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Control Effects of Two-Batch-Duck Raising with Rice Framing on Rice Diseases, Insect Pests and Weeds in Paddy Field

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Abstract: Rice-duck farming system is one of the means of organic rice farming, in which the weeds, diseases and insects could be effectively controlled with minimal or no pesticide and herbicide application. Whereas in conventional rice-duck farming system the controlling effect on diseases, insect pests and weeds was slowly disappeared after the rice heading stage at which ducks were driven out of the paddy field. To fill up the blank period of pasture activities of ducks, this study put forward two new rice-duck farming systems innovated from the conventional rice-duck farming system, in these new systems, two batches of ducks were raised with rice within one rice planting season. The results revealed that the overall controlling effect of ducks on rice diseases, insect pest and weeds was significantly enhanced in the two new rice-duck farming systems without agrochemicals application. It might be suggested that these two new systems have potential application as biocontrol agent for the organic rice agriculture.

Keywords: Biocontrol, disease, insect, pest, rice, two batch of duck-rice system, weeds

INTRODUCTION

Organic farming has been proposed and practiced in the world for many years (Mäder *et al*., 2002; Peterson *et al*., 2007), whereas in present rice production system, the weeds, diseases and pests control relies heavily on the use of agrochemicals. The excessive application of the agrochemicals will aggravate the problems of food security and is surely not compatible with organic farming. Establishing a species-diversified cropping system has been suggested to solve these problems (Martin, 2000; Buhler *et al*., 2000; Wang *et al*., 2006). In recent years, several novel species-diversified farming systems such as rice-fish, rice-duck have been documented to be highly effective in controlling crop diseases, insect pests and weeds in paddy field with less pesticide and herbicide application (Zhang *et al*., 2008; Xie *et al*., 2011). Among these systems, rice-duck farming system is a complex planting model of rice wetland system with a long history, which utilizes the instinctive scavenging nature of ducks, such as moving and seeking for food industriously to control the rice disease, pests and weeds, in addition, it can increase the farm products and income of farmers. As a form of ecological engineering, rice-duck farming system can effectively make full use of the symbiotic relationship between ducks and rice plants to utilize nutrients and it was documented to decrease pollutants discharged from the rice-field by reducing the chemical fertilizer and pesticide inputs and to increase product safety and overall productivity by excreting organic duck manure which fertilizes the rice plants (Zhang *et al*., 2002; Wang *et al*., 2004, Choi *et al*., 2004). Previous experiments have shown that the occurrence and damage of pests (Liu *et al*., 2004; Huang *et al*., 2005; Yu *et al*., 2008) pathogens (Yang *et al*., 2004; Zhen *et al*., 2006) and weeds (Hossain *et al*., 2000; Ahmed *et al*., 2004; Wei *et al*., 2005) can be effectively controlled under the rice-duck farming system with minimal or even no agrochemicals application.

At present, rice-duck farming system has been widely adopted in Asian countries such as Japan, South Korea, Malaysia and Philippines (Choi *et al*., 1996; Furuno, 2001; Zhang *et al*., 2002) and it's being combined with organic rice production and becoming a popular stereoscopic agriculture mode in China due to the reduction or elimination of pesticide and herbicide use (Zhang *et al*., 2009a), thereby ensuring the quality of organic products. However, most information currently available focuses only in the controlling effect of ducks in the period between rice tillering and heading stage and less researches have been concentrated on the period after ducks were driven out

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of the paddy field. Recent researches have demonstrated that with the absent of ducks pasture in the later growing period (from grain filling stage to rice mature stage), the occurrence of some pests and pathogens in rice-duck system significantly increased (Huang *et al*., 2005; Zhen *et al*., 2006). Thus the biological control problem in the rice mature stage needs to be solved in the rice-duck farming system. This study put forward a new kind ecological agriculture engineering innovated from the traditional rice-duck farming system. In this mode two batches of ducks were pastured in one rice farming season. Study of this study focused on the effects and mechanisms of multiple species coexistence on rice diseases, pests and weeds control in this new kind of rice-duck farming system. It aimed at improving the conventional technology of rice-farming system and providing a theoretical basis and practical reference for the wider application of this new ecological agriculture mode in organic rice farming.

