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Development of an Intelligent Robot for an Agricultural Production Ecosystem (V) – Experiments on Predation of Paddy by Golden Apple Snails –

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Experiments were carried out in small lots at Kyushu University Farm in order to measure the parameters of predation and get models of the biomass of rice plants and weeds and population of golden apple snails over different phases of season of rice production ecosystem.

INTRODUCTION

The activity of snails is based on water temperature and water depth. The growth of rice plants depends on the predation by snails and the competition against weeds. The predation of rice plants and weeds by snails involves parameters such as, the shell height and weight of snails, the attack efficiency of snails, reproduction rate of snails, mortality and intrinsic rates of snails and predation rate of superior plants by snails. In this study, we will establish several experiments in order to obtain the parameters of predation and model the populations of snails and biomass of rice plants and weeds during the rice crop season at Kyushu University Farm.

MATERIALS AND METHODS

Experiments about the predation of plants and weeds by golden apple snails

In order to estimate the parameters of predation considering the interaction among golden apple snails, rice plants, and weeds, 16 experimental plots (1×3 m) were set up for each treatment at water depth 5 cm of height in Kyushu University Farm on June 23th and 28th. The treatments consisted of 8 plots for mortality and birth rate with only four snails: 2 female snails averaging 34.3 mm of shell height and 9.52 g of weight and 2 males averaging 34 mm of shell height and 8.82 g. In addition, 2 lots for consumption of weeds by only 0 snails, 2 plots for consumption of weeds by only 1 snails, 2 plots for consumption of weeds by only 2 snails and 2 plots for consumption of weeds by only 3 snails were set up.

Measuring populations, shell height and weights of snails

We measured the amount, weights and shell heights of snails inside of all lots for 168.2 m^2 in these experiments and another experiments on July 8th considering snails have at least a shell height from 20 mm to 40 mm because in this range of shell heights the snails are more destructive (Joshi *et al.*, 2002 and Luna and Nakaji, 2008, Luna *et al.*, 2008a, Luna *et al.*, 2008b). We did again a sampling for snails over 120 m^2 on July 11th of 2008 but now we also classified them by gender.

We modeled the biomass ate by snails using the sigmoidal form of Viggs and Burley (Viggs *et al.*, 1991), which considers the temperature response function and we get the predation rate by using the Richards equation (Richard, 1959) as follows,

$$P_r = W_d A_p \left(\frac{C_{\max}}{1+e^{-\alpha_t (T - T_{inf})}} \right) \quad (1)$$

Where, P_r: predation rate of plants (rice plants or weeds) in the paddy, W_d =snail activity coefficient according to the water depth, A_p =snails density or abundance, C_{max} = maximum consumption of rice plants by snails per day, e=2.718, α_t =a slope parameter, T =water temperature (Celsius degrees) and T_{inf} =water temperature (Celsius degrees) in the inflection point of the curve.

The W_d is calculated considering a shallow water depth of 10–20 mm should be maintained to immobilize snails and prevent them from attacking rice plants. We considered that the snails at T_{inf} of 12 Celsius degrees will start hardly to move around the paddy.

Measuring the water temperatures in paddy and activity of snail

We measured the water temperatures in paddy from day of transplanting (June 20th) until day which rice plants have reached 400 mm of height (July 20th). We also conducted experiments in the laboratory on November 4th and 5th, in order to know the activity of snail based in the speed of snail at different temperatures. We used 4 snails whose shell heights were between 22 to 25 mm. The water depth was 30 mm. The speed of snails was measured in mm/s.

RESULTS

The severe predation of rice plants by snails occurs

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in early growth of paddy. After transplanting on June 20th, the snails voraciously consumed rice plants. The snail ate 8 rice plants of 140 mm of height (0.30 g of dried biomass) per day when water depth was 50 mm of height where as the snail ate 2 rice plants of 190 mm of height per day when water depth was 20 mm of height.

The number of snails, taking in account only snails with shell height ≥ 20 mm, after transplanting was 17 only per 168.2 m^2.

Table 1 shows the mortality rate of snails. We found that only 1 snail was died of a total of 12 snails (≥ 20 mm of shell height) distributed in 6 plots on June 23th. On June 28 we found that of a total of 12 snails (≥ 20 mm of shell height) distributed in 6 plots only one was found died.

Table 2 shows the number of eggs laid by female snails (≥ 20 mm of shell height) on June 29th. They were numerous; however the hatching of them takes 8–12 days (Teo, 2004) and then the snails require 25 days to reach 20 mm, of height, therefore those snails are not harmful for rice plants between 120 mm to 400 mm of height (Luna and Nakaji, 2008).

