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Luna Maldonado, Alejandro Isabel
Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University

Nakaji, Kei
Department of Plant Resources, Faculty of Agriculture, Kyushu University

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Development of an Intelligent Robot for an Agricultural Production Ecosystem – New Concept of Robot and Dynamics of a Golden Apple Snail in Paddy–

Alejandro Isabel LUNA MALDONADO[1] and Kei NAKAJI*

Laboratory of Agricultural Ecology, Division of Agricultural Ecology, Department of Plant Resources,
Faculty of Agriculture, Kyushu University, Fukuoka 811–2307, Japan
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A new concept of an intelligent robot for agriculture was discussed from the viewpoint of agricultural production ecosystem. In the case of the paddy field in temperate and subtropical zones, a mollusk named golden apple snail (*Pomacea canaliculata* (Lamarck)) often causes serious damage to the rice plant seedlings, however, the snail is very useful in the control of weeds that cause also detriment of the production of rice, especially in organic agriculture. After the golden apple snails invaded the paddy field of Kyushu University Farm, the superior weed well–known as Tamagayatsuri (*Cyperus difformis* L.) was not found there, because the snails consumed all the weeds. Experiments on the dynamics of the golden apple snails showed that almost all the snails were gathered inside of the furrows, after water was drained from the bath or paddy. The intelligent robot supposed to realize the agricultural production ecosystem in the paddy will estimate the populations of snails, and make decisions and operations to remove the snails based on the appropriate model.

INTRODUCTION

Nowadays, agricultural production ecosystems on rice cultivation have become imbalanced and unsteady by high input of chemicals and poor management of paddy fields. In the southern district in Kyushu, Japan, a mollusk named the golden apple snail was introduced and raised to be served as a new food at restaurants in 1970s. But it was abandoned because of unpopular taste. It was not so long before the golden apple snail invaded paddy field dispersed through extensive irrigations networks to the west part of Japan. In 1978, the Ministry of Agriculture, Forestry and Fisheries of Japan, designated the golden apple snail as a pest for rice cropping, because golden apple snail eats rice seedlings vigorously as shown in Fig. 1. Golden apple snail spreads not only in the west part of Japan but even also in the Kantou region now. The golden apple snail also eats the weeds as well as young plants of rice. That technology of prevention of damage by golden apple snail should be developed. It is urgent in many Asian countries cropping paddy.

Fig. 1. Golden apple snails eating voraciously small paddy field plants.

The weed control in paddy field was very arduous work under warm climate until the herbicide with high effect appeared. In recent years to preserve the farmer's health and maintain the environment, other control methods different to the chemical control became a strong requesting. Instead of the chemical control, the mechanical control is newly researched, and a new machine for the weeding is developed. Takahashi *et al.* (2002) developed the mechanical method to exterminate snails with rotary tiller. They reported that the submerged direct seeding cultivation was damaged by snails only 23% area in the field cultivated by the above method as compared with 48% area in the ordinary field. Straight blades of the rotary tiller were developed to enhance the snail killing effect in conventional tillage. Wada *et al.* (2004) found that the density of snails decreased 50% after using the manufactured prototype of snail controlling rotary tiller.

The cropping rotation is significant to decrease remarkably the number of golden apple snail, but it is difficult for an individual farmer to adopt it in Japan.

The biological control of golden apple snail is possible by using the natural enemies such as catfish, carp, tortoises, rats, and birds, etc., although the method shows high population of weeds. Several farmers practice the method of bio–ecological control, however, the farmers should manually to pick up hundreds of snails to decrease the number of them every day, because the number of snails increases exponentially in paddy. It is a tedious work to gather hundreds of golden apple snails by hand or with a net. Some skillful farmers make a furrow, gather the snails and pick them effectively. But it is feared that the agricultural ecosystem may lead to poor biodiversity.

[1] Laboratory of Agricultural Ecology, Division of Agricultural Ecology, Graduate School of Bioresources and Bioenvironmental Sciences, Kyushu University
* Corresponding author (E–mail: knkjfam@mbox.nc.kyushu–u.ac.jp)

The purpose of this research is to clarify the habit of golden apple snail in the paddy field based on the agricultural ecosystem of the rice farming system and to develop an intelligent robot which executes the tasks of control of weeds and snails in the paddy field.

