Some Aspects of Population Dynamics of Rice Leafhoppers in Korea

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韓國에 있어서 벼 멸구·매미충의 個體群動態에 關하여

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ABSTRACT

Regional differences in economic importance of the four species of rice leafhoppers, viz., *Laodelphax striatellus*, *Nephotettix cincticeps*, *Nilaparvata lugens* and *Sogatella furcifera*, were analyzed and discussed based on population surveys conducted in Suweon and in southern and south-western coastal areas.

The economic importance of *L. striatellus* and *N. cincticeps*, which are found throughout the year in Korea, seems to be less in middle regions. This is believed due to effective natural control through severe winter climate, cultural practices in rice and barley growing, and natural enemies such as spiders. However, the economic importance of these two species is significantly greater in southern regions with a less severe winter climate and where cultural practices in rice and barley favour synchronization between the life cycles of insects and the seasonal succession of host plants. With regard to *N. lugens* and *S. furcifera*, which cannot overwinter in Korea, initial populations are the result of long distance migration across the East China Sea. Weather elements related to their migration result in more abundant immigrants of these two species in southern than in middle regions. Thus, different policies are needed for the integrated control of rice leafhoppers in middle and southern Korea.

Introduction

Innovation of agrotechnology in Korea, represented y the selection and gradual diffusion of a new high ielding rice variety 'Tongil' over the country since he later half of 1960' s, has resulted in the selfsus- enance of staple crops, rice and barley. On the other and, it has also inducedyearly increases in the use f chemical fertilizers and insecticides. This situation is analogous to that in Japan during the decades after World War II. Tongil differs from rice varieties cultivated in Japan in that it has some indica rice characteristics resulting from the triple crossing of Yukara, Taichung Native 1 and IR 8. Tongil also has strong resistance to rice stripe virus disease transmitted by *L. striatellus*, and to the hitherto known bacterial races of rice leafblast disease in Korea. So, it can be said that the problems of rice

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insect pests in Korea have entered into a new sta e where establishment of reliable forecasting and effecti e control systems of rice pests are urgently needed.

Like the pest status of rice leafhoppers in Japan, the important species of rice hoppers in Korea are the green rice leafhopper (*Nephotettix cincticeps*), the small brown planthopper(*Laodelphax striatellus*), the brown planthopper(*Nilaparvata lugens*) and the white backed planthopper (*Sogatella furcifera*). The former two species can live througout the year in Korea and are important as the vectors of rice dwarf virus(RDV) in *N. cincticeps* and rice stripe virus (RSV) in *L. striatellus*, respectively. The latter two species cannot overwinter in Korea and Japan. It has now been established that macropterous adults of *N. lugens* and *S. furcifera* migrate annually in the rainy season from somewhere in southern China into Japan and Korea, flying across the East China Sea(Kisimoto, 1971;1975). *N. lugens* is considerabley more important than *S. furcifera* as the incitant of 'hopperburn' at the time of maximum population. *N. lugens* is also important as a vector of grassy stunt disease in Southeast Asia.

The senior author had the good fortune to work with Korean entomologists of the Institute of Agricultural Sciences in Suweon for three months from 5 June-4 Sept., 1975. This study was sponsered by the Korea-Japan Agricultural Cooperation Project initiated in 1974. Emphasis was on the population survey of the four important species of rice leafhoppers in a paddy field in Suweon. Although our cooperative study was limited to a short period, results involve some important implications for advances in population dynamics, forecasting and control of rice leafhoppers in Korea.

Fields and Methods

A plot of *ca.* 10 *a* in area was set in the study paddy field at Kotmoe, Suweon. This field has been used by the UNDP project team since 1973 with no insecticidal controls(Fig.1). Rice seedlings of var. Akibare (a japonica) were transplanted on June 4. Three seedlings per hill were planted at a spacin gof 30cm×15cm. No insecticides were used throughout the course of this study.

A block (block A in Fig.1) containing 5,000 hills

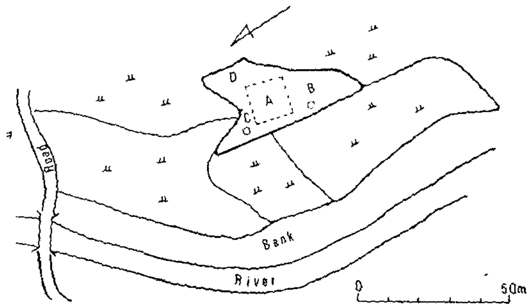

Fig.1. Map of the census plot and its surroundings. Open cricle shows the yellow water pan trap set in the plot.

(50×100 hills) was delineated in the center of the plot for regular census of adult densities of the four species by direct counting. The dirdct counting census was conducted from June 12 to Sept. 29 at 3-day intervals. The leafhopper adults and spiders on 500 hills were sampled systematically each census date from June 12 to 30 (for *N. cincticeps* up to July 3). Thereafter, the sample size was successively reduced to 250 hills until July 12, 125 hills to July 24, 100 hills to July 30 and 50 hills until Sept. 29.

In blocks B and C (see, Fig.1), one yellow water pan trap of the type used by Kisimoto (1968) was set for sampling macropterous adults of *L. striatellus*, *N. lugens* and *S. furcifera*. The water pan traps were examined daily from June 13 to Sept. 5 at 10 a.m.

A cage of acrylic plate (upper and bottom opened), 50cm on a side and 40cm in height, was used for the collection of spiders. One of the three blocks B, C and D was used by rotation for spider collection at the time of direct counting census. The spider collection did not cover the whole period of the regular census. Usually, six hills were enclosed by the cage per replication, and whole spiders within the cage were collected by aspirator or large glass tube. Ten to two replications were taken at each date of collection from June 14 to Aug. 11, considering the spider density and plant growth. Thereafter until Sept. 8, three hills were enclosed per replication and three replications were taken. Collection of spiders was also made with a butterfly net. In this case, two samples of 25 sweeps each were made in each of blocks B, C and D for the period from June 27 to Sep. 29. Sweepings were not made on rainy days. Spiders were kept separately for collocted dates and collecting methods in glass tubes containing 75% alcohol for later identification of species.

Fifty hills selected systematically in block A were cut at the base and brought back to the laboratory on July 8. Similarly, 25 hills were sampled on Aug. 23 and Sept. 23. Samples were dissected to find egg masses of *N. cincticeps* laid in leaf-sheaths. For all egg masses found in a hill, the numbers of total eggs in an egg mass, hatched and unhatched, and dead or parasitized eggs within the egg mass were examined under a binocular microscope.

Beside the above surveys conducted in Suweon, we made a short survey trip to southern and south-western coast areas, viz., Gochang county in Jeon-bug province on Aug. 4, Boseong county in Jeon-nam province on Aug. 5, Jinju city in Gyeong-nam province on Aug. 6 and Gimhae county in Gyeong-nam province on Aug. 7. We visited City and County Guidance Office in Gochang and Gimhae, its branch at Yedang village in Boseong, and the Provincial Office of Rural Development in Junju. Comparative surveys of the incidence of rice leafhoppers and virus diseases (RSV and RDV) were made on Tongil and local japonica varieties. These were cultivated side by side at the demonstration paddy plots which had received no insectcidal control.