Figure 1 shows the distribution histogram for shell heights and weights of snails handpicked up on July 8th. The population of snails was 266 (≥ 20 mm of shell height) per 168.2 m^2. The mean shell height and mean weight were 28.45±3.60 mm and 5.71±2.10 g, respectively.

Figure 2 shows the distribution histogram for shell heights and weights of snails sorted by gender and handpicked up of an area of 120 m^2 on July 11th. The mean shell heights and mean weight for females (≥ 20 mm of shell height) (≥ 20 mm of shell height) and males (≥ 20 mm of shell height) were 28.44±3.40 mm and 27.31±3.20 mm, respectively. The mean weights and mean weight for females (≥ 20 mm of shell height) and males (≥ 20 mm of shell height) were 4.87±1.61 g and 4.6±1.57 g respectively. The number of females was 104 whereas the number of males was 110.

Figure 3 shows the distribution histograms of female snails (a), male snails (b) and total number of snails found in 16 lots of 3 square meters on July 11th of 2008. The total number of snails (≥ 20 mm of shell height) found in those 16 lots was 164 (number of females and males were 95 and 69, respectively).

Table 3 shows the shell height and weights of snails (≥ 20 mm of shell height) sorted by gender. The shell heights of male and females were increased 2.09 mm and 2.17 mm, respectively after three days. The weights of male and females were increased 0.66 g and 0.66 g, respectively after three days.

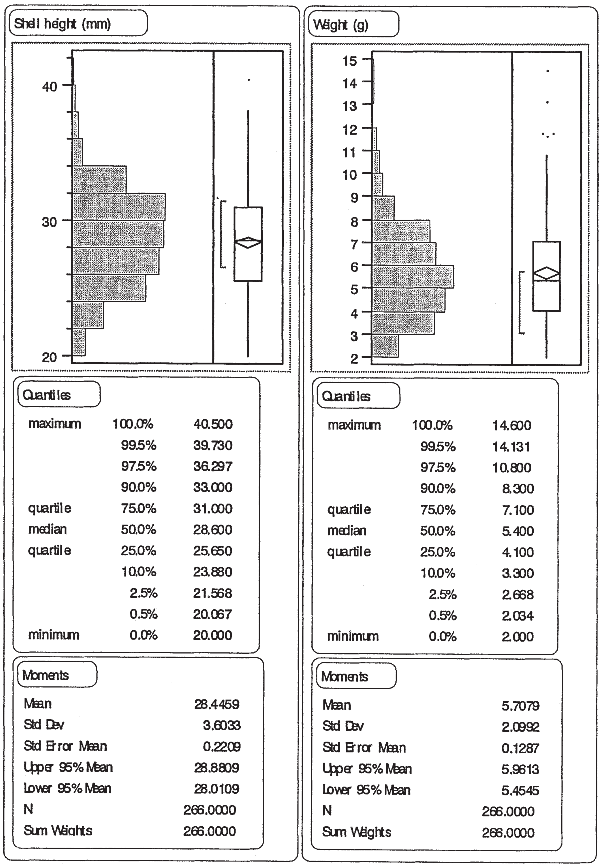
Table 1. Mortality rate of golden apple snails (≥ 20 mm of shell height) on June 23th, and June 28th of 2008

Number of snails and date	Mortality rate
a. 12 snails distributed in 8 plots on June 23th.	0.083
b. 12 snails distributed in 8 plots on July 28th.	0.083

Table 2. Eggs laid by female snails (≥ 20 mm of shell height) on June 29th of 2008.

Lot	Number of Clusters	Eggs
1	2	378
2	4	756
3	3	567

* Each plot had an area of 3 square meters.



(a) (b)

Fig. 1. Spread of distribution of shell height (a) and weight (b) of snails (≥ 20 mm of shell height) found in an area of 168.2 m^2 on July 8th, 2008.

Table 3. Shell height and weights of snails (≥ 20 mm of shell height) sorted by gender on July 8th, and July 11th of 2008

Date	Shell height (mm)		Weight (g)	
	Male	Female	Male	Female
July 8th, 2008	23.20±2.80	23.35±3.22	3.20±1.23	3.24±1.65
July 11th, 2008	25.29±3.63	25.52±3.83	3.86±1.82	3.90±1.81

