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Prediction of Long Distance Migration of Rice Planthoppers to Northern Kyushu Considering Low-Level Jet Stream

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Abstract

Rice planthoppers are major pest for rice plants in Asian countries. They immigrates from overseas to Kyushu in Japan in the Baiu season every year. To predict the long distance migration of rice planthoppers to northern Kyushu, a migration model was developed with a hypothesis that rice planthoppers were transported by low-level jet stream at 1,000–2,000 m heights. The weather conditions for the migration period (June to July) were analyzed with the 850 mb chart at 21 h in 1980–1985 and at 09 h and 21 h in 1986, and possible migration days were decided. On the other hand, actual migration flight waves were decided with the number of catches by two nets. The possible migration flights decided by the weather chart agreed approximately with the actual flights. The accuracy of this prediction method was improved by using the 850 mb chart at 09 h additionaly. Finally, the prediction procedure was described.

1. Introduction

Rice planthoppers (whitebacked planthopper and brown planthopper) are known as major pests for rice plants in Asian countries. They cannot overwinter in temperate countries like Japan, but occur in paddy fields in the Baiu season (pre-summer rainy season) every year. Kisimoto (1971) proposed that rice planthoppers migrated from overseas to Japan. After migration, they rapidly increase their population. When a certain population density is attained, the host plant withers (Kisimoto, 1976).

The source of migrations has not been definitely clarified, but Kisimoto (1976) proposed the central and southern part of the Chinese continent. Rosenberg and Magor (1983) described that the southeastern part of China, Taiwan and Okinawa were the possible source area. Assuming that the southeastern part of China is the source area, the distance between the area and the Kyushu island of Japan is about 1,200 km or more. Therefore, it is difficult to consider that rice planthoppers fly themselves from China to Kyushu, and it is evident that weather participates in their migration. Kisimoto (1976) analyzed the surface weather charts on the days of rice planthoppers migrations at Chikugo in northern Kyushu, and showed that most migrations were induced by a depression or successive depressions that emerged from the central part of the Chinese continent between 25°N and 35°N and proceeded eastward through a range between northern Kyushu and about 600 km north. He categorized these migrations as "typical" ones. In the "typical" migrations, strong SW or SSW winds blew at Chikugo, ranging in speed from 5–11 m/s at 10 m height, and lasting for 9–46 h.

Depression is certainly an important factor on the rice planthoppers migration. However, it is difficult to consider that they fly in a depression. As heavy rainfall area exists in a depression and its vicinity, flying rice planthoppers may be immediately dropped down to ground or sea surface. According to the raindrop observation carried out

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in Kyushu in the last stage of the Baiu by Shiotsuki (1974, 1976), insects such as rice planthoppers were never collected with raindrops. Therefore, it is considered that insects are migrating the area except the convergence or rainfalling zone.

The existence of long-lasting and strong wind over the East China Sea is an essential condition to immigrate long distance of 1,200 km or more, because rice planthoppers are probably transported by wind rather than fly themselves in wind. Recently, Rosenberg and Magor (1983) described that long distance migration of brown planthopper could occur in winds at 1.5 km height. In the Baiu season, southwesterly strong wind is predominant over the East China Sea at 1,000–3,000 m heights (Murakami, 1959). Furthermore, southwesterly strong air stream often appears at 1,000–3,000 m heights, and is called as low-level jet stream (Akiyama, 1973). It develops often in the vicinity of heavy rain area in the Baiu season, but does not steadily exist. It appears in a warm sector of depression which progresses eastward on the Baiu front.

The wind field mentioned above is very suitable for long distance transportation of insects such as rice planthoppers, moth, or butterfly (Miyata and Hanamiya, 1983). Furthermore, the airplane observation by Dung (1981) showed that the migrating brown planthoppers were caught mostly at 1,500–2,000 m heights. In this paper, we paid attention to the air stream at 1,000–2,000 m heights, and proposed a method to predict rice planthoppers migration accurately and easily.

2. Methods and Materials

Insects were caught by two net traps which were sited at a 15 m height in a paddy field area of Kyushu National Agricultural Experiment Station, Chikugo in northern Kyushu. The net was made of tow and had 1 m diameter and 1.5 m depth (Kisimoto, 1976). The collected insects were classified and counted once a day at 09 h JST (Japan Standard Time). The migratory flight waves of rice planthoppers in 1980–1986 were identified with the counted daily number. In the case of small peak in flight wave, the light trap data was supplementally used to confirm the migration. The light trap had a 60 W tungsten filament bulb of pearl glass, and was placed 1.5 m above the ground. As whitebacked planthoppers and brown planthoppers immigrate to Kyushu at the same time, we did not take species into consideration.