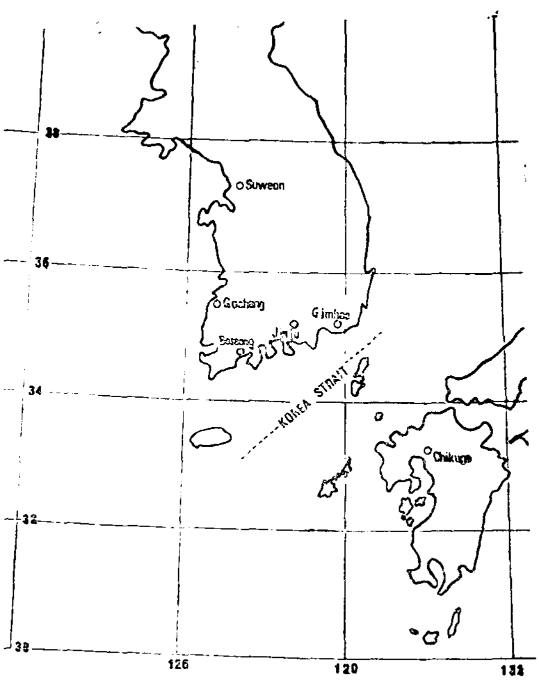

Fig.2. Geographical locations of the study area.

Results and Conclusions

1. Characteristics in Seasonal Prevalence of Rice Leafhoppers at Suweon Paddy Field

a) *L. striatellus* and *N. cincticeps*

As shown in Fig.2, Suweon is situated far north-west from Chikugo, northern Kyushu. The latitudinal line on which Suweon is located cuts the Noto Peninsula and passes through Takada in Niigata prefecture, Hokuriku district in Japan. Therefore the winter is more severe in Suweon than in Chikugo, and the development of overwintering nymphs of *L. striatellus* and *N. cincticeps* is slower in Suweon than in Chikugo. However, detailed studies on the development of overwintering populations of the two species were not available in Korea, except Chon's (1975) study on *L. striatellus*. Table 1 shows our estimation of mean (50%) dates of the main developmental stages of *N. cincticeps* in the overwintering generation (G-O) and in the first generation (G-I) in Suweon based on the estimation method proposed by Hokyo (1972;1975). For this purpose, daily maximum and minimum temperatures during the period from January to early July in 1975 observed at the Agricultural Weather Station in Suweon were consulted. Chon (*l.c.*)' s data for the developmental process of overwintering *L. striatellus* are also cited in Table 1.

It is plausible from Table 1 that the development of overwintering populations of *N. cincticeps* in Suweon would be delayed by 10-13 days compared with the average developmental process in Chikugo. Such a delay in development would continue until the emergence of G-I adults in fallow paddy fields. The mean date of occurrence of the fifth instar nymphs observed for *L. striatellus* in Suweon was almost the same with that estimated for *N. cincticeps*, but the mean date of emergence of *L. striatellus* adults in April was 4-9 days earlier than that of *N. cincticeps*. A faster rate of development of the overwintering generation of *L. striatellus* compard with *N. cincticeps*

Table 1. Assessment of mean (50%) occurrence time for *N. cincticeps* in the overwintering and the first generations and *L. striatellus* in the overwintering generation

	N. cincticeps		*L. striatellus*
	Chikugo ⓐ	Suweon ⓑ	Suweon ⓒ
Initial developmental stage for overwintering	4th instar	4th instar	4th instar
Mean occurrence date of 5th instar nymphs	March 15	March 28	March 29-31
Mean emergence date of G-O adults	April 14	April 24	April 15-20
Mean date of eggs deposited	May 5	May 20	——
Mean hatching date of eggs	May 26	June 9	——
Mean emergence date of G-I adults	June 21	July 4	——

ⓐ Annual average figures assessed by Hokyo (1972).
ⓑ Assessed for the case in 1975.
ⓒ Cited from Chon (1975).

is generally observed in Japan. Kisimoto (1966) reported the mean emergence of *L. striatellus* adults to be in middle March in Zentsuji, northern Shikoku. Hirao (1972) reported for the mean emergence of this insect to be in late March in Fukuyama, Chugoku district.

The G-O adults of *N. cincticeps* have a fairly long life span, e.g., approximately one month (Hokyo, *l.c.*). Eggs preferably are laid in leaf-sheaths of a gramineous weed, *Allopecurus aequalis*, growing in fallow paddy fields and dikes. In mid-Korea (*e.g.* Suweon area), where rice seed beds are made in mid-April, rice seedlings would be also exposed to the oviposition of these adults from early May onward. It should be noted, however, that the mean date of hatching or eggs laid by G-O adults (see, Table 1) would come later than the usual time of transplanting of rice seedlings into paddy fields, *e.g.*, late May in Suweon. Such a cultural practice may cause a high mortality of G-I eggs and nymphs of this insect by destroying their habitats for breeding. On the other hand, the G-O adults of *L. striatellus* migrate mainly into barley fields for feeding and oviposition, where the G-I adults begin to emerge from mid-June. Although the acreage of barley fields in mid-Korea is small compared with southern Korea, cultivation of barley as an upland crop during the period from April to June provides an advantage for *L. striatellus* over *N. cincticeps* in building up the G-I population.

Fig. 3 shows the sequential changes in adult densities of *L. striatellus* and *N. cincticeps* obtained by direct counting census. *L. striatellus* as well as *N. lugens* and *S. furcifera* have two winged forms in adult stage, *i.e.*, *macroptère* and *brachyptère*. The sequential change in percentage of macropterous females in the total female population is also shown in Fig.3. *N. cincticeps* has no brachypterous adults.

In direct counting of adult rice leafhoppers, some underestimation of their densities is inevitable. This is affected by such factors as plant growth, increase in densities as the result of reproduction, escape of adults by hand disturbance, *etc.* However, females can be more exactly counted than males because of sexual differences in diurnal activities. According to the experience of the senior author, the range of such underestimation for females of *N. cincticeps*, which tended to be conspicuous with advance of the generation, was about one half to unity (no underestimation) of the actual densities (Hokyo, *l.c.*). Female adults of the species other than *N. cincticeps* are usually less active, especially in the case of brachypterous females, than those of *N. cincticeps*.

