Appl. Ent. Zool. **15** (1) : 10—19 (1980)

Insecticide Susceptibility and Wing-Form Ratio of the Brown Planthopper, *Nilaparvata lugens* (STÅL) (Hemiptera : Delphacidae) and the White Backed Planthopper, *Sogatella furcifera* (HORVATH) (Hemiptera : Delphacidae) of Southeast Asia

Toru NAGATA and Takeo MASUDA

Kyushu National Agricultural Experiment Station, Ministry of Agriculture, Forestry and Fishery, Chikugo, Fukuoka 833, Japan

(Received May 15, 1979)

The brown planthopper and the white backed planthopper collected from Thailand and Philippines were considerably more susceptible to 8 insecticides, especially to DDT than those of Japan.

Furthermore, they produced significantly higher percentages of brachypterous form than the Japanese strains when reared on rice seedlings. One of the two strains of the brown planthopper collected from Taiwan was quite similar to the Japanese strain with respect to insecticide susceptibility and wing-form ratio, and the other showed a coasiderably higher DDT-susceptibility and a higher percentage of brachypterous form.

These results suggested that the tropical populations of the two species of rice planthoppers are differentiated in physiological and ecological properties from the temperate populations.

INTRODUCTION

The accidental finding of large swarms of the white backed and the brown planthoppers in the ocean about 500 km off mainland Japan (ASAHINA and TSURUOKA, 1968) and the following surveys in the East China Sea (KISIMOTO, 1971) rendered the long-distance migration of the two species indisputable facts.

In studies of insecticide resistance of the brown planthopper, a unique seasonal fluctuation of BHC susceptibility was found and this was considered to be due to the population displacement by migration (NAGATA and MORIYA, 1973).

Furthermore, development of insecticide resistance in the two species was found to be very slow as compared with those of closely related rice leaf-or planthoppers, which was attributed to the population seplacement with susceptible migrants (NAGATA et al., 1979).

Although the route and the source of migration have not been fully elucidated, the most probable origin is southern China. However, migration from Southeast Asia particularly from the Philippines cannot be ruled out from the analysis of meteorological data etc. So we initiated studies to determine the insecticide susceptibility of the two species of rice planthoppers collected from these areas.

MATERIALS AND METHODS

The planthoppers were sent by air mail as eggs deposited into the rice seedlings. The strains and the collection data were as follows: The Philippine field strain (The experimental field of IRRI, Los Baños, Philippines, April, 1977), Philippine laboratory strain (derived from the IRRI field in 1965 and reared in the laboratory), Thailand strain (Banglen, Nakhonpathom district, Thailand, an outbreak area in 1976, February, 1977), Touliu strain (Touliu, Tainang, Taiwan, September, 1977), Chiayi strain (Chiayi, Tainang, Taiwan, September, 1977). They were reared on rice seedlings in cubic glass vessels ($11 \times 11 \times 18$ cm), each of them was provided with 25 g (wet weight) of Antiformin®-sterilized rice seeds (Variety:Reiho).

Uniform germination and growth was secured by covering the seeds with a thin layer of peat (Finnhumus Växttorv®). The food plants were changed every two weeks, each vessel could support a maximum number of 7–9 hundred planthoppers. The top of the vessel was covered with nylon cloth to permit aeration. The temperature was kept at 25 ± 1 °C with artificial light condition of 16 hr daylight.

Insecticidal tests were conducted by the micro-topical application technique of Fukuda and Nagata (1969). Technical grade insecticides with purity higher than 95% were supplied from manufacturers. The insecticides used in this study were BHC, DDT, malathion, fenitrothion, diazinon, MTMC (*m*-tolyl methyl carbamate), carbaryl and MIPC (2-isopropyl phenyl N-methyl carbamate). A 0.05 μl droplet of acetone solution of insecticides was applied to the dorsal pronotum of individual female adults which were anaesthetized with carbon dioxide. They were younger than 4 days after emergence. The mortality records were taken 24 hr after the treatment at 25 °C and converted into probit to obtain LD_{50} and analysed by probit analysis by Bliss's formula (Bliss, 1936). Each test was conducted in 2–3 replicates using 15 females for each replication.

