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Nonchemical pest control in China rice: a review

Shiwen Huang · Ling Wang · Lianmeng Liu · Qian Fu · Defeng Zhu

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Abstract Major pests such as blast, sheath blight, bacterial blight, plant hoppers, leaf folder, and stem borers occur in rice paddy fields. These pests cause high damage to the grain and straw yield. The application of high N fertilizer loads increases the predisposition of rice crops to be infected by pests. Many agrochemicals used to control pests lead to pest adaptation and resistance, loss of soil fertility and organic carbon, soil erosion, decreasing biodiversity, and desertification. Chemical fertilizers and pesticides unduly applied also lead to major impact on environment and food safety. Here, we review nonchemicals control methods such as genomic diversity of rice host; cultural practices; physical measures; duck, fish, and bullfrog with rice commensalism; and biogas fermentative liquid and residue. We also discuss the current progress of nonchemical control methods in China.

Keywords Rice · Rice major pests · Pests management · Nonchemical approaches

Contents

1 Introduction	2
1.1 China and world confronting problem	2
1.2 Crop yield loss caused by pests.....	2
1.3 Vital function of pesticides in agricultural production.....	3
1.4 Adverse effect of pesticides	3

1.5 Resolve measures of side effect caused by pesticides.....	4
2 Rice pests management by mixed growth of different resistance rice varieties.....	5
2.1 Disease management through genetic diversity.....	5
2.2 Control efficiency of plant hoppers by inheritance diversity.....	6
2.3 Effects of mixture planting on rice yield.....	6
3 Adjusting rice seeding and transplanting date to reduce pest injuries.....	7
3.1 Effect of seeding and transplanting date on insect pests.....	7
3.2 Effect of seeding and transplanting date on sheath blight.....	7
4 Releasing fish and frog in rice paddy field to control pests.....	8
5 Rearing duck in paddy field to control pests.....	9
6 Seeds soaking with biogas fermentative liquid and seedling cultivation with biogas fermentative residues.....	10
6.1 Seeds soaked with biogas liquid.....	10
6.2 Rice seedling cultivation with biogas residues.....	10
7 Rice Insect Pests Control by Jiaduo Frequoscillation Pest-killing Lamp	11
7.1 Installation of pest-killing lamp and control distance range.....	11
7.2 Control efficiency of pest-killing lamp to different insect pests.....	12
(1) Control effect on rice leaf folder (<i>Chaphalocrocis medina</i>)	12
(2) Control effect on rice stem borers.....	12
(3) Control efficiency to plant hoppers.....	12
7.3 Effect of pest-killing lamp on natural enemies.....	13
7.4 Effects of pest-killing lamp on on rice yield.....	13
7.5 Benefit analysis of pest-killing lamp.....	13
Acknowledgements.....	14
References.....	14

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1 Introduction

1.1 China and world confronting problem

The seven billion global populations are projected to grow by 70 million per annum, increasing by 30 % to 9.2 billion by 2050. This increased population density is projected to increase demand for food production by 70 % notably due to changes in dietary habits in developing countries towards high quality food, e.g., greater consumption of meat and milk products and to the increasing use of grains for livestock feed (Popp et al. 2013). Global food production must increase by 50 % to meet the projected demand of the world's population by 2050 (Chakraborty et al. 2011). Thus, we need to grow food on even less land, with less water, using less energy, fertilizer, and pesticide than we use today (Popp et al. 2013).

China is the biggest developing country with the population of more than 13.47 billion (2011) and still increasing its population at the natural growth rate of 4.79‰ annually (2011) (the population of China statistical table, 2012) that signify 6.45 million persons added each year. China is facing one of the largest challenges of this century to continue to increase annual cereal production to about 600 million tons by 2030 to ensure food security with shrinking agro-land and limited resources, while maintaining or improving soil fertility, and protecting the environment (Miao et al. 2011).

Rice production possesses vital position in China. China now is the biggest country of rice production and consumption in world. In China, the total rice sown area was 29,873 thousand hectares and the total output was 195.76 million tons in 2010, the total rice output of China account for about 35 % of the world rice total output. There are 65 % of Chinese people that (about 0.87 billion) feed on rice as their staple food. The measure of consumption of rice was 186.50 million tons in 2010 account for 94.7 % of rice total output in China; thereinto, 156.25 million tons were consumed as grain ration, account for 83.8 % of rice measure of consumption, and account for 33.7 % of the measure of consumption of grain (China National Rice Research Institute (CNRRI) 2011).

1.2 Crop yield loss caused by pests

Crop productivity may be increased in many regions by high-yielding varieties, improved water and soil management, fertilization, and other cultivation techniques. An increased yield potential of crops, however, is often associated with higher vulnerability to pests attack leading to increasing absolute losses and loss rates (Oerke et al. 1994). An important constraint to achieving higher rice yield is losses caused by pests. Pests are organisms that attack the rice crop or compete with it for nutrients, causing yield reductions. The common organism pests of rice are insects, weeds, molluscs, mammals, birds, fungal and bacterial pathogens, and viruses.

The annual global chemical-pesticide market is about 3 million tons associated with expenditures around USD 40 billion (Popp 2011). The studies estimate that aggregate crop losses amounted to 37 % of total output in 1986, up from 33 % in 1974 (Pimentel 1993).

The reduction of current yield losses caused by insect pests, diseases caused by pathogens, and weeds are major challenges to agricultural production (Oerke and Dehne 2004), globally, an average of 35 % of potential crop yield is lost to preharvest pests (Oerke 2005).

Since crop production technology and especially crop protection methods are changing continuously, loss data for eight major food and cash crops—wheat, rice, maize, barley, potatoes, soybeans, sugar beet, and cotton—have been updated for the period 1996–1998 on a regional basis for 17 regions (Oerke and Dehne 2004). Among crops, the loss potential of pests worldwide varied from less than 50 % (on barley) to more than 80 % (on sugar beet and cotton). Actual losses were estimated at 26–30 % for sugar beet, barley, soybean, wheat, and cotton, and 35, 39, and 40 % for maize, potatoes, and rice, respectively (Oerke and Dehne 2004).

1.3 Vital function of pesticides in agricultural production

Pest and disease management has played its role in doubling food production in the last 40 years. Pesticides, as an important input substance in agricultural production, have made enormous contribution to the development of agriculture and food supply to mankind (Wang and Li 2007). Existing data indicate that one third (1/3) losses of the potential crop yield due to the pests' injure were avoided and recovered worldwide because of chemicals application (Liu et al. 2002). China, with only 7 % of agricultural acreage of the world, has managed to provide food for 22 % of the world population; thereinto, pesticides make a great contribution (Huang and Qiao 2002). Increased agricultural pesticide use nearly doubled food crop harvests from 42 % of the theoretical worldwide yield in 1965 to 70 % of the theoretical yield by 1990. Unfortunately, 30 % of the theoretical yield was still being lost because the use of effective pest management methods was not applied uniformly around the world and it still is not. Without pesticides, 70 % of crop yields could have been lost to pests (Oerke 2005).