It is obvious from Fig. 3. that *L. striatellus* repeated two adult generations, *i.e.*, G-II and G-III, following immigration of G-I adults from outside. The peak density of adult females were observed in late June, July and August for G-I, II and III, respectively. Most of the immigrant females of G-I were macropterous but a few barchypterous females were also observed. At the beginning of G-II (July 15), the percentage of macropterous females dropped to 50% and approximated 83% on July 21. This

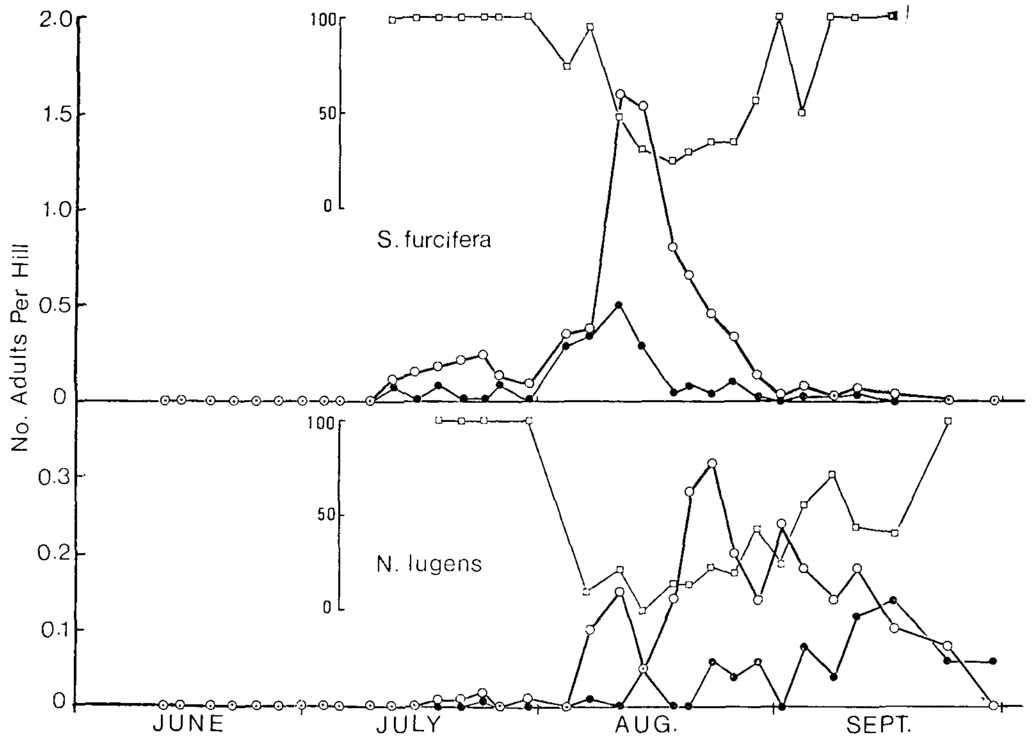

Fig. 3. Sequential trends in the adult densities of *L. striatellus* and *N. cincticeps* in the census plot. (-○-) : females; (-●-) : males; (-□-) : percentage of macropterous females.

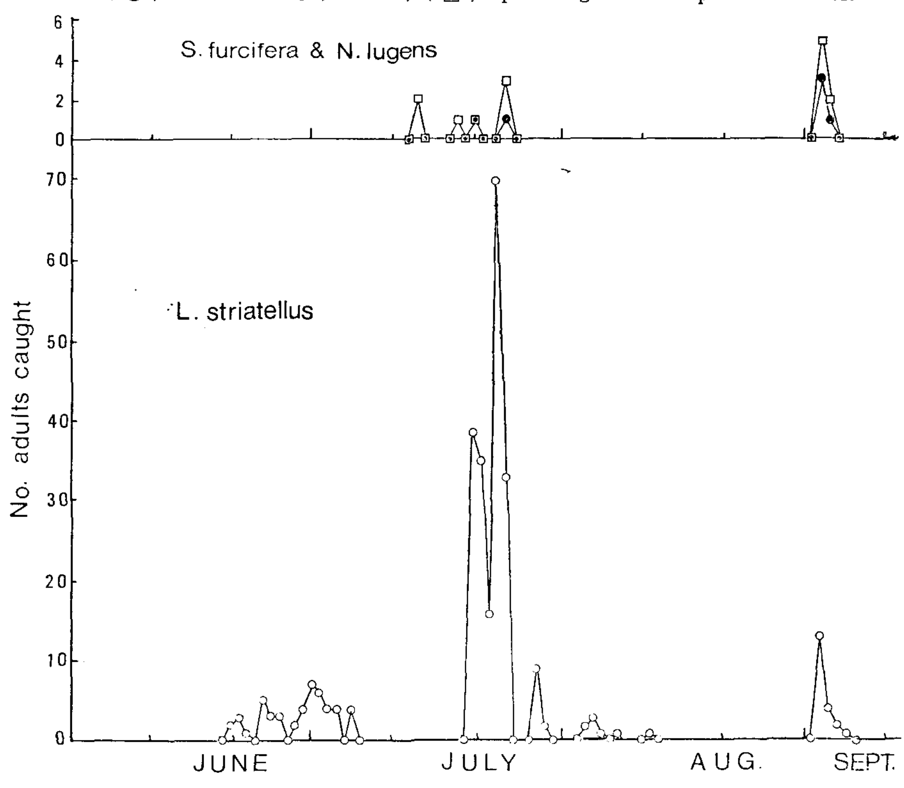

Fig. 4. Sequential trends in the numbers of macropterous adults of *L. striatellus* (-○-), *S. furcifera* (-□-) and *N. lugens* (-●-) caught by the two yellow water pan traps set in the census plot.

was probably due to a slightly faster developmental rate of the brachypterous nymphs than those determined to be macropterous (Kisimoto, 1965).

From July 21 onward, the percentage of macropterous females decreased steadily until the end of this generation (Aug. 14), suggesting an active emigirations of the macropterous females from the census plot. The sequential trend in catches of *L. striatellus* adults by the yellow pan water traps (Fig. 4) coincided well with the adult population trend in Fig. 3, and also with the dispersal activity of macropterous females. The macropterous females of G-I accounted for only 14.3% of the total of 49 macropterous adults caught by traps during the period from June 20 to July 9. This indicated a slackened flight activity of females after settlement in the paddy field. In contrast, the macropterous females of G-II and G-III occupied 48.8% and 57.1% in the total numbers of 215 and 21 macropterous adults caught during the periods from July 20 to Aug. 14 and Aug. 18 to Sept. 4, respectively, indicating an active flight actity of these females after emergence.

Considering the different roles of the two winged forms, macropterous females migrate to other new and more suitable habitats, while brachypterous females produce progeny in the habitat they emerged. It is therefore necessary to estimate the relative proportion of the two winged forms of *L. striatellus* in G-II and G-III. However, the estimation of the relative proportion from the total incidence numbers of macropterous and brachypterous females in each generation must result in a considerable underestimation of the proportion of macropterous females in total females emerging in the census plot. This is because the mean longevity, or more exactly, the mean length of stay, of the macropterous females after emergence is far shorter than that of brachypterous females due to active emigration. Therefore, we estimated the propotion of macropterous females by calculating the value of $\sum n_i \cdot q_i / \sum n_i$, where i denotes the three successive dates of census, centering the peak density date of female adults in each of G-II and G-III; n_i is the mean density of female adults on the date, i, and q_i is the proportion of macropterous females in female adults on the date, i. This resulted in estimates of 0.717 or 71.7% and 0.696 or 69.6% for the proportion of macropterous females in G-II and G-III, respectively. These data suggest the rice plant is not necessarily the best host plant for this insect during summer and autumn. According to a personal communication from Mr. K.R. Choe (IAS, Suweon), nymphs and adults of this insect, including many brachypterous females, can be easily collected on upland vegetation of crabgrasses, *Digitaria* spp., during August and September.

