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Prospects for Integrated Pest Management in Rice Cultivation

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Abstract
Paddy fields are interconnected by an irrigation drainage system, and form part of a water-dependent natural ecosystem. The rice insect pest fauna in Asia is so rich that each niche in the paddy field in both the temperate and tropical zones is almost fully occupied by the same species, or by the ecological homologues of different species. Paddy fields as a semi-permanent agroecosystem of an annual crop provide a habitat for both migratory and residential pests. An increase in rice yield and its stabilization by means of high-yielding varieties have been the first priority of agricultural programs, after which the production of high-quality grain rice by cost-and labor-effective methods has been pursued. These changes were associated with a decrease in residential species, e. g. borers, while migratory pests, e. g. planthoppers, became more serious. However, the so-called BPH problems will be overcome eventually by the integrated use of selective insecticides, resistant varieties and cultural practices. Leafhoppers are an intermediate species, and remain important as virus vectors, as do planthoppers. The rise in temperature due to the greenhouse effect will have a profound influence on virus epidemiology. Since virus diseases require the most sophisticated system for integrated pest management (IPM), the systems approach will become important. In particular, the efficient utilization of local information on pest occurrence, in terms of decision-making for control, should be encouraged.

Discipline: Insect pest
Additional key words: agroecosystem, IPM, rice pest fauna

Introduction

It is estimated that rough rice production in the world must increase by around 70% during the coming 30 years to keep up with world population growth. However, many countries, particularly those in Asia, lack unused arable land where rice production can be extended. Most of the need for more rice must therefore be met by increasing the productivity of existing ricelands, while sustaining their fertility and protecting the environment[9].

With regard to field losses caused by rice insects, Cramer[4] estimated the loss of rice production in Asia at 16.2%. Pest faunas are closely correlated with the production system used for rice, and are the main determinant of how to implement an integrated pest management for rice in any particular area.

This paper attempts to review current changes in rice pest status in Asia, which have been associated with the changes in rice production system. Precise understanding on the mechanisms involved is a prerequisite in predicting target species and establishing an adequate strategy for rice IPM for the future.

Rice pest fauna

1) *Regional differences*

The beginning of rice cultivation dates back to 10,000 years in river valleys in south and southeast Asia. The insect pest fauna of rice is therefore composed of the species native to Asia in general or to selective regions in Asia with a few exceptions such as rice water weevil (*Lissorhoptrus oryzophilus*), which invaded Japan, Korea and Taiwan, in 1976, 1988 and 1990, respectively. Such indigenousness of pest fauna may possibly be related to the general failures of biological control attempts that have been made to control rice insects in the past, in spite of the fact that there is a large parasitic and predacious fauna in that area[10].

Grist and Lever[6] listed over 800 species as damaging sources to either standing rice plants or stored rice grains. They identified 28 species in Asia, 9 in Australia, 15 in Africa, and 13 in America as the principal insect pests of rice. Wilson and Claridge[19] reported 34 species in Asia belonging to Auchenorrhyncha as species regularly observed in paddy fields, while only 6 in North and South America, 7 in Africa, south of the Sahara, 4 in North Africa and the Middle East, and 3 in Europe. This suggests that Asia has a more complex fauna of insect pests than the other regions. In fact, the absence of major problems of rice stem borers, planthoppers, and insect-vectored diseases in the United States presents a striking contrast to the situation in Asia[5].

2) Differences between temperate and tropical Asia

Asia extends from the tropics to the temperate zone. Some of the pest species limit their habitat to either the tropics or the temperate zone only. A comparison of rice pest fauna in temperate and tropical Asia shows that each niche in paddy fields is almost fully occupied by the same species, or by the ecological homologues of different species (Table 1). The only noticeable exceptions are the absence of mealy bug and the presence of root-infesting weevils, i.e. rice water weevil, *Lissorhoptrus oryzophilus*,

Table 1. Comparison of ecological homologues of rice pests in temperate and tropical Asia