1.4 Adverse effect of pesticides

Pesticides play an important role in agricultural production, especially to increase crop yield and farmer's income though. However, it cannot be denied that adverse effects of pesticide application can be seen everywhere, and on human health and on the environment in and around intensive systems. The intensity of crop protection has increased considerably as exemplified by a 15–20-fold increase in the amount of

pesticides used worldwide (Oerke 2005). Over the last century, agricultural production has steadily increased, mainly due to improved nutrient availability, crop breeding, and crop protection. However, these improvements have often caused environmental problems, such as water pollution, trace gas emissions, or soil degradation. More sustainable practices are needed to minimize the environmental impact of agricultural production and land use (Ludwig et al. 2011).

Both the production ability and application of pesticides of China were ranked first in the world at present. It brings a lot of issues, such as pollution and hazard which are more and more serious due to long-term slather pesticide, and causing the economic losses increase by years. Even more serious is that tens of thousands of people will experience toxicosis, injuries, and deaths (State Environmental Protection Administration 2001; Gao et al. 2002), especially when chemicals misuse. Chemicals misuse is defined as the “improper or incorrect use.” Thus when an insecticide is used for the wrong target pests or at the wrong time, or both, it can be considered to be misused (Heong et al. 1995). Pesticides that were used in quantity lead to produce “three R” (i.e., resistance, residue, and resurgence) increasingly severe (Wang and Li 2007). Table 1 shows the chemicals use of the major rice production provinces in China. The chemicals usage amount in unit area (in kilogram per hectare) varied from the lowest of 18.54 kg/hm² in Guizhou to highest of 87.68 kg/hm² in Liaoning in 2010. Table 2 indicated that the chemicals usage amount in unit area of the major counties in Jiangxi

Province, a middle-level developing province in central China.

1.5 Resolve measures of side effect caused by pesticides

Farmers are facing serious plant protection issues and phytosanitary risks, in particular in the tropics. Such issues are food insecurity, lower income in traditional low input agroecosystems, adverse effects of pesticide use on human health and on the environment in intensive systems, and export restrictions due to strict regulations on quarantine pests and limits on pesticide residues (Vandermeer et al. 1998). To provide more and better food to populations in both the southern and northern hemispheres in a sustainable manner, there is a need for a drastic reduction in pesticide use while keeping crop pest and disease damage under control (Ratnadass et al. 2012).

Due to increasing problems occurring from massive applications of pesticides, such as insect resistance to pesticides, the use of biotechnological tools to minimize losses from insect pests has become inevitable. Presenting alternative strategies for alleviating biotic stresses, biotechnological approaches for pest management and ecological sustainability explore how the modern tools of biotechnology can be used in pest management for sustainable crop production, the biosafety of transgenic crops, and environmental conservation.

Another way of reducing fungicide use is through cultural control. This includes all those techniques that will make the

Table 1 Rice production and chemicals use of the major provinces in China, 2009–2010

Rice growth regions	Provinces	Year 2009					Year 2010		
		Rice sown area (thousand hm ²)	Rice total output (thousand ton)	Unit area output (kg/hm ²)	Chemicals usage amount (thousand ton)	Chemicals usage amount in unit area (kg/hm ²)	Rice sown area (thousand hm ²)	Chemicals usage amount (thousand ton)	Chemicals usage amount in unit area (kg/hm ²)
Southwest	Sichuan	2,027.1	15,202	7,499	60.8	30.0	2,004.5	62.2	31.0
	Guizhou	698.2	4,532	6,490	12.9	18.5	695.8	12.9	18.5
	Yunnan	1,039.8	6,362	6,119	42.9	41.3	1,021.0	46.2	45.3
South China	Guangdong	1,953.7	10,581	5,399	103.7	53.1	1,952.7	104.4	53.5
	Guangxi	2,125.0	11,459	5,392	62.2	29.3	2,094.4	64.5	30.8
	Fujian	864.6	5,153	5,960	57.8	66.9	854.8	58.2	68.1
Northeast	Heilongjiang	2,636.0	15,745	6,313	66.8	25.3	2,768.8	73.8	26.7
	Jilin	660.0	5,050	7,647	42.4	64.2	673.5	42.8	63.6
	Liaoning	657.0	5,060	7,710	54.1	82.3	677.5	59.4	87.7
Central China	Hunan	4,047.2	25,786	6,371	126.7	31.3	4,030.5	118.8	29.5
	Hubei	2,045.1	15,919	7,784	127.9	62.5	2,038.2	140.0	68.7
	Jiangxi	3,282.1	19,059	5,807	138.8	42.3	3,318.4	106.5	32.1
East China	Jiangsu	2,233.2	18,029	8,073	90.1	40.4	2,234.2	91.1	40.8
	Zhejiang	938.7	6,667	7,102	65.1	69.4	923.2	65.8	71.3
	An'hui	2,246.9	14,056	6,256	116.6	51.9	2,245.4	117.4	52.3

Data come from China's agriculture yearbook, 2010 and 2011, Agricultural Publishing House of China, Beijing

Table 2 Rice sown area and chemicals use dosage of major counties in Jiangxi Province (2010)

County (city)	Rice sown area (thousand hm ²)	Chemicals usage amount (million kg)	Chemicals usage amount in unit area (kg/hm ²)	County (city)	Rice sown area (thousand hm ²)	Chemicals usage amount (million kg)	Chemicals usage amount in unit area (kg/hm ²)
Nanchang	79.27	4.09	51.60	Yushui	30.53	1.03	33.73
Fengcheng	78.07	2.60	33.30	Yuanzhou	30.47	0.77	25.27
Boyang	67.13	1.95	29.05	Xingan	27.33	1.82	66.59
Gao'an	61.13	2.45	40.08	Anfu	26.60	1.36	51.13
Xinjian	57.53	1.58	27.46	Jinxi	25.33	1.05	41.45
Linchuan	56.07	2.23	39.77	Shanggao	24.93	0.80	32.09
Yugan	52.67	1.06	20.13	Xingguo	24.80	1.32	53.23
Zhangshu	45.13	2.20	48.74	Dongxiang	24.80	2.22	89.52
Jishui	41.67	2.03	48.72	Yongxin	23.40	0.73	31.20
Jinxian	38.93	0.88	22.60	Yifeng	21.80	0.69	31.65
Taihe	38.00	0.98	25.79	Xinfeng	21.60	0.80	37.04
Ningdu	32.20	1.79	55.59	Yujiang	20.33	1.35	66.39
Leping	31.80	1.55	48.74	Wan'an	20.27	1.35	66.61
Duchang	31.20	1.04	33.33	Average			42.60

Data come from Jiangxi provincial agriculture yearbook, 2011

environment less favorable for pests to develop or multiply, but which still favors rice production. Cultural practices, such as rotations, cultivar mixtures, crop mosaics, and planting times have been part of the local practice in many rice-growing areas (Oka 1988). Flooding, stubble burning, fallow, intercropping, terracing, and plant spacing are other practices that have been used by rice farmers for centuries to help in producing a good crop (Bray 1990; Thurston 1990). With the support of state- and provincial-level projects, several approaches have been considered to control rice pests in more than ten provinces of China (view Fig. 1, the map of China) from 2004 to 2011. The aim of the study was to effectively control rice pests while maintaining rice yield and producing high quality products. Several nonchemical approaches for controlling rice diseases, insect pests, and weeds have been studied and applied, specifically:

- (1) Using rice resistance genomic diversity to control rice blast (*Pyricularia oryzae*) and plant hoppers (*Nilaparvata lugens* Stål, *Sogatella furcifera* Horvath).
- (2) Changing rice seeding time, transplanting date to reduce diseases and pests injures to rice.
- (3) Rearing fish and frog (bullfrog) in rice paddy fields to control plant hoppers, rice sheath blight (*Rhizoctonia solani*), and weeds.
- (4) Rearing ducks in rice paddy fields to control rice plant hopper, stem borer, sheath blight, and weeds.
- (5) Soaking rice seeds in biogas fermentative liquid and cultivating seedlings with biogas fermentative residues.
- (6) Using a Jiaduo Frequoscillation Pest-killing Lamp to control rice insect pests.

