Forecasting brown planthopper outbreaks in Japan

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Outbreaks in Japan of the brown planthopper *Nilaparvata lugens* (Stål) were more frequent in the last decade than in the one before. The number of insects and the frequency of outbreaks are usually higher in the regions southwest of Japan than elsewhere. It is important to measure population levels of the immigrating insects in June and July to forecast the levels of the outbreaks in subsequent generations. Traps and field surveys are reliable, but patrol-type surveys are essential in forecasting for large areas.

Generally, insecticide applications are timed to kill the nymphs that are produced by the immigrating adults, before the brachypterous females of the next generation appear. When the immigrant population is low, the level of the brachypterous female population should determine insecticide applications. If insecticide application is necessary, it should be timed to kill the younger nymphs of the second generation after they hatch.

ALTHOUGH HEAVY INFESTATIONS have occurred in tropical Asian countries only in recent years, the brown planthopper (BPH) *Nilaparvata lugens* (Stål) has been one of the most important pests of rice in Japan over a long period. It is said that famines in earlier days were caused by rice failures that resulted from either serious outbreaks of the blast disease or of insect pests, especially the BPH, or unusual cold weather during the rice plant's reproductive stage, or both.

Forecasting of the time of the insect's appearance and its numbers in the coming rice season requires knowledge of the insects' overwintering situation in temperate countries. The BPH and the whitebacked planthopper *Sogatella furcifera* Horvath have been observed to overwinter in Japan only in small numbers at isolated locations near hot springs [Ministry of Agriculture and Forestry (MAF) 1965, 1967]. But in July 1967, a weather ship happened to meet a mass flight of rice planthoppers on the Pacific Ocean far from Japan (Asahina and Tsuruoka 1968). That incident threw considerable light on the

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complex pattern of the BPH. Since then, surveys on sea or on land have suggested that there are transoceanic long-distance migrations of the planthoppers to Japan during the *baiu* (rainy) season in June and July (Kisimoto 1971, 1972; Iijima 1973; Itakura 1973; Hirao 1974; Mochida 1974). However, the origin of the migrating planthopper has not been definitely clarified.

Japan has more data on the bionomics and physiology of the BPH related to the overwintering problem than data related to forecasting problems. In general, diseases and insect pests are forecast on long- and short-term bases. Before the migration of BPH to Japan was discovered, long-term forecasting was based on the assumption that both species of planthoppers overwintered in Japan as diapausing eggs in the gramineous winter grasses. The data on long-term forecasting so far published are meaningless. This paper therefore focuses on the short-term forecasting of the BPH, with special reference to outbreaks in Japan.

Because of the regular or intensive insecticide applications in Japan, an "outbreak" in that country is difficult to define. But when the pests are abundant, farmers often fail to suppress them. As used in this paper, the word "outbreak" means a large-scale occurrence of pests or severe damage of rice plants. Damage is indicated by hopperburn.

OUTLINE OF GENERAL FORECASTING WORK

The 1940 large-scale outbreaks of the BPH and whitebacked planthopper led the Japanese Government to establish in 1941 a nationwide plant-protection system called "Forecasting Work of Disease and Insect Pest Occurrence." The work is carried out according to the general and detailed rules for the enforcement of disease and insect outbreak forecast work for ordinary crops in Japan (MAF 1971). In addition, a plant protection law was established in 1950. The rules for forecasting work are revised every few years on the basis of experimental results.

Systematic forecasting has been well developed. According to the 1975 census, there are 192 prefectural forecasters in 47 prefectures and 484 local forecasters at 265 observatory stations. Every forecaster belongs to a prefecture and is under the administrative control of the prefectural governor. However, the Division of Plant Protection, Ministry of Agriculture and Forestry, directs the technical work of the forecasters, subsidizing all or a part of their expenses. Every observatory station has traps and model fields for use in forecasting; representative rice varieties are grown in the model fields with the cultivation practices common in the region concerned. No insecticides or fungicides are applied in a model field. The local forecasters present to the prefectural forecasters survey results based on the overall information taken from the traps, from the model field, and from survey patrols of the farmers' fields. The prefectural forecasters periodically deliver forecasting information or extraordinary warnings or alarms to the office concerned. They publish annual reports.

