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Effect of drainage on damage to direct-sown rice by the apple snail *Pomacea canaliculata* (Lamarck) (Gastropoda: Ampullariidae)

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Abstract

Damage to direct-sown rice by the apple snail, *Pomacea canaliculata*, was investigated in two semi-field experiments using rain-free experimental plots (each 2 m^2 in area). Four snails (2 snails/m^2), with shell heights of approximately 19 mm or 24 mm, were released in the plots at the time of sowing. When the plots were irrigated soon after sowing (0 or 4 days after sowing), the snails fed avidly on young seedlings and no plants became established. Drainage after sowing greatly reduced snail damage. Eighty seven to 94% of plants as compared to the control plots without snails were established when plots were drained for two weeks. Three weeks of drainage could almost prevent damage by snails (95–99% of plant establishment) when the plant age was at about the 5.0 leaf stage. Snail damage was more severe when herbicide was applied. Water management after sowing in direct-seeded rice is discussed in view of reducing snail damage.

Key words: *Pomacea canaliculata*, apple snail, direct seeding, drainage, rice

INTRODUCTION

The apple snail, *Pomacea canaliculata*, was introduced to Japan and many other countries in South-east Asia in the early 1980s (Habe, 1986; Mochida, 1991; Litsinger and Estano, 1993; Halwart, 1994). This fresh water snail from South America was initially introduced to Asia as a source of human food. However, commercial markets failed, and discarded and escaped snails invaded rice ecosystems. In Japan, damage to rice by the snail was first recorded in 1984 (Hirai, 1989). The distribution of the snail gradually expanded mostly in southern Japan, and reached ca. 63,000 ha of paddy fields by 1997. The acreage damaged by snails also increased, to a maximum of ca. 4,700 ha of paddy fields in 1993.

Management of apple snails has generally been achieved in transplanted rice fields in Japan. Snails do not feed on transplanted rice in shallow water (Ozawa et al., 1988). Keeping paddy water shallow thus helps to control snail damage and is now the most commonly used management practice (Wada, 1997). Transplanting older rice is also effective because rice gradually becomes resistant to the snails as it grows. Using these two cultural practices, with occasional pesticide applications, snails can be reasonably well controlled in transplanted rice. However, in poorly drained paddy fields, or in regions where very young seedlings are transplanted, apple snails still remain important rice pests which are very difficult to control.

The Japanese Government has encouraged farmers to adopt direct-sowing of rice to reduce the costs of production. In direct-sown rice fields, however, the snails pose a serious threat because they feed avidly on very young seedlings. Farmers can not adopt such a practice in areas where the snails occur. Apple snails represent an important constraint on the implementation of direct-sowing of rice in southern Japan (Wada, 1997).

Although apple snail damage to transplanted rice has been studied by some workers (Oya et al., 1986, 1987; Yamanaka et al., 1988), no intensive research, except for short notes (Mihara, 1997; Fukushima et al., 1998), has been published on the damage done by the snails to direct-sown rice. Mobility of snails is reduced when the paddy water is kept shallow, and drainage immobilizes them. Thus, we report, in this paper, the effect of drainage after sowing on the establishment of rice in the presence of apple snails.

MATERIALS AND METHODS

General method. Snails used for experiments were collected in paddy fields or waterways in Kikuchi-gun, Kumamoto Prefecture, a few days before use. Concrete pools (2 m^2: 1×2 m) containing paddy soil were used as experimental plots. The plots were covered with a piped vinyl house having an open gap (about 1 m from the floor level) on each side. The experimental plots were thus shielded from rain but not from wind. Water levels in the plots were controlled with drains and tap water.

Before sowing, rice seeds were soaked in water for 48 h to induce germination. Seeds were coated with calcium peroxide (Calper 16: Nippon-kayaku Co., Japan). Calcium peroxide provides oxygen to rice and promotes germination and the establishment of seedlings in water. Two hundred seeds were sown per plot (100 seeds/m^2). The plots were surface-drained for varying periods after sowing and water was occasionally added to keep the soil moist. After the plots were irrigated plots, the depth of the water was kept at 5 to 10 cm. There were two replicate plots per treatment in each of the following two experiments.