2 Rice pests management by mixed growth of different resistance rice varieties

2.1 Disease management through genetic diversity

Actually, there are already extensive reviews of the ways intraspecific crop diversity nearly always reduces yield losses caused by pathogens (Zhu et al. 2000; Ngugi et al. 2001; Mundt 2002; Castilla et al. 2003; Cox et al. 2004), and sometimes by pests (Teetes et al. 1994; Johnson et al. 2006). Vilich-Meller (1992) reported that wheat–barley mixtures resulted in greater disease reduction in wheat than did applications of fungicide, illustrating the potential benefit of mixing cereal species in organic agriculture (Kaut et al. 2008). Polycultures of interplanted crops often support fewer pests at lower densities than monoculture and tend to increase number of natural enemies (Ludwig et al. 2011).

Intercropping can play an important role in reducing insect pest infestation (Root 1973; Potts 1990). Van Emden and Wratten (1990) have given a number of examples of the effect of intercropping on insect population densities. Intercropping may reduce pest damage by attracting pests to a less valuable crop or one where the pest is less serious (van Emden 1989).

Andow and Hidaka (1989) found that traditional varieties grown under organic culture in Japan had less disease and lower arthropod populations than conventional farms growing high-yielding cultivars. Methods to mix host genes by deploying these genes either in pyramids in the same cultivar, as multilines, or as multivars (mixtures of cultivars, each with a different gene for resistance) may be useful in disease management.

Fig. 1 China map showing the provinces where the project was carried out

In this study, the blast-resistant hybrid rice combinations Chuanxiangyou 2, Ilyou 7, and Yixiangyou and susceptible glutinous rice were selected. The experiments and production practices were conducted in Yunnan (Zhu et al. 2003; 2004a, b; Lü and Zhou 2004), Guizhou (Wu 2011; Feng et al. 2007), Sichuan (Mao et al. 1991; Zhao and Liao 2006), and Hunan (Liu et al. 2003). The varieties were large-scale grown in mixture ratios of 5:1, 4:1, 3:1, 2:1, 1:1, 1:2, and 1:3. Investigations of panicle neck blast were carried out at yellow ripeness stage. Results indicated that mixtures grown at different ratio of resistance to susceptible varieties showed significantly different of disease control effects. The control efficiency to panicle blast was 52.1–88.4 % without any chemical application in the experiments and large-scale production practices. According to the mixture ratio of resistance and susceptible varieties, control efficiency decreased with the increase of susceptible varieties. The average control efficiency to panicle blast reached 88.4 % in the 5:1–4:1 of resistance to susceptible mix growth models.

The experiments in Jilin Province also showed the same results of above provinces (Ren et al. 2004; Gan and Lou 2008). Control efficiency to panicle blast differed significantly for different resistance variety mixed plantings. When the resistant variety of japonica Songjing 6 was mixture grown with susceptible variety Jiyou 1 by the ratio of 5:1, the panicle blast ratio of Jiyou 1 decreased from 68.9 % (when it was planted alone) to 2.8 %, and the control efficiency reached 95.9 %. The leaf blast was not surveyed in the both experiments and production practice.

From the survey results during 1998–2003 in Yunnan Province, the mean disease incidence for traditional varieties (susceptible) in mixture decreased 72.0 % and the mean disease index decreased 75.4 % than monoculture. For modern varieties (resistance), the mean disease incidence in mixture decreased 32.4 % and the mean disease index decreased 48.2 % than monoculture.

The results during 2002–2003 in Sichuan Province showed that the mean disease incidence for glutinous varieties in

mixture decreased 58.1 % and the mean disease index decreased 67.4 % than monoculture. For modern varieties, the mean disease incidence in mixture decreased 28.6 % and the mean disease index decreased 35.5 % than monoculture. Because of different eco-environment of the planting regions and the different resistance of involved varieties, the effects of blast control had larger difference among different regions and different variety combinations, but the effects of mixture planting for blast control were all higher than that of corresponding monoculture. It indicated that mixture planting can be universally adopted (Zhu et al. 2003, 2004a, b).

2.2 Control efficiency of plant hoppers by inheritance diversity

Compared with resistance and susceptible varieties separately planted, the amount of adult plant hopper migrated into the fields, and egg laying amount per female show no significant differences when insect resistance variety RHT was mixed grown with susceptible variety TN1 in a 2:1 ratio. However, the nymph density of 100-hill and the average appetite per female plant hopper (measured by excretive honeydew) were significantly lower than that of the susceptible variety planted alone.

2.3 Effects of mixture planting on rice yield

From the survey results during 1998–2003 in Yunnan Province, the average yield of traditional varieties in mixture increased 4,753.52 kg/hm² and 117.4 % higher than that of monoculture. The average yield of modern varieties in mixture increased 748.29 kg/hm² and 9.39 % higher than that of monoculture. The results during 2002–2003 in Sichuan Province showed that the average yield of modern varieties in mixture increased 534–600 kg/hm² and 6.74–7.48 % higher than that of monoculture. The average yield of glutinous varieties in mixture increased 3,270–3,303 kg/hm² and 61.1–64.2 % higher than that of monoculture.

Mixed grown of blast resistant and susceptible varieties increased rice output compared with resistant or susceptible varieties planted alone. Yields of mixed grown resistant and susceptible rice variety increased from 6.92 to 8.73 % compared with that of separate plantings, respectively, viz. 631.5–955.0 kg of rice yield increased per hectare. At the same time, two times of chemical application for controlling blast were reduced. The average income of mixed grown of different resistance varieties increased by 1500 RMB ¥ (¥ from here onwards) per hectare due to the increased yield, reduction in chemicals used, and savings in time and labor (Zhu et al. 2003, 2004a, b; Liu et al. 2003).

The results indicated that the control efficiency to rice panicle blast vary from region to region, year to year, and

variety to variety because the diseases were affected by multiple factors. This agricultural system increases rice yield both of the resistant and susceptible varieties, particularly to increase the yield of susceptible varieties drastically than that of their monoculture.

