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Population Growth Pattern of the Rice Planthoppers, *Nilaparvata lugens* and *Sogatella furcifera*, in the Muda Area, West Malaysia

Takashi WADA* and Nik Mohd. Noor bin Nik Salleh**

* Research Division I, Tropical Agriculture Research Center (Tsukuba, Ibaraki, 305 Japan)
** Alor Setar Station, Malaysian Agricultural Research and Development Institute
(Alor Setar, Kedah, Malaysia)

Abstract
Population growth of the rice planthoppers, Nilaparvata lugens and Sogatella furcifera, in direct-seeded fields of the Muda area, West Malaysia was generally characterized by (1) a low immigrant density in the early rice stage, (2) two complete consecutive generations and a 3rd optional generation, (3) high population growth rates up to the 2nd generation, and (4) low population growth rate from the 2nd to the 3rd generations. However various population growth patterns were also observed in both planthopper species. In addition, no relationship was found between the immigrant density in the early rice stage and subsequent population size in the late rice stage. Most cases of hopperburn in the 1st cropping season of 1990 occurred in early-planted fields seeded soon after the crop-free fallow period implemented during the dry season, Field surveys also showed that both planthoppers reached high densities in an early-planted field, in spite of the very small number of immigrants, whereas the densities of planthoppers in a late-planted field exhibited a very low level, in spite of the large number of immigrants in the early rice stage. The paucity of natural enemies seemed to promote the rapid increase of the number of planthoppers in the early-planted field. Since natural enemies were numerically dominant and the survivorship of the young planthopper nymphs was relatively low in the late-planted field, it was assumed that natural enemies contributed to the suppression of the planthopper population in this field. On the basis of these results, it was concluded that the interaction between planthoppers and their natural enemies was a major factor determining the population growth patterns of planthoppers in the Muda area. The dry season, particularly with the implementation of crop-free fallow period presumably enabled to eradicate both planthopper species and their natural enemies. This environment seemed to provide favorable conditions for population growth of planthoppers in the earlyplanted fields in the 1st cropping season. Continuous planting appeared to promote natural enemy activity provided that the biotic community in the fields was not disturbed.

Discipline: Insect pest
Additional key words: brown planthopper, natural enemies, whitebacked planthopper

Introduction

The Muda irrigation scheme is the largest rice bowl area of Malaysia. It comprises 96,000 ha of paddy fields and accounts for about 50% of the national rice production. After the construction of the irrigation system, double cropping of rice was first

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* Present address: Department of Recalcitrant Disease and Pest Management, Kyushu National Agricultural Experiment Station (Nishigoshi, Kumamoto, 861-11 Japan)

implemented in 1970 and since 1974 over 90% of the fields have been subjected to double cropping[6]. The increase of the cropping intensity together with the promotion of fertilizer application and the introduction of high-yielding varieties resulted in the modification of the field environment and increase in the severity of the rice pest situation[1]. Extensive outbreaks of planthoppers were recorded in 1979, 1982 and 1983[6,16].

From 1981 to 1983, the rice crop in Muda was severely attacked by tungro disease which is transmitted by the green leafhoppers, *Nephotettix* spp. To control tungro disease as a main purpose, a simultaneous crop-free fallow period throughout the Muda area for more than one month during the dry season has been introduced since 1984. Thereafter, the incidence of tungro infection decreased abruptly and the disease has virtually not occurred recently in the Muda area.

Since rice is the only suitable host for the planthoppers, it was assumed that the planthopper occurrence would also be suppressed by the implementation of the fallow period[15]. The fallow period has promoted the synchronization of farm operations, particularly in the 1st cropping season. The 1st crop of rice (off-season crop) is mainly planted from late March to August and the 2nd crop (main season crop) is planted from September to January. However, since the two cropping seasons overlap, rice is more or less continuously present in the Muda area except for the crop-free fallow period. It is interesting to note that more planthoppers occur in the 1st cropping season than in the 2nd one, generally[7]. A question that arises is why the planthopper problem is more serious in the 1st cropping season after the fallow period during which planthoppers are supposed to be eradicated.