The 850 mb weather chart published by Japan Meteorological Agency (JMA) was used to analyze the weather condition in 1980–1985, because it was the only chart to represent the weather condition at 1,000–2,000 m heights. In this published chart, only the observation at 21 h JST was available, although the aerological observation was carried out at 09 h and 21 h. Furthermore, the charts at 09 h and 21 h which were obtained from the weather facsimile broadcasted by JMA were used to analyze the weather condition in 1986.

We paid attention to low-level jet stream on the 850 mb chart. The low-level jet stream is the name given to the strong wind area in the lower troposphere, but has not general definition (Ninomiya, 1979). Therefore, we considered the area of wind speed above 10 m/s (20 knots) on the 850 mb chart as the low-level jet stream, and decided the major axis as the center of low-level jet stream. Furthermore, trajectory analysis, in which wind speed and direction are used to study the movement of airborn particles, was used to identify potential sources of rice planthoppers. Trajectory was drawn upwind from Chikugo in northern Kyushu. The weather shown on 21 h JST was assumed to represent the conditions prevailing in 24 h period starting at 12 h JST, although wind field would have been changing progressively throughout the period.

3. Results and Discussion

3.1 Weather conditions suitable for long distance migration

As shown in Table 1, the phenomena of rice planthoppers migration and heavy rain in the Baiu season resemble each other in many points. Rice planthoppers migration is observed in a warm sector, 200 to 300 km south of the front, while heavy rain occures in the area within 300 km north of low-level jet stream. Assuming that heavy rain occurs at the center of the Baiu front, these facts mentioned above show that the axis of low-level jet stream coincides with the migration area of rice planthoppers observed at ground surface. Therefore, we set up a hypothesis that long

Table 1. Comparison of rice planthoppers migration with heavy rain in the Baiu season (after Kisimoto, 1976; Ninomiya, 1979)

Factor	Planthoppers Migration	Heavy Rainfall
Source	China	Water vapor convergence zone from China to the East China Sea
Transportation	Depression on front	Depression on front
Scale	From 1,000 to 2,000 km	Meso-scale disturbance (wave length from 1,000 to 2,000 km)
Period	Baiu season	Last stage of the Baiu
Locality	200 to 300 km south of front	Within 300 km north of low level jet stream
Condition	Flying: above 16.5°C above 85% R.H.	Dynamic Concentration

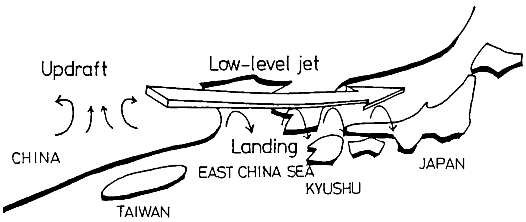

Fig. 1. Schematic view of long distance migration model of rice planthoppers to northern Kyushu

distance migratory insects such as rice planthoppers are transported in the low-level jet stream at 1,000–2,000 m heights. A model of long distance migration of rice planthoppers is schematically shown in Fig. 1.

Insects which take off broad area of rice cultivating district are brought to 1,000–2,000 m heights by updraft. In the Baiu season, many depressions occur in southeast China, it is expected that there exists broad updraft. Therefore, it is reasonable to consider that rice planthoppers which take off themselves are easily transported to upper layer. The existence of low-level jet stream makes long distance migration possible, and insects are transported from China to Kyushu by about one day. There may be many vertical circulations between ground surface and upper layer, and some of insects may be taken into downdraft to land on ground or sea surface. According to the model, the weather conditions suitable for long distance migration to northern Kyushu is written as follows:

1) the axis of low-level jet stream exists in northern Kyushu,

2) the trajectory drawn upwind from Chikugo reaches the rice cultivating district, for example, southeast China and Taiwan, and

3) the mean air speed along trajectory is above 10 m/s (20 knots).

Rosenberg and Magor (1983) described that some migrants would fly downwind for up to 30 h at altitudes where the temperature was at least 17°C. The speed of about 10 m/s is the minimum speed to migrate the distance of 1,200 km by about 30 h. Ohkubo (1973) showed the laboratory experiment that rice planthoppers could fly continuously in the condition of above 16.5°C in temperature and 85% in humidity. Air temperature at 1,000–2,000 m heights over northern Kyushu, on an average, ranges from 15° to 20°C in the Baiu season. As warm and humid wind blows from the southeast in a warm sector of depression, air temperature at the heights may be higher than the mean value mentioned above.

