

# **Management strategies for key insect pests of rice: critical issues**

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There is growing concern about risks that synthetic pesticides pose to the rice environment and human health. Insecticides also cause secondary pest problems such as brown planthopper (Heinrichs and Mochida 1984). Earlier work by economists had raised questions whether insecticides in rice production were economical (Herdt et al 1984, Waibel 1986, IRRI 1988). When all costs are included, Pingali and Marquez (1990) argued that the use of insecticides was not economical. At the same time, cultivars known to have insect resistance genes have been reported to suffer severe infestations in Indonesia, Thailand, and Vietnam. Adaptation by the brown planthopper was often accompanied by increases in species fitness (Sogawa 1980,1982; Claridge and Den Hollander 1982; Pathak and Heinrichs 1982) and virulence evolved rapidly when populations were exposed to selection by these varieties (Kaneda and Kisimoto 1979, Den Hollander and Pathak 1981, Sogawa 1981).

In spite of advancements in pest management research, farmers' practices have changed little. The working scenario of rice farmers' pest management beliefs and practices described by Lim and Heong (1984) have remained relatively unchanged. Farmers rely only on insecticides for insect pest management (routine spraying with broad-spectrum compounds) and appear to have limited knowledge of pests and their natural enemies. Farmers do not adopt an integrated approach because they do not perceive it will make them better off (Norton and Heong 1988) or the steps are far too complicated (Goodell 1984).

In this paper, attention is focused on critical issues and challenges that are faced by researchers, implementors, and policymakers. Comments are made on existing controversies that bear on recent concepts and technologies, and suggestions are provided to enhance the development of sustainable strategies for insect pest management.

## The economic and social context of pest management

An organism that interferes with another, either directly by predation or indirectly by competition, tends to be regarded as a pest. With this definition, only very few creatures would not be pests. Therefore, a pest is characterized by the damage or illness it causes and by the value placed on these consequences by society (Norton and Conway 1977). In agricultural production, this value is the difference between the attainable and the actual yield, i.e., crop loss.

A widely acceptable concept of economic decisionmaking to avoid crop loss is the economic threshold (Stem et al 1959). They defined economic damage as the amount of injury that will justify the cost of control. In most cases, the threshold represents time for control (Norgaard 1976) and assumes that the pest population will increase substantially. Because population developments are uncertain, decisions that use economic thresholds are often made under a great deal of uncertainty (Pedigo et al 1986). In Asian rice-growing environments, where pest information is often lacking, the question of practicality becomes crucial. It is also doubtful that farmers would count pests to make decisions (Andrews and Bentley 1991).

Farmers' knowledge of pest management is highly uneven. Bentley (1989) showed that Honduran farmers have extensive folk taxonomies and cultural lore for relatively conspicuous organisms that are of perceived cultural importance. Farm surveys in the Philippines (Escalada et al 1992) and Vietnam (Vo Mai et al 1993) showed that rice farmers apply more insecticides to control early season leaf feeders than any other pest. Farmers tend to overestimate the associated crop losses partly because the damage symptoms are highly visible. However, crop loss due to leaf feeders is extremely low (Heong 1990, Litsinger 1991).

In the early crop stages, the common pests are leaf feeders, particularly the rice leaffolder *Cnaphalocrocis medinalis*. The literature contains numerous reports of heavy infestation by *C. medinalis* (Khan et al 1988) but none had assessments of extent, frequency, and crop loss. The average larval density observed in Japan was less than 2 per hill (Wada and Shimazu 1978, Kobayashi and Wada 1979); in the Philippines, it was less than 1 per hill (Guo 1990). Because negligible yield loss is to be expected with larval populations below 3 per hill (Graf et al 1992), serious yield loss from early season leaffolder infestations is very unlikely.

However, farmers' aversion to risk seems deeply entrenched. This is due, partly, to overemphasis on insect infestations (rather than crop loss), to the abundance of advertising campaigns to promote insecticides (Escalada and Heong 1992), to the association of pesticide use with modernism (Kenmore et al 1985, Bentley 1989), and to government support programs in favor of insecticide use (Conway and Pretty 1991).