The reproductive rate between the successive generatians of *L. striatellus* was assessed from the ratio of peak densities of femal adults in the two consecutive generations. The reproductive rate from G-I to G-II was as high as 9.1, but that of G-II to G-III was as low as 0.6. Assuming no contribution of macropterous females of G-II in producing G-III population in the census plot, the reproductive rate from the brachypterous females in G-II to the female adults (macropterous+brachypterous) was 2.0. This was still much smaller in value than the reproductive rate from G-I to G-II. Such a decrease in the reproductive rate from G-II to G-III suggests a low fecundity of G-II brachypterous females, or otherwise a high mortality during egg and nymphal period in G-III.

The RSV infected hills in the census plot were surveyed five times during the period from Aug. 18 to Aug. 29. Of 250 hills examined, 17 hills or 6.8% were infected with RSV. Most of the infected hills showed only light symptoms, and severely infected hills were very few. No RDV infected hills were observed.

In contrast to *L. striatellus*, the density of immigrant adults of *N. cincticeps* was very low with no conspicuous peak (see, Fig. 3). This low density status lasted from June 24 to July 24. Taking the median date of this period, *i.e.*, July 9, to be the peak date of immigration of G-I adults of *N. cincticeps*, this median date came 9 days after that of immigration of *L. striatellus* adults. The differential rate of development between the overwintering populations of the two species as mentioned already might cause the above difference in the time of immigration of G-I adults into the paddy field. As a result of such low density and delayed immigration of G-I adults, the peak density dates of the female population in G-II and G-III for this insect came about two weeks after the respective peaks of *L. striatellus* (see, Fig. 3).

The reproductive rate between the successive generations for *N. cincticeps* was asessed in the same way as for *L. striatellus.* As no conspicuous peak for G-I immigrant females was observed, an average density for the period was calculated. This gave the value of 0.01 females per hill, about one fourteenth of the peak density of immigrant females of *L. striatellus.* The reproductive rate from G-I to G-II, and from G-II to G-III became 26.7 and 1.7, respectively. Here again a marked depression in the reproductive rate from G-II to G-III occurred similar to that observed for *L. striatellus,* although the rate of reproduction exceeded unity.

From the results of the egg census for *N. cincticeps,* we can assess the relative values of mean fecundity of the female in the respective generations, the mortalities of eggs in G-II, III and IV, and the relative values of total mortality during the nymphal periods in G-II and III (Table 2). In Table 2, the actual egg density obtained for G-II was doubled, because the sampling date (July 8) was too early to assess the eggs laid by G-I immigrant adults (see, Fig. 3). From Table 2, the following can be concluded: (1) relative value of mean fecundity per female was greatest in G-I females and smallest in G-II females: (2) egg mortality was greater in G-II and G-III than in G-I (mainly due to the additional parasitism of eggs): and (3) relative value of total mortality during the nymphal period increased conspicuously from G-II to G-III. Thus, it is plausible that a high fecundity of G-I females contributed to the conspicuous population increase from G-I to G-II adults. On the other hand, a low fecundity of G-II females coupled with a high mortality during the nymphal period in G-III checked a marked population increase from G-II to G-III adults.

It was further concluded that most of the nymphs hatched from G-IV eggs of *N. cincticeps* and *L. striatellus* enter into diapause development induced by the shortening of day length from early-middle September, and hibernate mainly as the fourth instar nymphs. Therefore, in paddy areas of mid Korea these two species have four adult generations, viz., G-O, I, II and III, although there is a possibility that *L. striatellus* produces a partial fourth adult generation on *Digitaria* grasses.

b) *N. lugens* and *S. furcifera*

As indicated in Fig. 5, none of the adult of these species were found by the direct counting census until July 12. A sudden appearance of macropterous adults of *S. furcifera* was observed in the census plot on July 12. At that time, adults of *N. lugens* were difficult to find, probably due to scarcity in relative abundance of immigrant adults. The density of macropterous females of *S. furcifera* continued to increase from the initial density of 0.11 per hill to the peak density of 0.25 per hill on July 24. Thereafter, the density decreased until July 30. The immigrant density of macropterous females of *N.*

Table 2. Estimation of mean fecundity per female and mortalities during egg and whole nymphal periods for each generation of *N. cincticeps* in the census paddy field

Generation	No. females per hill(A)	No. eggs per hill(B)	Mean fecundity per female(B/A)	Egg mortality			Total mortality during whole nymphal period[1]
				para.	unknown	total	
I	0.01*	—	184.0	—	—	—	—
II	0.27**	1.84	99.1	0.0	21.7	21.7(%)	81.2(%)
III	0.42**	26.76	126.8	19.3	14.1	33.4	97.6
IV	—	53.24	—	15.9	17.9	33.8	—

* Overall average during the generation.
** Peak density during the generation.
1) For example, the estimate for G-II can be obtained as: $100\times(1-0.27/(1-0.217)\times1.84)$.

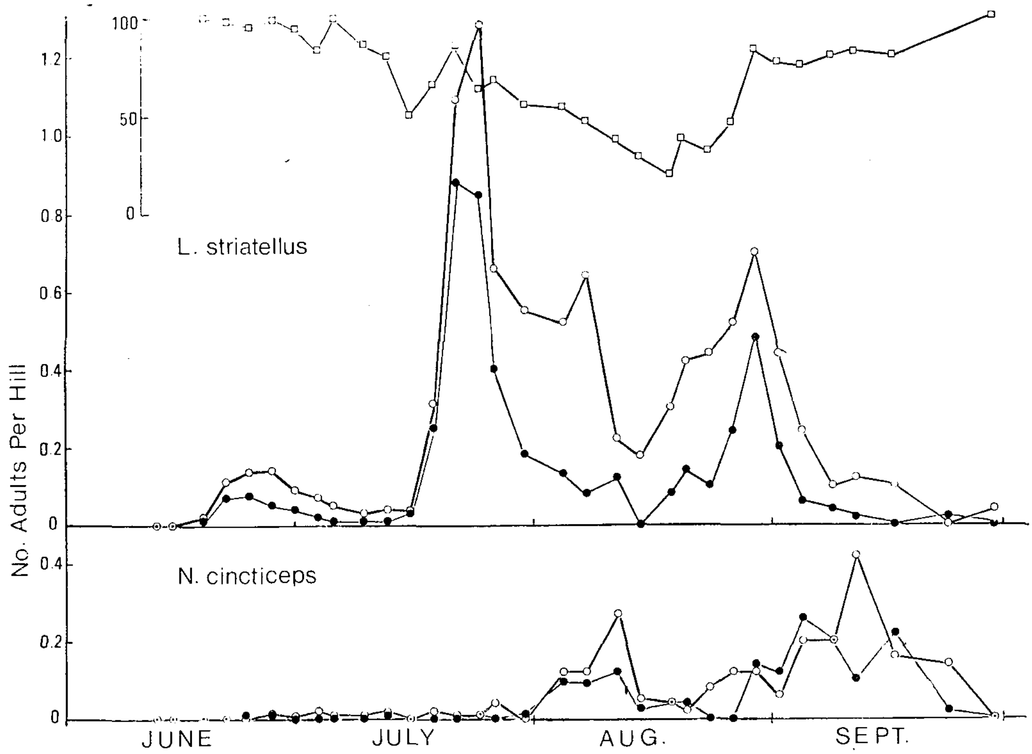

Fig. 5. Sequential trends in the adult densities of *S. furcifera* and *N. lugens* in the census plot. (-○-) : females; (-●-) : males; (-□-) : percentage of macropterous females.