The rules to be followed in surveys for forecasting the occurrence of the whitebacked planthopper and the BPH are specified. Planthopper catches in the light trap (a bow-frosted bulb with double filament) are to be recorded daily throughout the rice-growing season. A sticky trap (80 × 25 cm) at the plant-top level and a net trap (1 m in diameter) more than 10 m high are also recommended for catching immigrating adult insects from April to July. During that period, a sweep net (37 cm in diameter) with a handle (1 m long), or a suction catcher, if available, is used to determine the density of adult and nymph populations on gramineous grasses around the paddy fields.

To record the population density, samples are taken from the nursery beds with 20 strokes of the sweep net. In the paddy fields, plants are pushed aside and the insects on the plants are counted or the plants are tapped and the insects that fall into the paddy water are counted. It is well to use a sweep net at the same time.

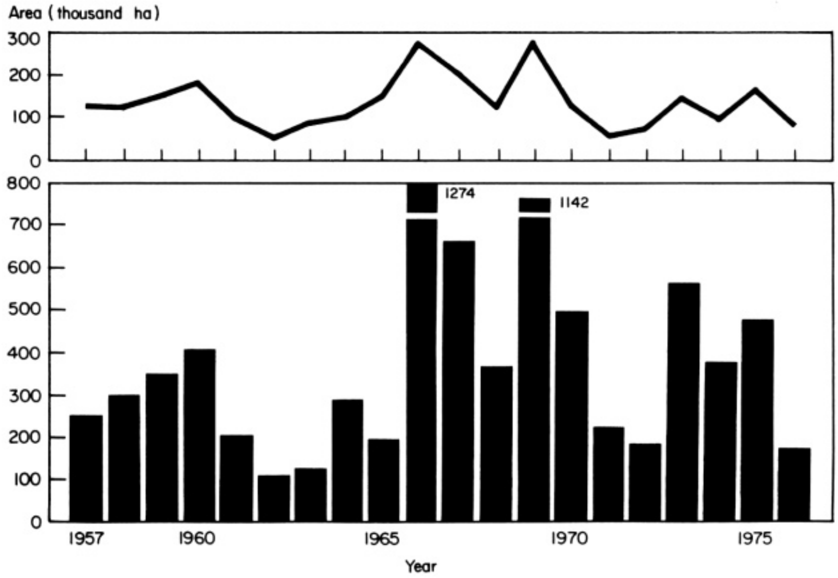
The rice fields of a region are evaluated twice during July and August, and, finally, in mid-September; the degree of insect occurrence is recorded according to the following scale : none : 0 adults and nymphs found per hill with push-aside or tap-and-count method (0 insects found/20 strokes of sweep net), rare: 1–10 adults and nymphs (1–100 insects/20 strokes of net), medium: 11–50 (101–300), abundant: 51–100 (301–700), severe: over 101 (over 701); hopperburn may accompany this rating.

Forecasting of the planthopper in Japan is conducted under these rules. In addition, sampling methods are tried to make the results accurate.

OUTBREAKS IN RECENT YEARS

An outbreak of the BPH was recorded in 697; from that time until World War II, more than 100 small or large outbreaks occurred occasionally, causing miserable famines in old days (Suenaga and Nakatsuka 1958; Hirashima 1965).