## Brown planthopper virulence and resistant varieties

The brown planthopper (BPH) is monophagous on rice and, because of many years of coexistence, BPH virulence is probably very diverse. The most intensive interactions between rice and BPH can be seen in south India and Sri Lanka where the most virulent

**Table 1. Brown planthopper (BPH) biotype reactions on different rice varieties.**

Differential variety	Resistance gene	Biotypes		
		1	2	3
TN1	None	S <sup>a</sup>	S	S
Mudgo	<i>Bph</i> 1	R	S	R
ASD7	<i>bph</i> 2	R	R	R
Rathu Heenati	<i>Bph</i> 3	R	R	R
Babawee	<i>bph</i> 4	R	R	R

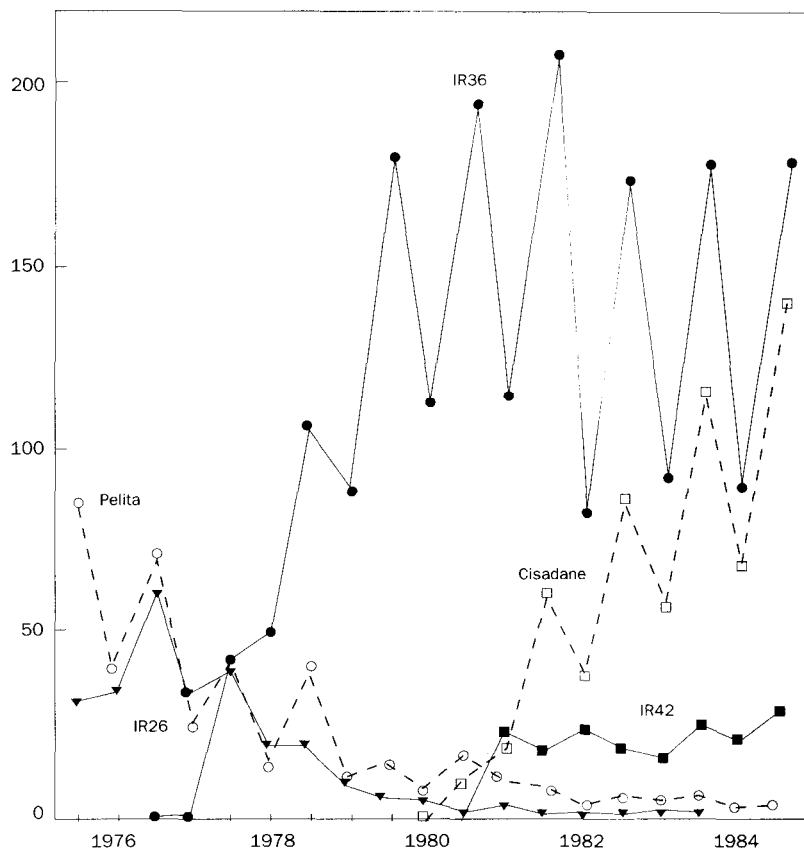
<sup>a</sup>S = susceptible; R = resistant.

populations are found. This region is also the source of many BPH resistance genes (Sogawa 1979). Three BPH laboratory populations, commonly referred to as “biotypes,” were established using artificial selection (Pathak and Heinrichs 1982). One population, biotype 1, virulent on all known resistance genes is often bred on the cultivar Taichung Native 1 (TN1). Biotype 2 is virulent on *Bph1* but not on other genes, and biotype 3 is virulent on *bph2*. In addition, another population, biotype 4, virulent on *Bph1* and *bph2*, but not on *Bph3* or *bph4*, is known in South Asia (Khush 1984). Based on these relationships, standardized differential reactions of each biotype to a set of rice cultivars were established (Table 1).

This model of biotype-variety interactions assumes a gene-for-gene relationship between biotype and variety. For every gene in rice that confers resistance, there is a corresponding gene in BPH that confers virulence to that plant gene (Gallun and Khush 1980). Although this concept appears to be true for the Hessian fly, *Mayetiola destructor*, a pest of wheat (Everson and Gallun 1980), there is no evidence for such a relationship in BPH (Claridge 1991). In fact, virulence seems to be polygenic (Den Hollander and Pathak 1981), and studies on the biotypes have shown that they are genetically very closely related (Claridge and Den Hollander 1982). In terms of virulence characteristics, BPH is a labile species capable of rapid adaptation to new host cultivars (Claridge 1991).