MATERIALS AND METHODS

The development of the robot demands strategic stages divided in the following manner: the first stage is composed of the understanding of an agricultural ecosystem. It involves information about the crops and artificial ecology in order to generate a new concept, in addition, the researching on elemental and peripheral technologies in order to realize an intelligent robot for agricultural production ecosystem. The second stage is to recognize many factors and to identify problems that cause the imbalance of the ecosystem, such as the competition between rice plants and weeds and the plague of the golden apple snail. In order to control the behavior of the golden apple snail, it is significant to make full use of information technology to the paddy ecosystem and introduce an intelligent robot (Fig. 2).

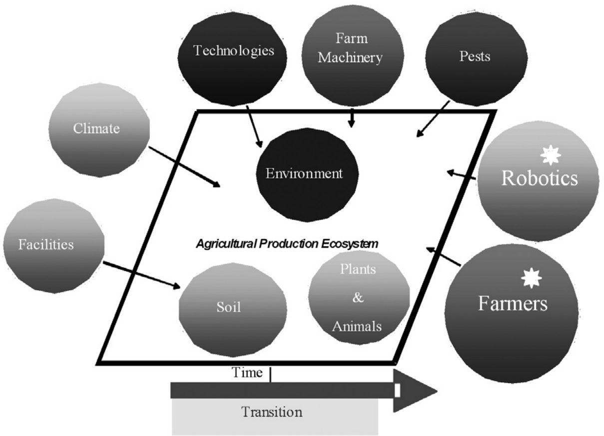


Fig. 2. Dynamic balancing of the agricultural production ecosystem.

Results of the experiments in Kyushu University Farm

Golden Apple Snail as Weeder

In the paddy field of Kyushu University Farm practicing organic agriculture, 496 plants of Tamagayatsuri, one of the most superior weeds in this area, appeared in an experimental lot of 50 square meters in 1996 (Fig. 3a), whereas Tamagayatsuri was not found in the same experimental site in 1997 (Fig. 3b). The golden apple snails were very scarce in 1996, whereas the snails invaded the paddy field in a great amount in 1997 and they ate greedily the weeds in the experimental lot (Table 1). Many kinds of weeds such as Azena and Kikashigusa were observed in the paddy and they were controlled by the use of herbicides as a habitual practice in one of the experimental lots. In a different experimental lot practicing organic agriculture without chemicals, the weeds were not observed at the same level of the lot of habitual practice with herbicides, because the weeds were ate and controlled by golden apple snails.

Several experiments were carried out to obtain the characteristics of rice plants. The rice seedlings had a height of about 100 mm and a leaf stage of about 3.5 at the time of transplanting. The plants had a height,

Table 1. Results of researching on kind and population of weeds in lowland paddy field and weeding time by hand at Kyushu University Farm

Experimental Site	Tainubie	Ooinubie	Tamagayatsuri	Kikashigusa	Konagi	Azena	Hotarui	Total Weight	Time
1996									
a. Organic Agriculture Without chemicals	10	10	496	35	18	38	1	1004 g	32 min
b. Habitual Practice (Herbicide)	1	0	0	0	0	0	0	10 g	2 min
1997									
a. Organic Agriculture Without chemicals (Golden apple snail)	0	0	0	0	0	0	0	0	0
b. Habitual Practice (Herbicide)	0	0	0	4	0	3	0	4 g	

Tainubie: early watergrass (Ecinochioa oryzicola Vasing. → [Echinochioa oryzoides (Ardo) Fritsch])
Ooinubie: bamyardgrass (Echinochloa crus–galli (L.) Beauv. var. crus–gall)
Tamagayatsun: smallflower umbrella sedge (Cyperus difformis L.)
Kikashigusa; Indian toothcup Rotala indica (Willd.) Koehne var. uliginosa (Miq.) Koehne → [Rotala indica (Wild.) Koehne]
Konagi: Monochoria vaginalis (Burm. f.) Presl var. piantaginea (Roxb.) Solms–Laub.
Azena: common false pimpernel (Lindemia procumbens (Krock.) Borbas → [Lindemia pyxidaria L.])
Hotarui: Japanese bulrush Scirpus juncoides Roxb. var. hotarui Ohwi → [Scirpus hotarui Ohwi]

In a and b, weights of weeds were researched on August 12th, 1996 in an experimental site of 50 squared meters.
c and d were researched on September 8th, 1997 in an experimental site of 50 squared meters.
Only once were performed works with a paddy weeder on July 14th, 1997.
However, the weeds were extremely few on the researching day in the experimental site in organic agriculture and where the cultivation was not weeded.

