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Decrease in density of the apple snail *Pomacea canaliculata* (Lamarck) (Gastropoda: Ampullariidae) in paddy fields after crop rotation with soybean, and its population growth during the crop season

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Abstract
We compared the densities of the apple snail, *Pomacea canaliculata*, between fields that had been planted with soybean or rice in the previous summer. The densities of overwintered snails soon after irrigation at the beginning of rice planting were all very low in the fields after soybean. These values were much lower than the control threshold for the apple snail in direct seeding. Therefore, crop rotation with soybean seems to be a good economic measure to control the apple snail in direct seeding. The snail populations increased very rapidly in both types of fields, in particular, after soybean. Within two and a half summer months, the snail densities in the fields after soybean reached almost the same level as those in the fields after rice. This rapid population recovery in fields after soybean seems to be caused by density-dependent growth and reproduction in this species.

Key words: Apple snail; crop rotation; direct seeding; *Pomacea canaliculata*; soybean

INTRODUCTION

The freshwater apple snail, *Pomacea canaliculata*, originating from South America, was introduced as human food into Japan and many other Asian countries in the early 1980s (Halwart, 1994; Wada, 1997). However, the commercial market failed and it adapted superbly rice ecosystems, becoming a pest in many Southeast and East Asian countries. It feeds avidly on germinating sprouts and young, soft seedlings. Therefore, it causes much more damage to direct-seeded rice than to transplanted rice (Wada et al., 1999; Wada, 2002). In countries such as the Philippines, Vietnam, and Thailand where direct seeding is popular, it has become one of the most important rice pests. Although the Japanese Government has been promoting direct seeding to reduce rice production costs, the proportion of rice fields that are direct-seeded is still small in Japan. In Kyushu, southern Japan, where the apple snail is distributed, it is one of the major constraints on the adoption of direct-seeded rice culture.

The shell of the apple snail is thin compared with that of viviparid freshwater snails native to Japan. Partly because of this, the apple snail seems to have less resistance to desiccation. In addition, the snails are often killed by rotary tillage (Takahashi et al., 2002). Therefore, cultivation of an upland crop in paddy fields may drastically reduce the apple snail density. If so, crop rotation with an upland crop such as soybean could be a good measure against the apple snail in direct-seeded rice. To test this hypothesis, we investigated the densities of overwintered apple snails in paddy fields, which had been planted with soybean in the previous summer, comparing them with densities in paddy fields without crop rotation. In addition, we investigated population build-up of the apple snail after the onset of rice cultivation in the two types of fields.

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MATERIALS AND METHODS

Paddy fields surveyed. The densities of the apple snails were investigated in mid and late June 2000 in paddy fields in Akitsu, Kumamoto City, Kumamoto Prefecture and Yasu, Asakura-gun, Fukuoka Prefecture, Japan. In both regions, a rice-soybean block rotation system had been implemented in considerably large areas (Akitsu: 153 ha, Yusu: 206 ha). In this system, the area was divided into three blocks, and in each block, soybean was planted once every three years (thus, rice was planted twice every three years). In each region we selected several to ten paddy fields, which had been planted with soybean as a summer crop in the previous year and an approximately similar number of fields which had been planted with rice. A fine net was placed in advance at the water inlet of each field before irrigation to prevent snails from invading the field through waterways. After transplanting or sowing rice, we intended to carry out the surveys for snail densities in all fields selected. However, we canceled density surveys in the fields where molluscicides had been applied or paddy water was not clear enough to do a survey. Ultimately, we were able to carry out surveys for overwintered snail densities in five fields owned by different farmers for each type of field in each region (thus, a total of 20 fields were surveyed in both regions). The acreage of the fields surveyed varied from 0.14 to 0.6 ha with an average of ca. 0.3 ha. The fields were mostly transplanted fields except for four fields which were directly sown by a submerged hill-seeder (Yoshinaga et al., 2002) in Yasu region.

Prior to the surveys after net setting, many snails were caught in some nets placed at the water inlets in Yasu, but no snails were caught in Akitsu. This is probably because water was pumped up from creeks and the water supply pipes were covered with screens to block snails in Akitsu. Thus, it was not likely that snails invaded fields from waterways during the crop season in Akitsu. In this region, the snail densities were again investigated at the milk-ripe stage of rice in early September in the same paddy fields as those in June to calculate population increase during the crop season. In Yasu, many snails probably entered the fields through waterways after the surveys, because we removed the nets set in the inlets. Therefore, we did not carry out the second surveys for snail densities in September there.