The direct-seeding practice which was initiated from the early 1980s has been gradually disseminated in the Muda area. The coverage of direct-seeded fields has reached 60–90%, recently. Although the occurrence and outbreaks of pests including planthoppers appear to be more frequent in direct-seeded fields than in transplanted fields[14], no detailed studies on the changes of the planthopper population in direct-seeded fields have been carried out not only in the Muda area but also in the fields of other rice-growing countries.

The population growth pattern of the planthoppers observed in 1989 and 1990 in direct-seeded fields of the Muda area is described here along with some factors which influence the planthopper occurrence.

Materials and methods

Periodical population surveys for the planthoppers, *S. furcifera* (WBPH) and *N. lugens* (BPH) and their natural enemies were conducted in farmers' direct-seeded fields in the Muda area from the 1st cropping season of 1989 to the 2nd cropping season of 1990. Two or three fields were selected in each season and a total of 10 field-data were collected. The rice variety used was MR84 (non-resistant to the planthoppers), which accounts for about 60% of the rice fields in the Muda area. Herbicides (molinate and 2, 4, D butylester) were applied in these fields 10–30 days after sowing (DAS). No insecticides were used in all the fields.

The densities of planthoppers and their major predators were determined by weekly samplings in the field using a suction machine with a petroleum engine and a flexible collection tube (Univac Portable Suction Sampler; Burkard Manufacturing Co. Ltd.). The plastic cage shown in Fig. 1 was designed to set up a sampling unit in a field. This easy-to-carry

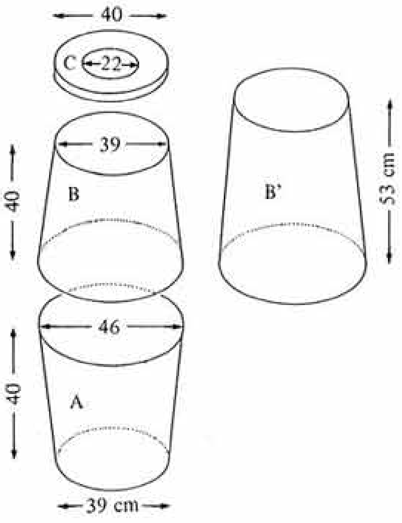

Fig. 1. Schematic representation of the plastic cage which was used for the sampling of arthropod populations in direct-seeded fields
Part B or B' was used as the upper part, depending on the stage of rice.

cage was placed in a field and the internal area of the cage (0.116 m^2) was considered to be a sampling unit. In order to collect the target arthropods in the cage, all the visible insects and spiders on the plant were first sucked and the plant was tapped by hand to force the arthropods to drop onto water in the paddy, and all the surface water was finally removed with the suction machine. Sampling plots (units) were systematically selected in the surveyed fields. The numbers of sampling plots on each day of the survey ranged from 16 to 100 depending on the density of the planthoppers (the number was basically fixed to 20 after 50 DAS). Arthropods collected in the fields were kept in 70% ethanol and identified under a binocular microscope.

In the 1st cropping season of 1991, three fields, A, B and C, which were seeded at different times, were selected for the study. Field A was direct-seeded on April 8, field B on April 24, and field C on May 22. Yellow water traps were set up in the fields to compare the immigrant densities in the early growth stage of rice among the three fields. In the same season, information on hopperburn cases occurring in the Muda area was collected by courtesy of the Muda Agriculture Development Authority (MADA).

To investigate the effect of predators on the planthopper population growth in fields, the two indices, HPR and HSI, were calculated, using weekly stage-specific frequency data of planthoppers and the numbers of major predators.

HPR (hopper predator ratio)
= (numbers of planthoppers)/
(numbers of major predators).

Planthoppers included adults and nymphs of WBPH and BPH. Major predators included adults and nymphs of spiders and adults of *Microvelia*, *Cyrtorhinus*, gerrids, coccinellids, carabids, staphylinids and damselflies.

HSI (hopper survival index)
= (total numbers of 4th and 5th instar nymphs of WBPH and BPH) / (total numbers of 1st, 2nd and 3rd instar nymphs of both planthoppers in the previous week).