The yearly records show that the frequency of the occurrence of the BPH outbreaks has varied considerably in the past 20 years (Fig. 1). The outbreaks occurred more frequently in the last decade than in the one before. There was no periodicity in the outbreaks. The 1966 outbreak was the largest both in area involved and in severity of damage; the 1969 outbreak was next (MAF 1968; Hirao 1976). In 1966 the BPH was found on 1,274,000 ha of 3,149,000 ha of paddy fields in Japan and severely damaged 780,500 ha, reducing yields to 348,900 t. In 1969. 1,142,000 ha were affected. Less severe outbreaks occurred frequently in 1967, 1970, 1973, and 1975, but none during the previous decade. The outbreaks of the BPH were always accompanied by outbreaks of the whitebacked planthopper, except in 1972, when an outbreak of only the whitebacked planthopper occurred, affecting 830,000 ha. Generally, damage from



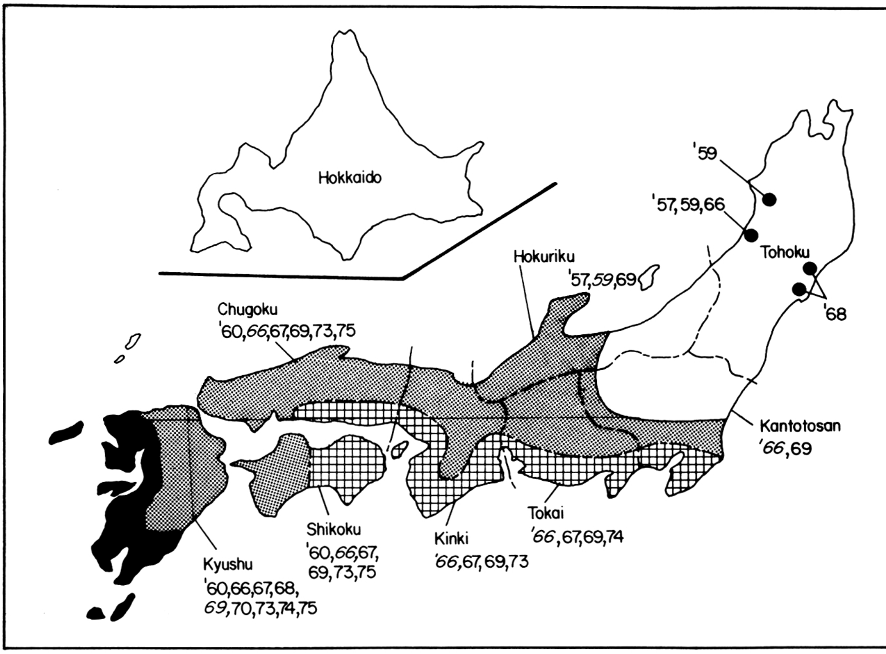
1. Areas affected by the brown planthopper during a 20-year period. Histogram = Japan; solid line = Kyushu.

the whitebacked planthopper is much less severe than that from the BPH.

Areas where the BPH occurs usually extend northward to the central part of the Japanese mainland (lat 36°N); the whitebacked planthopper occurs further north (lat 44°N). That fact is attributable to the difference in the migratory abilities of the two species. The geographical patterns of the BPH abundance and of the frequency of outbreaks are distinct (Fig. 2).

The largest light-trap catches, which reflect roughly the number of insects, were always seen in the southwestern regions, especially Kyushu, and in the southern region along the Pacific coast. Outbreaks occurred frequently in three regions, Kyushu, Shikoku and Chugoku. For instance, in the past 20 years there were 9 years of outstanding outbreaks in Kyushu, in contrast to 4 years in Kinki and only 2 years in Kanto-Tosan. Even in Kyushu, the insect population and severity of damage are usually much larger in the western coastal region and in the southern region, where the paddy fields, if left unsprayed, suffer from hopperburn almost every year. The area affected in Kyushu in the last decade varied from 80,000 to 290,000 ha, accounting for 29 to 80% of 360,000 ha of rice fields in Kyushu (Fig. 1).

Outbreaks of the BPH were recorded in three localities in Tohoku (Fig. 2), in the northern part of the mainland, where outbreaks of the whitebacked planthopper occasionally occur. Outbreaks of the BPH in Akita Prefecture in 1959 and in Miyagi and Iwate prefectures in 1968 were the first ever recorded there; the affected areas covered several thousand hectares (Watanabe 1960; Ito et al 1969; Yoshida and Hasegawa 1969).