Snail density surveys in June. The surveys for densities of overwintered snails were basically carried out within a week after the introduction of the water in transplanted fields. In direct seeding in Yasu, however, the fields were usually drained after sowing for a week or ten days. Without paddy water we could not carry out the density surveys, and therefore, the surveys were carried out within a few days after the drainage period when water was re-introduced into the fields.

For the snail density survey, a square steel frame ($1\,m \times 1\,m$) was prepared. This frame was placed as a survey quadrat at certain points in a submerged paddy field, and the snails inside the quadrat were collected by hand. In the paddy field after rice, 12 quadrats were systematically selected for estimating the density of overwintered snails: six near levees and six in the center of the paddy field. In a few fields after rice where snail densities were low, 24 quadrats were selected (12 near levees and 12 at the center). In the paddy fields after soybean, 24 quadrats were similarly selected. When we could find no snails or very few snails in the 24 quadrats in a field, we continued to look for snails for a considerable time (10 to 20 min by a few persons) to determine the presence or absence of snails and to increase snail samples for size measurement. All snails found were brought into the laboratory, and their shell heights were measured with calipers to the nearest 0.1 mm.

Snail density surveys in September. A 3-m string was placed along rice rows (0.33 m wide) in a submerged paddy field to make a survey quadrat (nearly $1\,m^2$: $3\,m \times 0.33\,m$). Eight quadrats were systematically selected near levees. Snails measuring 15 mm or larger in shell height inside each quadrat were collected by hand. In addition, a plastic frame ($0.1\,m^2$: $0.2\,m \times 0.5\,m$ wide, 0.2 m deep) was placed in each quadrat. Small snails (<15 mm shell height) inside the frame were collected together with paddy soil by a fine fish net. The snails collected were measured for shell height with calipers in the laboratory. Since the snails develop to maturity with shell heights reaching ca. 25 mm (Kaneshima et al., 1986; Estoy et al., 2002), snails 25 mm or larger were regarded as adults.

Table 1. Apple snail densities in paddy fields soon after irrigation in relation to the previous summer crop

Previous crop	No. of paddies	Snail density/m²			
		Mean±S.D.	*t*-test[a]	Minimum	Maximum
Akitsu region					
Rice	5	3.81±4.45	$p<0.01$	0.83	11.5
Soybean	5	0.14±0.16		0[b]	0.33
Yasu region					
Rice	5	1.72±2.40	$p<0.01$	0.17	5.92
Soybean	5	0.07±0.05		0[b]	0.13

[a] The density data (x) were statistically analyzed after transformation to $\log(x+1)$.
[b] Snails were found outside the density-survey quadrats in the fields.

RESULTS

The densities of overwintered snails after rice varied from 0.17 to 11.5/m^2, with means of 3.81/m^2 in Akitsu and at 1.72/m^2 in Yasu (Table 1). On the other hand, the snail densities were very low in the paddy fields after soybean. The maximum density was 0.33/m^2 in one of the fields at Akitsu. The means of the densities were 0.14/m^2 in Akitsu and 0.07/m^2 in Yasu. There were three fields (one in Akitsu and two in Yasu) where no snails were found in 24 quadrats (thus, the estimated densities were 0, but when the population growth rate was calculated in each field, a density of 0.01/m^2 was tentatively used). However, snails were found outside the quadrats in these fields, indicating that snails were not eradicated in any field where soybean had been planted during the previous summer. The shell height of overwintered snails varied from 5 to 30 mm in both regions (Fig. 1). The majority were 7.5 to 20.0 mm (covering 91%) in Akitsu and 10.0 to 22.5 mm (89%) in Yasu. The snails collected in the paddy fields after soybean were slightly smaller in Akitsu and bigger in Yasu than the snails in the fields after rice. These differences in size were statistically significant in both regions.

The snail populations increased greatly for two and a half summer months. Total snail densities varied from 32 to 609/m^2, with means of more than 250/m^2 in both types of fields (Table 2). The majority (99.5%) were juveniles. Adult densities were low: the means were 1.58/m^2, with a maximum of 2.0/m^2 in the fields after rice, and 0.85/m^2, with a maximum of 1.6/m^2 in the fields after soybean. The differences in the mean densities of both juveniles and adults were not significant between the two types of fields. The frequency of each size class of snail is shown in Fig. 2. Size distributions were almost similar in both types of field, except that there were no snails larger than 37.5 mm in the fields after rice.