Results

1) Population growth patterns of planthoppers

In most cases the population trends of the planthoppers in each development stage showed discrete peaks representing the respective generations. In a few cases, however, the trends did not show clear peaks. Therefore, we tentatively divided the population trends in the respective generations according to the method of Hirose et al.[8], i.e. generations were identified on the basis of heat accumulation of one generation. However, since the temperature does not fluctuate appreciably throughout the year in the tropics, we used the length (days) of one generation, instead of heat accumulation. The length of one generation of the planthoppers in the field was

Table 1. Average pattern[a)] of population growth of the rice planthoppers in the Muda area

Species	Max. density[b)] of immigrants /m^2	Mean density[c)] of 3–5 instar nymphs/m^2			Max. density of 3–5 instar nymphs/m^2	Population growth rate[d)]		
		1st generation	2nd generation	3rd generation		r'_{01}	r_{12}	r_{23}
Sogatella furcifera	3.7 (0.2–25)	32 (6–126)	288 (0.6–576)	129 (0–575)	474 (24–1,239)	22.6 (1.5–63)	12.3 (0.1–30)	0.4 (0–1.0)
Nilaparvata lugens	18 (0.1–159)	40 (3–187)	187 (36–624)	67 (1.2–195)	365 (39–1,131)	21.1 (0.6–42)	10.9 (0.3–18)	0.4 (0.1–0.8)

a): Numerals in parentheses indicate the minimum and the maximum values.
b): Maximum density of macropterous adults before 30 DAS for *S. furcifera* and before 50 DAS for *N. lugens*.
c): Defined by Kuno (1968)[11].
d): r'_{01}, r_{12} and r_{23} indicate the population growth rates from immigrants to the 1st generation, from the 1st to the 2nd and from the 2nd to the 3rd generations, respectively, based on the numbers of adults for r'_{01} and on the number of the 3rd to 5th instar nymphs for r_{12} and r_{23}.

determined based on the average intervals of population peaks of aged nymphs or adults which showed clear peaks. The average duration of one generation was 24 days for the WBPH and 29 days for the BPH. These values for the generation lengths coincided with the results of the field-released planthopper experiment conducted in the Muda area by Hirao[7].

Both WBPH and BPH immigrants seemed to invade the fields more or less continuously after the appearance of rice seedlings. Nevertheless, population trends showed a few peaks corresponding to the respective generations in most cases, presumably due to the fact that both planthopper species display a preference for certain rice stages during their migration. These stages seemed to correspond to 10–30 DAS for the WBPH and 30–50 DAS for the BPH.

Table 1 indicates the average pattern of the population growth of the two planthopper species in 10 fields for a period of two years. The magnitude of the initial invasion of planthoppers was expressed as the maximum density of macropterous adults up to 30 DAS for the WBPH and up to 50 DAS for the BPH, although occasionally adults of the 1st generation (the next generation originating from immigrants) already appeared around 30 DAS for the WBPH and 50 DAS for the BPH. The population growth rate from immigrants to the 1st generation (r'_{01}) was expressed as the rate of the number of the 1st generation adults relative to the number of immigrants (adults up to 30 DAS for the WBPH and 50 DAS for the BPH). The population growth rates between generations in other cases (r_{12}, r_{23}) were expressed as the rate of the number of aged nymphs (3rd to 5th instars) between generations.

The density of the immigrants in the paddy fields in an early growth stage which caused subsequent population build-up was very low in general. The mean of the maximum immigrant densities was $3.7/m^2$ for the WBPH and $17.9/m^2$ for the BPH. If we exclude an extreme case of high level of immigration (field C in the 1st cropping season of 1990), the mean was $1.2/m^2$ for the WBPH and $2.0/m^2$ for the BPH. The number of immigrants, however, largely differed depending on the fields and time. The maximum density ranged from 0.2 to $24.8/m^2$ for the WBPH and from 0.1 to $159/m^2$ for the BPH.

Although the population growth pattern varied from field to field, the following characteristics were generally revealed in both planthopper species: (1) two complete consecutive generations and a 3rd optional generation occurred after the onset of immigration, (2) population growth rates up to the 2nd generation were very high, (3) population growth rate from the 2nd to the 3rd generation was low, below 1, and (4) consequently, the 2nd generation reached a population peak in most cases.