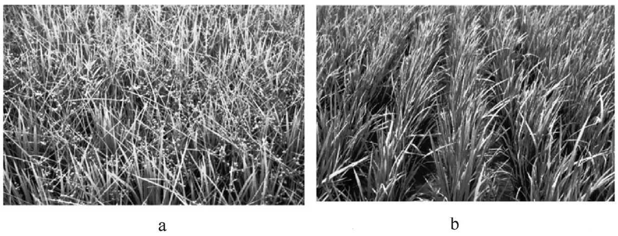


Fig. 3. (a) Weed in paddy field without applying of herbicide, August 12th, 1996, (b) biological control of golden apple snail, September 8th, 1997.

length and maximum leaf stage of 770 mm, 780 mm and 14 leaves respectively, after 70 days. It was observed that the snails would eat rice plants less than about 400 mm height.

Characteristics and Dynamics of Golden Apple Snail

Fig. 4 shows that the number of eggs clusters increased rapidly and exponentially from 3 eggs clusters for day 1 to 5831 for the day 32 in a field of 3100 square meters. The density of snails was 15.5 per square meter (10.5 females and 5 males) (Table 2). The percentages of female snails and male snails were 67.8 and 32.2, respectively. The shell height of female snails ranged from 20 mm to 36 mm and the number of eggs found in their clusters ranged from 41 to 198 per square meter (Table 3). On the other hand, the shell height of male snails ranged from 25.5 to 32.5 mm.

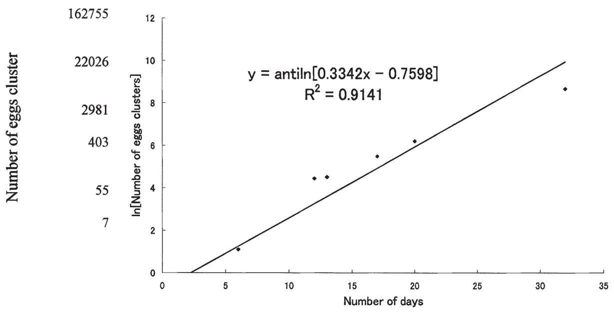


Fig. 4. Eggs clusters of golden apple snail in the experimental lot at Kyushu University Farm, 2007.

Table 2. Density of snails found in the plot 1 in paddy field, 2007

Density of snails per square meter	Density of female snails per square meter (percentage)	Density of male snails per square meter (percentage)
15.5	10.5 (67.8%)	5 (32.2%)

During the sampling, the snails considered had shell heights of at less 20 mm for both males and females. There were many snails with shell height of 3 mm but they were not considered because of they are not eating rice plants neither weeds

Table 3. Shell's height of female snails and the number of eggs found in the clusters, 2007

Shell's height of female snail (mm)	Number of eggs found in the clusters
20–36	41–198
Number of Samples=31	Number of Samples=14

On the dynamics of the golden apple snails, some experiments were carried out in Kyushu University Farm on September and October, 2006. Furrows were dug to the paddy soil layer of 100 mm thick in a bath with triangular and rounded shapes. Each furrow had the following dimensions: a depth of 70 mm and a width of 100 mm. The bath was watered 100 mm deep over the soil layer. Twenty golden apple snails previously classified by shell's height as big, middle, small and very small sizes (5 mollusks from each category) were immersed in the bath, and then water was drained at a constant speed of 60.4 mm per hour. The number of snails by category inside and outside of the furrow was counted after the water level reached soil surface. The results showed that percentages of snails inside and outside of an enclosed round furrow in baths were 90% and 10%, respectively (Fig. 5a).