The variety IR26 with *Bph1* was released and widely planted over Southeast Asia between 1975 and 1978, but it was found to be susceptible in many locations (Feuer 1976, Huynh 1977, Mochida et al 1977, Oka 1978, Stapley et al 1979). Subsequently, release of IR varieties with *bph2* created biotype 3 in some areas and another biotype virulent on *Bph1* and *bph2* genes (Oka and Bahagiawati 1984, Ho 1985, Medrano and Heinrichs 1985, Huynh and Nhung 1988). In Indonesia, sequential release of BPH-resistance genes was used to cope with outbreaks. Between 1976 and 1984, large areas were planted to resistant varieties with *Bph1* and *bph2* genes (Fig. 1). Consequently, virulence development differed significantly. Based on differential reactions to rice varieties, BPH populations could be categorized according to the varieties grown in the location (Sogawa et al 1989). The varieties (IR36 and Cisadane) grown in West Java did not cause dramatic changes in virulence. However, in North Sumatra, where IR42 and IR54 were widely grown, BPH populations were virulent to both *Bph1* and *bph2* genes (Sogawa 1989). In Central Java, where the variety Kruang Aceh was grown, a

Planting area ( $\times 10,000$  ha)



1. Yearly fluctuations in planting areas of the major rice varieties in Indonesia.

population virulent on Cisadane and Kruang Aceh developed (Sogawa et al 1987). Screening in West Java using laboratory BPH populations cultured on TNI, Mudgo, and ASD7 to represent biotypes I, 2, and 3 showed that these varieties had the *bph2* gene for resistance (Table 2) and may be used to substitute for IR36. However, reactions to BPH populations from West Java, Central Java, and North Sumatra were different in these varieties.

It is evident that the virulence traits in BPH populations are more complex. Each biotype population is composed of great variability of individuals with diverse genetic backgrounds, and there is a broad range in virulence within the population (Sogawa 1980, 1981; Claridge and Den Hollander 1982, Claridge et al 1982). Virulence might also be inherited in a polygenic manner and have no distinct recognizable segregation. There is some evidence of persistence and compounding of virulence. BPH populations preselected on one resistant cultivar are virulent on more than one resistant cultivar (Claridge and Den Hollander 1982). Cross-virulence is also evident in preselected

**Table 2. Reactions of Indonesian BPH populations to selected rice varieties with the *bph2* gene.**

Differential variety	Resistance gene	Populations		
		West Java	Central Java	North Sumatra
IR36	<i>bph2</i>	R <sup>a</sup>	R	MR
IR42	<i>bph2</i>	R	R	S
Cisadane	<i>bph2</i>	R	S	S
Krueng Aceh	<i>bph2</i>	MS	S	S

<sup>a</sup>R = resistant, MR = moderately resistant, S = susceptible, MS = moderately susceptible.

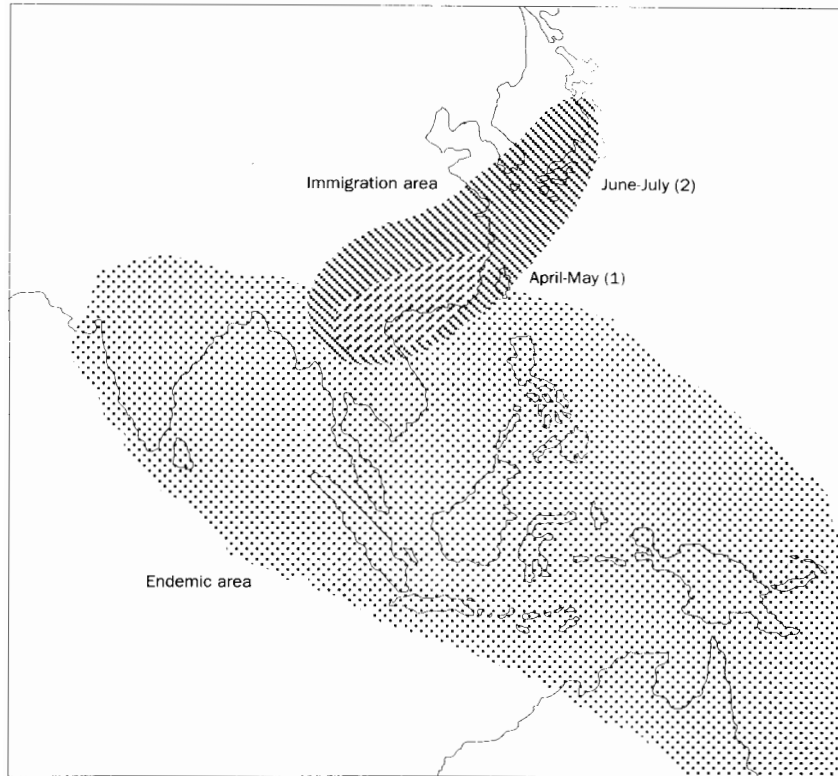
populations that were virulent on cultivars to which they were exposed. For example, populations preselected on Cisadane were virulent to both Cisadane (*bph2*) and Mudgo (*Bph1*). Similarly, populations selected on IR56 (*Bph3*) were virulent to Babawee (*bph4*). The biotype concept and its application to BPH was reviewed by Claridge and den Hollander (1983). Clearly, the biotype concept is of little value, and in many cases it may be confusing and misleading.