The large variation of the parameters reflecting the population growth pattern characterized the population trends in the Muda area, too. For example, r'_{01} varied from 0.6 to 42 and r_{12} from 0.3 to 17.9 in the BPH, which indicated that the peak generation occurred sometimes in the 1st generation or even at the time of immigration in the early rice stage. This was also the case for the WBPH. The population peak occurred sometimes in the 1st generation or in the 3rd generation although the population reached its peak in the 2nd generation in most cases.

Another important characteristic was that the magnitude of immigration was not correlated with the later population occurrence (Fig. 2). The correlation coefficients between the maximum densities of immigrants in the early rice stage and the maximum densities of aged nymphs until harvest were −0.6 in the WBPH and 0.5 in the BPH. These coefficients were not statistically significant.

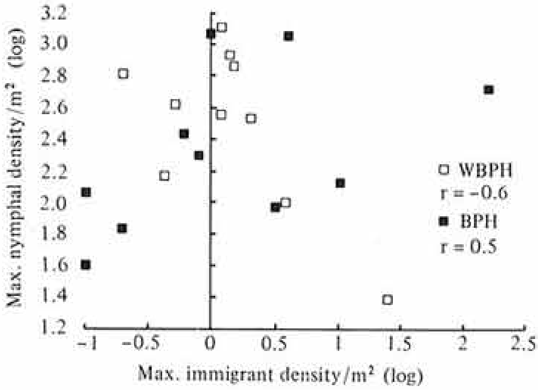

Fig. 2. Relationship between the maximum densities of immigrants in the early rice stage and the maximum nymphal (3rd–5th instars) densities throughout the cropping season
WBPH: *S. furcifera*, BPH: *N. lugens*.

2) *Population occurrence of planthoppers in the 1st cropping season of 1990*

Extensive surveys were conducted, together with the collection of hopperburn information in the Muda area in the 1st cropping season of 1990. The data obtained enabled to explain the variations in the planthopper population growth patterns.

(1) Immigrants caught in yellow water traps

The numbers of planthoppers caught in yellow water traps in the early stage of rice were very different among the fields; very small in field A, intermediate in field B and very large in field C (Fig. 3). If we compare the numbers of immigrants among the three fields before 30 DAS for the WBPH, the number of immigrants was 62 times and 12 times larger in field C than in fields A and B, respectively. Similarly, the number of BPH immigrants before 50 DAS was 436 times and 30 times larger in field C than in fields A and B, respectively. It is noteworthy that the numbers of immigrants were correlated with the time of seeding in the fields, i.e. fewer immigrants were caught in the early-planted field which was seeded soon after the fallow period, as compared to the late-planted field.

(2) Population trends of the planthoppers in the fields

The population trends of the planthoppers observed by weekly samplings in the three fields are shown in Fig. 4. In the WBPH, the numbers of immigrants (macropters before 30 DAS) were very small in field A, intermediate in field B and high in field C (not shown in Fig. 4 because of the scales of the vertical axes), although some of the macropterous adults in field C were not immigrants but were born in this field based on the detection of aged nymphs in the 18 and 25 DAS surveys. This tendency of immigrant density was similar to the results obtained by the use of yellow water traps.

Population trends of WBPH after immigration were largely different depending on the fields. Subsequent three complete generations seemed to occur in fields A and B. The maximum density was observed in the 3rd generation in field A, reaching a value of 1,236 (aged nymphs)/m², the highest among the three fields, despite the very small number of immigrants in the early rice stage. The maximum