Experiment I. Rice seeds (variety: yumehikari) were sown on 13 September, 1996. Four snails (two snails/m^2) with shell heights of 19.5 ($\pm$1.3; range) mm were released in each experimental plot soon after sowing. No snails were released in control plots. Plots were drained for 0, 7, 10, 14, or 20 days after sowing. Herbicide (9% ACN granular; 6 g/plot) was applied at weekly intervals to the plots in one of the treatments to prevent occurrence of algae. Numbers of healthy rice plants and numbers of plants partially damaged by snails were counted on 8, 11, 15, 21 and 39 days after sowing. Rice growth stage in leaf number without an incomplete leaf was also checked on each census day. Healthy and partially damaged plants on day 39 were regarded as established plants. The average air temperatures recorded at a nearby meteorological station during the first three weeks of the experiment were 24.5, 22.1 and 20.1°C, respectively. The temperature around the experimental plots was likely to be slightly higher than these temperatures.

Experiment II. In order to cope with higher snail density (equivalent to bigger snails) and to check damage in the proper planting season (rice is sown in June in Kyushu), we conducted experiment II. Rice seeds (variety: hinohikari) were sown on 23 June, 1997. Four snails with shell heights of 24.0 ($\pm$1.5; range) mm were released in each plot. The plots were drained for 0, 4, 7, 10, 14 or 21 days after sowing. Established rice plants and plant growth stage were recorded every week until 30 days after sowing. Average air temperature in the vicinity of the plots was about 27°C throughout the study.

RESULTS

Experiment I

The snails fed avidly on germinating young seedlings in some treatments. No plants became established throughout the experimental period in the plots irrigated just after sowing (D0) (Fig. 1, left). Drainage greatly reduced snail damage. Sixty-nine and 82 plants/m^2, corresponding to 73 and 86% of those in the control plots, became established in plots which were drained but kept moist for 7 (D7) and 10 (D10) days after sowing, respectively (Table 1). Most plant loss occurred soon after irrigation. More than 90% of plants became established in the treatments with 14 and 20 days of drainage (D14, D20). Herbicide application increased snail damage. The numbers of established plants were significantly lower in the plots with herbicide applications (D7-H) than those in the plots without applications (D7), in the same 7-day drainage regime.

Experiment II

Larger snails (shell height: 24 mm) were used in this experiment. No plants became established in the treatments with 0- and 4-day drainage, though a few plants were once observed on day 8 in D4 (Fig. 1, right). Although drainage had the same effect as in Experiment I, snail damage was much heavier in Experiment II. In particular, plant numbers in D7 were reduced from 86 to 24/m^2 during the first week of irrigation (8–15 days after sowing), and only 16 plants finally became established on day 30 (Fig. 1, right). As the period of drainage increased, loss of plants was greatly reduced. Seventy-eight and 88 plants, corresponding to 87 and 99% of