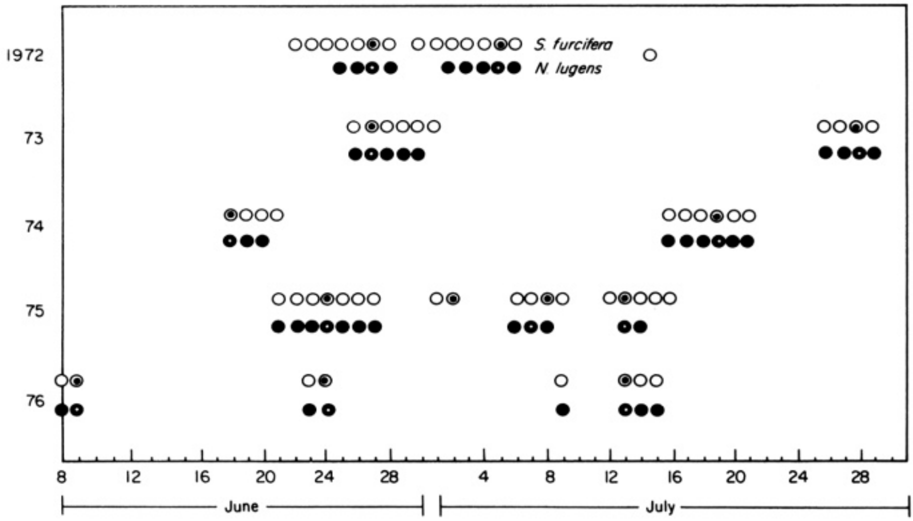
2. Geographical distribution of brown planthopper populations, based on light-trap catches and outbreak frequencies in 1957-1975. Italics indicate year of severest outbreaks in an area. Darker areas have higher population densities.

The geographical distribution of the BPH over the country is attributable to transoceanic movement of insects from the west or the southwest into Japan. The reason for the frequent outbreaks in the last decade is uncertain. Transoceanic migration may link the recent outbreaks in Asian countries to those in Japan.

There is no periodicity in the BPH outbreaks. Therefore, intensive and extensive forecasting work is important in predicting the insect occurrence and resultant hopperburn especially in the southwestern and southern parts of the country, where the BPH occurs much more abundantly and frequently than in other north and northeastern regions.

FORECASTING OUTBREAKS

The rice plants normally are transplanted in mid-June in the southwestern regions. The *baiu* (rainy) season is from early June to late July. Planthopper migrations usually last for about a month from mid-June to mid-July (Fig. 3). Earlier immigrations, especially of the whitebacked planthopper, are occasionally seen in the coastal region of the west and south of Kyushu facing the East



3. Immigrating waves of the planthoppers in Chikugo in recent years.

China Sea in late April or May; population density is low. The BPH usually goes through four generations in a paddy field, multiplying abundantly as the generations advance until harvest. Hopperburn usually occurs after heading in the generations later than the third. Many entomologists state that it is important to know the dates and frequency of immigration waves and their density, to forecast the population of subsequent generations.