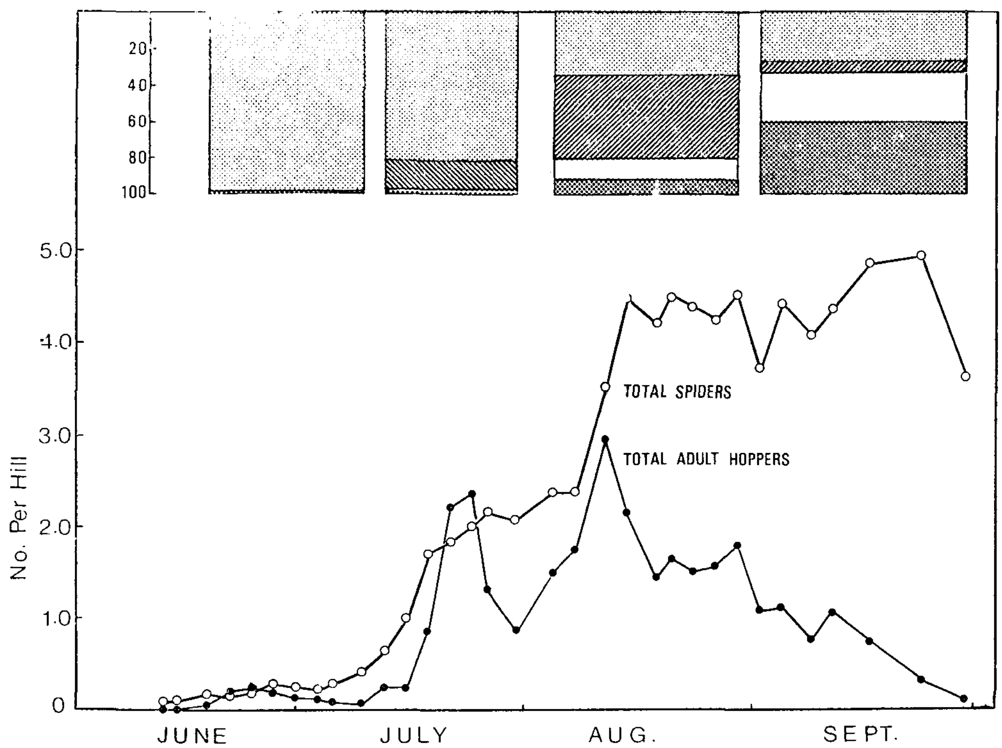

Fig. 6. Sequential trends in the densities of rice leafhopper adults and spiders, and successive changes in the species composition of rice leafhoppers as prey. Each stratified portion in the percentage histograms shows *L. striatellus* (smaller dotts), *N. cincticeps* (small dotts), *S. furcifera* (oblique line) and *N. lugens* (blank).

lugens was very low, even at its peak density on July 24, *e.g.*, 0.016 per hill. The immigration of macropterous adults of the two species was closely related to the meteorological changes observed in Suweon, as will be discussed later.

The first date when the percentage of macropterous females was less than 100% indicates the beginning of the new generation following the immigrant generation (see, Fig. 5). For convenience, the generation of macropterous immigrants is termed the first generation or G-I. Subsequent generations are designated G-II, III. *etc.*

The G-II female population of *S. furcifera* formed a distinct unimodal curve in sequential trend of density. The peak density was 1.60 females per hill on Aug. 12, indicating a 6.4-fold increase from the peak density in G-I. However, there was no notable increase after G-II. This response in population growth has been observed in Korea and Japan (*e.g.*, Kuno, 1968). The proportion of macropterous females in G-II was estimated by the same method applied for *L. striatellus*. The result gave the value of 0.463 or 46.3%. In other words, the remaining 53.7% were brachypterous females in G-II, which were almost ineffective in producting a G-III population. Most of the G-III adults were macropterous.

The G-II female population of *N. lugens* formed a bimodal not a unimodal curve, in sequential trend of density. A minor and major peak were observed on Aug. 11 and on Aug. 23, respectively (see. Fig. 5). This suggests that G-I macropterous adults of *N. lugens* flew into the census plot intermittently during middle and late July. These two peaks in the G-II female population are denoted as G-IIa and G-IIb peaks, respectively. Similarly, we can observe an earlier peak on Sept. 1 and a delayed peak on Sept. 11 for G-III female populations.

The estimated percentages of macropterous females were 16.0, 17.5, 39.3 and 52.4 for G-IIa, IIb, IIIa and IIIb, respectively. Thus, the proportions of macropterous females in G-II and III were lower in *N. lugens* than in *S. furcifera*, or the proportions of brachypterous females in *N. lugens* were higher than those of *S. furcifera*. This indicates that *N. lugens* is more fitted than *S. furcifera* for reproduction of progeny on rice. The successive increase in the proportion of macropterous females from G-IIa to G-IIIb would be a reflection of decreasing suitability of rice as a host plant and the effect of seasonal factors such as temperature and photoperiod for breeding of this insect.

In order to evaluate the reproductive rate from G-I to the respective subgenerations of G-II, *i.e.*, G-IIa and IIb, the averaged densities of G-I macropterous females during the periods from July 12 to 21 (G-Ia) and July 24 to 30 (G-Ib) were calculated. Results gave values of 0.004 and 0.009 females per hill for G-Ia and G-Ib, respectively. The reproductive rates from G-Ia to G-IIa and from G-Ib to G-IIb were 37.5 and 35.6, respectively. Similarly, the reproductive rates from G-IIa to G-IIIa and G-IIb to G-IIIb became 1.6 and 0.6, respectively. Itis apparent from these results that *N. lugens* has a far greater reproductive rate compared with *S. furcfera*, although *N. lugens* failed to increase population density after G-II. However. the fact that early females in G-IIa had a greater reproductive rate compared with G-IIb is indicative of the possibility of population explosions of this insect and resultant hopperburn if invasion of G-I macropterous adults occurred at an early stage after rice transptanting. Besides time, the density of immigrant macropterous adults is another important factor.

c) *Spiders as a general feeders on rice leafhoppers*

The four species of rice leafhoppers are known to be attacked by several parasites, predators and fungi throughout their life stages. Among natural enemies, spiders occupy a unique position as general feeders on all four species. Although spiders would not act as a density-regulator of rice leafhoppers (Kuno, *l.c.*; Kuno and Hokyo, 1970), elimination of spiders by insecticides often resulted in an increase of rice leafhoppers, especially *N. cincticeps*(Kobayashi, 19 61). This study indicated the important role of spiders in controlling rice leafhoppers.

Fig. 6 shows the population trends of all spider species and four species of adult rice leafhoppers obtained by the direct counting census. Changes in the species composition of rice leafhoppers as prey are also shown corresponding to the four periods in the poulation growth of spiders. Small spiders or spiders in immature stages were discarded in the direct counting census. Estimates of spider densities were about 1.5 times smaller than spider densities obtained by collection with the spider cage on an average. The dominant spider species were *Pirata subpiraticus* (Lycosidae) and the two species of Micryphantidae, *Oedothorax insecticeps* and *Gnathonarium dentatum*. The complete list of spider species and the characteristics of the sequential changes in density and age composition for several important spiders will be reported elsewhere.