## Mass displacements of pests and implications for management

In temperate regions (Japan, Korea, and northern China), insect pests of rice may be indigenous, introduced, or migratory (Table 3). Migratory pests have their origins in the tropics and invade the temperate areas by wind-aided mass displacements. Brown

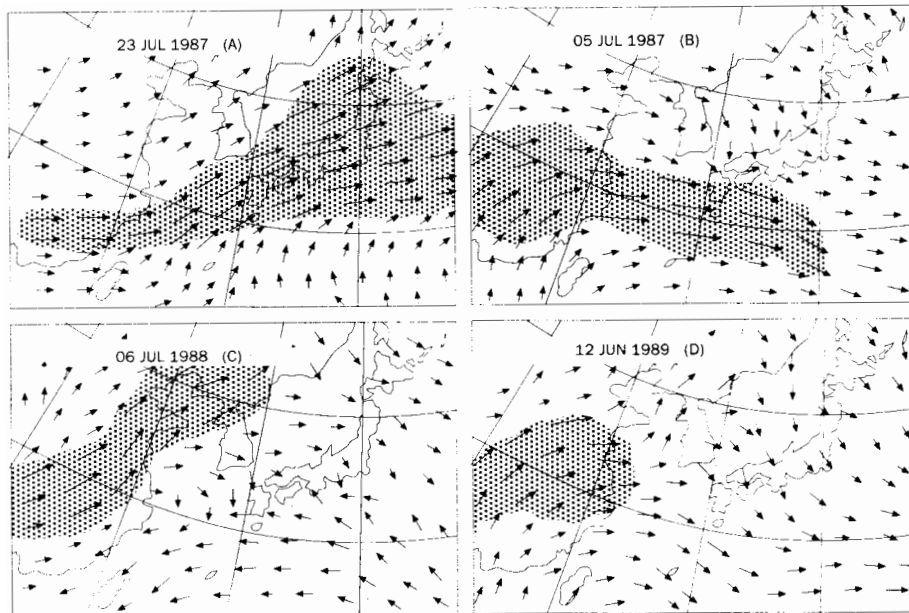
**Table 3. Ecological characteristics of rice insect pests in Japan.**

Species group	Ecological characteristics	
1. <i>Chilo suppressalis</i>	Distribution	: Mostly temperate
<i>Nephotettix cincticeps</i>	Food habit	: Graminaceous weed feeders
<i>Laodelphax striatellus</i>	Dependent on rice	: Incomplete to complete
<i>Oulema oryzae</i>	Diapause	: Yes
<i>Chlorops oryzae</i>	Migration	: Sedentary, dispersal
	Inhabitant status	: Indigenous
2. <i>Lissorhoptus oryophilus</i>	Distribution	: Temperate to subtropics
	Food habit	: Graminaceous weed feeder
	Dependent on rice	: Incomplete
	Diapause	: Yes
	Migration	: Dispersal
	Inhabitant status	: Invader
3. <i>Nilaparvata lugens</i>	Distribution	: Tropics
<i>Sogatella furcifera</i>	Food habit	: Rice-monophagous feeder
<i>Cnaphalocrocis medinalis</i>	Dependent on rice	: Complete
	Diapause	: None
	Migration	: Long-range migratory
	Inhabitant status	: Temporary



**2. Geographical distribution of the BPH; endemic habitats in the tropics and summer temporal habitats in temperate East Asia. The BPH is transported from the endemic habitats in tropical Asia to the summer temporal habitats in temperate East Asia by monsoonic wind systems taking two major process of redistribution associated with the stationary locations of the frontal zones.**

planthoppers, for example, are endemic in the tropics and are unable to survive the harsh winters of the temperate region. Starter populations are displaced annually by winds from the tropics (Fig. 2). These displacements are closely related to the frontal depressions in the “Bai-u” season (Kisimoto 1976). The displacements are closely related to the low-level jet streams (LLJET), which are southwesterly air currents that develop in the lower troposphere in the warm sector of the frontal depressions about 200-300 km south of the Bai-u front (Seino et al 1987). Weather charts from the World Meteorological Organization provide wind information for weather forecasts. The LLJETs are closely related to winds at an altitude of 850 millibars (mB) (or 3000 m). This daily information can be used to define potential displacement routes. A computer program to monitor these routes into Japan has been developed (Watanabe et al 1988). The program outputs profiles of winds greater than 20 knots (37 km/h) and displays the potential displacement routes (Fig. 3). No information on influx densities are available. Additional pest information from net traps, light traps, and field samples are used to generate forecast information.