Catching the immigrants

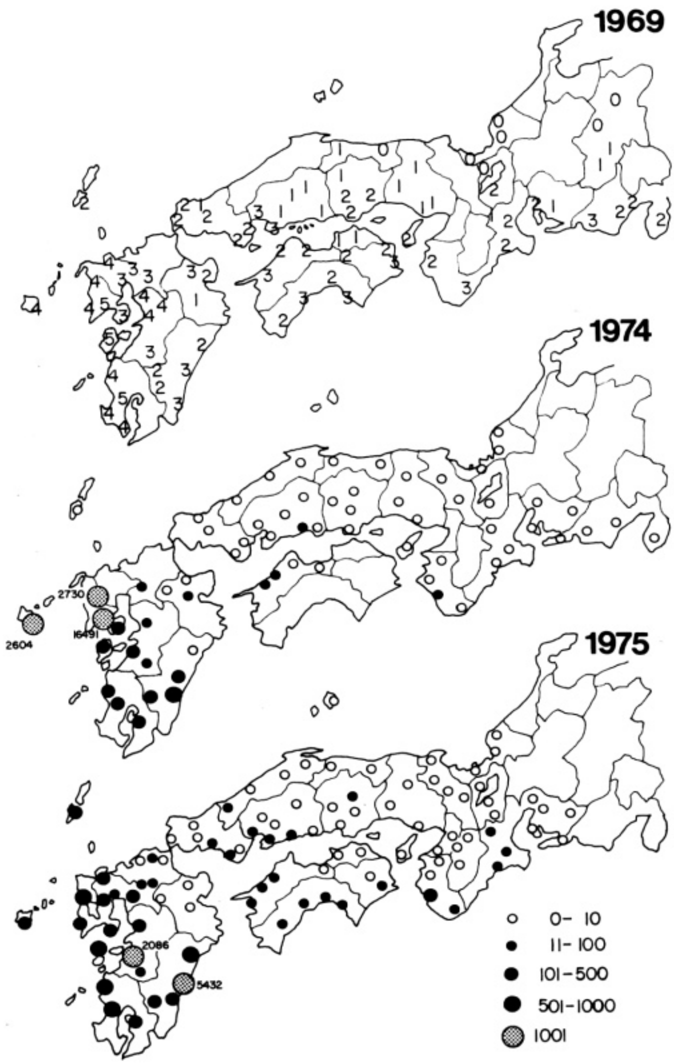
Light traps. Light traps are commonly used to record the seasonal fluctuations of insect numbers. Figure 4 shows the light-trap catches of the BPH during immigration. A large number of immigrants were trapped in 1969 and severe hopperburn occurred widely in the same regions. The same phenomenon was observed in other outbreak years (Yamashita and Nagai 1968).

According to the historical records (Hara et al 1967), the largest light-trap catches were 0.2 million BPH together with 1.31 million whitebacked planthoppers caught per trap at Taniyama on the night of 9 July 1966, and 0.14 million BPH and 1.28 million whitebacked planthoppers at Sendai on the night of 11 July of the same year. In addition, 0.38 million BPH at Sendai and 3.01 million whitebacked planthoppers at Izumi were trapped in a 6-day period beginning on 7 July 1966. The trapping stations were in Kagoshima Prefecture at the southern tip of Kyushu. The year 1966, of course, was unusual.

According to the light-trap record for the past 20 years at the Kyushu National Agricultural Experiment Station, Chikugo, Fukuoka, the average BPH catch during immigration periods was 406 (2,149 in 1969—24 in 1963). Kuno

(1968) indicated a high correlation between the density of immigrants in the field and the total number of adults in the light trap near the field during the immigration period. Similar results are shown in recent data (Fig. 5).

It is difficult to standardize the relationship between the number of insects caught in a light trap during the immigration period and the occurrence of hopperburn in subsequent generations, because the environments in which



4. Light trap catches of planthopper immigrants up to July 20. Figures for 1969 indicate logarithm values; for 1974 and 1975, the symbols are defined in the legend.

Table 1. Brown planthopper immigrants up to 20 July and hopperburn. Kyushu National Agricultural Experiment Station, Chikugo.

Year	Insects trapped (no.) by		Density[b]	Hopperburn[c] (rating)
	Light trap	Net trap[a]		
1968	204	7		+
1969	2149	197		++
1970	177	21	0.038 (0.010–0.159)[d]	++
1971	98	7		0
1972	31	9		+
1973	89	25	0.013	+
1974	97	10	0.036	++
1975	266	8	0.041	++
1976	191	6	0.012	+

[a] Average of 2 traps. [b] Highest number of adults/hill in a field. [c] ++ = overall; + = patch; 0 = none. No insecticides used. [d] After Kisimoto (1975).