In the tests to compare wing-form ratio, 1st- and 2nd-stage nymphs were introduced into vessels with fresh seedlings at different population density and the adults emerged were counted and removed. The wing-form ratios were expressed as percentages of brachypterous form per pot (Br-ratio). Hybrid between the Japanese and Philippine strains were obtained and the progeny of reciprocal crosses were combined. The adult planthoppers within 24 hr after emergence were used for these crossings.

RESULTS

Insecticide susceptibility

The Thailand strain of the brown planthopper were generally the most susceptible in these tests. Based on the comparison among macropterous individuals, the Thailand strain was about 30 times more susceptible to DDT than the Japanese strain collected in Kagoshima pref. in 1976 (Nagata et al., 1979). The Thailand strain was considerably susceptible to carbamates with ca 1/5–1/6 of that for the Japanese strain. Both wing-forms occurred in approximately equal numbers from the Thailand strain at a moderate rearing density. The brachypterous form was generally more susceptible to the insecticides than the macropterous form. There was about 2–5 times difference

Table 1. INSECTICIDE SUSCEPTIBILITY OF THE BROWN PLANTHOPPER OF THAILAND

Insecticides	Brachypterous form		Macropterous form		Japan, 1976[a]	
	LD_{50}[b]	b[c]	LD_{50}	b	LD_{50}	b
BHC	0.0041	2.3	0.017	2.3	0.022	1.8
DDT	0.0002	4.3	0.0010	4.7	0.034	2.3
Malathion	0.025	3.3	0.040	4.0	0.12	2.8
Fenitrothion	0.0082	2.3	0.017	2.7	0.12	2.3
Diazinon	0.0041	2.7	0.010	1.8	0.032	3.8
MTMC	0.0029	2.7	0.014	5.2	0.011	4.7
Carbaryl	0.0005	2.0	0.0015	3.8	0.0070	3.0
MIPC	0.0004	3.0	0.0009	5.7	0.0060	6.6

[a] Macropterous form, Data were quoted from NAGATA et al. (1979).
[b] μg/female.
[c] Slope of regression line.

Table 2. INSECTICIDE SUSCEPTIBILITY OF THE BROWN PLANTHOPPER OF THE PHILIPPIES

Insecticides	Field collected (1977)[a]		Laboratory reared since 1965[a]	
	LD_{50}[b]	b[c]	LD_{50}	b
BHC	0.0090	2.7	0.0073	2.0
DDT	0.0016	2.3	0.0007	3.7
Malathion	0.090	2.7	0.055	2.3
Fenitrothion	0.012	2.3	0.016	1.3
Diazinon	0.030	3.3	0.014	3.0
MTMC	0.022	2.7	0.0065	3.3
Carbaryl	0.0042	2.3	0.0024	2.7
MIPC	0.0062	1.5	0.0017	4.0

[a] Brachypterous form.
[b] μg/female.
[c] Slope of regression line.

Table 3. INSECTICIDE SUSCEPTIBILITY OF THE BROWN PLANTHOPPER OF TAIWAN

Insecticides	Touliu (M)[a]		Chiayi (M)[a]		Chiayi (B)[b]	
	LD_{50}[c]	b[d]	LD_{50}	b	LD_{50}	b
BHC	0.056	1.0	0.050	1.8	0.0056	2.8
DDT	0.015	3.3	0.0021	5.3	0.0002	6.0
Malathion	0.60	2.0	0.16	2.0	0.082	1.7
Fenitrothion	0.050	1.7	0.080	3.0	0.024	3.3
Diazinon	0.050	3.3	0.030	2.2	0.019	3.7
MTMC	0.014	3.7	0.0080	4.7	0.0040	2.3
Carbaryl	0.0064	3.7	0.0031	3.3	0.0025	2.3
MIPC	0.0028	3.3	0.0036	6.0	0.0019	3.3

[a] Macropterous form.
[b] Brachypterous form.
[c] μg/female.
[d] Slope of regression line.