3 Adjusting rice seeding and transplanting date to reduce pest injuries

3.1 Effect of seeding and transplanting date on insect pests

Experiments were carried out in Sichuan, Hubei, Jiangsu, and Zhejiang. Pest injury to rice can be significantly reduced by using crop rotation and intercrops, by modifying ecological conditions, and by changing the seeding and transplanting dates. In Sichuan, Hubei (Zhang et al. 2009a, b), and Zhejiang (Zhu et al. 2011a, b), rice seeding dates of March 5 and March 20 were selected, and rice plants infested by stem borers (*Chilo suppressalis* (Walker) and *Tryporyza incertulas* (Walker)) were investigated. The infestation ratio of rice plants by first generation of stem borers on the earlier seeding date (March 5) was 8.33 %, while the later seeding date (March 20) demonstrated a less severe infestation of 2.15 %. Furthermore, the infestation ratio by the third generation of stem borers on March 5 and March 20 were 44.4 and 7.72 %, respectively, indicating that intensity of early seeded rice infestation was 5.78 times higher than that of the late seeded crops.

Results also showed that rotation of irrigated crop (rice) and dry land crops (e.g., vegetable, strawberry, potato, or soybean) reduced the rice injury ratio of sheath blight and stem borer by 60.3 and 30.0 %, respectively, compared with continuous irrigated rice.

In Jiangsu, the japonica variety of 9915 was chosen to investigate the effect on stem borer of different seeding dates. May 4–6 was the traditional seeding date of single season rice at local, in this experiment, the seeding date was postponed. Six seeding dates of May 10, 14, 17, 20, 23, and 26 were selected; the seedlings were transplanted 30 days after seeding, so six corresponding transplanted dates were June 9, 13, 16, 19, 22, and 25, respectively (Table 3). The data were analyzed according to Tang Qiyi's DPS and the Statistical Soft Ware (Tang 2007). Rice injured of the traditional seeding date (May 4–6) were more severe compare with the six seeding and transplanting dates caused by stem borers. Generally, the earlier seeding and transplanting date exhibited more serious injuries, and the postponed rice seeding and transplanting dates had reduced injuries. In Jiangsu Province, a good control efficiency to stem borer in relation to optimal seeding and transplanting date of single season rice was May 20–23 and June 20–26, respectively (Sun et al. 2002).

Table 3 Effect of stem borer on rice for different seeding and transplanting date

Seeding date (month/day)	Transplanting date (month/day)	Egg piece density after seeding (egg piece/hm ²)				Dead heart ratio in transplanting date (%)	Infested by second generation		Infested by third generation	
		10 days	20 days	30 days	Average		Dead heart ratio (%)	Remnant stem borers (larva/hm ²)	White panicle ratio (%)	Remnant stem borers (larva/hm ²)
5/10	6/9	1,290	12,840	6,120	6,750a ^a	5.24a	5.03a	8,400a	15.8a	53,400a
5/14	6/13	2,340	11,280	5,550	6,390a	3.63b	5.12a	8,400a	15.9a	53,730a
5/17	6/16	2,235	5,970	4,800	4,335a	1.89c	4.14b	5,850b	9.64b	43,350b
5/20	6/19	2,430	2,040	2,550	2,340b	1.83c	3.62b	4,290c	5.63c	29,407c
5/23	6/22	2,235	840	570	1,335b	1.25d	2.89c	2,340d	4.90d	16,809d
5/26	6/25	1,875	585	60	840b	1.12d	1.14d	2,130e	3.70e	13,389e

^a Values followed by common letters within a column are not significantly different at $P=0.05$ level. All data were analyzed according to “Tang (2007). The following tables are the same.

3.2 Effect of seeding and transplanting date on sheath blight

The occurrence of rice sheath blight (*R. solani*) was also markedly influenced by seeding and transplanting date. In Sichuan, the disease index of sheath blight was 39.6 when the sowing date was March 5, but the index decreased to 11.8 when the seeding date was postponed to March 20.

Experiments on the relativity of seeding (transplanting) date and sheath blight severity were carried out in 2006 and 2007 at the experimental base of CNRRI, Hangzhou, Zhejiang (Huang et al. 2009a). Three seeding date of May 12 and 23 and Jun 2 was selected, and corresponding three transplanting dates after 20 days of seeding. Moderately susceptible to sheath blight super hybrid rice Guodao6 and moderately resistant Liangyoupeijiu were chosen as the testing hybrid rice combinations. Each treatment had three replicates and with the area of 50 m²/plot. Investigations on sheath blight were carried out August 15 and September 25. Two-year average values are shown in Table 4. The results showed that the disease indices of late seeding (June 2) and transplanting (June 22) were significantly lower than that of early seeding (May 12) and transplanting (June 1) for both Guodao6 and Liangyoupeijiu super hybrid rice combinations. The sheath

blight disease indices were quite low when the seeding and transplanting dates were postponed to June 2 and June 22, respectively, because of rice growth stage that was susceptible to sheath blight avoiding the weather condition in favor of the disease. When the seeding and transplanting dates of Guodao6 and Liangyoupeijiu were the same, the severity of sheath blight of Guodao6 was more serious than that of Liangyoupeijiu, which indicated that Guodao6 was more susceptible to sheath blight than that of Liangyoupeijiu. Table 4 also show that sheath blight intensity of Guodao6 for late seeding (May 23) had a significantly lower disease indices than that of early seeding (May 12) of Liangyoupeijiu though the former was more susceptible to sheath blight. The results indicated that the occurrence of sheath blight was significantly affected by seeding and transplanting date as well as weather conditions during the rice growing period.

4 Releasing fish and frog in rice paddy field to control pests

Rearing fish and frog in paddy field cannot only effectively controls insect pests and weeds but also increase

Table 4 Comparison of rice sheath blight for different seeding and transplanting dates of super hybrid rice combinations

Super hybrid rice combinations	Seeding date (day/month)	Transplanting date (D/mM)	Heading date (D/M)	Flowering date (D/M)	Dough grain date (D/M)	Disease index of sheath blight	
						15/Aug	25/Sept
Guodao 6	A:12/5	1/6	12/8	16/8	20/9	41.6a	45.2 a
	B:23/5	12/6	17/8	21/8	26/9	9.35 c	20.5 c
	C:2/6	22/6	18/8	24/8	5/10	2.07 e	5.14 d
Liangyoupeijiu	A:12/5	1/6	14/8	18/8	22/9	35.4 b	39.9 b
	B:23/5	12/6	24/8	28/8	9/10	4.72 d	5.33 d
	C:2/6	22/6	30/8	2/9	14/10	0.00 f	1.33 e

comprehensive benefits to a great extent. For example, grass carp (*Ctenopharyngodon idellus*) feeds on young weeds, frogs prey on larva or nymph of insects. From 2007 to 2010, experiments and demonstrations were carried out in Chongqing, Jiangxi, and Zhejiang (Zhou and Zhang 2011; Zhu 2000; TEMSAPZP 2012). Native frog (tiger frog, *Hoplobatrachus rugulosus*) and grass carp were used in fields during the early and middle rice growing seasons (April to June) and bullfrog (*Rana catesbiana*) were released in the late rice growing season to eliminate pests. The animals feed on pests, with one adult bullfrog able to eat more than 100 insects per day. Compared with not releasing fish, frog, and bullfrog paddy, dead heart of rice plants and white panicle ratio caused by stem borers (*C. suppressalis*, *Scirpophaga incertulas*) were reduced by 62.9–83.4 % and 58.3–84.8 %, respectively. The plant hoppers amount of 100-hill and the density of weeds per square meter were reduced by 38.9 and 41.7 %, respectively. The number of injured tillers decreased by 21.8 %, and pesticide application was reduced twice (Figs. 2a, b and 3).