MATERIALS AND METHODS

Experimental site introduction: The experiment conducted from March 2007 to December 2008, the field trial site located at the Zengcheng Teaching and Research Farm (23°14′N, 113°38′E) of South China Agricultural University, Guangzhou, China, which belongs to a subtropical monsoon climate with average frost-free period of 335-360 days. The mean annual air temperature was 21.8°C, the mean annual precipitation was 2137 mm and the mean annual air humidity was 78%. The paddy soil of the experimental sites was developed from the lactose with a pH of 6.0, Soil Organic Matter (SOM) of 29.35 g/kg, available N of 107.98 mg/kg, total N of 1.57 g/kg, available P of 27.59 mg/kg, total P of 1.57 g/kg, available K of 25.32 mg/kg, total K of 18.27 g/kg.

Experimental design: The rice cultivar used in this study was Oryza sativa cv. Shengbasimiao. The duck variety used in the trials was Tadorna tadorna. The following 4 treatments each with 3 duplicated plots of 134 m^2 were arranged according to a randomized complete block design (Fig. 1).

- **Conventional Rice cultivation treatment (CR treatment):** No ducks were reared
- **Conventional rice-Duck pasture (CD treatment):** Five 7-day-old ducklings were released into each plot at the beginning of rice returning green stage and were removed in the heading stage
- **Rotational Pasturing treatment (RP treatment):** during the whole rice season, two batches of ducklings were pastured in sequence, the treatment of the first batch was consistent with CD, the second batch (7 ducklings of 7 days old) was released into each plot in the rice heading stage (after the first batch was removed from the field) and removed in paddy drainage stage
- **Mixed Pasturing treatment (MP treatment):** The treatment of the first batch duck was consistent with CD, the second batch (6 ducklings of 5 days old) was released into each plot 10-15 days before the removing of first batch duck and was driven out of the paddy field 10 days before the drainage stage.

In this treatment, two batches of ducks were mixed together in the same plots for 15 days. Each plot was separated by plastic nets with a height of about