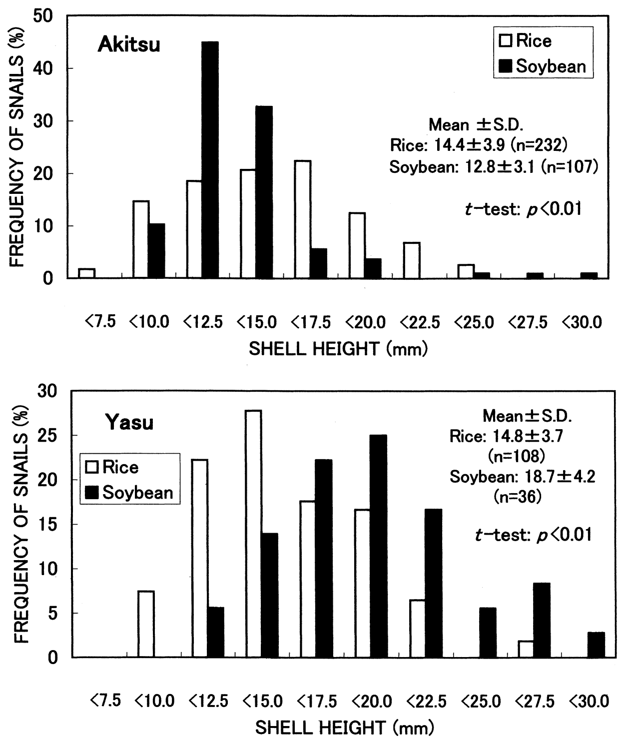

Fig. 1. Distribution of snail size soon after irrigation in fields, which were planted with rice or soybean in the previous summer.

The densities of juveniles and adults in the autumn were plotted against the densities of initial overwintered snails (including both juveniles and adults) in June (Fig. 3). There was no correlation between the initial densities and the autumn densi-

Table 2. Snail densities[a] in paddy fields at the milk-ripe stage of rice in Akitsu region

Previous crop	No. of paddies	Snail density/m^2			Shell height (mm)		
		Juvenile	Adult	Total (±S.D.)	Juvenile	Adult	Total (±S.D.)
Rice	5	262.5	1.58	264.1±207.0	7.3	31.7	7.9±4.3
Soybean	5	255.0	0.85	255.8±244.5	6.5	36.1	6.7±2.0
	t-test[b]	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[a] Snail densities near levees were estimated in early September. Snails larger than 25 mm were regarded as adults.
[b] The density data (x) were statistically analyzed after transformation to $\log(x+1)$. The mean in each field was tested at the 5% confidence level, where n.s. indicates no significant difference.

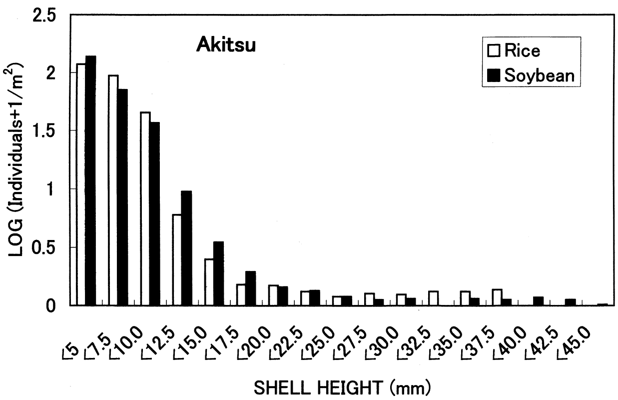

Fig. 2. Size distribution of the snails collected in the paddy fields at the milk-ripe growth stage of rice in relation to the previous summer crop (rice or soybean). Snails were collected in early September at Akitsu, Kumamoto.