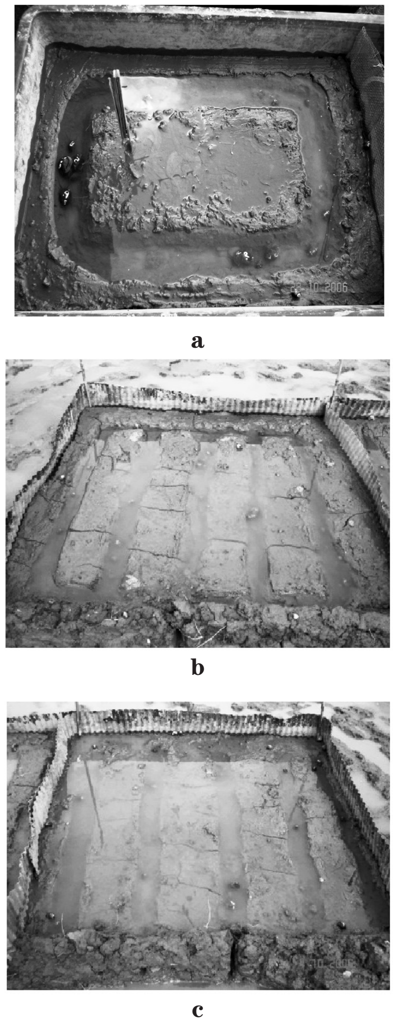


Fig. 5. (a) Snails inside and outside of an enclosed round furrow using baths,(b) and (c) snails inside and outside of an enclosed and open area with triangular furrows in lots during tests carried out on October, 2006.

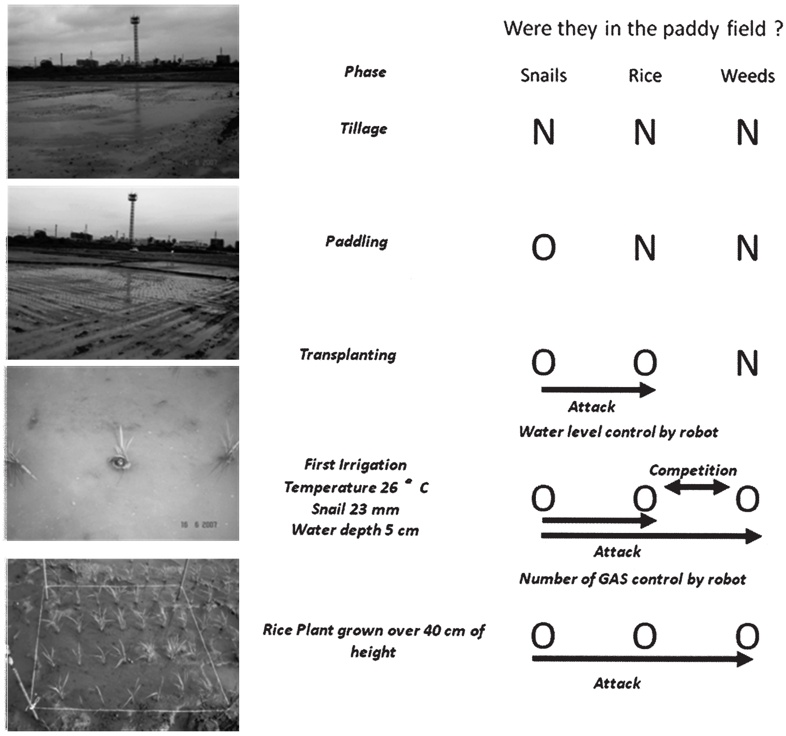


Fig. 6. Conceptual model of paddy field in Kyushu University Farm. X; No, O; Yes.