	Temperate	Tropics
Plant suckers:		
Mealy bug	absent	*Pseudococcus* spp.
Rice bug	*Leptocorisa chinensis*	*L. oratorius*
Rice black bug	*Scotinophara lurida*	*S. coarctata*
Green stink bug	*Nezara antennata*[c)]	*N. viridula*
Green leafhopper	*Nephotettix cincticeps*	*N. virescens*
Planthopper	*Laodelphax striatellus*	*Nilaparvata lugens*[a)]
		Sogatella furcifera[a)]
Stem borers/Stem feeders:		
Stem borers	*Chilo suppressalis*	*C. polychrysus*
		C. suppressalis
	Scirpophaga incertulas	*S. innotata*
		S. incertulas
	Sesamia inferens	*S. inferens*
Gall midge	absent	*Orseolia oryzae*[b)]
Leaf feeders/Root feeders:		
Leaffolder	*Marasmia exigua*[c)]	*Cnaphalocrocis medinalis*[a)]
Caseworm	*Paraponyx vittalis*[c)]	*Nymphula depunctalis*
		(= *P. stagnalis*)
Armyworm	*Pseudaletia separata*	*P. separata*
	Spodoptera mauritia	*S. mauritia*
	Spodoptera litura	*S. litura*
Rice skipper	*Parnara guttata*	*Pelopidas mathias*
		Telicota augias
Leaf beetle/Hispa	*Oulema oryzae*	*Dicladispa armigera*
Rice water weevil	*Lissorhoptrus oryzophilus*[d)]	absent
Rice plant weevil	*Echinocnemus squameus*	absent
Rice whorl maggot	*H. griseola*	*H. philippina*

a): The pests that immigrate into the temperate areas, but cannot overwinter.
b): The pest not found in Malaysia and the Philippines.
c): Minor pests of rice.
d): The pest invaded Japan, Korea and Taiwan in 1976, 1988 and 1990, respectively.

Table 2. Ecological traits of insect pests in temperate areas in relation to the type of agroecosystem

Agroecosystem	Crop and culture condition	Ecological traits of insect
Open system:		
Evergreen perennial crop	Citrus orchard	Residential with/without diapause
Deciduous perennial crop	Apple	Residential with diapause
Continuous cropping of annual crop	Paddy	Residential with diapause + migratory without diapause
Single cropping of annual crop	Soybean, Vegetables	Residential with diapause + migratory without diapause
Closed System:		
Single cropping of annual crop under structures	Green/Vinyl house culture of vegetables	Residential without diapause and parthenogenic reproduction
Storage facilities	Stored products e.g. grain in warehouses, etc.	Residential without diapause

and rice plant weevil, *Echinocnemus squameus*, in temperate Asia.

3) Ecological characteristics of the fauna

Southwood and Way[18] have specified some characteristics for each agroecosystem based on stability and isolation. Several agroecosystems, including the paddy field, have been classified on the basis of these criteria (Table 2). Unlike upland crops, irrigated rice plants are generally grown successively in the same field without any deleterious effect from continuous cropping. Paddy fields, therefore, provide a habitat for both migratory and residential pests as a semi-permanent agroecosystem of an annual crop. As shown in Table 2, a greater difference between the two types of rice pests, i.e. migratory and residential, takes place in diapause responses in the temperate zone as compared with the tropics.

Recent changes in rice pest status

1) Temperate zone

In the past 40 years, the pest status of rice insects in Asia has undergone a great change, which was related with an extensive use of synthetic insecticides in the temperate areas and an expanded cultivation of high-yielding varieties in the tropics. During that period, in Japan for example, an increase in rice yield with stabilized production was the top-priority objective to be attained, which was followed after this was achieved, by pursuance of production of high-quality grain rice with cost- and labor-effective methods.

These changes were associated with a decrease in residential species, e.g. borers, while the incidences of migratory pests, e.g. planthoppers, became more serious. Table 3 presents a list of those rice pest species which have recently changed their pest status in temperate and sub-tropical Asia, including Japan, Korea, Taiwan and mainland China.

In general, univoltine and mono/oligophagous species were the insect pests which showed a marked decrease during that period. In contrast, those species that thrived in the same period could be characterized as polyphagous, multivoltine, small in body size and with relatively high mobility[7]. Consequently, outbreaks of virus diseases, e.g. stripe, dwarf, etc., transmitted by leafhoppers and planthoppers, occurred during that period.

In Japan, *Scirpophaga incertulas* began to decrease sharply in 1952–53; no measurable infestation has been reported since 1960. *Scotinophara lurida* and *Oxya* spp. also disappeared already before 1960[10]. Similarly, in Taiwan, ROC, the populations of *Dicladispa armigera*, *Oulema oryzae*, *Scotinophara lurida*, and *Scirpophaga incertulas* declined in number or even disappeared in paddy fields before 1970[3,16]. A decrease in light trap catches in areas infested by *C. suppressalis* was observed first in the late 1950s in Japan, followed by the same pattern in Taiwan and Korea successively[13]. The decline in *Chilo* has been reported after the decline of *S. incertulas*, with a time lag of 15 years in Japan and 5–6 years in Taiwan.