Seven thousand five hundred fishes were released in 1 ha combined with the use of “lǜ lang” (or green wave, a biological pesticide with low toxicity) to control leaf folder and plant hoppers, and 5 % Jinggangmycin (a biological fungicide) 3, 000 mL + 20 % Tricyclazole 1,500 g to control sheath blight and blast. The results showed that the injured ratio of rice hill by leaf folder and the number of plant hoppers (*N. lugens*, *Sogatella furcifera*) per 100-hill were significantly reduced compared with that of no fishes and frogs were released. Compare with no fishes and frogs, rice yield of releasing fishes and frogs increased by 10.1 %; moreover, 1,180 kg of fish and frogs were harvested per hectare (Peng 2012; Huang and Huang 2012; Wang 2004). Very good economic, ecological, and social benefits were gained from this rice cropping pattern, as shown in Table 5.

5 Rearing duck in paddy field to control pests

Using the duck's habits of eating pests and young weeds, and excreting feces as fertilizer, releasing duck in rice paddy field can effectively controlled rice pests, reduced the application

Frogs in paddy field

Fig. 3 Frogs in paddy field

dosage of fertilizer and chemicals, decreased environmental pollution, and increased rice yield and quality and farmers' income (Deng et al. 2007; Deng and Pan 2008; Yu et al. 2008a; Zhang et al. 2009c). More than 500,000 ha of rice paddy fields were established with rice–duck mutualism to control pests in southern China (Zhang et al. 2009c), Yunnan (Peng et al. 2002), Jiangxi (Li et al. 2004), Hunan (Wang and Huang 2002; Liu et al. 2006), Hubei (Lin and Jin 2002), Anhui (Zhu et al. 2001; Zhen et al. 2004; Wang et al. 2004), Zhejiang (Yu and Jin 2006; Yu et al. 2004a, b, 2005, 2008a, b), Jiangsu (Wei et al. 2005), Shanghai (Zheng et al. 1997), Henan (Zhang et al. 2002), Heilongjiang (Asano 2000), and Jilin (Jin et al. 2009; Hou et al. 2009) from 2005 to 2011. The control efficiency of rice insect pests, diseases, and weeds by releasing ducks in paddy fields was investigated in more than 12 provinces (cities).

At rice active (maximal) tillering stage, 225–375 young ducks (20 days old) per hectare were released to the paddy and allowed to mutualism for 50–60 days. Generally, an adult duck (weight over 1.0 kg) can ate more than 150 pests (including few natural enemies) per day. The investigated average results show that the total number of insects in released duck fields (the followings abbreviated duck fields) reduced by 87.7 % compared with non-duck fields. Plant hoppers and leaf folder were reduced by 37.6 and 48.3 % 1 day after ducks were released compared with the day before release.

In Zhejiang, the experiments' results showed that the total number of plant hoppers and leafhopper in duck fields were reduced by 63.9 and 77.3 %, and weeds were reduced by 50.6

Fig. 2 a Fish in paddy field. b Harvest fish

a Fish in paddy field

b Harvest fish

Table 5 Effect on rice pests of rice–fish and frog coexisting rice paddy system

Content	Plant hoppers 100-hill	Infected hill ratio (%)	Rice yield (kg/hm ²)	Fish and frog yield (kg/hm ²)
Fish and frog	280.0	10.2	9,180.0	1,177.5
No fish and frog	2,150.0	34.6	8,337.0	0.00
Efficiency (%)	86.9	70.5	10.1	100.0

and 94.2 % 12 and 42 days after ducks were released compared with non-duck fields, respectively. The sheath blight disease incidence at maximal tillering and full heading stage decreased by 67.2 and 52.5 % compared with the non-duck fields, respectively, and the quantity of natural enemy of spiders in duck fields were 1.66–2.61 times than that in non-duck fields. This indicated that pests were effectively controlled in duck fields compare with non-duck fields (Fig 4). The pests control effects of native and hybrid ducks were also tested. During the maximal tillering and full heading stages, pests control by native duck was 66.8 and 73.9 %, and hybrid duck was 60.7 and 80.8 %, respectively.

Rice–duck farming agro-ecosystem reduced 30.6 % fertilizers and 59.4 % pesticides compare with conventional farming system. The quality of rice produced in rice–duck mutualism was significantly improved due to no herbicide and less pesticide was applied (Yu et al. 2008a; Zhang et al. 2009c). According the China State Standard of Rice (GB/T 1789, 1999), coarse rice rate, head rice rate, gel consistency, and chalkiness rate of rice produced in rice–duck farming were superior to traditional farming (Wang et al. 2004). The contents of malathion, phosphide, chloride, arsenic(As), mercury(Hg), benzex, and DDT of duck field rice were obviously lower than the contents of the national regulation values (Li et al. 2003). Rice produced in rice–duck mutualism fields almost had no pollution with pesticides and fertilizer (Zhang et al. 2002). Compare with rice monoculture, rice yield of rice–duck mutualism system increased 4.42 %. However, the rice quality improved and economic benefits increase by 2, 000–4,500 ¥ per hectare through ducks sale (Zhang et al. 2002; Deng et al. 2007; Deng and Pan 2008). In Zhejiang Province, a total area of 86.4 thousand hectares of rice–duck

mutualism were implemented from 2001 to 2003. Compared with traditional rice farming, duck fields increase 3,404.1 ¥ per hectare because of increasing revenue and reducing expenditure, grain yield increased 295.5 kg per hectare. The total income add up to 294 million ¥ and increased 25,000 tons grain (Yu et al. 2004a, b).

6 Seeds soaking with biogas fermentative liquid (BFL) and seedling cultivation with biogas fermentative residues (BFR)

To study the effects of biogas manure on rice, rice seeds were soaked with biogas liquid, and rice seedlings were treated with biogas residues (manure). The results showed that (1) seeds germination was promoted and seedling quality was enhanced when rice seeds were soaked with biogas liquid; (2) when biogas manure was combined with a small amount of chemical fertilizer and applied in paddy fields, the soil organic matter and nutrient elements such as N, P, and K were increased and the ability of rice in taking up N and P nutrients was improved (Xiong et al. 1996); (3) injured rice caused by diseases and insect pests reduced when biogas manure was applied; (4) biogas manure not only increase rice grain yield but also improved rice quality, such as the grain appearance was better and nutrition content more plentiful; (5) using biogas manure on rice reduced production costs and decreased environmental pollution caused by chemical fertilizers application.