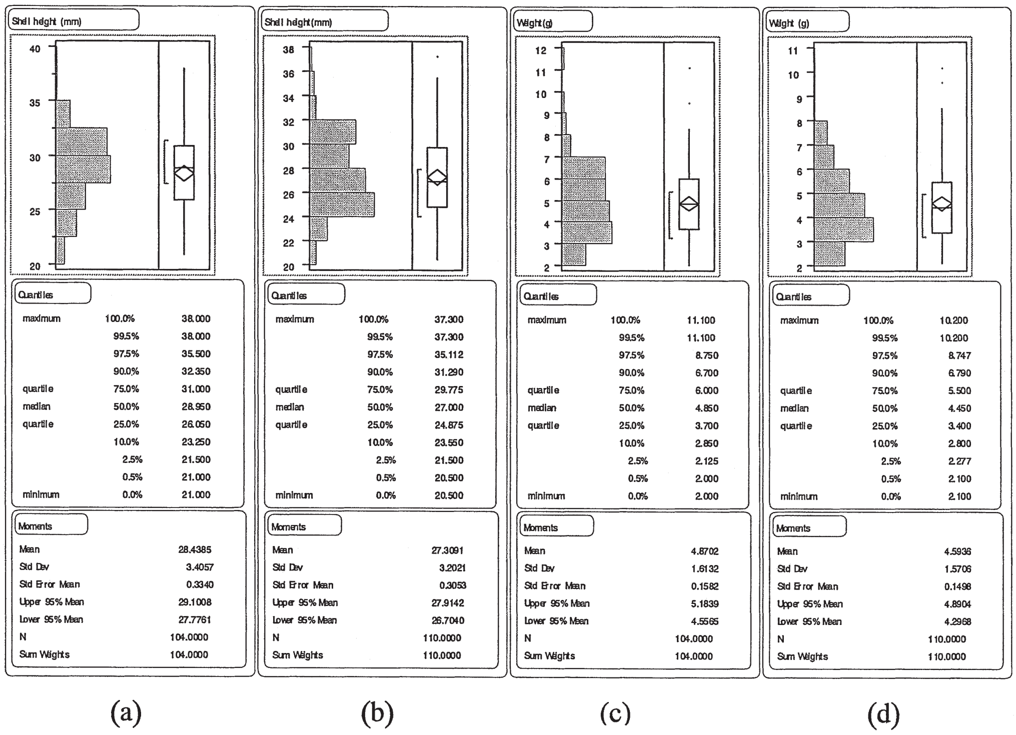


Fig. 2. Distribution of shell height of female snails (a) and shell height of male snails (≥20 mm of shell height) hand picked up in an area of 16.8 m^2 on July 11th, 2008 and distribution of weight of female snails (a) and weight of male snails (≥20 mm of shell height) hand picked up in an area of 120 m^2 on July 11th, 2008.