Table 3. Recent changes in the status of rice pests in Asia

	Temperate	Tropical
Species decreased:	*Chilo suppressalis*	*Chilo suppressalis*
	Dicladispa armigera	*Chilo polychrysus*
	Donacia provosti	*Gryllotalpa orientalis*
	Echinocnemus squameus	*Locusta migratoria manilensis*
	Lagynotomus elongatus	*Pseudaletia (Mythima)* spp.
	Oulema oryzae	*Scirpophaga innotata*
	Oxya spp.	*Spodoptera* spp.
	Scirpophaga incertulas	
	Scotinophara lurida	
Species increased:	*Cnaphalocrocis medinalis*	*Cnaphalocrocis medinalis*
	Nephotettix spp.	*Hydrellia philippina*
	Nilaparvata lugens	*Naranga aenescens*
	Sogatella furcifera	*Nephotettix virescens*
		Nilaparvata lugens
		Nymphula depunctalis
		Rivula atimeta
		Scirpophaga incertulas
		Stink bugs
		Sogatella furcifera

In mainland China, *Oulema oryzae*, *Oxya chinensia* and *Dicladispa armigera* declined in the 1950s, *Lagynotomus elongatus (Niphe elongata)*, *Echinocnemus squameus* and *Donacia provosti* in the 1960s; while the control of *S. incertulas* and *C. suppressalis* was successfully achieved in eastern China and the northern part of central China in the 1970s[2].

2) Tropical zone

The seed dissemination of high-yielding varieties with photoperiod insensitivity and early maturity has developed double or even triple cropping farming, where irrigation or rainfall is adequate[14]. The spread of dry season cultivation has led to a number of consequences on rice insects.

As shown in Table 3, aestivating larvae of Asian white rice borer, *Scirpohaga innotata*, are destroyed by dry season land preparation. Species dependent on standing water, such as *Hydrellia philippina, Nymphula depunctalis, Naranga aenescens,* and *Rivula atimeta*, have become more abundant, but the mole cricket has diminished in importance. A reduction in the area planted to alternate crops has favored specialized rice pests with monophagous and oligophagous habits at the expense of those which are polyphagous.

In Malaysia, the polyphagous borer, *Chilo polychrysus*, has been replaced by monophagous *Scirpophaga incertulas*. Likewise, *C. suppressalis* has been replaced by *S. incertulas* in Laguna, the Philippines. Finally, two species of monophagous plant suckers, *Nephotettix virescens* and *Nilaparvata lugens*, have been responsible for major crop losses since the early 1970s in many tropical and subtropical countries in Asia. Futhermore, double cropping of rice with direct seeding induced more frequent outbreaks of stink bugs, *Scotinophara coarctata, Nezara viridula* and *Leptocorisa oratorius*, and rice leaf roller, *Cnaphalocrocis medinalis*, in Malaysia[8].

In general, a certain sort of specialized pest fauna is now predominant in each of the intensively cultivated rice areas. It is responsible for increased crop losses in both absolute and proportional terms.

Predicted changes in pest status in relation to varied rice production systems

1) Past

Table 4 summarizes the foregoing accounts of changes in the rice production system and in rice pests. Cultivation of dry season rice in the tropics increased the stability of the paddy agroecosystem, and this stabilized condition has worked in favor of mono/oligophagous residential species.

In the temperate zone, a single cropping of rice during the summer season without any rice plants

Table 4. Projected changes in pest status in relation to rice production systems (1)

Objectives of rice production	Resources & technology	Cropping system	Change in pest status	
			Temperate	Tropics
Increase and stabilization of rice yield	Pesticides Host resistance HYV Irrigation Fertilizer	Early and staggered planting Dry season cropping	**Decreased** Mono/oligophagous, residential, univoltine spp. **Increased** Polyphagous, residential, multivoltine, vector spp. **No change** Multivoltine, non-diapause migratory spp.	**Decreased** Polyphagous, migratory spp. **Increased** Mono/oligophagous, residential, vector spp.

Table 5. Projected changes in pest status in relation to rice production systems (2)

Objectives of rice production	Resources & technology	Cropping system	Change in pest status	
			Temperate	Tropics
High and diversified quality of rice	Mechanization: combine harvester, planting machine & tiller	Synchronized cropping of a few major varieties	**Decreased** Polyphagous, multivoltine, residential spp.: stem borers & virus diseases	**Decreased** Monophagous, residential spp.: stem borers & leafhoppers
Minimum labor & low cost rice production	Nursery-tray treatment Use of CT/EIL Selective pesticide (IGR)	Rotation with other crops or fallow	**Increased** Polyphagous, multivoltine, residential pests: stink bugs (spotted grains)	**Increased** Mono/oligophagous, migratory spp.: planthoppers & stink bugs

in winter, except stubbles in fallow, is the common ecological condition for rice pests. Residential species pass the winter season in a diapause state in and around paddy fields. Some of them are univoltine. The intensive use of chlorinated hydrocarbon insecticides, i.e. BHC, DDT, etc., is likely to be responsible for the decline in particular of monophagous and univoltine residential species such as *Scirpophaga, Scotinophara, Oxya, Oulema* and *Dicladispa*.