Table 4. INSECTICIDE SUSCEPTIBILITY OF THE WHITE BACKED PLANTHOPPER OF TROPICAL AREAS[a]

Insecticides	Philippines (1977)		Thailand (1977)		Japan (1976)[d]
BHC	0.0081[b]	0.0075[c]	0.0072[b]	0.0036[c]	0.0054[d]
DDT	0.0006	0.0003	0.0009	0.0005	0.030
Malathion	0.0030	0.0029	0.0015	0.0040	0.0032
Fenitrothion	0.0009	0.0002	0.0004	0.0001	0.0018
Diazinon	0.0024	0.0019	0.0003	0.0002	0.0025
MTMC	0.0007	0.0014	0.0013	0.0001	0.0021
Carbaryl	0.0002	0.0003	0.0006	0.0005	0.0006
MIPC	0.0014	0.0012	0.0016	0.0004	0.0012

[a] LD_{50}: μg/female.
[b] Macropterous form.
[c] Brachypterous form.
[d] Data were quoted from NAGATA et al. (1979).

in LD_{50} (Table 1).

The brachypterous form of the Philippine field strain was more susceptible than the macropterous form of the Japanese strain. Although the comparisons have been made with the same wing-form, the macropterous form of the brown planthopper was scarcely obtained form the Philippine strain. The difference in the susceptibility to DDT and fenitrothion was large and the LD_{50}'s in the Philippine strain were 1/20 and 1/10, respectively as compared with those in the Japanese strain. The Philippine laboratory strain was generally more susceptible than the Philippine field strain, which might have been partly due to rearing for many generations. Only the brachypterous form was obtained from the latter strain (Table 2).

From Taiwan, 2 different strains were collected simultaneously. While one of them, the Touliu strain, was quite similar to the Japanese strain in its insecticide susceptibility, the Chiayi strain showed a particularly high susceptibility only to DDT. The latter produced equal numbers of both wing-forms and the macropterous form was significantly less susceptible to insecticides than the brachypterous form as in the Thailand strain (Table 3).

In the Philippine and Thailand strains of the white backed planthopper, sufficient numbers of both wing-forms were obtained for insecticide tests. Like the brown planthopper, the brachypterous form was generally more susceptible than the macropterous form. The Thailand and Philippine strains were considerably more susceptible than the Japanese strain. In particular, the DDT susceptibility of these population from tropical Asia was markedly higher than in Japan as indicated by the LD_{50} values as low as 1/30–1/50 of those in Japan. As compared with the Japanese strains, the Philippine strain was rather susceptible to MTMC and carbaryl, and the Thailand strain to fenitrothion and diazinon with LD_{50} values 1/5 and 1/8, respectively, of those of the Japanese strain (Table 4).

Wing-form

The Japanese strain of the brown planthopper showed a well-known density-dependent wing-form determination, i.e., the proportion of the brachypterous form gradually decreased with increase of density (Fig. 1, A). However, remarkably higher percentages of brachypterous form (Br-ratio) were obtained from both sexes of the Philippine field strain and significant decrease of the Br-ratio did not occurr even near the maximum carrying capacity of the rearing vessel (900 planthoppers) (Fig. 1, B).