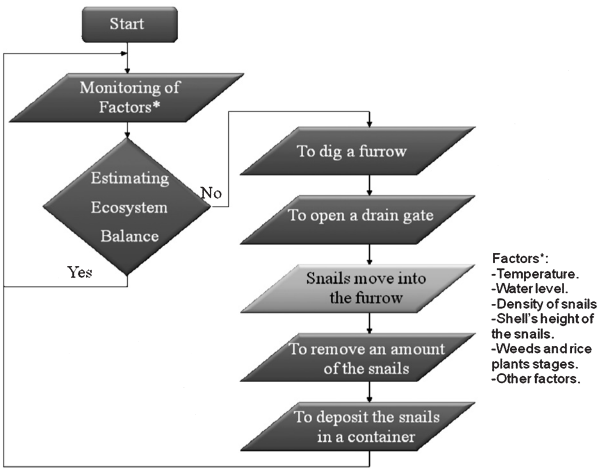
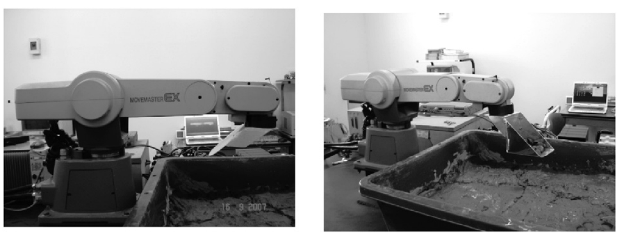


Fig. 7. Flow diagram of the robot's tasks in control of population of snails in paddy.



a b

Fig. 8. (a) The furrow opener and (b) bucket attached to the intelligent robot in the laboratory.

Additional experiments were carried out in two lots of paddy field. Seven triangular furrows connected within a lot were made and 30 snails of different sizes were released into the water. After more than 1.25 hours of drainage, the snails observed inside and outside of the furrow were 93% and 7%, respectively (Fig. 5b). In the case of another lot, they were 87% and 13%, respectively (Fig. 5c).

Design of Technology

From the viewpoint of agricultural production ecosystem, the design of technology is very important to realize the artificial ecosystem of paddy field to reduce density of the golden apple snail until a percentage into that the apple snail becomes a beneficial mollusk which eats only the seedling of weeds in the paddy field. Fig. 6 indicates a conceptual model of paddy field with the fluctuation of an agricultural production ecosystem by means of farm work in Kyushu University Farm. After transplanting, small plants of rice, 100 mm high, are susceptible to be devoured by golden apple snails, therefore the robot should restrict the snails moving by the water drainage. After the first irrigation, various kinds of weeds show up in the field and compete with the rice plants for nutrients and living spaces. At the time the robot should control the number of harmful snails so that they eat only the weeds. After the rice plants become 400 mm high, the snails would prefer eating only young weeds.

Fig. 7 shows one of the flow charts as the robot would execute the different tasks in the production ecosystem of paddy field to decrease the population of golden apple snail. The intelligent robot would collect many information and data concerned, check the suitable state of production ecosystem comparing to the model, and work autonomously to execute farm operation if necessary. For example, the robot will open a drain gate in the paddy, when the height of rice plant is smaller than 400 mm, the water temperature is higher than 24 Celsius degrees at a certain water level and density of snails larger than 20 mm in shell height is high. The robot will dig some furrows to concentrate the snails on strategic points of the paddy field at the next stage. Finally, the robot will scoop up snails in furrows to maintain the number of snails for agricultural production (Fig. 8).

DISCUSSION AND CONCLUSIONS

The weed control should be considered not to damage the ecosystem of paddy field. By controlling a golden apple snail appropriately in paddy, we can change a harmful golden apple snail to a profitable mollusk eating the weeds which are the serious problem of farm work in organic agriculture and environmental preservation. The snail cannot move easily when the water depth is less than snail shell's height even if water temperature is suitable.

It is necessary to consider the competition between rice plants and weeds, the relationship between predator (golden apple snail) and preys (rice plants and weeds), moreover the farm work to remove the snails from the paddy by farmer or the intelligent robot. A competition coefficient between weeds and rice plants within crop season may be predicted using the Lotka–Volterra model. The number of harmful snails to be removed from the paddy can be modeled by analysis of absolute sensitivity using transfer functions, which consider births and deaths of snails, the snails entering from the outside through irrigation canals and the biomass of rice plants and weeds. The intelligent robot will estimate the populations of snails, and make decisions and operations to remove the snails based on the appropriate model.

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