Historical Development in Research and Management of Long-distant Migratory Rice Planthoppers

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Occurrence of migratory planthoppers in Japan

Migratory planthoppers, the brown planthopper (BPH) *Nilaparvata lugens* (Stal) and the whitebacked planthopper (WBPH) *Sogatella furcifera* (Horvath) have been serious threats to the stable rice production in Japan for centuries (Figs. 1&2). The most catastrophic hopperburn disaster in history occurred in 1732 when the yield loss caused by migrant planthoppers was estimated at 70% in western Japan, resulting in the death toll of one million people due to starvation. Another historical outbreak of migratory planthoppers was recorded in 1897. This triggered the establishment of the Department of Entomology at National Agricultural Experiment Station. Serious yield loss caused by migratory planthoppers occurred subsequently in 1903, 1912, 1924, 1929, 1940, 1966, and 1969 (Kisimoto, 1975). Massive immigration of WBPH continued for several years in the late 1980s to the early 1990s (Fig. 3). The highest BPH infestation in the present decade was recorded in 1998. Although serious yield reduction of rice was prevented in that year by prompt pest forecasting information service and advanced control technologies, it was enough to recall the destructive nature of BPH and the importance of reliable forecasting technologies of BPH occurrence.

Fig. 2 Macropterous adult of BPH

Fig. 3 Massive invasion of WBPH to young rice plants

Population dynamics of BPH in paddy fields

Forecasting technologies of pest occurrence have played an essential role in the management of migratory planthoppers in Japan since the nation-wide pest forecasting service system came into operation in 1950. The basis of forecasting technologies was founded in the 1960s and 1970s through intensive ecological studies on the population growth patterns of migratory planthoppers and factors affecting their popula-

Fig. 1 Hopperburn caused by BPH

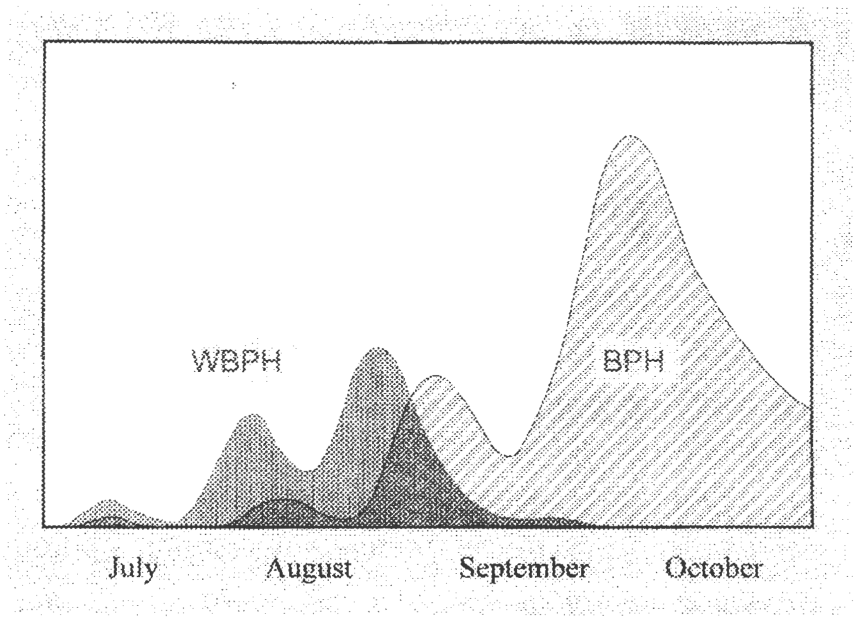

Fig. 4 Population growth patterns of BPH and WBPH in western Japanese rice fields