The Thailand strain showed an intermediate Br-ratio between the Philippine and the Japanese strains and also clear density-dependence (Fig. 1, C). In the female, the Br-ratio decreased in proportion to the increase of density, but the optimal density for the appearance of brachypterous male was not the lowest but in a middle range

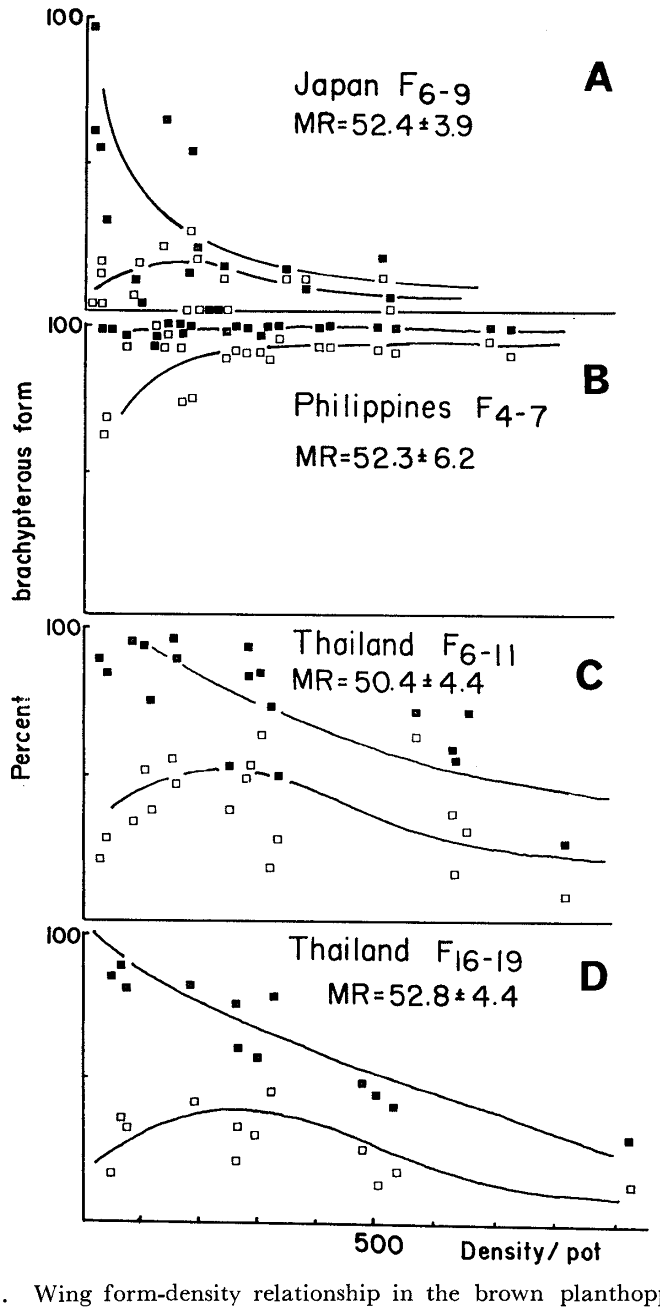

Fig. 1. Wing form-density relationship in the brown planthopper of tropical regions. ■ : female, □ : male. MR indicates % male ±S.D.