6.1 Seeds soaked with biogas liquid

Compared with the seeds soaked in fresh water, rice seeds soaked in biogas liquid for 24–48 h, and then washed with clear water, aerated, germinated, and seeded had germination rate increased by 5–10 %, seedlings emerged 1–2 day earlier, and the seedling survival rate increased by 10–20 %. When rice seeds were soaked with biogas liquid, the seedlings grow healthy and strong, seedlings revive faster, and tiller earlier than that of water soaked. Compared with seeds soaked with fresh water, rice yield of seeds soaked with biogas liquid increased by 5–10 % (Cao 1999; Wang et al. 2003), Fig. 5a.

Fig. 4 Ducks in paddy fields at early and late growth stage of rice. Download from www.ooopic.com (left) and www.zsnews.cn (right)

Fig. 5 **a** Seeds soaked with biogas fermentative liquid (BFL) (1, 2), with chemicals (3) and control (4, with fresh water). **b** Mature stage of rice seeds soaked with BFL (*left*) and control (*right*, seeds soaked with water)

6.2 Rice seedling cultivation with biogas residues

Rice seeds soaked with biogas liquid and combined with seedling cultivation using biogas residues, the results showed that the seedlings quality was significantly improved, and injured seedlings by diseases decreased. The occurrence date of the diseases, such as bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*) and blast (*Pyricularia grisea*), was postponed than that of chemical fertilizer treatment. When rice seedlings were cultivated with biogas residues, the natural control effect on bacterial leaf blight was better than that of using fertilizer and pig manure. The injured rice plants, leaves, and disease index of biogas residues treatment were reduced

by 82.0 %, 77.2 % and 72.7 compared with the chemical treatment, respectively, and decreased by 58.5 %, 53.6 % and 50.3 compared with pig manure treatment, respectively (Cao 1999; Wang et al. 2003; Zhang et al. 2001).

When biogas residues was applied in paddy fields, the density of rice plant hoppers, leafhoppers, the occurrence rate of leaf folder, and rice sheath blight disease index reduced compared when chemical fertilizer and pig manure were used. Plant hoppers decreased by 59.0 and 69.0 % and leafhoppers decreased by 66.0 and 54.0 % in early and late rice, respectively, and sheath blight disease index were reduced by 45.0–66.5 (Zhang et al. 1996, 2008; Sun and Zhu 1990; Sun et al. 1999; Dai et al. 2000), Fig. 5b.

Fig. 6 **a** Old model of Jiaduo frequoscillation pest-killing lamp, with manual control of light; the killed insects were collected in the bag. **b** New model of Jiaduo frequoscillation pest-killing lamp, with power supplied by solar energy and automatic control of light and temperature

7 Rice insect pests control by Jiaduo Frequoscillation Pest-killing Lamp

A Jiaduo Frequoscillation Pest-killing Lamp (“pest-killing lamp” hereafter) (Henan Jiaduo Science and Industry Trade

Company, China) is a physical device used to trap insects based on phototaxis, the strong attraction to light, waves, and colors. The wavelength, wave band, and frequency of light are set in special scopes, with nearby pests trapped with light and color. High voltage wires then electrocute the pests, which fall

Table 6 Species, amounts, and main peak days of rice insect pests occurrence

Order	Family	Amounts	Species	Trapped amounts	Main peak day (month/day)
Orthoptera	Catantopidae	1	<i>Oxyavelox</i> (Fabricius)	2	
	Pyrgomorphidae	2	<i>Airactomorpha sirnensis</i> I Bolirvdr	3	
	Tettigoniidae	3	<i>Conocephalus gladiatus</i> Redtenbacker	4	
	Gryllidae	4	<i>Teleogryllus occipitalis</i> (Audinet-Serville)	29	
	Gryllotalpidae	5	<i>Gryllotalpa orientalis</i> Burmeister	72	
Homoptera	Cicadellidae	6	<i>Tettigella spectra</i> (Distant)	126	
		7	<i>Nephotettix cincticeps</i> (Uhler)	258	
		8	<i>Inazuna dorsalis</i> (Motschulsky)	1,582	9/11
		9	<i>Empoasca flavescens</i> (Fabricius)	987	
		10	<i>Inemadara oryzae</i> (Matsumura)	562	
		11	<i>Telligella viridis</i> (Linne)	111	
		12	<i>Thaia rubiginosa</i> Kuoh	363	
		13	<i>Nephotettix virescens</i> (Distant)	205	
		14	<i>Sogatella furcifera</i> (Horvath)	2,014	9/14
		15	<i>Nilaparvata lugens</i> (Stal)	1,366	9/14
	Delphacidae	16	<i>Leptocorisa acuta</i> Thunberg	31	
		17	<i>Cleus punctiger</i> Dallas	7	
Hemiptera	Pentatomidae	18	<i>Ezara viridula</i> (Linnaeus)	72	
		19	<i>Cnaphalococcus medinalis</i> Guenee	554	8/31, 9/18
Lepidoptera	Pyralidae	20	<i>Susumia exgua</i> (Butler)	6	
		21	<i>Tryporyza mivella</i> Fabricius	2	
		22	<i>Tryporyza incertulas</i> (Walker)	501	10/2
		23	<i>Chilo suppressalis</i> (Walker)	9	
		24	<i>Chilo trazea auricilia</i> (Dudgeon)	11	
		25	<i>Nymphaula depunctalis</i> (Guenee)	7	
		26	<i>Nymphaula flucyusalis</i> Zeller	13	
		27	<i>Ancylolomia japonica</i> Zeller	16	
		28	<i>Talanga sexpunctalis</i> Moore	4	
		29	<i>Aulacodes sinensis</i> Hampson	3	
	Noctuidae	30	<i>Naranga aenescens</i> Moore	5,084	9/10, 9/19
		31	<i>Prodenia litura</i> Fabricius	133	
		32	<i>Spodoptera mauritia</i> (Boisduval)	92	
		33	<i>Sesamia inferens</i> Walker	22	
		34	<i>Leucania separata</i> Walker	13	
		35	<i>Leucania venalba</i> Moore	8	
		36	<i>Leucania Loreyi</i> (Duponchel)	6	
		37	<i>Creatonotus tronsiens</i> (Walker)	306	
		38	<i>Porthesia scintillans</i> (Walker)	130	
		39	<i>Pelopidas agna</i> Moore	5	
Diptera	Satyridae	40	<i>Melaniitis leda</i> (Linnaeus)	4	
	Cecidomyiidae	41	<i>Orseolia oryzae</i> (Wood-Mason)	144	

Table 7 Control efficiency of leaf folder by pest-killing lamp

Treatments	Moth amount per hm ²	Moth control efficiency (%)	Infected hill ratio (%)	Hill control efficiency (%)	Infected plant ratio (%)	Plants control efficiency (%)	Roll up leaf ratio (%)	Roll leaf control efficiency (%)
Light and chemical control	2,599.5	95.0a	11.7	88.3a	1.3	98.6a	0.50	98.7a
Light and no- chemical control	3,000.0	94.2a	16.7	83.3a	5.2	94.2a	1.98	95.0a
No-light and chemical control	13,275.0	74.3b	64.0	36.0b	15.4	82.9b	5.54	85.9b
No-light and no-chemical control	51,750.0	0.00 c	100	0.00 c	90.1	0.00 c	39.5	0.00 c

into a pest-collecting bag (Fig. 6a, b). The pest-killing lamps have been widely used in agriculture, forestry, vegetable and tobacco growing, warehouse storage, wine brewing, gardens, orchards, urban landscaping, and aquiculture in China. They can trap and kill a very large number of insects in a number of crops, including rice.