The population growth of spiders was tentatively divided into four periods from Fig. 6. The first (P-I) is the period of spider immigration into the paddy field (mid-late June). During that period, the main prey of spiders was *L. striatellus.* During July (P-II), the first increase of spider densities occurred. During that period, *L. stratellus* was the main prey and *S. furcifera* was the subsidiary prey of spiders. The third period (P-III) was set during August where both *S. furcifera* and *L. striatellus* were main prey, and *N. cincticeps* and *N. lugens* were secondary prey. The fourth period (P-IV) occurred in September and there was no further increase of spider densities. *N. cincticeps*, *N. lugens* and *L. striatellus* contributed almost equally to the *menu* for spiders during that period.

The spider populations in P-I, II and III reached successively higher plateaus following each peak of the total prey densities in the respective periods, *e.g.*, *ca.* 0.22, 2.20 and 4.40 spiders per hill. Apparently, the rate of population increase from P-I to P-II spiders was greatest, *i.e.*, *ca.* a 10-fold increase. But the rate of increase from P-II to P-III spiders declined to *ca.* only a 2-fold increase. There was no increase in P-III to P-IV spiders, probably due to the increasing shortage of the total prey population and decreasing suitability of habitat conditions such as temperature and photoperiod for breeding of the spiders.

A similar mode of population growth of spiders was also observed at the ceusus paddy field in Chikugo (Kuno, *l.c.*), where, however, the rice leafhopper population would predominate over the spider population during the entire period in contrast to the case observed in the Suweon paddy field· Considering spider predation which is rather inversely density-dependent in nature, their effectiveness as a natural controlling agent of rice leafhoppers would be more pronounced in a situation such as observed in the Suweon paddy field where populations of the rice leafhoppers started from relatively low densities of immigrant adults.

2. Results of Survey Trip to Southern and South-western Coast Areas

The results of our survey trip are summarized in Table 3. The time of rice transplanting is usually 2-3 weeks later than that practiced in mid-Korea. Rice seedlings were transplanted during the period from June 16 to 23. Such a delay in transplanting time may coincide well with the emergence time of *L. striatellus* and *N. cincticeps* adults of G-I. Thus it is expected that immigrant adult densities of the two species in paddy fields would be much higher in the southern part than in mid-Korea. This is more likely to occur for *L. striatellus*, because the acreage of barley fields, which are main breeding habitats of G-I population, occupy about 80% or more of the total acreage of paddy fields in southern Korea.

From Table 3 it is apparent that, on Tongil variety, *L. striatellus* and *N. cincticeps* populations especially the former species, were much lower than the local japonica variety, Akibare or Nonglim-6, and that Tongil was highly resistant to RSV transmitted by *L. striatellus*. Although *L. striatellus* were fewer than *N. cincticeps* on the local variety at the time of survey, the rate of infection with RSV, *e.g.*, an average of 66% was much higher than the rate of infection with RDV transmitted by *N. cincticeps*, *e.g.*, 15% on an average. This is, however, an apparent contradiction, because the time of our survey probably coincided the declining phase of the density of G-II *L. striatellus* adults in which about 72% were brachypterous females in the total number of 18 females found. All the infected hills with RSV showed a severe symptom of earlier infection effected by the G-I immigrant adults. Moreover, resistance of Tongil against RDV-infection is questionable or Tongil may be mildly resistant to RDV; because the average infection rates with RDV between Tongil and the local variety did not differ greatly than expected from the relative abundance of *N. cincticeps* on the two varieties. This point should be ascertained from

Table 3. Results of the survey trip in southern and south-western coast areas (Aug. 4–7, 1975)

Place	Variety	No. insects and spiders on 25 hills (direct count)									% virus-infected hills	
		L. striatellus		*N. cincticeps*		*N. lugens*		*S. furcifera*		Spiders		
		♂	♀	♂	♀	♂	♀	♂	♀		RSV	RDV
Gochang	Tongil	0	0	10	3	0	4	0	5	57	8.0	12.0
	Akibare	0	3	18	37	1	7	2	19	67	0.0	44.0
Boseong	Tongil	1	0	4	1	0	3	0	0	24	0.0	4.0
	Nonglim-6	2	8	12	11	1	7	0	0	51	100.0	20.0
Jinju	Tongil	0	0	0	0	0	1	0	1	66	0.0	12.0
	Akibare	0	4	2	1	1	0	1	2	87	84.0	24.0
Gimhae	Tongil	0	0	0	1	0	1	0	0	40	0.0	0.0
	Akibare	1	3	2	7	0	0	0	1	19	36.0	16.0
Total	Tongil	1	0	14	5	0	9	0	6	187	2.0	7.0
	Local var.	3	18	34	56	3	14	3	22	224	66.0	15.0

Sweeping (25 times single-sweeping; 3 repls. each except Jinju)

Place	Variety	*L. striatellus*		*N. cincticeps*		*N. lugens*		*S. furucifera*	
		♂	♀	♂	♀	♂	♀	♂	♀
Gochang	Tongil	5	0	63	7	5	0	25	7
	Akibare	11	1	130	70	9	0	19	11
Jinju	Tongil	2	4	2	0	0	0	10	4
	Akibare	7	5	20	3	0	0	3	0
Gimhae	Tongil	0	0	16	12	0	0	2	1
	Akibare	3	2	26	18	0	0	1	0
Total	Tongil	7	4	81	19	5	0	37	12
	Akibare	21	8	166	91	9	0	23	11

future studies.

For *N. lugens* and *S. furcifera*, the result of direct counting gave a lesser abundance in both of the two species on Tongil than on the local variety. On the other hand, the result of sweeping gave an almost equal abundance in both of these species on the two varieties. In general, direct counting tends to find more females than males, and more of the species sluggish in behaviour, *e.g.*, *N. lugens*, than active species, *e.g.*, *S. furcifera*. The reverse is the case in sweeping. Considering these factors, it is probable there were no significant differences in the relative abundance of species on the two varieties.

No brachypterous females were found for *N. lugens* and *S. furcifera* throughout the course of this survey. Fifth instar nymphs of *N. lugens* were found at the time of the direct counting census in Boseong, Jinju and Gimhae. Eight and four fifth instar nymphs were found on Tongil and the local variety, respectively. The period of immigration of the two species in southern Korea thus approximated that in mid-Korea (Suweon), and the adult new generation, *i.e.*, G-II, from the immigrant adults was ready to commence. The average densities of macropterous females of the two species throughout the survey, e.g., 0.14 per hill (local var.) for *N. lugens* and 0.22 per hill (local var.) for *S. furcifera*, were much higher than immigrant adult densities observed at that time in the Suweon paddy field. Regrettably, we overlooked regional differences in the density of immigrant adults before the detailed analysis of this data. Later in September, several regions in central and southern Korea experienced a severe outbreak of *N. lugens*.

