Occurrence and Population Density of the Rice Water Weevil, *Lissorhoptrus oryzophilus* KUSCHEL (Coleoptera: Curcurionidae) in the Higher and Lower Elevation Areas of Nagano Prefecture¹

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The rice water weevil (RWW), *Lissorhoptrus oryzophilus* KUSCHEL, has widely infested paddy fields which are located at altitudes of 270 to 1,200 m in Nagano Prefecture. The appearance and development of the RWW in the higher elevation area (alt. 1,150 m) were observed ca. 10–20 days later than in the lower area (alt. 400 m). Population density was higher in the higher elevation area than in the lower one. Immigrant adults that were collected immediately after transplanting laid eggs at temperatures of higher than 20°C in the laboratory. Almost all eggs were laid in the first 2 weeks after the start of rearing at 20–30°C. It is considered that the temperature of a flooded paddy field is favourable for oviposition by immigrant adults, and that intensive oviposition by adults prevented a delay in the subsequent larval occurrence. There was no remarkable difference in survival rate from egg to adult emergence between the higher and lower elevation areas and mortality during the winter is not particularly high. It is, therefore, considered that the periods before entering hibernation in autumn and before immigration into the paddy field in spring are crucial for survival in the next generation.

Key words: rice water weevil, *Lissorhoptrus oryzophilus*, higher elevation, occurrence, survival rate

INTRODUCTION

The rice water weevil (RWW), *Lissorhoptrus oryzophilus* KUSCHEL, was first discovered in 1976 in Aichi Prefecture, central Japan (TSUZUKI and ISOGAWA, 1976), and it rapidly spread throughout Japan (MATSUI, 1987). In Nagano Prefecture, the RWW was first observed in the south in 1980 (KOBAYASHI et al., 1980), and over the next 6 years it spread over most paddy fields located in the lower elevation areas. Recently, RWW infestation has even been observed in paddy fields which are located at higher elevations (ca. alt. 1,200 m). Many studies on the life cycle, occurrence and population changes of the RWW have only been done in the lower elevation areas in Japan (e.g. TSUZUKI et al., 1984; KAYUMI, 1986).

ICHIKAWA (1966) has divided the agricultural areas in Nagano Prefecture into higher and lower elevation areas based on a yearly mean temperature of 10°C. The higher eleva-

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tion agricultural area consists of areas located higher than 650 m in the northern part and higher than 800 m in the central and southern parts of Nagano Prefecture, whereas the lower elevation agricultural area consists of areas located lower than 650–800 m. In Nagano Prefecture, paddy fields are distributed from 270 to 1,200 m, and ca. 45% of these are distributed in the higher elevation area. Rice planting usually starts in early May in the lower elevation areas and in late May to early June in the higher elevation areas, corresponding to the different temperature conditions in each area.

Temperature conditions for RWW development, patterns of population fluctuation and survival rate may differ between the higher and lower elevation areas in Nagano Prefecture. However, the factors regulating population density of the RWW from generation to generation in the higher elevation area have not been studied.

We studied the occurrence, i.e., the period of immigration by overwintered adults into the field, the population density of overwintered adults and survival rate from egg to adult emergence in the higher and lower elevation areas in Nagano Prefecture. In addition, in order to clarify the factors related to the occurrence in both areas, the effect of temperature on reproductive performance was examined under constant laboratory conditions.

MATERIALS AND METHODS

1. *Occurrence of different stages in higher and lower elevation paddy fields.* The number of overwintering adults, larvae, pupae and newly emerged adults was counted at 7-day intervals from May to September in 1981 and 1982 at Kaida (alt. 1,150 m) and Nagiso (alt. 400 m). Mature seedlings of the *Nanei* variety were hand-planted on May 25th in the higher elevation paddy field, and young seedlings of the *Yamahikari* variety were mechanically transplanted on May 10th in the lower elevation paddy field. Figure 1 shows the locations and altitudes of each survey field.