**3. Typical examples of LLJETs which brought about massive overseas immigration of the BPH into Japan (A,B), and those which did not cause it (C,D).**

Because BPH in the temperate region is a migratory population, the recruitment periods are well-defined. Forecast information may be useful for early warning. In the tropics, however, recruitment patterns are poorly defined and often uncertain, which makes forecasts difficult and of little value. In addition, there is overwhelming evidence that natural enemy fauna in the tropics are richer, more diverse, and abundant and that rates of population growth from initial recruitment are much lower (Cook and Perfect 1985; Kuno and Dyck 1985; Heong et al 1991, 1992). It seems clear that pest management strategies must adhere closely to these differences between pest developments in the tropical and temperate regions.

## Discussion

Because agricultural development focused on the problem of feeding a rapidly increasing world in the 1960s and 1970s, the obvious solution was to increase per capita food production. The green revolution that followed had a dramatic impact in many Third World countries. Rice yields, in particular, showed impressive increases from high-yielding varieties (HYVs) and the distribution of technology packages with high pay-off inputs (fertilizers, pesticides, and water availability). However, these results were associated with an increased incidence of insect pest, disease, and weed problems, and the obvious solutions were host-plant resistance and pesticides. The power of natural control mechanisms and the abilities of pests to adapt or migrate was grossly

underestimated. Because of the desire of technology innovators to effect adoption by farmers, most implementation programs followed a “technology push” approach (Conway and Barbier 1990). These intensification programs and commercial advertising campaigns, which encouraged the use of pesticides, have led farmers to associate pesticide use with modernism (Kenmore et al 1985, Bentley 1989, Escalada and Heong 1992). As a result, most rice farmers tend to be risk-averse and resort to pesticides at the first sign of pest attacks.

The development of integrated pest management (IPM), which is principally governed by the economic threshold concept (Stem et al 1959), focused research on defining these thresholds and related sampling techniques (IRRI 1990). The basic assumption of the concept is that the decisions of farmers are based on economic evaluations. This may not be true (Mumford and Norton 1984). Mumford and Norton proposed an alternative behavioral decision model, which focused on farmers’ perceptions of pest problems. For example, early spraying may be caused by misperceptions and risk aversion that are deeply entrenched (Escalada and Heong 1992). Research to better understand how decisions are made at the farm level may be more beneficial because it is doubtful that farmers can be persuaded to count pests before making decisions.

Because many species of rice pests are highly mobile, individual management efforts by farmers may not suffice. Spray activities in individual fields often make pest populations unpredictable and encourage patches of extremely high densities (Cohen et al 1994). The average pest densities recover more rapidly than predator densities. Distance from the unsprayed areas and mobility of the species influence recovery rates. Therefore, an individual farmer’s effort to decrease pests may in fact result in a net increase of insect pests, and the farmer will have to pay an “ecological cost” in addition to the cost of the insecticide and labor.

To make pest management sustainable, these critical issues must be addressed. If research efforts are to change on-farm practices, efforts to bridge existing knowledge gaps must be emphasized. Conventional technology push approaches may not suffice. To achieve more impact and to sustain learning efforts, a “farmers’ needs” approach (Conway and Barbier 1990) is required. Farmer participation in research (Escalada and Heong 1993) and training (Kenmore 1991) is needed to discover and learn pest management decisionmaking skills.

Better understanding of virulence patterns, virulence in BPH, and the complexities of such a labile natural system suggest it is time to revise the concept of biotypes. Further analyses of responses of BPH populations to plant resistance genes must be considered. These characters might, instead, be used to describe population virulence.

Classical work in population ecology carried out in temperate countries has guided pest management in both the temperate region and the tropics. More recent evidence has shown marked differences in population characteristics between temperate and tropical rice; therefore, strategies for insect pest management must be reconsidered. In addition, some specialized predators have received close attention, but large numbers of generalist predators that forage in the rice ecosystems have not been studied. Still less is known about interactions between pest and predator species and the temporal



dynamics of their food-web relations, although some initial attempts have been made (Heong et al 1991, 1992). Because management tactics affect the whole faunal community in the rice ecosystems, better understanding of community ecology will enhance the design of more sustainable management practices.

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