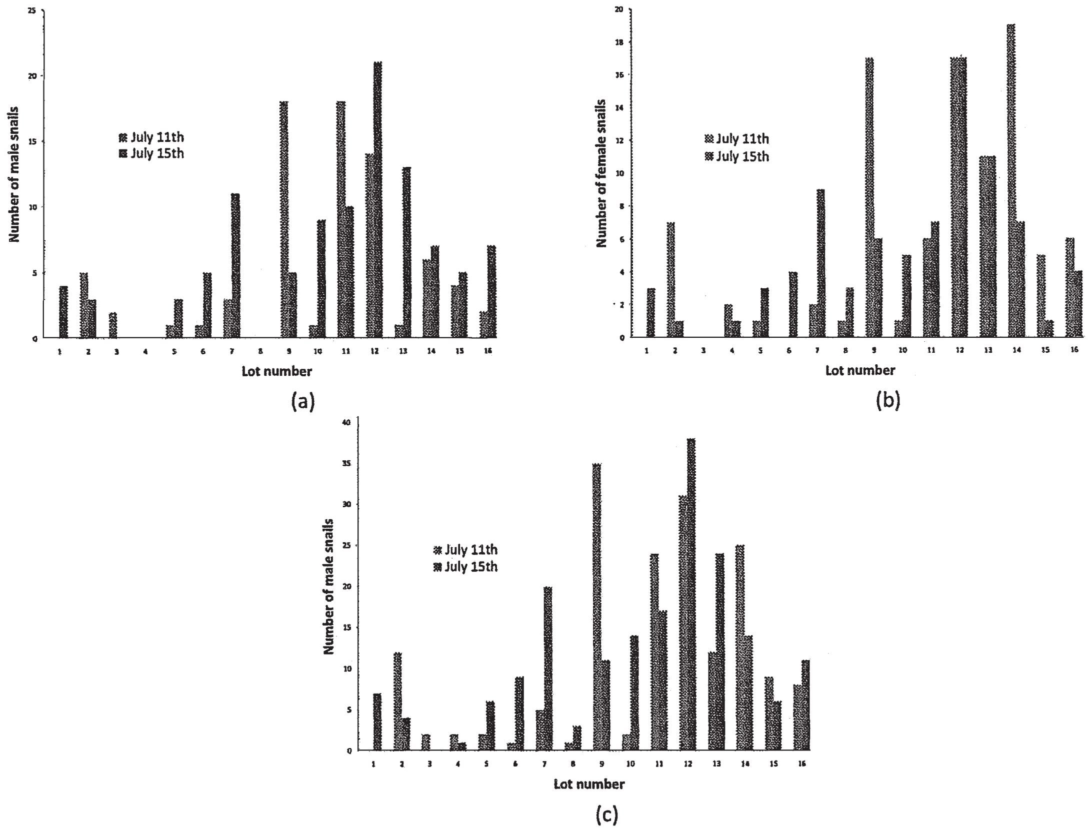


Fig. 3. Distribution per lot (3 square meters) of the populations of female snails (≥20 mmof shell height) (a), male snails (≥20 mm of shell height) (b) and total number of snails (≥20 mm of shell height) at July 11th of 2008.

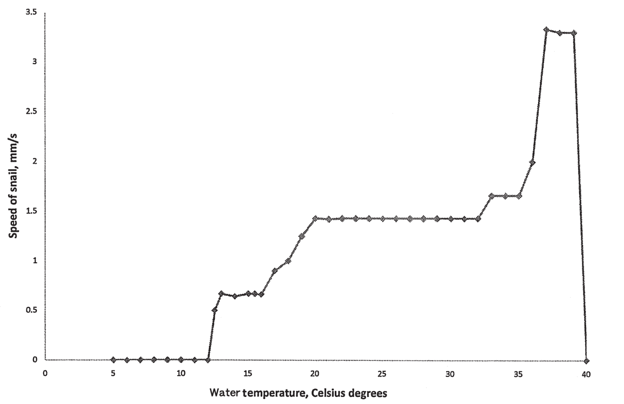


Fig. 4. Speed of snail (shell height of 22~25 mm) related to the water temperature and water depth of 30 mm, November 4th and 5th of 2008.

Figure 4 shows that snails started to move in water at 12 Celsius degrees at 0.5 mm/s and they could be active at 39 Celsius degrees. Water temperatures above 30 Celsius degrees have a harmful effect on snails (Teo, 2004). In our experiment when the temperatures were 20 to 32 Celsius degrees, the speed of snails was 1.43 mm/s. On the other hand at water temperatures between 33–38 Celsius degrees, the speed of the snail was 1.6 to 3.3 mm/s and the snails had desperation. When water temperature was 39 Celsius degrees, the snails had panic and tried to leave the container. On the other, at when water temperature reached 40 Celsius degrees the snails stopped moving.

Figure 5 shows the mean temperatures from day of transplanting until day which rice plants has reached 400 mm of height (July 20th). The temperature has an effect on the predation of rice plants by snails.

Figure 6 shows the dried biomass of rice plants (g–d.w.) consumed by a snail per day in function to the temperature. We used the sigmoidal form of Viggs and Burley to obtain temperature response function and we got the curve of predation rate by using the equation of Richards and it was significant with a correlation coefficient r= 0.999***at 99% of confidence level. The proposed coefficient of depth water rate was 0.7. A snail of 34 mm of shell height and 9 g of weight consumed 0.3 g–d.w. per day. The density of snails observed per square meter on June 20th, July 18th and July 21th were 1, 16, and 39 snails respectively.

Figure 7 shows the population of snails (≥20 mm of shell height) predicted by the equation of Richards was significant with a correlation coefficient r=0.999***at 99% of confidence level. Figure 8 shows curves of biomass of rice plants, Tamagayatsuri and non superior weeds per square meter. The biomass of rice plants Tamagayatsuri and non superior weeds were predicted by Verhulst logistic model (Luna *et al.*, 2008c). The data of density of snails (≥20 mm of shell height) per square meter was fitted by Richards's equation in paddy. Rice plants, Tamagayatsuri and non superior weeds competed