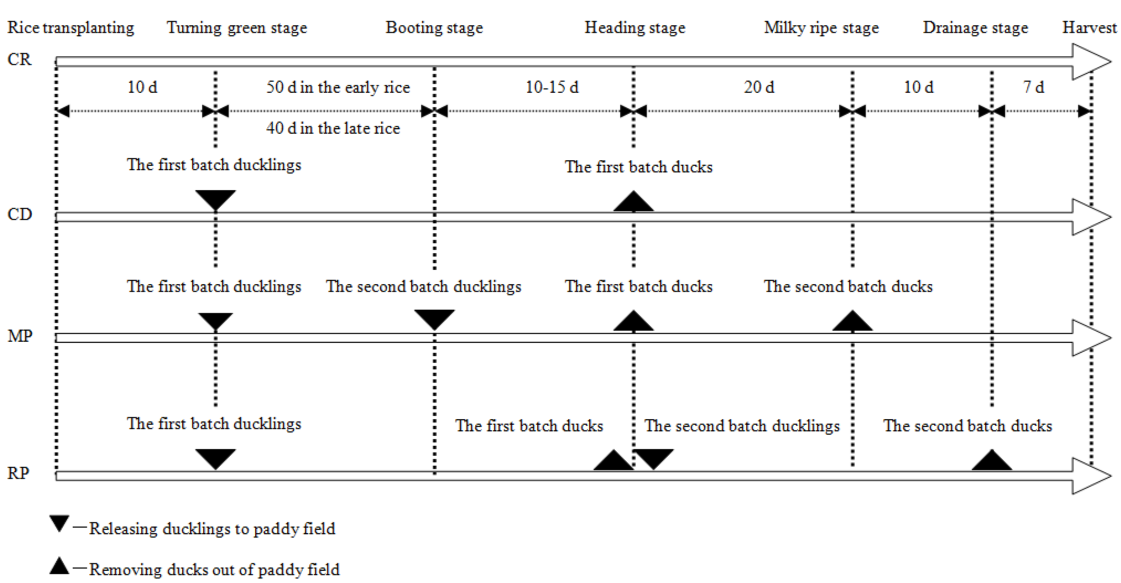

Fig. 1: The flow diagram of the different rice-duck farming systems

60 cm to avoid the escaping of ducks. Chemical compound fertilizer was used in CR with the application amounts of 100, 100, 25 and 50 kg/ha for SOM, N, P and K, respectively. The pesticides used in CR were 18% dimephypo and 40% chlorphrifos. The fertilizer used in rice-duck treatments was the chicken manure at the application amount of 3750 kg/ha which contained about 51% of SOM, 3.26% of N, 3.08% of P_2O_5 and 1.7% of K_2O. No pesticide was applied in the all rice-duck treatments. Rice seedlings were transplanted with spacing distances of 40 cm between rows and 30 cm between hills within the same rows. Four seedlings were planted in each hill. Water was kept at a 3-5 cm depth in the early stage and increased gradually to 10 cm depth when ducks grew up.

Experimental methods: The occurrence of pathogens, weeds and pest insects were surveyed every 7 days after ducks were stocked for 40 days. In each plots, 15 sampling points with 2 hills for each point were surveyed with parallel jumping sampling method. The number of insect's individuals in 100 hills was evaluated for the occurrence of rice hopper. The percentage of infected plants in 100 hills was evaluated for the occurrence of Chilo suppressalis, sheath blight and rice blast disease, the percentage of rolled leaves in 100 hills was evaluated for the occurrence of Cnaphalocrocis medinalis. Weeds community research was carried out 5 days after the harvest, 3 samples with an area of 1 m^2 in each plot were taken for the investigation. The Shannon-Wiener Index (H) is calculated by the following formula (Zhou *et al*., 2006):

$$H=-\sum_{i=1}^{m} P_i \ln P_i \tag{1}$$

where,

P_i : N_i/N, N_i is the individual number of the i weed species
n : The total number of individuals in the sample
m : The total number of weed species

The Pielou Evenness Index (J) is calculated by the following formula (Ma and Liu, 1994):

$$J = H/\ln S \tag{2}$$

where,

H : The Shannon-Wiener Index
S : The total number of the sampled weed species

Data analysis: Statistical analyses were executed using SPSS version 11.0 (SPSS Inc., Chicago, USA). Data were evaluated for normality and homogeneity of variances. Means of different treatments were compared by Duncan's New Multiple Range Test at p = 0.05.

RESULTS AND DISCUSSION

Effects of rice-duck farming systems on insect pests in paddy field: The pests occurred in experimental field are mainly rice hopper, Chilo suppressalis and Cnaphalocrocis medinalis. CD treatment presented efficiency in controlling rice hopper in the early stage of rice growth, but its effect was insignificant after the heading stage as ducks were driven out of the paddy field. Whereas the results showed significant difference between the conventional rice-duck system and the two-batch-duck systems, the RP and MP treatments not only significantly ($p<0.05$) decreased the density of rice hopper in rice heading stage but also kept a lower occurrence of rice hopper after the heading stage. Compared to the CD treatment, the rice hopper density in MP was decreased by 30.5% in the early rice season and 25.4% in the late rice season and the rice hopper density in RP was decreased by 12.2% in the early rice season and 21.4% in the late rice season, suggesting a better effect than the conventional rice-duck system.