Rice insect pests control using pest-killing lamp was conducted in Guangdong, Guangxi (Liu et al. 2004; Luo et al. 2007; Deng and Li 2010; Wei and Chen 2003), Hunan (Zhou 2004; Huang et al. 2009b), Sichuan, Chongqing (Liu et al. 2004), Guizhou (Yang et al. 2004; Wang et al. 2011), Jiangxi, Anhui (Xia and Bao 2009; Xu et al. 2009), Jiangsu (Wang et al. 2010), Yunnan (Long et al. 2012), Hubei (Wang et al. 2006), and Zhejiang (Dong et al. 2011). More than 15 million hectares of rice crops used this technology for controlling insect pests between 2004 and 2011. Good control efficacy was gained and both the dosage and frequency of pesticides application were reduced. The average results showed that 4 orders, 16 families, and 41 species of rice insect pests were trapped and killed by pest-killing lamp. Among them, *Naranga aeneascens*, *Sogatella furcifera*, *Inazuna dorsalis*, *N. lugens*, *Empoasca flavescens*, *Inemadara oryzae*, *Chaphalocrocis medinalis*, and *T. incertulas* were trapped and killed in large number, more than 500 were killed for each species, as shown in Table 6.

7.1 Installation of pest-killing lamp and control distance range

Pest-killing lamp should be installed at the center of target fields. The best height for the lamps was 155–170 cm from the

ground to the middle of the lamp (or the bottom of the lamp was above 5–10 cm the height of the rice canopy). The control area of pest-killing lamp differed depending on different environments and crops. Generally, one pest-killing lamp can control 3.0–4.0 ha of rice crop.

7.2 Control efficiency of pest-killing lamp to different insect pests

The control efficiency of pest-killing lamp differed with rice insect pests. The control efficiency experiments were carried out in several different rice growing regions, e.g., Guangxi, Sichuan, Guizhou, Hunan, Hubei, and Jiangxi. The experimental treatments were as follows: (1) light and chemical control—pest-killing lamp was used and insecticide was applied twice; (2) light and no-chemical control—pest-killing lamp was used without using insecticides; (3) no-light and chemical control—no pest-killing lamp was used but insecticide was applied twice; (4) no-light and no-chemical control (as control)—no pest-killing lamp and insecticide was used. The area of each treatment was 3 ha and with no repeat, the lamp was installed in the center of the fields. The investigation was implemented every 10 days after the lamp installed. The results shown in Tables 7, 8, 9, 10, 11, and 12 were averages from different places.

1. Control effect on rice leaf folder (*Chaphalocrocis medina*). The control efficiency to leaf folder of the treatments of (1) light and chemical control and (2) light and no-chemical control were similar; however, the efficiency (3)

Table 8 Control efficiency of rice stem borer by pest-killing lamp

Treatments	Dead sheath ratio (%)	Control efficiency of dead sheath (%)	Dead heart ratio (%)	Control efficiency of dead heart (%)	White head ratio (%)	Control efficiency of white head (%)
Light and chemical control	2.98±0.25c	62.0a	0.53±0.05c	88.5a	0.91±0.26c	80.9a
Light and no-chemical control	5.57±0.33b	29.0b	1.83±0.11b	60.2c	1.26±0.17bc	73.6b
No-light and chemical control	5.75±0.73b	26.7b	0.70±0.06c	84.8ab	1.44±0.18b	69.8c
No-light and no-chemical control	7.84±0.71a	0.00c	4.60±0.25a	0.00d	4.77±0.20a	0.00d

Table 9 Control efficiency of plant hoppers by pest-killing lamp

Treatments	Average of Guangxi, Sichuan and Guizhou		Average of Hunan, Hubei and Jiangxi	
	Insect pests amount of 100-hill	Control efficiency%	Insect pests amount of 100-hill	Control efficiency (%)
Light and chemical control	97.9	92.4 a	225.4	93.4 a
Light and no-chemical control	335.0	73.9 c	684.0	79.6 c
No-light and chemical control	188.3	85.4b	350.5	89.7 b
No-light and no-chemical control	1285.0	0.00 d	3,400.0	0.00 d

no-light and chemical control was significantly lower than that of the former two treatments, as shown in Table 7.

- Control effect on rice stem borers. Rice stem borers include the striped rice borer (*C. suppressalis*) and yellow rice borer (*Scirpophaga incertulas*). Stem borer caused different injured symptoms depending on the infected period of rice growing. The control efficiency to rice sheath dead of the treatment of (1) light and chemical was better than that of the treatments of (2) light and no-chemical control and (3) no-light and chemical control. Control efficiency to dead heart of the treatments of (1) light and chemical control, (3) no-light and chemical control were similar, but significantly higher than that of the treatments of (2) light and no-chemical control and (4) no-light and no-chemical control. This suggests that pesticides application was quite important for effective control of dead heart caused by stem borer. The control efficiency to white head showed significantly different between treatments, from high to low was (1) light and chemical control, (2) light and no-chemical control, and (3) no-light and chemical control treatments, as shown in Table 8.
- Control efficiency to plant hoppers. The investigation data were divided into two groups: group A includes Guangxi, Sichuan, and Guizhou provinces, and group B includes Hunan, Hubei, and Jiangxi provinces. Compared with the

control (no-light and no-chemical control), the best control efficiency to plant hoppers was observed under the (1) light and chemical control treatment, the control efficiency of group A and group B was 92.4 and 93.4 %, respectively, followed by the treatment of (3) no-light and chemical control with 85.4 to 89.7 %. The treatment of (2) light and no-chemical control was relatively lower than the former. The results indicated that pesticides application without light was better than that of the treatment of light and no-chemicals for controlling plant hoppers. See Table 9.

The amount of plant hoppers per 100-hill, the ratio of roll up leaf caused by leaf folder, and natural enemy of *Cyrtorhinus lividipennis* per 100-hill were surveyed every 10 days over 2 months (from 18 July to 16 September). Compare with no-light fields, the amount of plant hoppers of 100-hill in light fields were reduced by 52.6 %, and roll up leaves caused by leaf folder reduced by 71.4 %. The amount of natural enemy *Cyrtorhinus lividipennis* per 100-hill was reduced by 3.49 % only, as shown in Table 10.

