of granules in paddy water. In 11 experiments, hopperburn of the most severely damaged treatment averaged 75%; that of the untreated plots was 14%. Diazinon has commonly caused resurgences (Fig. 8; IRRI 1972). In 1976, IRRI plots treated with 2 kg a.i. carbofuran/ha at 14-day intervals were hopperburned while untreated plots remained relatively undamaged (R. S. Rejesus and G. D. Salinas, unpubl.). The BPH population of the treated plot was four times that of the untreated plot.

The mechanisms of planthopper resurgence have not been determined. A combination of factors may be involved. We might consider these possibilities:

- failure of sprays to reach the plant bases where the planthoppers feed, lack of residual effects to kill hatching nymphs, and resistance to the insecticide;
- decrease in populations of natural enemies (Toyoda and Yoshimura 1967; pers. comm. J. H. Stapley);
- changes in the chemical nature of the rice plant, affecting planthopper nutrition ; and
- stimulation by the insecticide of planthopper oviposition, feeding, or hatching.

CONCLUSIONS

The proper use of insecticides can provide effective control of the BPH. There is much more to chemical control, however, than simply, applying chemicals.

Several years' experience with highly toxic organic insecticides has made extremely clear the need for a more thorough understanding of the biology, ecology, and behavior of the pest and a better knowledge of the action of insecticides to maximize insecticidal effectiveness.

In most Asian countries the BPH has only recently become a pest, and many countries need to develop effective and economical means of controlling it. Chemical control may prove effective and economical, but not without investment in research. A long-lasting solution can be achieved only through the development of interdisciplinary national programs where the applied-research entomologist works closely with the chemist, ecologist, physiologist, biological control specialist, agronomist, and plant breeder.

Several research areas deserve immediate attention :

- *Evaluation of insecticides.* Evaluation of insecticides must be a basic part of every nation's research program. Imported field test data from other countries can be used in making initial recommendations, but there is no substitute for in-country testing under conditions peculiar to the particular country.
- *Insecticide application.* Methods that allow foliar sprays to reach the insect at its feeding site at the base of the plant must be developed.

The literature indicates the importance of time of application in relation to the life cycle of the planthopper. Additional research should be conducted in the tropics to determine whether it is possible to base timing on the life cycle of the insect. Easy monitoring methods for farmer use in determining proper application time should be developed.

- *Insecticides' mode of action.* Insecticides applied as foliar sprays should be evaluated to determine their effectiveness as systemic insecticides that move from the upper leaf area down to the lower leaf sheath area where the BPH feeds. The ovicidal, antifeedant, and repellent action of insecticides should be evaluated, and development of additional chemicals with such types of action should be considered.
- *Resurgence.* There is an urgent need to determine the role of insecticides in BPH resurgences. The evaluation program should eliminate insecticides that stimulate BPH populations to increase to outbreak levels.
- *Resistance to insecticides.* As insecticide use increases we can expect the BPH populations to develop insecticide resistance. Because of the high cost of developing insecticides, fewer may be developed in the future. Ways preventing the development of resistance to insecticides and of increasing the active life of the currently available must therefore be sought.

Insecticides have not been a panacea. It is distressing to note that in Japan abnormal increases in BPH populations occurred when insecticide applications reached a high level after 1957 (Miyashita 1963). The problems experienced in Japan, where insecticides were extensively used in rice-insect control for over two decades, are today confronting nations throughout Asia. The battle between the farmer and the BPH will continue. A thorough understanding of the BPH ecology and integration of control by insecticides with that by varietal resistance, and biological and cultural control will increase man's chances of winning the battle.

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