Overwintered adults were counted on 100 rice plant hills randomly selected in the fields. Ten rice plant hills were removed from the field and taken to the laboratory together with the soil blocks (13 cm in diameter, 10 cm in depth) containing the rice roots. They were then washed with water, and the larvae and pupae were separated from the soil using the sieves (mesh size: 5 and 30) for counting. Newly emerged adults were examined by a net cage (1 m in length, width and height each with mesh size 20), which covered 20 hills. Adults trapped in the cages were counted and then released.

2. *Population change of overwintered adults in the paddy field.* During 1985 to 1994, the density of overwintered adults was surveyed in insecticide-free paddy fields in the higher elevation area (alt. 660 m) of Nagano city and lower elevation (alt. 360 m) of Suzaka. For each year the survey was carried out in the same four and two paddy fields in the higher and lower elevation areas, respectively. However, the number of fields surveyed was two in 1991 and three in 1993 at the higher elevation area because an insecticide was applied to the fields. The number of overwintered adults was counted after transplanting in each paddy field at 7-day intervals from mid-May to mid-June each year. One hundred rice plant hills were randomly selected for each field and the number of adults was counted. The yearly population density of adults for each field was expressed as the maximum density.

3. *Effect of temperature on reproductive performance of overwintered adults.* Immigrant adults were collected from insecticide-free paddy fields just after transplanting at Koshoku on June 12th in 1993 (Fig. 1). Because rice transplanting in this region had not taken place until June 10th, adults might not have oviposited by the 12th. Overwintered parthenogenetic

Fig. 1. Locations (●) and altitudes of survey fields in Nagano Prefecture. Figures in parentheses at each location show altitude.

females were individually reared in a test tube (1.6 cm in diameter, 18 cm in length). One rice seedling (30–40-day old) was supplied as food in a tube with a small amount of water. Adults were reared at constant temperatures of 15, 20, 25, 27.5, and 30°C under a 16 h light/8 h dark cycle with about 40 replications for each temperature. Rice seedlings were replaced daily, and the number of eggs oviposited in the stem tissue of the leaf sheath was counted daily until the oviposition ceased.

4. *Survival rate of the different developmental stages in the higher and lower elevation areas.* The number of eggs, larvae, pupae and newly emerged adults was counted in both a higher (Kaida: alt. 1,150 m) and lower (Iida: alt. 430 m) elevation area. Table 1 shows rice cultivation type and survey schedule in paddy fields at the 2 different elevation areas. Survival rate of different developmental stages was estimated from the data for seasonal prevalence using KIRITANI and NAKASUJI's method (1967). The surveys were carried out at 5- to 7-day intervals from May through September.

Table 1. Outline of the cultivation and survey schedule for different developmental stages of the rice water weevil in paddy fields

Locality (Altitude m)	Date of transplanting	Variety of rice	Interval of survey (May–Sept.)
Kaida (1,150 m)	May 25 1981	Nanei	7 days
	May 25 1982	Nanei	7 days
Iida (430 m)	May 20 1981	Yamahikari	5 days
	May 25 1982	Yamahikari	5 days

Number of rice hills surveyed was 10 and 5 for egg and other stages, respectively.

Paddy rice plant hills were transferred to the laboratory, and the number of eggs, larvae and pupae for each hill was counted. The 1st and 2nd stadia larvae were counted together, but the 3rd and 4th stadia larvae were counted separately at Iida. On the contrary, the 1st and 2nd stadia larvae and the 3rd and 4th stadia larvae were counted together at Kaida. Newly emerged adults were counted by net cage in the higher elevation area at Kaida. In the lower elevation area at Iida, however, the number of newly emerged adults was estimated by the number of empty cocoons and adults which remained in the cocoons.

RESULTS

1. Occurrence of different stages in the higher and lower elevation paddy fields

Figure 2 shows the occurrence of different developmental stages of the RWW in the higher (Kaida: alt. 1,150 m) and lower elevation paddy fields (Nagiso: alt. 400 m). Overwintered adults in the paddy fields reached a peak in early to mid-June in the higher elevation area and in late May to early June in the lower elevation area. The period of occurrence of larvae and pupae was 10–20 days later in the higher elevation area than that in the lower one. Newly emerged adults reached a peak in late August and early or mid-August in the higher and lower elevation areas, respectively.