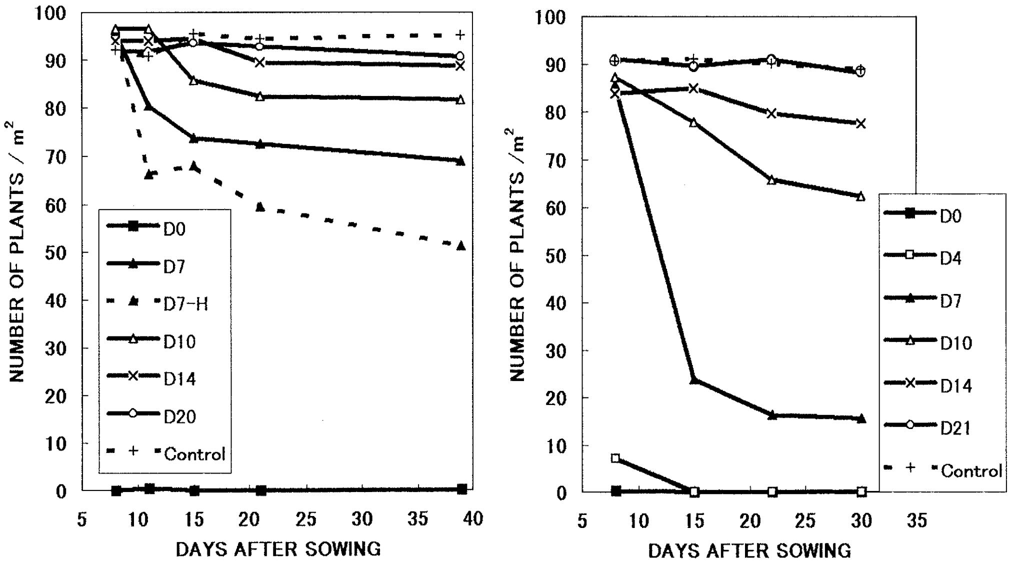

Fig. 1. Changes in the numbers of rice plants after direct sowing in Experiment I (left) and Experiment II (right). Explanations for the symbols which designate the different treatments are given in Table 1.

those in the control plots, became established in the D14 and D21 plots, respectively (Table 1). In these two treatments, the majority of plants reached 3.6–4.1 and 4.6–5.3 leaf-stage at the initiation of irrigation. Very few, if any, plants were lost in any treatment after day 21 (Fig. 1). Plant consumption by snails was estimated by comparing the numbers of plants established in the control and other plots (Table 1). The larger snails in Experiment II consumed more rice than their smaller counterparts in Experiment I, the former feeding on 31 plants per snail in D7 plots and the latter feeding on 14 plants in the equivalent treatment. The consumption of germinating seedlings by snails was calculated as 45 to 48 seeds in the D0 and D4 plots in both experiments. However, the real capability of snails to feed on young plants is probably much greater than these values because the snails fed on all the young seedlings available soon after irrigation.

DISCUSSION

Drainage greatly reduced snail damage in direct-sown paddy rice. Snails tended to bury themselves in the soil or move to places with deeper water when they encountered drained fields or fields with shallow water. Mihara (1997) reported that a satisfactory rate (82%) of rice was established with 9% of rice damage by snails when a field was drained for 25 days after sowing. Fukushima et al. (1998) found that 10 and 0% of rice seedlings in experimental pots were lost due to snail damage when the pots were irrigated at the three and five leaf-stage, respectively. This study agrees closely with our findings that two weeks of drainage after sowing can greatly reduce damage and three weeks of drainage can prevent it, since it takes about two and three weeks after sowing for rice to reach the three and the five leaf-stage, respectively.

Damage to rice by snails is affected by various biological and physical factors. Larger snails attack more seedlings (Table 1). According to Oya et al. (1986), food consumption by snails increases proportionally with the cube of shell height. The extent of damage caused by snails is thus a function of both snail density and size. The snail density used in Experiment II (two 24 mm snails/m^2) appears to have been an adequate density at the season of rice sowing, since the majority of overwintering snails have shell heights of about 10 mm and very few snails exceed 24 mm in the beginning of the rice growing season (Ozawa and Makino, 1989; Shobu, 1996). Low temperatures in the latter half of Experiment I may have reduced snail activity and hence damage. On the other hand, low temperatures caused a delay in rice development, thus keeping the rice susceptible to snails in the experimental period. Generally, rice transplanted in seasons with low temperatures is less damaged by snails (Wada, 1997).

Table 1. Effect of drainage after sowing rice on reducing damage by *Pomacea canaliculata*