Multivoltine residential species in temperate areas have survived intensive chemical controls through developing their resistance against insecticides. This was true of *Nephotettix cincticeps, Laodelphax striatellus*, and to a lesser extent *Chilo suppressalis*. Early and late cultivation of rice has resulted in staggered planting in a locality, which has worked in favor of multivoltine species, but not for the univoltine. Staggered cropping also encouraged the multiplication of migratory insects, by providing them with rice plants at a vulnerable stage during the time of their immigration.

The decline of *Chilo* observed in Japan, Taiwan and Korea during this period seems to have been induced by the early planting of rice, which seriously affected the survival rate of overwintering larvae by depriving them of food before they were well nourished for overwintering[12,13]

2) Present

The year 1970 was the turning point for rice production systems in Japan (Table 5): a 30% reduction plan in rice production was introduced by the Government and the mechanization of rice cropping by means of transplanters and combine harvesters started in that year. The mechanized planting of rice seedlings considerably advanced the planting time. The nursery tray treated with insecticides came into a practice, which replaced the

Table 6. Projected changes in pest status in relation to rice production systems (3)

Objectives of rice production	Resources & technology	Cropping system	Change in pest status in the temperate & tropics
Rice cropping as low input and sustainable agriculture	Organic farming Integrated pest management Increased dissemination of pest information Mechanization with contract farming	Minimum tillage Direct sowing Multicropping	**Increased** Low-density & residential pest spp.: stink bugs, virus diseases vectored by leafhoppers

broadcasting of insecticides.

The priority in the national rice production program was shifted from the increase and stabilization of rice yields to the labor-saving production of high-quality rice. The use of a control threshold (CT) for making decisions about insecticide applications became more popular. Mechanized rice production has intensified environmental resistance against *Chilo*, having resulted in a continuous decline in *Chilo* after 1970.

The other cultural practices, such as synchronized cropping, raising of seedlings under special facilities and insecticidal treatments for nursery trays, also contributed greatly to the reduced incidence of various virus diseases transmitted by leafhoppers. Various kinds of heteropterous stink bugs, which are polyphagous, multivoltine and residential pests, have gained economic significance because of the spotted grains caused by their sucking.

In view of the successful experience in Japan, monophagous and residential pests will be controlled when synchronized cropping with a fallow period becomes widely practiced in the tropics.

Prospects and conclusion

In future, BPH problems will be overcome eventually by the integrated use of selective insecticides such as IGR, resistant varieties and management of cropping system (refer to Sawada et al. in this issue). Leafhoppers are an intermediate species[15], and are likely to remain important as virus vectors, as in the case of planthoppers. The expansion of minimum tillage practices and direct sowing in rice production systems may have a profound influence on the virus epidemiology (Table 6). In addition, the possible rise in temperature due to the greenhouse effect may also have the same implications.

Direct sowing may work in favor of virus epidemics, since the susceptible stage during which rice plants are exposed to the attack of vectors lasts longer, as in the case of minimum tillage by increasing the density of overwintering vector population. The rise in temperature may not only assist a northward extension in the distribution range of virus vectors, but also accelerate the revolution rate of epidemic cycles of virus diseases resulting in the expansion of range of occurrence to the further north[11].

Since virus diseases require the most sophisticated IPM practices, the systems approach will become important. Surveillance and monitoring may contradict with the demand for cost- and labor-effective rice production systems. In particular, the lack of in-field walking space in direct-seeded fields may be one of the main factors allowing pest multiplication to escape early detection[8]. Therefore, the demand for detailed information on pest will further increase to promote low input and sustainable agriculture.

Pest population information is expected to contribute to lessening crop losses and reducing pesticide use, thereby stabilizing farm incomes. Pest populations, however, vary from farm to farm. In managing the pests, not all farmers may be willing to take an equal risk of pest damage. Recognizing that the control threshold is highly site-specific[17], one of the major problems for the implementation of an area-wide pest management program is, therefore, how to determine an appropriate level of pest suppression to be provided[1]. With the purpose of assisting individual small-scale farmers, an efficient and effective method for utilizing local information about pest occurrence in their decision-making about pest control, should be established through strengthened IPM studies.

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