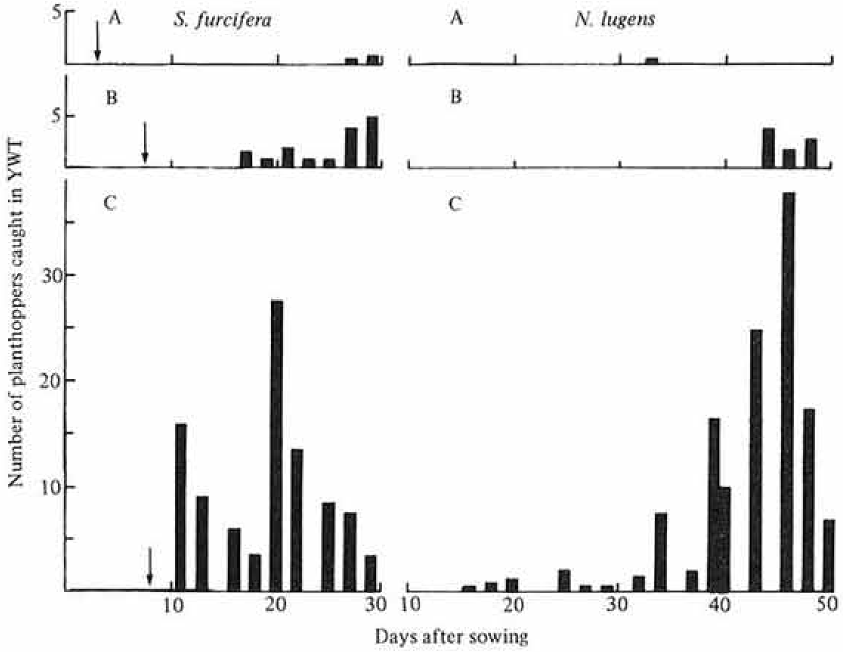

Fig. 3. Numbers of planthoppers (per trap) caught in yellow water traps (YWT) in the early stage of rice

Arrows indicate the time from which the yellow water traps were set up in the fields. A, B, C: fields A, B and C.

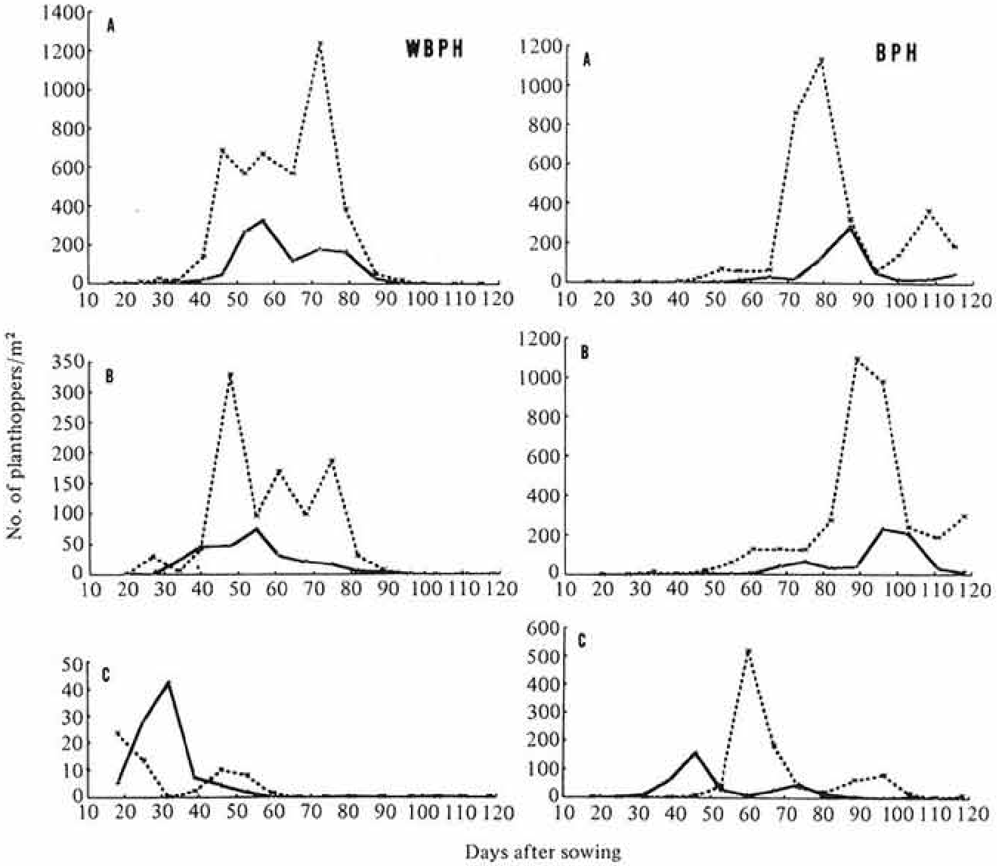

Fig. 4. Population trends of *S. furcifera* (WBPH) and *N. lugens* (BPH) in three direct-seeded fields in the 1st cropping season of 1990
A, B, C: fields A, B and C.
Solid line: adults. Dotted line: aged nymphs (3rd–5th instars).