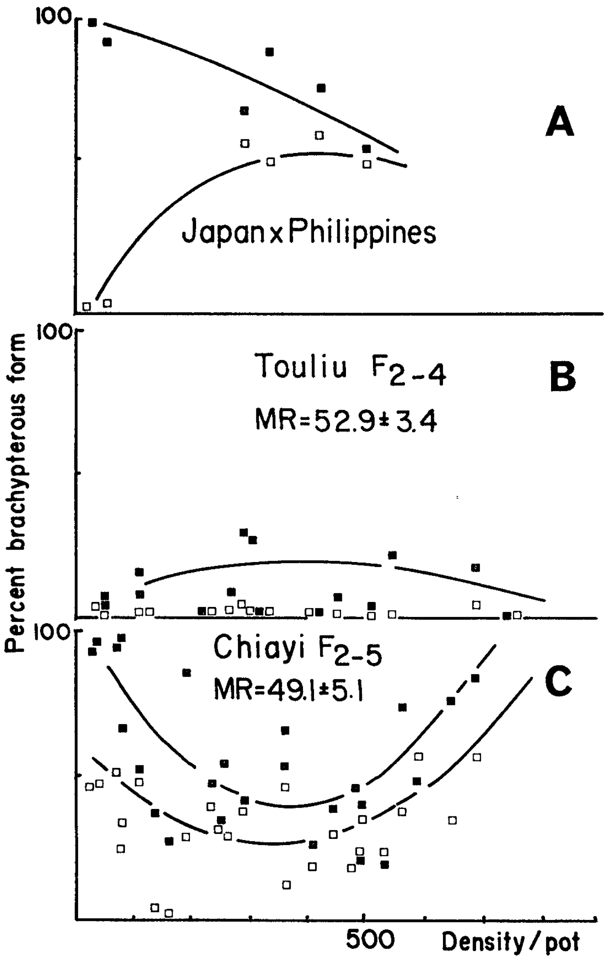

Fig. 2. Wing-form-density relationship in the brown planthopper of the cross strain and Taiwan. See Fig. 1 for symbols

as pointed out by KISIMOTO (1956). No substantial change in the wing-form response occurred after ca 1 year of laboratory rearing (Fig. 1, C. D). The hybrid strain between the Philippine field strain and Japanese strain showed an intermediate Br-ratio (Fig. 2, A).

Touliu strain produced the lowest Br-ratio among the strains tested (Fig. 2, B). However, Chiayi strain which had been collected ca 50 km east of Touliu on the same day produced more brachypterous form, especially at the lower and higher extremes of density, showing a U-shaped curve (Fig. 2, C). In all the strains examined, the percentage of brachypters was generally higher in the female than in the male. In

Table 5. NYMPHAL MORTALITY IN SEVERAL STRAINS OF THE BROWN PLANTHOPPER

Strain	No. of nymphs/pot	Replicated	% mortality (avg ±SD)	min-max
Chiayi	111—344	4	19.8± 8.6	9.9—27.9
Touliu	50—150	4	11.7±12.4	0—22.7
Thailand	100—200	4	17.7±12.0	0—25.9

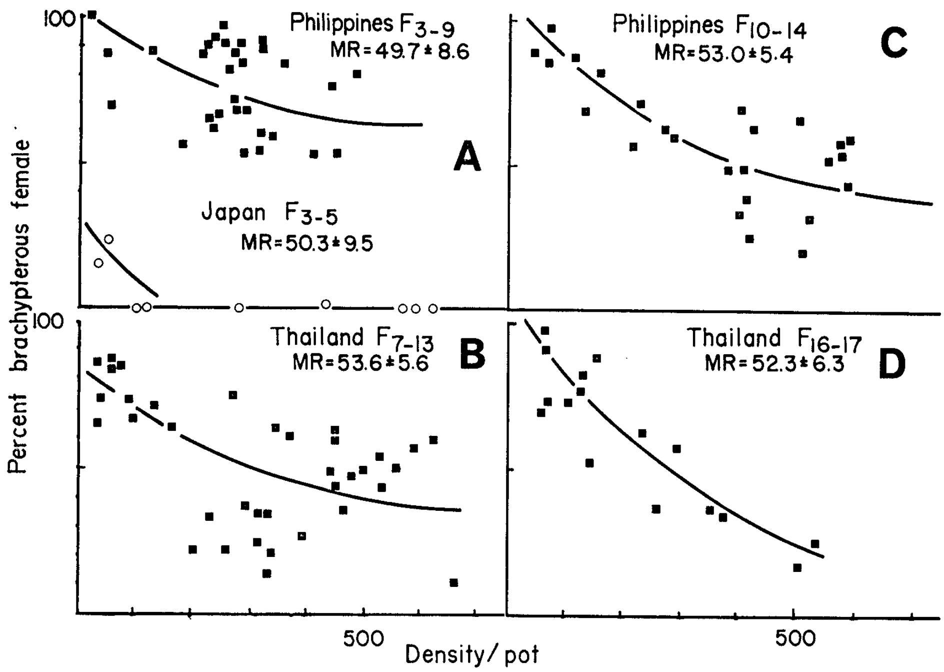

Fig. 3. Wing-form-density relationship in the white backed planthopper. MR indicates % male ±SD.

these laboratory rearings, the average mortality during nymphal stage ranged from 10–20% (Table 5).