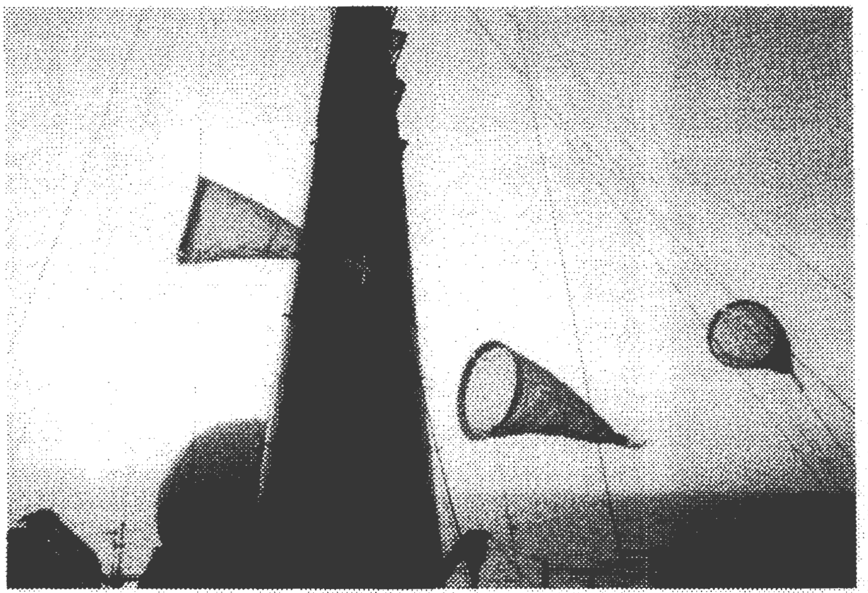

Fig. 5 Net traps set on a weather ship for monitoring transoceanic migration of rice planthoppers

tion dynamics. These studies made it clear that macropterous adults invade paddy fields mainly late in the rainy season, followed by three reproductive generations during a crop season (Fig. 4). Kuno (1968) who conducted a 6-year field study in northern Kyushu revealed that BPH population density increases monotonously until harvesting time, despite a density dependent process operating on the population growth rate.

One of the most important conclusions Kuno (1968) drew was that the key factor responsible for the yearly fluctuations in the density of BPH peak generation is the density of the immigrating population: 69% of the variance in the peak generation density is explained by the variance in the immigrant generation density. Kuno (1968) also pointed out that if the population census is made for the 1st generation nymphs and adults occurring in late July to early August, then the forecasting of peak generation density can be much improved. These results have served for timely control operations based on early forecasting of BPH occurrence. Other major studies so far made in Japan in relation to BPH management include the following topics: wing form determination, effect of natural enemies, control threshold, simulation models of population growth and hopperburn formation, yield loss analysis, shift in biotypes and insecticide resistance.

Forecasting long-distance migration of BPH

A long-lasted debate on the source of macropterous adults invading paddy fields shortly after transplanting was terminated by the late 1960s, following the observation of massive BPH landing on a weather ship stationed on the Pacific Ocean in 1967 as indisputable evidence of transoceanic migration of BPH (Asahina and Tsuruoka, 1968). Kisimoto (1976) demonstrated a close connection between BPH arrival and the barometric depression that moves eastwards from China (Fig. 5).

Seino *et al.* (1987) paid attention, as the medium of BPH migrants traveling from China to Japan, to the low-level jet stream that develops in the south of stationary front specifically in the rainy season. They were successful in developing a model that accurately forecasts BPH invasion. A computer program was then developed by Watanabe and Seino (1991) to monitor the low-level jet stream at 850 hPa layer in East Asia to forecast the time and area of BPH immigration. Real-time graphical information on the development of low-level jet stream has been available on JPP-NET (Japan Plant Protection general information NETwork system) hosted by Japan Plant Protection Association since 1997 (Fig. 6). A much advanced simulation model of planthopper migration has recently been developed by Otsuka *et al* (in press). The new model simulates 3-dimensional movement of planthoppers by incorporating their detailed behavioral properties to attain very high precision level of forecasting.

Direct and indirect interactions among planthoppers and rice

In the 1980s, it became increasingly evident that the out-

Fig. 6 Wind field at 850 hPa layer provided by JPP-NET for forecasting migration of rice planthoppers