As shown in Fig. 2, the rice-duck systems exerted significant controlling effect against Chilo suppressalis, which was mainly presented by the lower diseased plant rate of Chilo suppressalis in 3 types of rice-duck systems for most periods. Compared with CR, the diseased plant rate in CD, MP and RP were decreased by 23.4-66.2% in the early rice season and 15.4-66.6% in the late rice season. Whereas there was no significant difference in the diseased plant rate of Chilo suppressalis among 3 types of rice-duck systems in both rice seasons. The ratio of rolled leaves caused by Cnaphalocrocis medinali showed no difference between 4 treatments at the early period, whereas in the mid-term of rice growing season, the rolled leaves ratio was significantly ($p<0.05$) lower in MP treatment as compared to the other 3 treatments (Fig. 2e and f). As compared with CD, the ratios of rolled leaves in MP decreased by 14.2% in the early rice season and 18.4% in the late rice season.

Effects of rice-duck systems on rice pathogens in paddy field: The results indicated that although CD treatment presented efficiency in controlling sheath blight disease in the early rice (Fig. 3a and b), the ratios of diseased plants significantly ($p<0.05$) declined by 22.1-37.8% in the early rice and 15.7-49.2% in the late rice ($p<0.05$), respectively, compared with the CR treatment, but the effect was insignificant after the heading stage as ducks were removed from the plots. However, as compared with CD treatment, the diseased plant ratios of RP and MP in the early rice decreased by 15.9 and 26.1% respectively and for the late rice the ratio decreased by 13.5 and 19.8%, indicating that both RP and MP treatments had a stable and long controlling effect on rice sheath blight.