The results of the present study indicated that the occurrence and subsequent development of the RWW in the higher elevation field were later than those in the lower elevation field.

2. Yearly population changes of overwintered adults during 10 years in paddy fields in the higher and lower elevation areas

Figure 3 shows the population changes of overwintered adults in paddy fields in the higher and lower elevation areas from 1985 to 1994. The population density varied with the year and the locality. Adult population densities in the higher elevation area were generally higher than those in the lower one. In the higher elevation area, adult population density was highest in 1986 with a value of 1.9 per hill, and the mean yearly adult population varied from 0.5 to 1.3 per hill. On the contrary, in the lower elevation area, an adult population that exceeded 1.0 per hill was observed only in 1985.

Overwintered adult density decreased gradually both in the higher and lower elevation areas. The adult density established a stable state at 0.5–0.7 and 0.2–0.3 individuals per hill in the higher and lower elevation paddy fields, respectively.

Fig. 2. Occurrence of the rice water weevil in the higher and lower elevation fields. A: higher area, Kaida. B: Lower area, Nagiso. — : overwintered adult, ■ : larva, □ : pupa, - - - : newly emerged adult.

3. Effect of temperature on reproductive performance of immigrant adults

Figure 4 shows the cumulative percentage of eggs laid per day at various constant temperatures. Adults did not lay eggs at 15°C. The adults began to lay eggs immediately after the start of rearing at temperatures higher than 20°C. The percentage of eggs laid increased rapidly during the first 2 weeks, and reached ca. 90% of the total number of eggs laid at temperatures of 20–30°C. Adults ceased oviposition 33, 26, 24 and 22 days after the start of rearing at temperatures of 20, 25, 27.5 and 30°C, respectively. The average number of eggs laid per female adult was 20.4, 40.2, 32.1 and 33.9 at 20, 25, 27.5 and 30°C, respectively. The average longevity of adults was 49.0, 37.4, 35.4 and 32.2 days at 20, 25, 27.5 and 30°C, respectively.

Under constant laboratory temperature conditions at 20–30°C, immigrant adults which were collected from the paddy field laid eggs intensively for ca. 2 weeks after the starting of rearing, and the number of eggs per female adult was relatively constant at temperatures of 25–30°C.

Fig. 3. Population density of overwintered adults per rice plant hill in Nagano Prefecture. A: Higher elevation field; alt. 660 m. B: Lower elevation field; alt. 360 m. Lines indicate yearly density.

4. Survival rate of different developmental stages in the higher and lower elevation areas

The survival rates of different developmental stages of the RWW at the higher (Kaida: alt. 1,150 m) and lower (Iida: alt. 430 m) elevation areas are shown in Fig. 5. Survival rates of the 2nd stadium larvae at Iida in 1981 and 1982 were 85% and 64%, respectively. However, the factors causing this difference in survival rate between the two years remain uncertain. The declining curve of the Iida population after the 2nd stadium larvae in 1981 and 1982 showed a similar pattern. The survival curves from the egg stage to the 4th larval stadium in the higher elevation area of Kaida in 1981 and 1982 showed an intermediate pattern between 1981 and 1982 at Iida.

The survival rate after the 4th larval stadium at Kaida was slightly lower than that at Iida. However, it is difficult to compare the survival rate from the 4th larval stadium to the time of adult emergence, because the density of newly emerged adults was surveyed by different methods in each elevation area, i.e., counting by net cage in the higher elevation area and counting of empty cocoons and those with alive adults in the lower elevation area.

DISCUSSION

Occurrence and rice cultivation schedule in 2 different elevation areas

The immigration time of the RWW from hibernacula into paddy fields is mainly controlled by temperature (MATSUI, 1987). The rice cultivation schedule in Nagano Prefec-

Fig. 4. Effect of temperature on the number of eggs laid by immigrant adults of the rice water weevil. ●: 20°C, ○: 25°C, ×: 27.5°C, ▲: 30°C.

ture is also determined by the temperature conditions of the respective paddy field elevations. A mean daily temperature of higher than 12.5°C is required for root growth of rice seedlings (Nagano Agricultural Experiment and Extension Division, 1990). Therefore, transplanting must be started in late April in the lower elevation area and late May in the higher elevation area in Nagano Prefecture (cf. Table 2). Because the rice growing season is limited by temperature conditions, it is necessary to cultivate an early ripening rice variety for the higher elevation area. The present study showed that the immigration of the RWW in the higher elevation fields occurred later than those in the lower elevation fields.