Discussion

From results and considerations hitherto made, it is evident that the economic importance of these rice leafhoppers is much greater in southern Korea than in mid-Korea. Regional differences in pest status were made in more detail by Park (1973) based on recent (1968-1972) light trap data in Korea. Needless to say, however, both intensive and extensive studies of field populations of major rice pests are required in order to elucidate the mechanisms determining such regional differences.

The present study indicated a reduction in breeding of G-O and G-I populations of *N. cincticeps* and *L. striatellus* in mid-Korea due to the severe winter and the cultural practices in rice and barley. The severity of environmental conditions was lessened, especially for *L. striatellus*, progressively towards southern Korea. The regional trends of light trap catches of the two species during June and July in 1975 (Fig. 7) seem to reveal these characteristics for populations of the two species. There existed a general trend of increase and earlier occurrence in catches of G-I adults of *L. striatellus* from the middle regions towards the southern regions. From middle July, catches of the G-II adults began to increase. But, in this case, the directional increase in catches of G-I adults was reversed somewhat. It is suspected that the pattern of population growth of this insect in paddy fields would shift from a type of dominance of the G-II adults in the middle, to a type of dominance of the G-I adults in the south. A similar trend, as observed in the catches of G-I adults of *L. striatellus*, is also seen for G-I adults of *N. cinctceps*. The trend in catches of G-II adult *Nephotettix* was not fully revealed in Fig. 7, probably because of the delayed emergence of the G-II adults (from late July) compared with *L. striatellus* (from mid July).

In mid-Korea, which normaly has a low population density of both *N. cincticeps* and *L. striatellus*, the proportions of viruliferous individuals in populations, especially in *N. cincticeps*, would also be low in contrast to southern Korea. To clarify these points, serological tests of viruliferous rates should be conducted for the respective local populations.

Economic importance of *N. lugens* and *S. furcifera*, especially that of *N. lugens*, is also much greater iu southern regions of Korea. There is a mass transoceanic migration of the two species closely associated with the movement of frontal systems in the rainy season, which brings more immigrant adults into southern regions than in northern areas. In this regard, the south-western and southern regions of Korea, viz., Chung-nam, Jeon-bug, Jeon-nam and Gyeong-nam, may be worthy of special attention. Fig. 8 shows the trends of light trap catches of the two species in these regions and Gyeonggi during June and July 1975. Except Jeon-nam, where *S. furcifera* adults were caught as early as mid-June, adults of the two species were mostly caught from July 10 onward. *S. furcifera* predominated over *N. lugens* in numbers in each region, and *N. lugens* was trapped somewhat later than *S. furcifera*. In Jeon-nam and Gyeong-nam, two peaks in cathes of *N. lugens*, *e.g.*, mid-July (early wave) and late July (later wave), were detected. In Jeon-bug, Chung-nam and Gyeonggi, numbers of *N. lugens* were relatively small compared with those caught in Jeon-nam and Gyeong-nam, and only the later wave was seen in Jeon-bug and Gyeonggi.

Some meteorological factors related to the immigration of *N. lugens* and *S. furcifera* are shown in Table 4 based on data recorded at the Suweon Agricultural Weather Station. Judging from the weather conditions that favour a mass immigration of the two species, *i.e.*, continuous blowing of SW wind with a considerable rainfall (Kisimoto, *l.c.*), July 10, July 15-16 and July 24-25 seem to satisfy such requirements. The actual incidence of immigrant adults of the two species in the census plot was not contradictory with that expected.

According to Hirao (1976), three main waves were observed for the immigration of the two species in Chikugo (see also Table 4). The first wave observed during June 21 to 27 in Chikugo preceeded considerably the general immigration of the two species from mid-July in Korea. This difference was, of course, induced by the earlier rainy season in Kyushu. Southern and western coast regions of Kyushu, including Chikugo, would have mass immigrations of the two species as a front in Japan. The immigrant adult densities (males and females) of the two species surveyed on

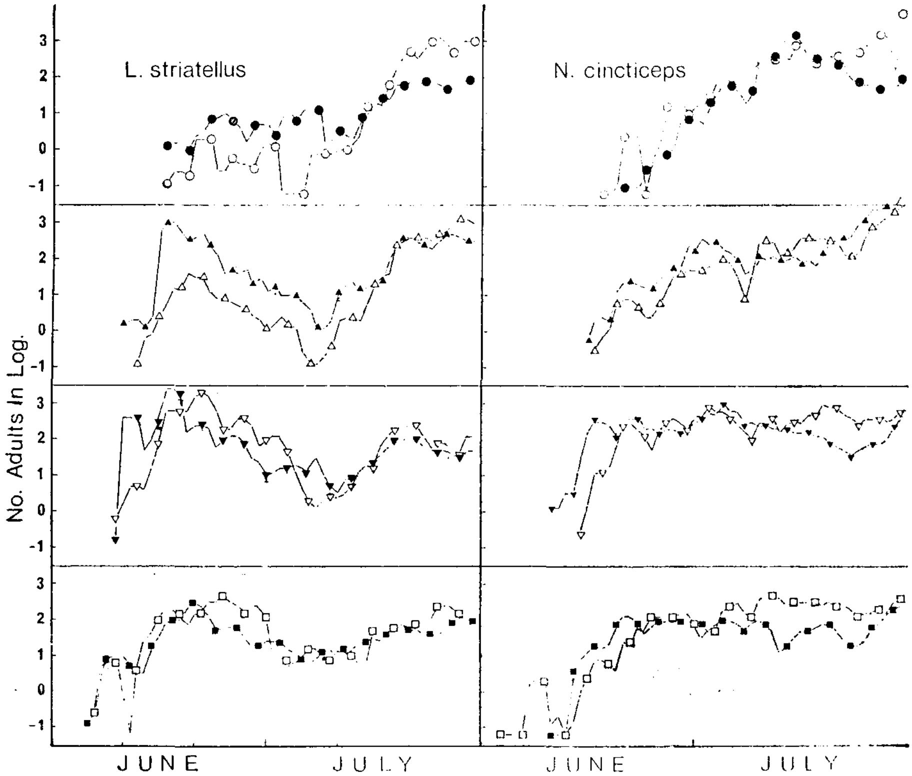

Fig. 7. Sequential trends in light trap catches of *L. striatellus* and *N. cincticeps* during June and July in 1975 in Gang-weon(-●-), Gyeonggi(-○-), Chung-bug(-△-), Chung-nam(-▲-), Jeonbug(-▽-), Jeon-nam(-▼-), Gyeong-bug(-□-) and Gyeong-nam(-■-). The daily averaged numbers of adult caught in several localities of each province were plotted by the three point moving average.