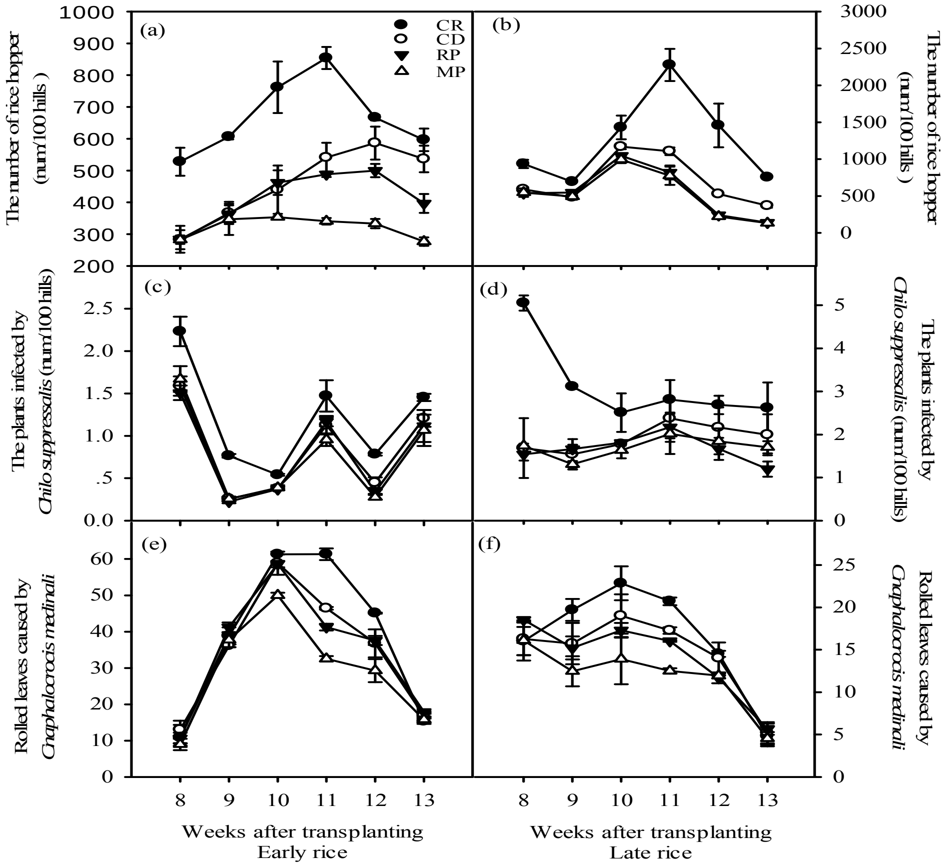

Fig. 2: Dynamic changes of insect occurrence in the different treatments

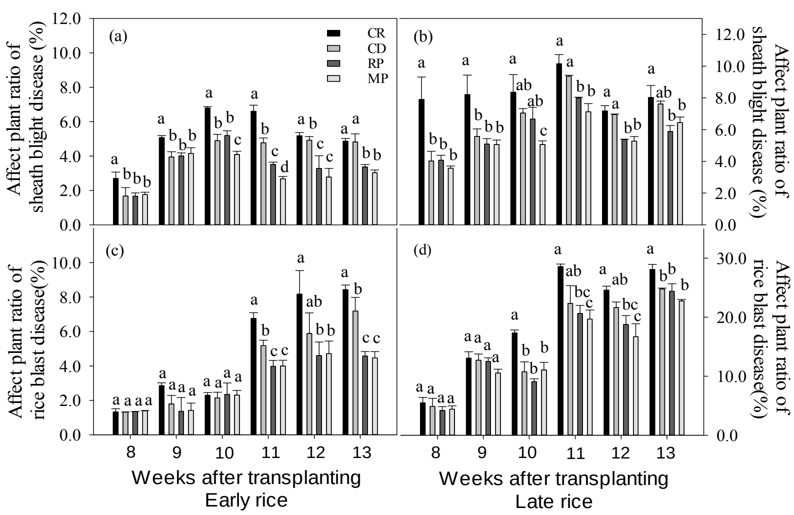

Fig. 3: Dynamic changes of rice diseases in the different treatments

As is shown in Fig. 3c and d, there was no significant difference on the ratio of plants infected by blast disease between CR and CD treatments for most periods, however, after the rice heading stage, the incidence of blast disease in RP and MD was significantly ($p<0.05$) lower than that of CR treatments in both early and late rice seasons. The ratio of diseased plants was significantly ($p<0.05$) lower in PR than that of CD treatment in the early rice season and the ratio of diseased plants in MP was significantly ($p<0.05$) lower than that in CD at both rice seasons.

Effects of rice-duck systems on weeds in paddy field: Results showed that less weed species were found in

Table 1: The occurrence of weeds density (ind/m^2) in paddy field under the different treatments

	Early rice season				Late rice season			
	CR	CD	MP	RP	CR	CD	MP	RP
Echinochloa crusgalli	3.69^{a}	1.91^{b}	1.37^{c}	1.75^{b}	4.45^{a}	1.56^{b}	1.29^{c}	1.53^{b}
Cynodon dactylon	1.85^{a}	1.67^{a}	0.18^{b}	0.31^{b}	2.68^{a}	1.18^{b}	1.17^{b}	1.26^{b}
Leptochloa chinensis	0.44^{a}	0.00^{b}	0.00^{b}	0.00^{b}	3.61^{a}	0.00^{b}	0.00^{b}	0.00^{b}
Cyperus difformis	3.83^{a}	0.88^{b}	0.05^{b}	0.40^{b}	4.29^{a}	0.85^{b}	0.08^{c}	0.37^{c}
Juncellus serotinus	1.80^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
Cyperus rotundus	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.02^{a}	0.00^{b}	0.00^{b}	0.00^{b}
Fimbristylis miliaceae	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	4.25^{a}	1.07^{b}	0.00^{c}	0.00^{c}
Jussiaea linifolia	8.75^{a}	0.06^{b}	0.00^{c}	0.00^{c}	5.27^{a}	2.35^{b}	1.81^{c}	2.18^{b}
Ammannia arenaria	0.26^{a}	0.22^{a}	0.11^{b}	0.18^{a}	2.46^{a}	1.03^{b}	0.22^{c}	0.78^{b}
Rotala indica	12.45^{a}	2.53^{b}	1.38^{c}	2.31^{b}	15.14^{a}	0.77^{b}	0.52^{b}	0.59^{b}
Lindernia antipoda	0.43^{a}	0.12^{a}	0.00^{b}	0.00^{b}	0.23^{a}	0.00^{b}	0.00^{b}	0.04^{b}
Lindernia procumbens	4.70^{a}	1.32^{b}	0.58^{c}	0.79^{b}	0.93^{a}	0.49^{a}	0.18^{b}	0.23^{b}
Sphenoclea zeylanica	2.46^{a}	1.22^{b}	0.91^{b}	0.78^{c}	2.74^{a}	1.60^{b}	0.69^{c}	1.09^{b}
Alternanthera philoxeroides	1.12^{a}	0.27^{b}	0.19^{b}	0.10^{b}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
Monochoria vaginalis	0.17^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
Eclipta prostrata	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.99^{a}	0.33^{b}	0.00^{c}	0.00^{c}