density of 328/m² was recorded in the 2nd generation in field B. On the other hand, the maximum density of aged nymphs in field C was only 24/m² in the 1st generation, the lowest among the three fields in spite of the large numbers of immigrants in the early rice stage. A peak of aged nymphs which seemed to be a mixture of the 1st and the 2nd generation nymphs was found at 35–60 DAS and almost no 3rd generation occurred in field C. The values of the population growth rates corresponding to r'_{01} and r_{12} which were calculated routinely, were 44.8, 24.5, 1.5 and 17.9, 11.7, 0.1 in fields A, B, C, respectively. It is worth noting that the population growth rates up to the 2nd generation were inversely correlated with the immigrant densities.

In the BPH the densities of immigrants (macropters before 50 DAS) were very low in field A, low in field B and high in field C. These results were similar to those obtained by the use of yellow water traps.

Population trends of BPH after immigration were very different between field C and the other two earlier-planted fields. BPH developed two generations and an incomplete 3rd generation in both fields A and B. Populations reached their peaks in the 2nd generation with values of more than 1,000 (aged nymphs)/m² and then declined rapidly in both fields. On the other hand, the maximum density of 519 (aged nymphs)/m² was recorded in the 1st generation in field C, which was the lowest maximum value among the three fields. The values of the population growth rates corresponding to r'_{01} and r_{12} were

43.1, 22.1, 0.6 and 15.3, 6.3, 0.3 in fields A, B and C, respectively. A negative correlation was again observed between the immigrant densities and the population growth rates up to the 2nd generation.

(3) Changes in the two indices representing the relative abundance of natural enemies and relative survivorship of young nymphs of planthoppers

As we assumed that natural enemy activities may have influenced the population growth pattern in the three fields, we calculated the relative density of planthoppers to major predators (HPR) as an index to evaluate the relative abundance of natural enemies to planthoppers. Fluctuations of HPR in relation to the crop stage in the three fields are shown in Fig. 5. The values of HPR in field A increased rapidly from 35 DAS, remained high until 75 DAS and then decreased. The increase of the HPR values from 35 DAS may indicate the 'escape' of planthoppers from their natural enemies. The time of the HPR changes coincided with the changes of the populations of total planthoppers in the field. The HPR values in field C were consistently very low throughout the cropping season, which may account for the low population growth rates of planthoppers. The HPR values in field B were generally intermediate.

High values of HPR with a relatively small number of natural enemies may not be the cause of the planthopper increase but the result from the explosion of the planthopper population. In addition, there is no evidence that the abundance of predators contributed to the suppression of the planthopper population, particularly in the case of the polyphagous predators. Therefore, we developed another index, HSI, which expresses the relative survivorship of young planthopper nymphs in each field.

The HSI values in fields A and B which were high in the early rice stage (Fig. 6), resulting in the increase of the planthopper population in both fields, may be attributed to the high values of HPR. The HSI values in both fields gradually decreased and were low in the late rice stage. On the other hand, the HSI values in field C remained very low throughout the cropping period, presumably due to the relative abundance of natural enemies as indicated in Fig. 5. The low HSI values accounted for the marked suppression of the planthopper populations in this field. HSI was generally correlated with HPR (Kendall's coefficient = 0.39, $P<0.01$), indicating that polyphagous predators such as spiders, *Microvelia*, etc. contributed to some suppression of the planthopper populations.