Daily maximum temperature usually rises to about 21 to 23°C (mean 15 to 17°C) during the peak of overwintered adults, i.e. mid- to late May and early to mid-June in the lower and higher elevation areas, respectively (cf. Table 2). The daily maximum temperature of the flooded water in a paddy field from May to June is higher than the daily maximum air temperature of ca. 6°C (TANAKA, 1982). It is believed that water temperature rose to a level higher than 25°C when overwintered adults immigrated into the paddy fields. These thermal conditions are favourable to adult oviposition both in the lower and higher elevation areas in Nagano Prefecture. GRIGARICK and WAY (1976) reported that adults

Fig. 5. Survival curves of each developmental stage of the rice water weevil in higher and lower elevation fields. △, 1981; ▲, 1982: Kaida. ○, 1981; ●, 1982: Iida.

Table 2. Daily mean temperatures during the rice growing season in 2 different elevation areas in Nagano Prefecture (1979–1990).

Locality (Altitude m)		Temperature						
		April		May			June	
		Mid-	Late	Early	Mid-	Late	Early	Mid-
Nagano (418 m)	Daily mean	9.8	12.6	14.5	15.3	16.7	19.3	19.9
	Daily max.	15.6	19.3	21.0	21.1	22.8	25.0	25.1
Kaida (1,130 m)	Daily mean	5.4	8.2	9.8	11.0	12.2	14.5	15.2
	Daily max.	11.3	15.5	16.7	17.3	19.1	21.0	20.9

collected in a field after it had been flooded in May oviposited over a period of 40 to 65 days. TUZUKI et al. (1984) pointed out that the oviposition peak was observed 5 to 7 weeks after rearing of overwintered adults. TAKEDA (1990) stated that oviposition of overwintered adults peaked 4 to 5 weeks after rearing. These results were obtained from overwintered adults that were collected from overwintering sites. However, overwintered adults that are taken from overwintering sites may be in a different stage of post-diapause development. On the other hand, in the present study, immigrant adults that were collected from the paddy fields immediately after transplanting were used. These immigrant adults oviposited during the first two weeks after rearing (Fig. 4).

It appears that intensive adult oviposition prevents a delay in the subsequent larval occurrence in late planted paddy fields, and relatively higher temperatures of water in flooded paddy fields contributes to the development of RWW. Thus, the occurrence of

RWW in paddy fields is well synchronized to the rice cultivation schedule in Nagano Prefecture.

Survival and population fluctuation in 2 different elevation areas

There was no remarkable difference in survival rate from egg to adult emergence between the higher and lower elevation areas. KAYUMI et al. (1984) reported that mortality from the egg to the young larval stage was important in determining the survival rate of the RWW.

The results of 10 years of survey (1985–1994), however, indicate that the population density of the RWW became stable, and this stable density remained at a higher level in the higher elevation area than in the lower one. The stable state in each area seems to be an equilibrium density as pointed out by KAYUMI et al. (1984). But the population density in 1981 and 1982 (Fig. 2) was lower in the higher elevation area than in the lower elevation area. This may have resulted from the fact that invasion of the RWW to the higher elevation area was delayed one year compared to that in the lower area.

Factors acting on the overwintering period may contribute to determining the survival rate of the RWW. KOBAYASHI et al. (1988) reported that the survival rate of overwintering adults in hibernacula was 64–90% in the higher elevation area. SATO (1982) demonstrated that heavy snow fall did not act as a serious selection pressure on the survival of the RWW during the winter. From these results, it was postulated that the mortality during winter was not so high.

It is therefore considered that the periods before entering hibernation in autumn and before immigration into the paddy field in spring are crucial for survival of the next generation. But, there is no information on survival rate during these periods. Further detailed investigations are needed to clarify the survival rate and mortality factors of the RWW during those periods.

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