Different letters within each column indicate significantly different means at a $p<0.05$ according to Duncan's New Multiple Range Test; Each S.D. is not shown because of the limited space and small number

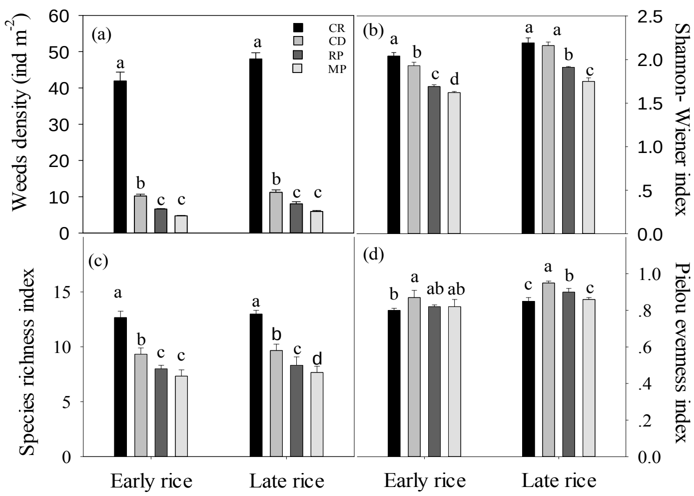

Fig. 4: The density and diversity indices of weed communities in the different treatments

the treatments of RP and MP as compared with CD. The total density of the weed community also differed significantly ($p<0.05$) among the treatments, the average control rates of MP and RP on dominant weed species such as Cyperus difformis, Jussiaea linifolia, Rotala indica, Lindernia procumbens were all above 80% in both seasons and the controlling effects on Leptochloa chinensis, Fimbristylis miliaceae, Juncellus serotinus and Eclipta prostrate reached 100% in both seasons (Table 1).

The order of total weed density among the treatments was CR>CD>RP>MP in both seasons. Compared with that of CD, the weed density was significantly ($p<0.05$) lower in the two-batch-duck systems (Fig. 4a).

In both early and late rice seasons, the Shannon-Wiener index and the species richness index in MP and RP were significantly ($p<0.05$) lower than those of the conventional rice-duck system (Fig. 4b and c). The Pielou Evenness index in CD was higher than that of CR, suggesting that the infestation of dominant weed species was reduced in the conventional rice-duck farming system. However as compared with CD, the Pielou Evenness index was reduced in the two-batch-duck systems (Fig. 4d), suggesting that the lengthening of pasture time, increasing of pasture disturbance and grazing selectivity of the ducks in the two-batch-duck systems accelerated a further variance of weed community structure.