(4) Fields experiencing hopperburn in the Muda area

Fifty cases of hopperburn were reported in the Muda in the 1st cropping season of 1990. The

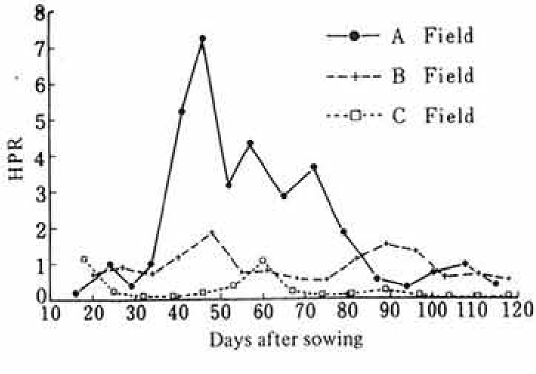

Fig. 5. Changes in the ratio of the number of planthoppers to the number of major predators (HPR) in relation to the rice stage in three fields in the 1st cropping season of 1990
Planthoppers include adults and nymphs of *S. furcifera* and *N. lugens*. Major predators include adults and nymphs of spiders and adults of *Microvelia*, *Cyrtorhinus*, gerrids, coccinellids, carabids, staphylinids and damselflies.

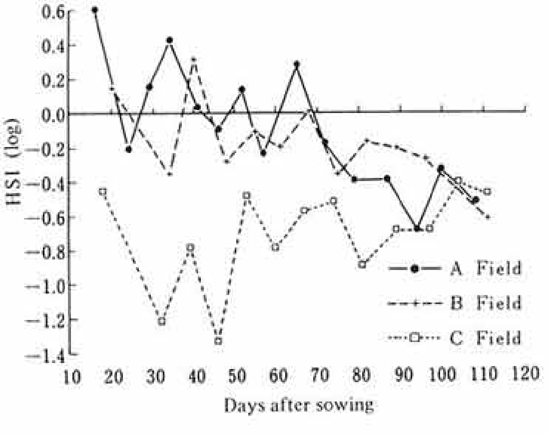

Fig. 6. Changes in HSI in the three fields in the 1st cropping season of 1990
HSI (hopper survival index) = (total numbers of 4th and 5th instar nymphs of *S. furcifera* and *N. lugens*)/(total numbers of 1st, 2nd and 3rd instar nymphs of both planthoppers in the previous week).

frequency distribution of the hopperburn cases and rice planting areas in relation to the time of planting is shown in Fig. 7.

Most hopperburn cases occurred in the fields where rice was seeded soon after the crop-free fallow period. Namely, 16% and 64% of the hopperburn cases occurred in the fields which were seeded before April 3 and April 24 in contrast to only 0.3% and 25% of the total paddy fields where planting had started by these dates, respectively. It is, therefore, obvious that early-planted fields were much more prone to hopperburn in the 1st cropping season in the Muda area.

Discussion

The general pattern of population growth of the planthoppers in the direct-seeded fields described previously, was basically similar to that observed in transplanted fields of the Muda area by Hirao[7]. Kuno & Dyck[13] and Kisimoto[10] reported that a high immigration density and subsequent low population growth rates characterized tropical planthopper populations as compared with temperate populations. However, immigrant densities were generally very low and population growth rates up to the 2nd generation were very high in the Muda area. The low immigration density is probably due to the fact that the planting practice in the Muda area is more synchronous than in other rice areas in the tropics. In fact a high level of immigration was observed even in the Muda fields when rice in various stages was present, as exemplified in field C in the 1st cropping season of 1990. The strong population regulation (suppression) which was pointed out by Kenmore et al.[9] in tropical planthoppers was commonly observed in the Muda area, in particular, after the 2nd generation in most cases.

Various types of population growth patterns for both planthopper species were observed as another important characteristic in the Muda area. Cook and Perfect[3] also reported various patterns of population growth in Philippine populations. In the temperate areas, planthopper occurrence in the late rice stage can be successfully predicted using only data of immigrant density in the early rice stage as a biotic parameter, as is the case of the models of Kuno[12] and Chen et al.[2]. There was, however, no relation between the immigrant densities and subsequent population sizes in Muda planthoppers as shown in Fig. 2, due to the various population growth patterns prevailing in the Muda planthoppers.