3.2 Possible migration days of rice planthoppers in 1980–1986

The weather conditions mentioned in previous section were applied to the migratory period (from June to July) in 1980–1986, and possible migration days of rice planthoppers were decided. The 850 mb weather chart at 21 h was used to analyze the weather condition in 1980–1985, while the 850 mb weather charts at 09 h and 21 h obtained from the weather facsimile were used in 1986. The result is shown in the left column in Table 2.

Table 2. Comparison of possible migration days with actual migration days.

Year	Possible Migration Days	Actual Migration Days
1980	15–17, June 22–28, June 04–08, July 13–14, July 23–28, July	14–17, June 23–28, June 01–08, July 12–14, July 24–28, July
1981	23, June 27–30, June 02–03, July 09, July	23, June 27–30, June 01–03, July 09–11, July
1982	13, June — 11–13, July 16–18, July 24, July	13–14, June 19, June 11–13, July 16–19, July 22–27, July
1983	12, June 19, June — 02–04, July 14–17, July 19–23, July	12–13, June 16–20, June 23, June 02–05, July 14–18, July 19–23, July
1984	09, June 18, June 26, June 05, July 12–13, July 23, July	— 16–18, June — 05–06, July 11–13, July 22–23, July
1985	27, June 02–05, July 09–12, July 18, July	25–27, June 03–06, July 10–13, July 17–19, July
1986	16–19, June 21–23, June 25–26, June 27–29, June 03–07, July 13–16, July 17–19, July 20–22, July 24–28, July	16–19, June 21–23, June 25, June 27–29, June 04–06, July 13–15, July 17–19, July 20–22, July 24–27, July

The weather conditions of two cases in July, 1985 are indicated in Fig. 2. Fig. 2a shows the trajectories on 9 to 12 and low-level jet stream on 9 on the 850 mb weather chart. The Baiu front on the surface chart is also shown in the figure. The weather condition was suitable for rice planthoppers migration on 9 to 12. Assuming that migration started at this time, the migratory flight in northern Kyushu was predicted to be observed on 10 to 13. Fig. 2b shows the weather condition on 17 and 18. Only the trajectory on 17 reached southeast China, and the migration on 18 was predicted.

The change of number of rice planthoppers caught in two net traps in July, 1985 at Chikugo was shown in Fig. 3. From this figure, two major migration peaks were recognized. One was the migration on 10 to 13, and another was on 17 to 19. Comparing these actual migration days with possible days, the former case indicated good agreement. In the latter case, the migrations on 17 and 19 were not predicted. This disagreement is due to that only the 850 mb weather chart at 21 h was used to analyze. Since the weather shown on the chart at 21 h was assumed to represent the conditions prevailing in 24 h period starting at 12 h, predicted possible day has an error of about ±1 day.

The actual migration days in 1980–1986 decided from the change of number of rice planthoppers trapped by two nets are shown in the right column in Table 2. Since the rice planthoppers which have immigrated to a paddy field are sometimes caught in nets, the end of migratory flight extends 1 or 2 days under certain circumstances.

There were 37 events of actual migration and possible migration. Considering the prediction error mentioned above, 30 cases of possible migration coincided with actual ones. The prediction error of about ±1 day will be reduced by using the 850 mb weather chart at 09 h additionally. When we practically applied this method to the prediction of rice planthoppers migration, we used the weather charts at 09 h and 21 h everyday which were obtained from the weather facsimile broadcasted by Japan Meteorological Agency. In Table 2, the possible migrations in 1986 were predicted with the 850 mb weather charts at 09 h and 21 h. Therefore, most migrations in this period were well predicted.

From the comparison of the possible migration with the actual ones, it was found that major flight occurred when the axis of low-level jet stream existed in northern Kyushu, and minor flight occurred when the axis did not exist in northern Kyushu but low-level jet stream was wide to cover northern Kyushu.

In Table 2, there were four cases in which the possible migrations completely disagreed with the actual ones. The cases were classified into two groups. One group includes the cases on 19 June, 1982 and 23 June, 1983, and another includes