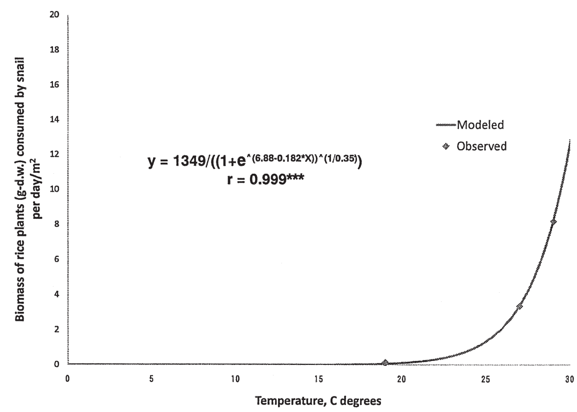


Fig. 6. Dried biomass of rice plants (g–d.w.) consumed by a snail (34 mm of shell height and 9 g of weight) per day as a function to the water temperature and related to a coefficient of depth water rate (W_d) of 0.7, abundance of snails per square meter (A_p) and maximum consumption (C_{max})of 0.3 g–d.w. per day by snail.

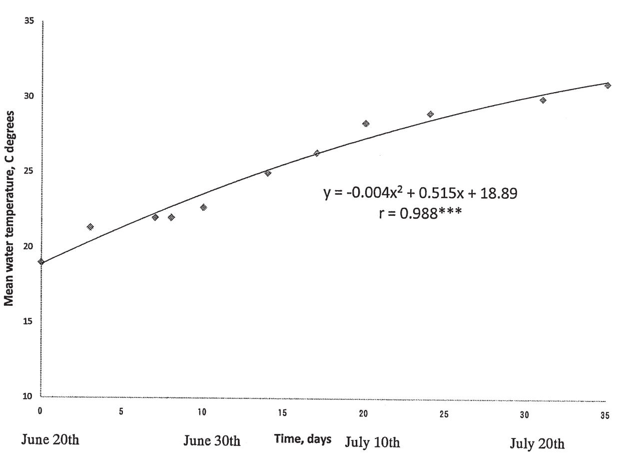


Fig. 5. Mean water temperatures at 7:00 pm in paddy field from transplanting day (June 20th) until day 35 (July 21th) of 2008.

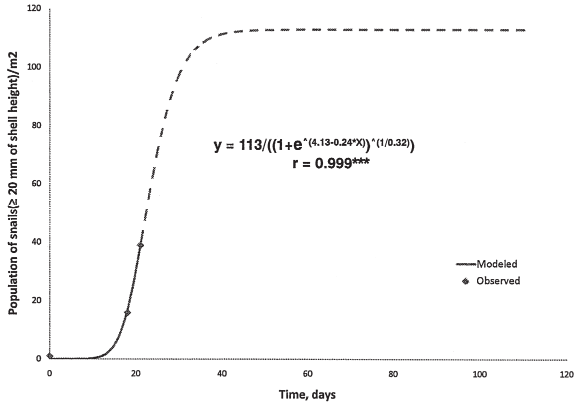


Fig. 7. Population of snails (≥20 mm of shell height) per square meter observed in rice cropping season of 2008 and modeled by Richards's equation.

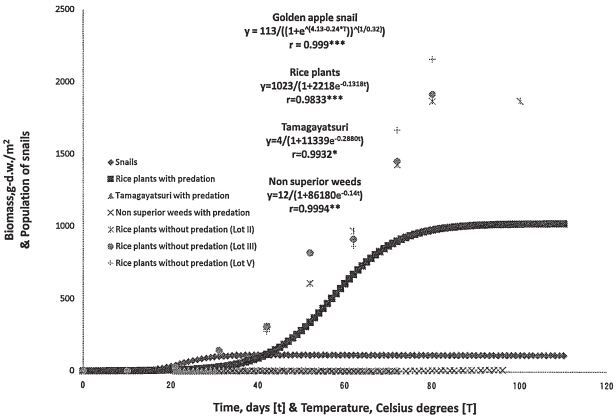


Fig. 8. Curves of biomasses of rice plants, Tamagayatsuri and non superior weeds per square meter predicted by Verhulst logistic model population of snails (≥20 mm of shell height) per m^2 fitted by Richards's equation in paddy during crop season, 2008. Rice plants, Tamagayatsuri and non superior weeds were predated by snail at 30%, 80% and 80% respectively in these prediction equations.

among them and were predated by snails at 30%, 80% and 80% respectively in the prediction equations shown in Figure 8.

DISCUSSION AND CONCLUSION

The severe predation of rice plants by snails occurred from June 20th of July 30th. In this critical stage the rice plants had heights from 12 to 400 mm. The water temperatures ranged from 19 to 31 Celsius degrees. Those temperatures were suitable for the maximum activity of snails.

The sigmoid of Viggs and Burley and equation of Richards had predicted significantly the temperature response function and predation rate respectively. The Richards's equation also modeled the populations significantly during the critical stage of rice crop season.

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