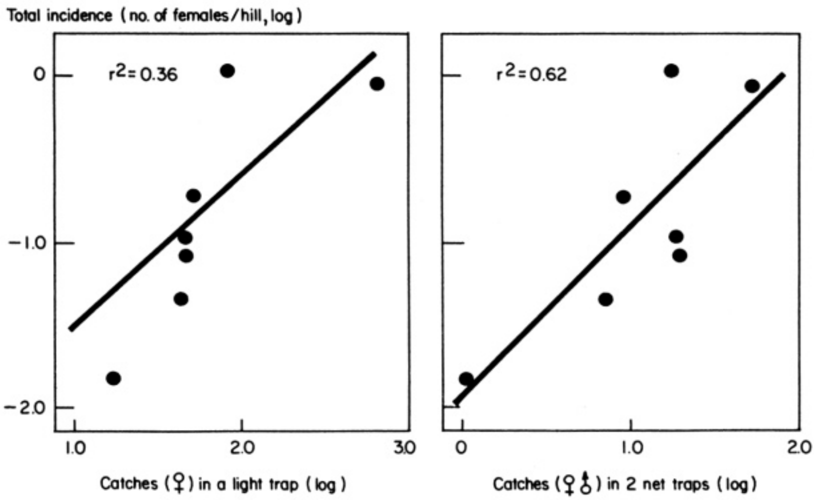
the generations develop, temperatures in the fall, and farming practices differ from place to place and year to year. However, it may roughly be said that a catch of more than 500 BPH during the immigration period results in a severe outbreak of hopperburn before heading and that a catch of 100 to 500 results in hopperburn of the whole field after heading, while light hopperburn occurs in October, when the catch is around 100. Roughly, a catch of 50 may be a threshold for hopperburn. Hopperburn occurred almost every year unless insecticides were applied in the field (Table 1).

It appears that light traps are useful for catching immigrant insects and forecasting subsequent outbreaks of hopperburn, especially when immigrant density is high. The area a light trap can forecast for has not been determined for any pest.

Other traps. A net trap is reliable (Fig. 5). But I recommend the use of two or more net traps for accuracy. Yellow-pan water and sticky traps could catch more males than females, probably because the sexes differ in activity. Since yellow-pan water and sticky traps reflect the population trends of the planthoppers after the insects have become established in a field, their use can substitute for visual counting.

Kisimoto (1974, 1975) suggested that catches of more than 10 individuals in a net trap or of more than 50 in a yellow-pan water-trap during immigration means the occurrence of hopperburn in the fall, and that catches of from more than 100 to several hundreds forecast severe outbreaks of hopperburn before heading (Fig. 6).

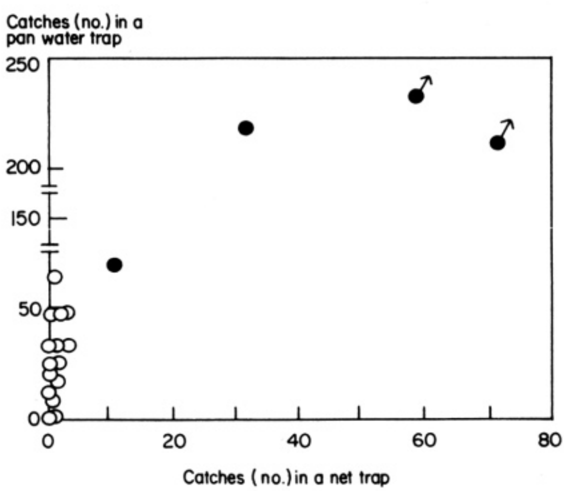
Visual counting. BPH immigrates before the maximum tillering stage of rice plants. It is therefore easy to count visually, hill by hill, without consuming much time or disturbing the insects. The distribution of BPH adults is random in this generation (Kisimoto 1965; Kuno 1968). The density of the immigrants is low (Table 1). Roughly, more than one individual male or female per 100 hills might cause hopperburn in the fall. When plant growth is more advanced,



5. Correlation of immigrating brown planthopper catches in traps and field populations near the traps.

the tap-and-count and push-aside methods are recommended for counting nymphs.