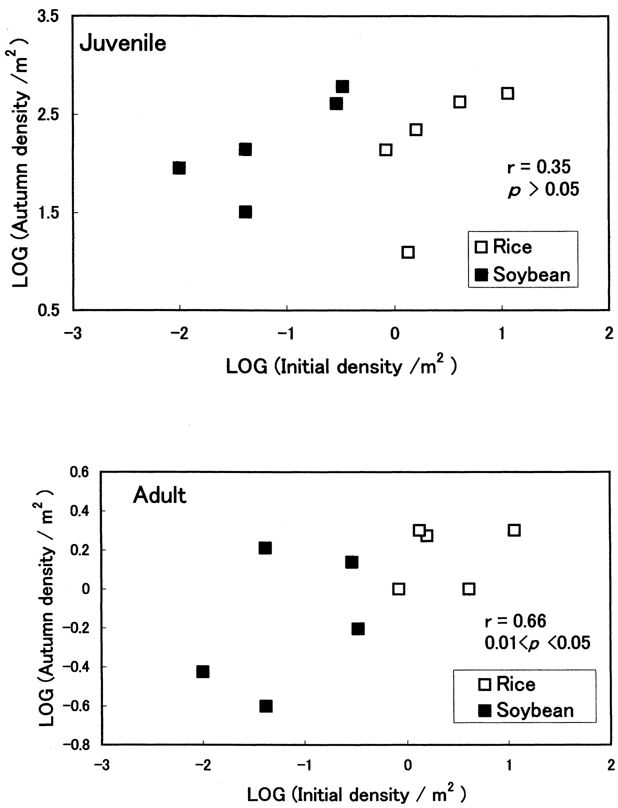

Fig. 3. Relationship between initial densities (including juveniles and adults) and densities at the milk-ripe stage of rice (autumn densities) in the apple snail populations of the Akitsu region.

ties for juveniles. On the other hand, a positive relationship ($r=0.66$) was found for adults.

DISCUSSION

Snail densities were very low in the paddy fields after soybean without exception in both Akitsu and Yasu regions. However, our result does not represent a direct evidence of the contribution of crop rotation to the low densities, since we did not check the snail densities before soybean cultivation in these fields. Nevertheless, we could find no other factor that could account for the difference in snail densities between the two types of fields except the kind of crops grown the previous season. In fact, the fields in both types were selected for the survey by similar procedures in the two regions. Moreover, great population increases of the snails after onset of rice cultivation, which we observed in the fields after soybean, indicates that these fields were basically suitable for similar snail multiplications as the fields after rice. Thus, we concluded that the great reduction of the snail densities in the fields after soybean, as compared to the densities in the fields after rice was attributed to the cultivation of soybean in the previous season.

The snail densities after crop rotation with soybean were much lower than the tentative control threshold for direct seeding, i.e., 0.5 snails/m^2 (Kiyota and Sogawa, 1996). Thus, we can expect that direct seeding of rice could be carried out without extra control measures in such fields, if snail invasion from waterways is properly blocked. We observed extremely low snail densities in a few paddy fields after tomatoes. Fukushima (pers. com.) made a similar observation in fields after cabbage. Therefore, crop rotation with not only soybean but also other upland crops seems to have similar effects. If the snail densities go down consistently below the control threshold, crop rotation becomes a good economic measure for snail management in direct seeding. This strategy may be promoted by the political situation whereby Japanese farmers are often forced to grow other crops in large areas (30–40% in Kyushu in recent years) of their paddy fields, because of a Government policy to reduce overproduction of rice.

Snail populations increased greatly after irrigation for two and a half months in both types of field in Akitsu. Snail density is usually higher near paddy levees than in the center of the fields (Hirai et al., 1986). Therefore, if we use the data for densities only near the paddy levees in the early summer survey (the mean densities were $4.50/m^2$ in the fields after rice, and $0.27/m^2$ in the fields after soybean), the populations in early autumn attained ca. 60-fold in fields after rice and ca. 940-fold in fields after soybean on average. Although snail densities were very different between the field types in June, the populations reached almost the same level by early September. This is attributed to density-dependent growth and spawning in this snail suggested by Tanaka et al. (1999), who reported that overwintered females at a low density mature very fast, and that their egg production is a negative function of snail density. Thus, the population recovered rapidly in the fields after soybean. This mechanism explains the absence of a correlation between the initial densities and the autumn densities of juveniles in Fig. 3. On the other hand, there was a positive correlation between the early summer densities and the autumn densities of adults (Fig. 3). It is natural that the adult populations comprised mostly overwintered snails.

According to the present data, the effects of crop rotation last only one year, due to the rapid population recovery after onset of rice cultivation. Mortalities of field snails during upland crop cultivation and the following season seem to depend on climate, in particular dryness in summer (Miyahara, 1987) and coldness in winter (Shoubu et al., 2001). Thus, total effect of the crop rotation and its durability must be influenced by the seasons and regions. In this respect, more data accumulation is necessary for a full understanding of the effects of crop rotation. Simultaneously, other control measures, which minimize rice damage even in high snail-density fields, should be developed for snail management in direct-seeded paddy fields, since availability of the fields after upland crops are often limited.

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