Experimental plot[a]	Duration of drainage (days)	Snail density (snails/m^2)	Plant age[b] in leaf number at irrigation	No. of plants established at the final census (S.D.)[c] (plants/m^2)	Relative % of plants established[d]	Estimated no. of plant loss by a snail[e]
Experiment I						
D0	0	2	—	0 (0) a	0	>47.5
D7	7	2	1.0–1.8	69.0 (7.0) c	72.6	13.8
D7-H[f]	7	2	1.0–1.8	51.3 (5.3) b	54.0	24.3
D10	10	2	1.8–2.8	81.8 (1.3) d	86.1	6.6
D14	14	2	2.8–3.6	88.8 (3.8) de	93.5	3.1
D20	20	2	3.6–4.3	90.8 (2.3) e	95.6	2.1
Control	7	0	1.0–1.8	95.0 (1.3) e	100	0
Experiment II						
D0	0	2	—	0 (0) a	0	>45.0
D4	4	2	—	0 (0) a	0	>45.0
D7	7	2	1.5–2.1	15.5 (0) b	17.5	30.9
D10	10	2	—	62.3 (6.0) c	70.1	9.5
D14	14	2	3.6–4.1	77.5 (4.3) d	87.3	3.1
D21	21	2	4.6–5.3	88.0 (2.1) e	99.2	0.9
Control	7	0	1.5–2.1	88.8 (1.8) e	100	0

[a] Snails with 19.5 (±1.3) mm shell height were used in Experiment I; snails with 24 (±1.5) mm were used in Experiment II.

[b] The range of the plant age in the majority of plants when the plot was irrigated. The age is expressed as the plant age in leaf number without an incomplete leaf.

[c] Within a column, treatments followed by the same letter are not significantly different at the 5% probability level, according to chi-square tests in multiple independent samples (Marascuilo and McSweeney, 1977).

[d] Percentage of established plants in each experimental treatment relative to the number of established plants in the controls.

[e] Numbers of plants that were entirely eaten were estimated from the difference between the numbers of established plants in the experimental and control plots. Plants that established but were damaged by *P. canaliculata* were scored as half-damaged (0.5).

[f] Herbicide was applied every week.

Snail damage increased when herbicide was used. Algae (Zygnemataceae) were not observed in the plots treated with herbicide but were common in the other plots soon after irrigation. Few other weeds grew in any of the plots. Algae are probably important as food sources for snails in paddy fields, and snail damage is therefore likely to be worse in algae-free plots.

The practice of wet direct seeding in Japanese paddy fields differs in some respects from that in other countries. Elsewhere in Asia, it is common for farmers to drain or puddle paddy fields after broadcasting germinating seeds (De Datta and Nantasomsaran, 1991; Fujii et al., 1995). In contrast, irrigation of fields just after sowing has been recommended until recently in Japan in order to improve weed control (Okuma et al., 1984; Oba, 1997). Sowing rates are also less in Japan, compared with rates used in South Asian countries: 20–35 kg (dry seed weight/ha) is recommended in Japan (Kagayama et al., 1984; Nishigaki et al., 1991) whereas 60–100 and 100 kg is recommended in Malaysia (Yasunobu, 1997) and the Philippines (De Datta and Nantasomsaran, 1991), respectively. Direct-sown paddies in Japan seem to suffer greater snail damage than direct-sown paddies elsewhere in Asia. With regard to plant establishment, 80 plants/m^2 has been considered the ideal plant density in Japanese practice (Ogata et al., 1997). However, since snails do not feed on plants randomly but patchily, it is difficult to determine the lower limit of plant density that will resist snail attack.

From the results obtained in this study we conclude that a considerable period of drainage after sowing (two or three weeks) should be adopted in direct-sown paddy fields in order to reduce snail damage. Otherwise, extremely low snail densities must be attained because snail damage to young seedlings can be very large. For example, a snail with a shell height of 24 mm has been observed consuming totally more than 400 germinating young seedlings (Wada, unpublished data). On the other hand, weed problems are exacerbated by increasing the period of drainage. Fortunately, due to the recent registration of new herbicides, it has become possible to keep paddy fields drained for a week or more after sowing. Drainage after sowing has also recently been recommended for improved plant establishment (Takahashi et al., 1998; Yoshinaga et al., 1998). The optimal extent of drainage after sowing should be determined by considering the local status of both snail and weed pests.

Drainage can be effective in controlling snail damage, but simplistic adoption of it does not always solve the problem. If the drainage of residual water is insufficient, snail infestations can spread rapidly. This can be especially so after heavy rain. Making ditches (Fukushima et al., 1998) or ridging (Mihara, 1997) can enhance drainage, but neither of these seems to be fully successful.

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