The plant hoppers density of 100-hill of different distance places to the light were surveyed. The best range in relation to the control efficiency of plant hoppers was 0–20 m from the light, and then gradually decreased as the distance from the light increased. At the place of 101–120 m distance from the light, the

Table 10 Variation trend of insect pest amount in rice fields with light and with no-light

Investigation date (month/day)	Rice fields with no-light ^a			Rice fields with light ^a				
	Plant hopper amount/100 hill	Ratio of roll up leaves (%)	<i>Cyrtorhinus</i> <i>lividipennis</i> / 100 hill	Plant hopper amount/100 hill	Reduced ratio of plant hopper (%) ^b	Ratio of roll up leaves (%)	Reduced ratio of leaf folder (%) ^b	<i>Cyrtorhinus</i> <i>lividipennis</i> / 100 hill
7/18	88d	9.60e	9b	40.3e	54.3c	2.3	76.0a	8
7/28	102c	15.6c	6	47.3d	53.7c	5.1	67.3d	6
8/07	155a	19.2b	5	63.5a	59.0a	5.3	72.4bc	3
8/17	147b	23.7a	7	62.8a	57.3b	6.2	73.7abc	6
8/27	94d	14.5c	8	58.8b	37.5e	3.7	74.4ab	9
9/06	102c	8.30e	10	52.0c	49.0d	2.8	66.3d	19
9/16	88d	12.7d	15	37.5f	57.4b	3.7	71.2c	7
Average	110.9	14.8	8.6	51.7	52.6	4.2	71.4	8.3(3.49 %)

^a Five plots in light and three plots in no-light areas were investigated with three replications. Numbers in the table are averages

^b Compare with no light

Table 11 Amounts of plant hoppers at different distances to the light

Investigation date (month/day)	No-light	Distance to the light (m)					
		0–20	21–40	41–60	61–80	81–100	101–120
7/18	88	21	30	35	50	53	75
7/28	102	25	28	43	59	63	102
8/07	155	20	42	59	73	76	148
8/17	147	27	29	69	80	81	135
8/27	94	18	40	71	83	83	100
9/06	102	10	25	65	75	72	99
9/16	88	9	22	35	49	57	75
Total	776	130	216	377	469	485	734
Average	110.9a ^a	18.6e	30.9d	53.9c	67.0b	69.3b	104.9a
Control efficiency (%)	0.00 g ^a	82.9a	72.1b	51.4c	39.6d	37.5e	5.41f

^a Values followed by different letters within a line are significantly different at $P=0.05$ level

light control efficiency in relation to plant hoppers was only 5.41 % compared with no light fields, as shown in Table 11.

7.3 Effect of pest-killing lamp on natural enemies

Pest-killing lamp device partly has adverse impact on the natural enemies. The total numbers of insect pests and natural enemies in Guangxi, Sichuan, and Guizhou (group A) from 5 April to 20 August, and in Hunan, Hubei, and Jiangxi (group B) from 18 June to 20 August were investigated. The main natural enemies killed by pest-killing lamp were dragonfly (*Odonata*) and ladybeetle (*Rodolia cardinalis*). In group A, the amount of trapped and killed insect pests was 14,119, including 542 dragonflies and ladybeetles, thus leading to a ratio of beneficial insect vs harmful insect of 1:25. In group B, the total number of trapped and killed natural enemies was 147 and insect pests were 5,005, the ratio of beneficial insect vs insect pests was 1:34. The results indicated that the adverse impact on natural enemies of pest-killing lamp was far below the control effect on insect pests.

7.4 Effects of pest-killing lamp on rice yield

Rice yields of conventional rice and hybrid were tested in the field by using pest-killing lamp. Generally, the effect on hybrid rice yield of pest-killing lamp was better than that on conventional rice. Compared with (4) no-light and no-chemical control treatment, the hybrid rice yield under (1)

light and chemical control, (2) light and no-chemical control, and (3) no-light and chemical control treatments increased by 36.9, 30.9, and 33.5 %, respectively. For conventional rice, the yield increased by only 8.83, 5.13, and 3.66 %, respectively (Table 12).

7.5 Benefit analysis of pest-killing lamp

The costs (calculation of the double season rice, e.g., early rice and late rice according to the price in 2010) are as follows: one pest-killing lamp costs 350 ¥ and the installation fee was 600 ¥ (including concrete pole, electric wire, accessories, labor force, and other costs). Total cost of a pest-killing lamp amounts to 950 ¥.

Generally, a pest-killing lamp can be used for 5 years, it means an annual cost of the lamp amounting to 190 ¥. Electricity costs: the lamp was operated from 7.00 pm to next day's 6.00 am, lamp began to open 21 March to the 20 August. The lamp opened 11 h every day for 153 days in total. The power of the lamp was 30 W and the cost was 0.8 ¥/kWh. The electricity charge for pest-killing lamp over a double rice season was $[(153 \times 11 \times 30) / 1,000] \times 0.8 = 63.1$ ¥. Hence, total costs of pest-killing lamp over a double rice season were $190 + 63.1 = 253.1$ ¥. Usually, a pest-killing lamp can control 4 ha of rice field, so the yearly cost of a hectare was 63.3 ¥.

Generally, to achieve the same control efficiency to rice insect pests, the treatment of light and chemical control

Table 12 Effects on rice yield by pest-killing lamp

Treatments	Conventional rice yield (kg/hectare)	Yield increased (%)	Hybrid rice yield (kg/hectare)	Yield increased (%)
Light and chemical control	5,743.5±3.11a	8.83a	8,607.3±1.95a	36.9a
Light and no-chemical control	5,548.1±2.11b	5.13b	8,231.6±1.29c	30.9c
No-light and chemical control	5,470.5±2.57b	3.66c	8,394.0±1.78b	33.5b
No-light and no-chemical control	5,277.5±2.92c	0.00 d	6,287.6±1.70d	0.00d

reduced insecticides application 1.5 times than that of no-light and chemical control treatment for a single rice season in a common year (that means the exception of the year that rice insect pests occurred particularly serious). This result in a three times reduction in chemical application in a year (double season rice). The costs of per hectare by increased three times of chemicals application in double season rice include 67.5 ¥ of pesticides and 75.0 ¥ of labor force. There are 270.0 ¥ of chemicals and 300.0 ¥ of labor force (totally 570 ¥) saved for 4 ha. Deducting the cost of a pest-killing lamp (253.1 ¥ for 4 ha), the cost of the treatment of light and chemical control was 316.9 ¥ less than that of the no-light and chemical control treatment for 4 ha. That means one pest-killing lamp saved 79.2 ¥ per hectare. The average yields of double season rice under light and chemical control treatment increased by 486 kg per hectare. The average rice price of early and late rice was 1.8 ¥ per kilogram; thus, the increased income from yield was 3,499.2 ¥ for 4 ha in a year. Total income for the light and chemical control treatment was increased by 3,816.1 ¥ (3,499.2+316.9) for 4 ha in a rice growing year (one pest-killing lamp increased 954.0 ¥ per hectare).

In addition, as above mentioned, rice quality was improved, and environmental pollution was reduced due to the reduction both of the dosage and times of pesticides application. On the other hand, using of pest-killing lamp trapped and killed the insect pest species, the insect pest amount and main peak day occurrence can be used for forecasting the occurrence of insect pests (Table 4) and to guide the insect pests management.

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