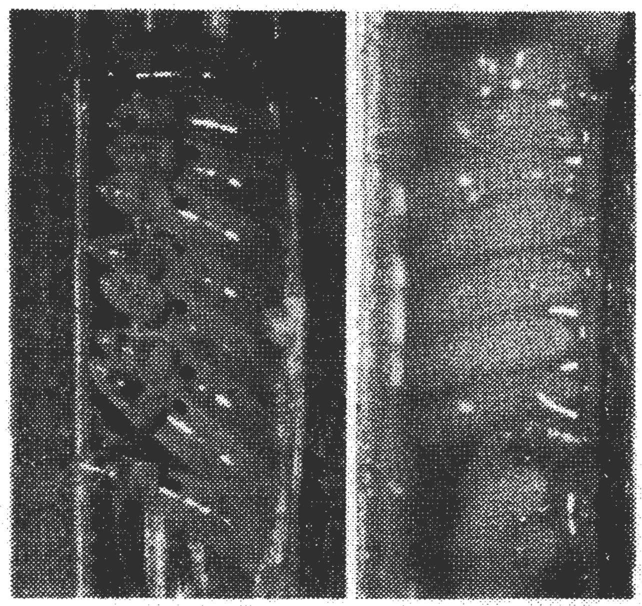

Fig. 7 Healthy WBPH eggs (left) and dead WBPH eggs at watery oviposition lesion (right)

break patterns of BPH are difficult to explain by traditional theories. A notable example is BPH occurrence in 1987. The immigration of BPH was so heavy in that year that devastating infestation was predicted, yet no serious outbreaks took place. It was apparent that this was not due to intensive control because BPH did not cause hopperburn even in those fields where no preventive action was taken. An analysis of light trap data accumulated for 40 years in northern Kyushu confirmed that the population growth pattern of BPH in paddy fields is no longer simple but variable, particularly in years of low immigrant densities (Watanabe *et al.* 1994). This finding indicated that thorough understanding of factors causing variations in the population growth rate is indispensable for improving BPH forecasting technology.

Recent studies have revealed the involvement of two new factors that greatly affect BPH population dynamics. One is the ovicidal response of rice plants, which was discovered through the study of WBPH-rice plant interaction (Sogawa, 1991). Soon after WBPH females lay their eggs in leaf sheaths of japonica rice and mid ribs of their leaves, watery lesions are formed on most of the oviposition sites. WBPH eggs in the watery oviposition lesions are killed at the early stage of embryonic development, while those in non-watery oviposition lesions develop normally (Suzuki *et al.*, 1996) (Fig. 7). A GC-MS analysis revealed that benzyl benzoate is produced in the watery lesions, and this compound shows an ovicidal activity at a concentration of 6.4 ppm or more (Seino *et al.*, 1996) (Fig. 8).

BPH eggs also suffer from ovicidal response of rice plants, though the mortality is not so high as WBPH eggs (Kiyonaga *et al.*, 1997; Kiyonaga and Suzuki, 1998). Egg mortality of BPH caused by rice plant response highly depends on the plant growth stage. It further depends on rice variety, and the difference between japonica varieties and indica varieties is most distinct. Genetic basis of rice ovicidal response was investigated by Yamasaki *et al.* (1999) using a set of 71 rice recombinant inbred lines derived from a cross of a japonica variety and an indica variety. They showed that a total of 7 quantitative loci were associated with the ovicidal response, with an essential locus on the chromosome 6.

Another finding of primary importance for BPH forecasting is the effects of WBPH on the wing form determination of BPH. Miyamoto *et al.* (1997) showed that the female wing form does not depend on the direct effect of crowding but on food conditions. On the other hand, Rubia *et al.* (2003) revealed that physiological condition and growth of rice plants are more seriously affected by WBPH than by BPH, despite the fact that the former sucks less amount of phloem sap. On these bases, Matsumura and Suzuki (1999) confirmed that, if the total number of planthoppers is the same, the proportion of BPH macropterous females becomes higher on a rice plant attacked by a mixed population of BPH and WBPH than that attacked exclusively by BPH. A significantly negative correlation between the density of immigrant WBPH and the population growth rate of BPH gives further evidence for the inter-specific interaction operating in the field.