CONCLUSION

Organic rice farming has been practiced for many years, however, it has been reported that crop production and quality decreased in many organic farming systems, mainly related to pests, diseases and weeds (Saitoh *et al*., 2001; Zinati, 2002). Thus, the establishment of agrochemicals-free approaches is important to control pests, diseases and weeds damage in organic crop productivity. Introducing biocontrol agents such as spiders, fish and duck into field can be an environment-friendly measure to solve these problems. Of these, duck was found practical and highly effective in rice wetland system, it played a multifunctional role by controlling rice pests, diseases and a variety of weeds. Compared with biological control by fish which requires keeping deep water in paddy fields, rice-duck farming system is more compatible with rice plantation and is easier to apply in the paddy field (Wada, 2004) and as a mature farming method, wetland rice-duck complex ecosystem has a long history and has been widely practiced in Asia. In Japan, South Korea and China, rice-duck farming is widely promoted in organic rice production to eliminate the use of chemical fertilizers and pesticides. However, growing evidences showed that although the occurrence of pest, diseases and weeds were effectively controlled under rice-duck system without agrochemicals in early period, whereas in later period, the effect was decreased because ducks were removed out at the rice heading stage (Huang *et al*., 2005; Zhen *et al*., 2006). Thus the current practice of rice-duck farming system still has a great potential for improvement. From the results of our experiment we can see that in CD treatment, the occurrence of strip disease, blast disease and rice hopper rebounded with the absent of ducks pasture in the later rice growing period, whereas in the same period, the rice hopper and sheath blight disease were maintained in a lower occurrence in the two-batch-duck systems. In addition, the occurrence of Cnaphalocrocis medinali and blast disease were significantly ($p<0.05$) lower in the two-batch-duck systems in most periods, suggesting there was an overall higher and longer effect than the conventional system. These results might be due to the increasing of pasture time and disturbance in the two-batch-duck-rice farming systems as the predation, disturbance and grazing activity of ducks almost ran through the whole rice growing period. The increasing effect of duck activity can help to reduce the sclerotia and hyphae growth by removing the dead and yellow leaves and to improve ventilation and light penetration which will contribute to reduce the habitat of pathogen.

Our experiment showed that the 3 types of rice-duck systems exhibited good performance on controlling weeds in paddy field, whereas the weeds densities in the two-batch-rice-duck systems were significantly ($p<0.05$) lower than those of the conventional rice-duck system. The better effect in the two-batch-rice-duck systems might mainly be due to the lengthening of pasture time and increasing effect of pasture disturbance. Whereas except the trampling and grazing effects of ducks on weeds and seeds, the disturbed water and muddy field created by full day walking, swimming and plowing activities of ducks may also inhibited the germination and growth of weeds by reducing light penetration in the water (Wei *et al*., 2006; Zhang *et al*., 2009b). Compared with the conventional rice-duck system, the two batches of ducks pasture decreased the species richness and diversity of weed communities in the two-batch-rice-duck systems, indicated that the structure of weed communities varied with different pasture management. The Pielou Evenness index has been reported to be increased in other researches in the rice-duck system (Wei *et al*., 2005; Zhang *et al*., 2009b), whereas our results further indicated that the Pielou Evenness index in the two-batch-rice-duck systems were lower than that in the conventional rice-duck farming system, the main reasons may include as follows: Firstly, in the two-batch-rice-duck farming system, the water maintained at a 3-15 cm depth helps to remove weeds such as Leptochloa chinensis, Fimbristylis miliaceae and Lindernia procumbens which cannot grow in deep water, whereas the aquatic weeds such as Monochoria vaginalis, Echinochloa crusgalli and Cyperus difformis can still survive. Secondly, several weeds species was eliminated for the increasing effect of selective grazing by ducks.

In conclusion, compared with the conventional rice-duck farming system, the two-batch-rice-duck systems can not only create more organic production of rice and duck meat, but also decrease investments of farmer with less agrochemicals application due to the fact that the overall effect of ducks on controlling diseases, insect pests and weeds was enhanced.

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