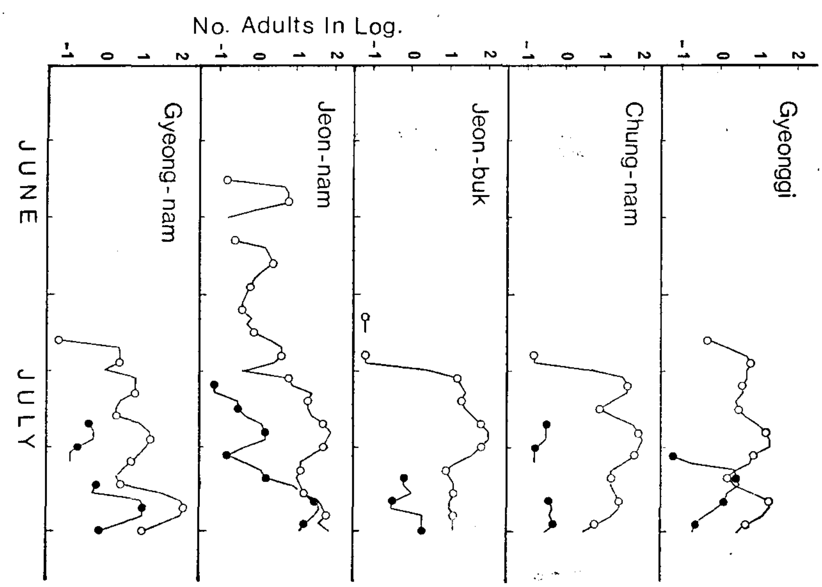

Fig. 8. Sequential tends in light trap catches of *S. furcifera*(-○-) and *N. lugens*(-●-) during June and July in 1975 in Gyeonggi, Chung-nam, Jeon-nam and Gyeong-nam.

Table 4. Wind direction, wind velocity and precipitation during the period from June 15 to July 31 in 1975 at Suweou

Date	Range of dominant wind direction	Averaged velocity (m/sec.)	Precipitation (mm/day)
June 15	NWN-NW	3.4	0
16	do.	2.6	0
17	do.	1.8	7.4
18	NWN-WNW	1.6	0
19	NWN-NW	2.9	0
20	do.	2.7	0
*21	ESE-S	2.3	0
*22	NW-WNW	3.1	0
*23	SE-SES	2.4	6.5
**24	E-ESE	2.3	5.0
*25	NW-WNW	2.3	0
*26	N-WNW	3.2	0
*27	NWN-WNW	2.8	0
28	do.	3.0	0
29	do.	1.8	0
30	NWN-NW	2.6	0
July 1	SES-S	1.4	0
2	SE-S	2.1	0
3	ESE	1.0	0
4	NWN-WNW	3.7	0
5	SES SW N-NW	1.4 2.1 1.3	0.2
*6	ESE-SES	2.1	26.8
*7	SW-SWS NEN-NE	2.7 2.0	11.5
**8	W-SW N-NW	1.9 2.9	0
*9	NWN-NW	1.9	0
*10	SW-S NW	3.5 2.8	49.5
11	none	—	0.9
*12	NWN-NW	2.9	0
**13	do.	1.7	0
*14	none	—	0.2
*15	SW-SWS	4.2	82.9
*16	NW	2.5	9.5
17	NWN	3.1	0
18	WSW-SW	1.1	0
19	do.	1.3	0
20	do. NWN-NW	1.4 1.7	0
21	SW-SWS	2.0	0
22	do.	1.9	0
23	WSW-SWS NW-W	1.4 3.7	0
24	WSW-SW N-NWN	2.2 2.6	7.7
25	WSW-SWS SE	1.4 0.9	31.9
26	ESE-SES N-NW	1.0 2.5	14.0
27	none	—	86.4
28	ESE-SE	1.3	46.5
29	do.	1.1	5.1
30	SE-SES	1.8	0
31	do. SWS-S	1.9 2.6	24.4

* denotes the date when macropterous adults of *S furcifera* and *N. lugens* were caught in Chikugo by the net trap.
** denotes the peak date of catches.

June 26 at the two paddy plots (transplanting dates: May 20 and June 10) in Chikugo, were 1.84 and 0.22 per hill on an average for *S. furcifera* and *N. lugens*, respectively (Hirao, unpublished data). These values are about 6.7 and 9.2 times greater than peak densities of *S. furcifera* and *N. lugens* in late July at the census plot in Suweon. Apparently, a longitudinal dilution of immigrant adults occurred with movement of warm frontal systems from the south. In addition to meteorological factors, the extended season of rice in southern Korea favours population growth of *N. lugens* after immigration compared with mid-Korea.

Different policies for controlling rice leafhoppers are needed, corresponding to the different situations of these pests in middle and southern Korea. For this purpose long term studies on population dynamics must be conducted. Meanwhile, the importance of natural control-in a broad sense the exclusion of insecticidal control-in checking the outbreaks of these rice pests cannot be overlooked. Since natural control is most effective in middle Korea, less applications of insecticides are required compared with southern Korea. The recent spread of Tongil variety in southern Korea has remarkably increased rice yields due to moderate resistance against RSV disease transmitted by *L. striatellus*. However, the present resistance of Tongil to RSV infection might diminish with expanded cultivation, which could contribute to the build up of resistant strains in populations of *L. striatellus*. Additional negative aspects of Togil, including susceptibility to RDV disease transmitted by *N. cincticeps* and infestation by *N. lugens*, are more than compensated for by positive attributes of this variety.

Thus, in southern Korea, the programme for controlling rice leafhoppers would not be so simple as in mid-Korea. A monoculture of Tongil should be avoided. Coexistence of Tongil with some practical japonica varieties in an appropriate proportion would be the best policy. Methods of effective control of *L. striatellus* and *N. cincticeps* should be considered using selective insecticides in the early cultivation periods of barley and rice. For the effective control of *N. lugens* together with *S. furcifera*, major peaks of their immigrations into paddy fields must be predicted by integrating information from weather observations, trends in catches by net and light traps, and actual counts of insects in census paddy plots. The time of effective control of *N. lugens* would come around about 3-4 weeks after major immigration peaks. The time for effective control of this insect is just prior to emergence of brachypterous females in the generation after immigrant adults (Nagata *et. al.*, 1973).

The planned and intelligent use of insecticides, together with the use of resistant varieties, will lead to the realization of truly productive agroecosystems in Korea.

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요 약

벼를 가해하는 4종의 멸구·매미충 즉 애멸구, 끝동매미충, 벼멸구 및 흰등멸구의 경제적 중요성에 대한 지역적 차이를 수원과 남부 그리고 남서 해안지역에서 수행한 개체군의 밀도조사를 토대로 분석 검토하였다. 한국에서 년중 볼수있는 애멸구와 끝동 매미충의 경제적 중요성은 중부지방이 덜한 것으로 보인다. 이는 겨울의 추운 기후조건, 벼, 보리의 경작 방법 및 거미류 같은 천적에 의해서 자연 치사작용이 효과적으로 일어나는 때문인 것으로 믿어진다. 그러나 남부지방에서는 겨울이 덜 춥고 벼, 보리의 경작방법이 이 두 해충의 생활환과 기주식물의 계절적 변천 양자의 齊一性에 유리한 편이어서 이들의 경제적 중요성은 확실히 크다고 하겠다. 한국에서 월동을 하지못하는 벼멸구와 흰등멸구의 매년 첫 발생개체군은 동지나해를 건너 원거리를 이동해 오는 것들에 기인된다. 이들의 이동과 관련을 갖고 있는 기상요소로 해서 이동되어오는 벼멸구와 흰등멸구의 양은 중부지방보다 남부지방에서 월등히 많다. 그러므로 벼를 가해하는 멸구·매미충류에 대한 종합방제책으로 중부와 남부지방 별로 지침을 달리 세울 것이 요망된다.

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