Progress in chemical control

Chemical control of migratory planthoppers has made a remarkable progress in terms of safety, effectiveness and stability since synthetic insecticides dominated in rice pest management half a century ago. Organochlorides which were banned in 1970 due to residue problems were replaced by selective insecticides, followed by an IGR, buprofezin. With its durable, prominent effects on leaf- and planthoppers, buprofezin contributed to halve the pesticide treatments in western Japanese paddy fields. A new era of chemical control of rice pests was triggered by the registration of a granule formulation of imidacloprid, a neonicotinoid insecticide for seedling-box treatment in 1993. Neonicotinoids and fipronil, with systemic action, show a broad spectrum against insect

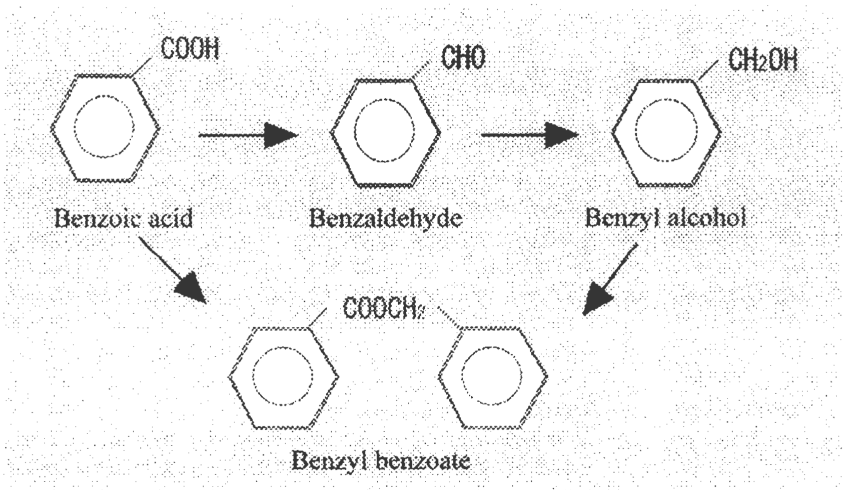

Fig. 8 Biosynthesis of ovicidal substance, benzyl benzoate in rice watery oviposition lesions

Fig. 9 *Cyrtorrhinus lividipennis*, a migratory predator of rice planthoppers

Fig. 10 *Pardosa (Lycosa) pseudoannulata*, an important domestic predator of rice planthoppers

pests. The seedling-box treatment with these insecticides has been swiftly accepted by a large proportion of farmers. Now various options of chemical control are available for farmers. Formulation and application technologies have also advanced to meet farmers' diverse needs and to reduce side effects on environment. It should be mentioned, however, that we have to be prepared for the development of insecticide resistance as before, unless resistance management is implemented in migrant source areas.

Making use of natural enemies

Although pesticides have been carefully selected to minimize adverse effects on natural enemies, intentional augmentation of natural enemies has been poorly practiced in Japanese paddy fields. It is known that rice planthoppers were not economic pests in tropical paddy ecosystem before the intensification program of rice production, which includes massive application of non-selective insecticides, was implemented. This provides evidence that natural enemies have potential ability to maintain the density of planthoppers below the economic injury level. Natural enemy fauna in temperate region is quite similar to that in the tropics, yet East Asian countries including Japan have suffered from serious outbreaks of rice planthoppers for more than a millennium. Why is the effectiveness of natural enemies unstable in temperate paddy fields? Comparative studies on the population dynamics of rice planthoppers and their major natural enemies between the temperate and the tropics have revealed that the natural enemies are much less abundant in temperate paddy fields early in the rice growing season and thus they often fail to suppress planthoppers. Some important natural enemies found in Japanese paddy fields are, like BPH and WBPH, long-distant migratory species which can not hibernate in temperate regions. A mirid bug *Cyrtorhinus lividipennis* is one of such natural enemies (Fig. 9). This predator is quite abundant in tropical paddy fields, while migrant generation adults arriving successfully in Japan together with migratory planthoppers are too few to effectively control planthoppers. Augmentative release of *C. lividipennis* has recently been attempted in Kyushu to increase its density early in rice growing season. The results showed that, if *C. lividipennis* is released to attain the ratio of *C. lividipennis* density to BPH density becomes more than 1:1 , then BPH outbreak can be prevented. Another attempt so far made to increase natural enemies on young rice plants is aimed at conserving spiders and their alternative prey species (Fig. 10). Augmentation of natural enemies may contribute to stable rice production, provided that it is combined with other methods reducing the reproductive rate of rice planthoppers such as the reduction of nitrogen fertilizer application. The importance of conserving natural enemies is well recognized in the tropics where avoidance of early treatment of insecticides is recommended (Way and Heong, 1994).

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