The white backed planthopper of the Thailand and Philippine strains produced many brachypterous females. The latter strain gave a percentage of brachypters significantly higher than that of the Thailand strain. Brachypters were far fewer in the Japanese strain (Fig. 3, A.B). This strong tendency to produce brachypterous females was maintained for more than 1 year of rearing after collection in the 2 tropical strains (Fig. 3, C.D).

DISCUSSION

When the patterns of insecticide susceptibility were compared, the tropical and one of the Taiwan strains (Chiayi strain) of the brown planthoppers showed similarity due to their high sensitivity to DDT. The Philippine strains generally showed a lower insecticide susceptibility than the Thailand strain including DDT. Ordinary populations in the Philippines, however, are supposed to be more susceptible than the IRRI population (which has been exposed to extremely intensive insecticide applications) and to be similar to the Thailand strain. However, one of the Taiwan strains (Touliu strain) and less variable Japanese strains gave patterns of insecticide susceptibility quite different from the tropical ones. Thus the high susceptibility especially to DDT generally associated with a high Br-ratio seem to be the characteristics of the brown planthopper of tropical regions (Fig. 4). This may also be the case in the white backed planthopper.

Geographic strains of at least two different types of the brown planthopper and the white backed planthopper thus seem to distribute over Southeast Asia. One of them has a strong tendency to be brachypterous and is highly DDT-sensitive and distributed in tropical Asia. The other exhibits opposite properties and occurs in temperate regions. However, exploration of wider areas is necessary to make any generalization.

The geographical variation in DDT susceptibility cannot be fully explained; it may or may not be due to local variation in selection pressure or indigenous tolerance. Although the populations from tropical Asia are characterized by their high Br-ratio in the laboratory, it is not known whether a similar situation occurs in the field.

There are few studies concerning wing-form of the wild population of the brown planthopper or the white backed planthopper in the tropical areas. Occasional observation of wild populations never gives correct information for the local comparison of the proportion of both wing-forms because the ratio changes from generation to generation after the first invasion of macropterous form into the paddies and escape of macropterous form from highly populated fields would sometimes give seemingly higher ratio of brachypterous form.

According to ÔTAKE (1976), the proportion of brachypterous male of *N. lugens* at Kalugomuwa, Sri Lanka, was not very low as in the finding of KISIMOTO (1965) and KUNO (1968) in Japan, and *N. lugens* females showed a pattern of generation-to-generation change in the proportion of brachypterous females different from that of Japan. Remarkable increase of brachypterous form was observed at the final stage of *Yala* rice season (April to August) when the host plants are considered to become less suitable for the insect. These facts seem to be related to the higher ratio of brachypterous form of the tropical strains of the brown planthopper observed in the laboratory rearing. However, the possibility cannot be excluded that the observed high incidence of brachypterous may be an artifact.