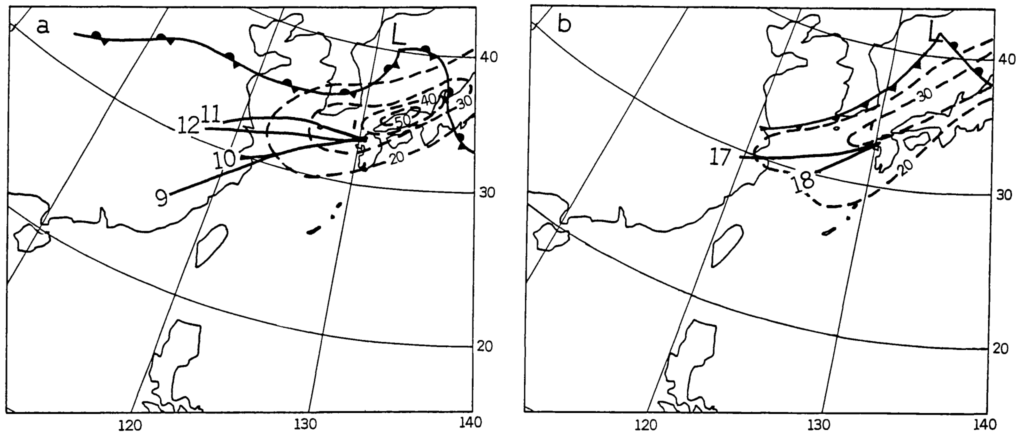

Fig. 2. Weather conditions on 9 to 12 (a) and on 17 and 18 (b) in July, 1985. Solid line shows the trajectory backtracked from Chikugo, and dotted line shows the contour of wind speed in knot unit on 850 mb weather chart (20 knots = 10 m/s). The Baiu front shows the position on the surface chart.

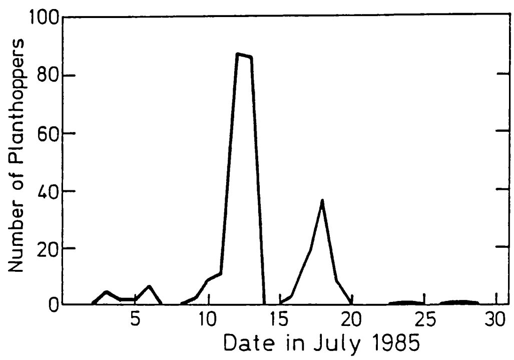

Fig. 3. Daily number of rice planthoppers catches in July, 1985 at Chikugo

those on 9 and 26 June, 1984. In the former group, the migrations were not predicted by the 850 mb weather charts, while a few whitebacked planthoppers were collected in two nets. As their peaks in number of catches were very small, we used the light trap data supplementally to confirm the migration. Since no rice planthoppers were trapped by nets before the day, it was considered that a migratory flight surely occurred. However, we could not decide whether they were the long distance migrations. In the latter group, the weather conditions in both cases were suitable for long distance migration. On these days, although the net trap data at Chikugo did not show the event of migration, the data at Isahaya in northwestern Kyushu about 65 km away from Chikugo showed clearly that migrations occurred on those days. However, the reason why rice planthoppers did not migrated to Chikugo could not be explained by our model. A meteorological analysis in small scale may be necessary to elucidate the phenomenon.

4. Conclusion

A hypothesis that rice planthoppers are transported in low-level jet stream was set up, and a method to predict long distance migration of rice planthoppers to northern Kyushu was proposed. The analytical procedure of this method is as follows:

1) draw contours of southwesterly wind above 20 knots in the area from southeastern China to Kyushu at 5 or 10 knots interval (wind speed is indicated in knot unit on the 850 mb weather chart),

2) decide the axis of low-level jet stream, and

3) draw trajectory upwind from Chikugo for 24 h in consideration of wind speed and direction.

When trajectory reaches southeast China, south of 30°N or Taiwan and the axis of low-level jet stream exists in northern Kyushu, rice planthoppers migration is predicted after about 24 h. When the axis of low-level jet stream does not exist in northern Kyushu but low-level jet stream is wide to cover northern Kyushu, minor flight occurs in northern Kyushu. While long distance migration is, at present, predicted on the previous day, it is possible to predict on 2 or 3 days before by using the prognostic chart obtained from the weather facsimile.

This method may be applied to the migration prediction in the other districts in Japan and to that of the other insects. A method to analyze the weather condition described above with computer was developed to use for the prediction operation (Watanabe et al., 1987).

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下層ジェット気流による九州北部における イネウンカ類の移動予知

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要　約

イネウンカ類はアジア各国の稲作の重要な害虫である。イネウンカ類の九州北部への長距離移動を予知するため，イネウンカ類が高度1,000－2,000 mに現われる下層ジェット気流に運ばれるという仮説をたて，その移動モデルを開発した。毎年の飛来時期（6－7月）の毎日の気象条件を，1980－1985年については21時の850mb 面天気図を，1986年については09時と21時の850mb 面天気図を用いて解析し，飛来が予想される日を決定した。一方，地上のネットトラップで得られたイネウンカ類の採集虫数から，実際の飛来波を決定した。両者はおおむねよく一致した。21時の850mb面天気図に加え，09時の850mb面天気図を用いることにより予測精度は向上することがわかった。最後に，本方法による予測手順が示された。

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