Interaction between the planthoppers and their natural enemies appeared to be a major factor in the determination of the population growth patterns in a field, as suggested by the planthopper occurrence of the three fields in the 1st cropping season of 1990. In field A where the HPR and HSI values were high,

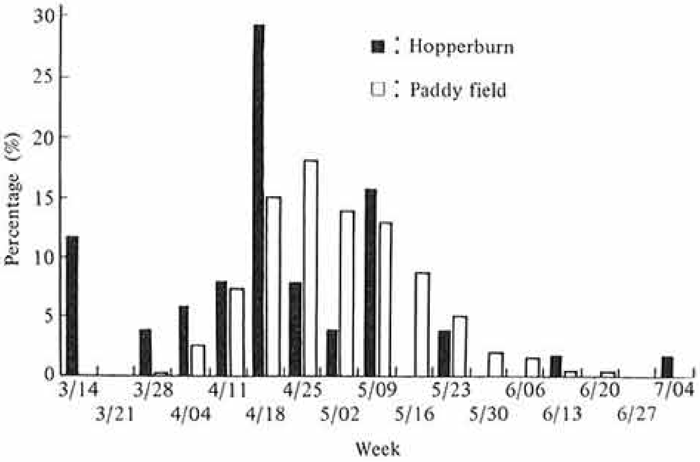

Fig. 7. Occurrences of hopperburn in fields and areas of paddy fields which were seeded or transplanted, in relation to the planting time in the 1st cropping season of 1990 in the Muda area
Numerals of the horizontal axis indicate the last day of the week.

planthoppers eventually reached highest densities in spite of the presence of very few immigrants invading the field in the early rice stage. On the other hand, the planthopper populations were suppressed and reached the lowest densities in field C with low values for HPR and HSI, in spite of a large number of immigrants in the early rice stage. This phenomenon can be interpreted only if natural enemy activities are taken into account. The importance of natural enemies in the control of planthopper populations has been often suggested in the tropics[3,9,13].

We developed the HSI index to evaluate the survivorship of young planthopper nymphs in fields. However, HSI does not correspond to the true rates of young nymph survivorship for the following reasons: (1) the accuracy of sampling varied depending on the growth stages of the planthoppers, and (2) the survey interval (one week) was too long as compared to the development speed of the planthopper nymphs. HSI, however, still seemed to represent the relative value of the survivorship of young planthopper nymphs, provided that the sampling accuracy was constant in every survey. Parasitism in the nymphal stage of both planthopper species was low in the Muda area (Wada et al., unpublished). The physiological death of a large number of nymphs seemed improbable. Therefore, the values of HSI appeared to be largely affected by predation by natural enemies.

The dry season, particularly with the crop-free fallow period, appears to increase the instability of the biotic community in the fields and, hence, to favor planthopper population growth. Early-planted fields in the 1st cropping season were most prone to planthopper outbreaks based on the analysis of hopperburn cases and field-data of planthopper occurrence obtained in 1990. The dry season probably leads to the death of not only the planthoppers but also of the natural enemy fauna. This environment may provide favorable conditions for population growth of planthoppers, when a few immigrants invade new paddy fields after the fallow period. Planthoppers, which seem to be adapted to unstable environments, multiply rapidly, taking advantage of the paucity of natural enemies. On the other hand natural enemies are more abundant in late-planted fields and probably in fields in the 2nd cropping season because rice (and preys of natural enemies) is, more or less, continuously present in the Muda area. In such fields the natural enemies appear to successfully control the planthopper populations, even when there are a large number of immigrants in the early rice stage. This observation may account for the fact that population levels of the planthoppers are higher in the 1st cropping season than in the 2nd one.

Therefore, continuous planting, itself, seems to favor the activity of natural enemies as pointed out by Greathead et al.[5]. Asynchrony in planting was often considered to be one of the causes of outbreaks of planthoppers[4]. Asynchronous planting undoubtedly offers a greater potential for immigration in the early rice stage and outbreaks may occur if the activities of the natural enemies are disturbed for some reasons (for example, application of improper insecticides, etc.). If not, however, planthopper populations may be expected to be efficiently suppressed by the natural enemies. A good example of such a case was observed in the fields of Seberang Perai, Penang, south of the Muda area, where rice is continuously planted all the year round and where the occurrence of planthoppers had been much lower than that in the Muda area, every season.

We described the importance of natural enemies in the regulation of planthopper populations in this paper. In the subsequent paper a description of effective natural enemies will be presented.

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