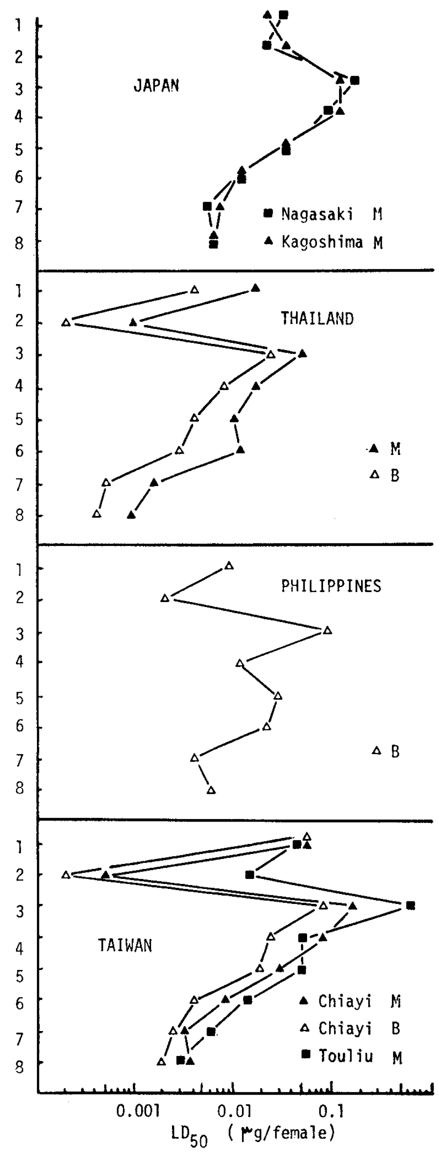

Fig. 4. Patterns of insecticide susceptibility of the brown planthopper. M: macropterous form, B: brachypterous form. 1: BHC, 2: DDT, 3: malathion, 4: fenitrothion, 5: diazinon, 6: MTMC, 7: carbaryl, 8: MIPC.

The wing-form of the planthopper have been known to be non-hereditary and mainly determined by population density. With increase in nymphal density, the percentage of macropterous female increased (KISIMOTO, 1956). However, a hereditary factor may also be involved in determination of the wing dimorphism. MOCHIDA (1975) obtained a strain with a relatively high frequency of brachypters from the stock culture of the red-eyed recessive mutant. It is possible that accumulated effects of inadvertent selection for brachypterous females may be effected in the laboratory during ca 130 generations of rearing because of the shorter pre-oviposition period of the brachypterous form. The shorter pre-oviposition period of brachypterous females may result in a longer oviposition period under field conditions if there is no difference in the adult longevity between the two wing-forms. Consequently, the proportion of progeny from brachypterous females may increase. In addition to this effect, repeated outbreaks and subsequent migration of macropterous form leaving brachypterous behind in the permanent breeding areas will also give cumulative effect of selection to establish abundant brachypterous population in that place by continuous efflux of macropterous form. This selection will lead to a high genetic tendency to brachypterism in permanent breeding areas.

This situation may be reversed in areas where the population starts from migrants. The founder genotype derived from migrants should give a high ability to produce macropters. Thus, a population which has frequently been subjected to high density and consequently a history of frequent migration may have a relatively lower Br-ratio. This wing-form ratio of a population may reflect its ecological history.

The two strains from Taiwan were different from one another in insecticide susceptibility and wing-form ratio. A possible explanation for this difference is that there might be 2 sources of invasion of the brown planthopper to Taiwan, and that the seasonal difference in growing the rice plant between the 2 collection sites might have established populations with different characters (Fig. 5).

In 1976, the immigration of planthoppers occurred twice in Taiwan. The first migrant (B) appeared in mid-April, invaded the paddy at Touliu when the first crop had been planted in early March, and established a population there but the crops were harvested in mid-July which probably caused the planthopper to move to the newly planted areas nearby. The ratoon from stubble which may provide reservoir for the hoppers after the harvest was not left since the paddies are customarily plowed immediately after harvest in Taiwan (T. MIYAKE Personal communication). Chiayi located ca 50 km east of Touliu and mono crop of rice was transplanted just after harvest

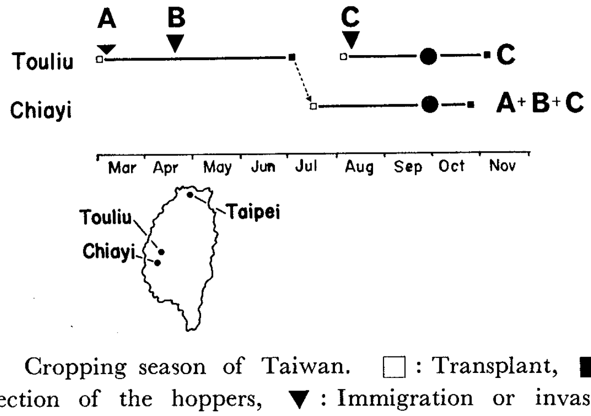

Fig. 5. Cropping season of Taiwan. □ : Transplant, ■ : Harvest, ● : Collection of the hoppers, ▼ : Immigration or invasion of the hoppers.

in Touliu. The hoppers that moved to Chiayi areas might have mingled with the second migrants (C) as well as the sedentary native insects (A).