Net sweeping. Net sweeping is commonly used to determine the population density of insects. Net sweeping in the field is unreliable during the immigration period, because plants are short and the planthopper inhabits the lower



6. Correlation of immigrating brown planthopper catches between light trap and net trap (Kisimoto 1974). The black circles with arrows indicate flights that eventually caused hopperburn.

part of rice plants close to the surface of the irrigation water. The results vary significantly between investigators or with weather conditions. Net sweeping and the push-aside methods are the only ones applicable to nursery beds.

Survey patrols. Each trap has merits and demerits. Light traps do not work in the daytime; net traps do not function under calm conditions. Planthopper catches are often significantly different even in light traps 200 or 300 m apart. The area covered by traps is uncertain. To remedy such deficiencies, visual counting by survey patrols as frequently as possible is necessary for checking insect density. Planthopper populations should be forecast from a broad base.

Establishment of the immigrants in a field

The adults of the second generation appear about 1 month after the immigration (allow 2 weeks for the egg period, including a few preoviposition days for the immigrant, and another 2 weeks for a nymphal period) (Suenaga 1963; Kisimoto 1969; Hirao 1972). They begin to appear in late July or mid-August, depending on the time of immigration. Most females are brachypterous but males are macropterous. The brachypterous females have a higher rate of reproduction (Kisimoto 1965) and, thus, are the sources of the subsequent generations that cause hopperburn. It is important to know the population of second-generation brachypterous females to forecast fall outbreaks of hopperburn.

In that generation, visual counts, including those that use tap-and-count and push-aside methods, are meaningful only for field surveys. The brachypterous females, unlike the macropterous immigrants of the previous generation, concentrate in certain areas. When there are more than 30 or 40 females/100 hills, hopperburn occurs first where the females can aggregate (Kisimoto 1969). About 20 females/100 hills are considered to be a threshold for hopperburn in the fall. If there are more than 200 females/100 hills, nymphs from the eggs they lay cause serious outbreaks before heading. Such was the case in 1969 and 1970.

Little is known about how environment affects the reproductivity of the BPH in a field. Suenaga (1963) said that continuing temperatures of above 30°C are unfavorable for nymphal growth under experimental conditions. However, such continuous high temperatures do not prevail even in midsummer in Japan.

As mentioned (Fig. 3), the time of the immigration has varied from year to year and from area to area. When the immigration occurs early, as in mid-June, or when high temperatures prevail in September, the BPH is able to extend itself into one more generation (the fifth) in October. That occurred in 1975, when severe outbreaks occurred in southwestern Japan. near harvest time. On the other hand, unusually low fall temperatures limited reproduction. My observations indicate that hopperburn occurs earlier on the early maturing varieties than on the late-maturing ones, even with similar population densities, probably because the rice plants' tolerance to the BPH is reduced as the plant approaches maturity. Such facts should be considered in forecasting.

The forecasting work begins with determining the times and frequency of occurrence of the immigrants by traps and field surveys. More than two kinds of traps are recommended for use, and field surveys of the population density are unavoidable in large-area forecasting. From the levels of the immigrant population thus obtained. the levels of outbreaks and resultant hopperburn in the subsequent generations can be predicted.

GENERAL CONCEPTS OF CHEMICAL CONTROL

The population peaks of successive generations of the BPH are rather clear. Nagata et al (1973) developed measures to control them. Insecticides should be applied 20 to 25 days after immigration, when the immigrant density is high. Insecticide applications kill nymphs produced by the immigrants before the nymphs become adults and lay eggs. If application is delayed, the eggs laid by the brachypterous females are not affected and become the source of outbreak in later generations. When immigrant density is low, insecticide applications should be timed to kill nymphs of the second generation after most eggs have hatched.

There are no efficient ovicides or insecticides that have long residual effect to control the BPH. When there are two or more waves of immigration within a short period, as in 1975 and 1976, the later insect stages follow erratic patterns. Such conditions make control of BPH with a single application of insecticides difficult.

For effective BPH control insecticide application should be properly timed on the basis of the results of forecasting work.

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