In Touliu, on the other hand, the population might have been descended from the second migrants (C) which breeded on the second crop of the year. If the 2 waves of immigration were of the same geographic origin, it is probable that the overwintering population might have been DDT sensitive and high in Br-ratio, but overwintering in Taiwan has not been fully demonstrated. KISIMOTO and DYCK (1976) inferred that overwintering of the brown planthopper in Taiwan only rarely occurs from the analysis of climatic factors.

Hence, it is quite probable that the population of the brown planthopper and the white backed planthopper found in Japan belong to the temperate zone type having higher migrating history when judged from the wing-form ratio and are supplied by migration from the temperate zone where populations of the planthopper with similar insecticide susceptibility and wing-form ratio were found.

ACKNOWLEDGEMENTS

Sincere appreciation is expressed to Prof. S. MASAKI of Hirosaki University for reading and criticizing the manuscript and to Dr. T. MIYAKE of Nihon Nohyaku Co., Dr. T. HIDAKA and Dr. K. SOGAWA of the Tropical Agricultural Research Center who cooperated in supplying the planthoppers from various countries and gave valuable consultation on the research. Thanks are also due to Dr. M. D. PATHAK of IRRI, the Philippines who kindly permitted us to study the planthoppers of IRRI.

REFERENCES

ASAHINA, S. and Y. TSURUOKA (1968) Record of the insects which visited a weather ship located at the ocean weather station "Tango" on the pacific. 2, *Kontyu* **36** : 109–202 (in Japanese with an English summary).

BLISS, C. I. (1936) The calculation of the dosage-mortality curve. *Ann. Appl. Biol.* **22** : 134–167.

FUKUDA, H. and T. NAGATA (1969) Selective toxicity of several insecticides on three planthoppers. *Jap. J. appl. Ent. Zool.* **13** : 142–149 (in Japanese with an English summary).

KISHIMOTO, R. (1956) Effect of crowding during the larval period of the determination of the wing-form of an adult plant-hopper. *Nature* **178** : 641–642.

KISIMOTO, R. (1965) Studies on the polymorphism and its role playing in the population growth of the brown planthopper, *Nilaparvata lugens* STÅL *Bull. Shikoku agric. Expt. Stn.* **13** : 1–106 (in Japanese with an English summary).

KISIMOTO, R. and A. DYCK (1974) Climate and rice insect. Proceeding of the at symposium on climate and rice. IRRI, Philippines. pp. 367–391.

KUNO, E. (1968) Studies on the population dynamics of rice leafhoppers in a paddy field. *Bull. Kyushu agric. Expt. Stn*, **14** : 131–246 (in Japanese with an English summary).

MOCHIDA, O. (1975) A strain producing abundant brachypterous adults in *Nilaparvata lugens* (Homoptera : Delphacidae). *Ent. exp.* & *appl.* **18** : 465–471.

NAGATA, T., T. MASUDA and S. MORIYA (1979) Development of insecticide resistance in the brown planthopper, *Nilaparvata lugens* STÅL. *Appl. Ent. Zool.* **14** : 264–269.

NAGATA, T. and S. MORIYA (1974) Resistance in the brown planthopper, *Nilaparvata lugens* STÅL, to lindane. *Jap. J. appl. Ent. Zool.* **18** : 73–80 (in Japanese with an English summary).

ÔTAKE, A. (1976) Studies on population of *Sogatella furcifera* HORVATH and *Nilaparvata lugens* STÅL (Hemiptera : Delphacidae) and their parasites in Sri Lanka. *Appl. Ent. Zool.* **11** : 284–294.