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Rice Pest Management by Ecological Engineering: A Pioneering Attempt in China

Zhongxian Lu, Pingyang Zhu, Geoff M. Gurr, Xusong Zheng, Guihua Chen, Kong Luen Heong

Abstract: Ecological engineering is a relatively new concept of environmental manipulation for the benefit of man and the environment. Recently, a pioneering attempt was made in China to see if rice insect pest problems could be solved through ecological engineering. Five years’ of experimentation at Jinhua, Zhejiang Province in eastern China involved habitat manipulation based on growing nectar producing flowering plants (preferably sesame) combined with trap plants on the rice bounds, reducing the intensity of pesticide use and nitrogenous fertilizers, and managing the vegetation in non-rice habitats including during the rice-free season. These practices increased biodiversity in the ecosystem, significantly increased biological control of rice pests and provided biological stability in the ecosystem. Experimentation with ecological engineering in China indicated that it offers immense opportunities to rice pest management using non-chemical methods leading to economic and environmental benefits. Ecological engineering is not a ‘high-tech’ approach so is simple and practical for rice farmers to implement. Having witnessed the benefits and utility of ecological engineering, the National Agriculture Technology Extension and Service Centre (NATESC) of Ministry of Agriculture has recommended it as the national rice pest management strategy in China.
Key words: Rice planthoppers; Ecological engineering; Rice pest; Trap plant, Nectar crop; Biological control

8.1 Introduction

Initial use of the term “ecological engineering” referred to the “environmental manipulation by man using small amounts of supplementary energy to control systems in which the main energy drives are still coming from natural sources”. (Odum, 1962). The term subsequently developed when Mitsch (2012) defined it as the “design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both”. Ecological engineering functions include designing an ecosystem to: reduce a pollution problem; reduce a resource problem; restore an area after a significant disturbance; bring stability to an area in an ecologically sound way, and improve the functionally of the system for human benefit (Mitsch & Jørgensen, 2004). Gurr (2009) stressed that the characteristics of ecological engineering are: to have low dependence on external and synthetic inputs and high a reliance on natural processes; to be based on ecological principles; and to have scope for refinement by ecological experimentation. The goals of ecological engineering as defined by Mitsch & Jørgensen (2004) and Mitsch (1996) are the restoration of ecosystems that have been substantially disturbed by human activities, and the development of new sustainable ecosystems that have both human and ecological values.

The application of ecological engineering for pest management includes use of cultural practices, usually based on vegetation management, to enhance biological control or the 'bottom-up' effects that act directly on pests (Gurr et al., 2004a). The latter include methods such as trap crops that divert pests away from crops and changing monocultures to polycultures to reduce pest immigration or residency. Providing resources such as nectar and pollen to natural enemies promotes biological control.

Rice is the most important staple food worldwide, especially in China (Peng & Hardy, 2001; Zeigler & Barclay, 2008; Yuan, 2014). Recent outbreaks of delphacid pests (brown planthopper (*Nilaparvata lugens*), white-backed planthopper (*Sogatella furcifera*), and small brown planthopper (*Laodelphax striatellus*)) have been very destructive in Asia (Cheng, 2009; Savary et al., 2012). In China, 26.7 million hectares were damaged by delphacids between 2005 to 2007 (Xia, 2008). Changes in cropping systems, including an increase in the use of susceptible hybrid rice varieties, high use of fertilizers and pesticides, combined with higher temperatures, created rice ecosystems that were more vulnerable to planthoppers, promoted population growth rates, and resulted in high population sizes and increased frequency of outbreaks (Cheng 2009). The impact of rice planthoppers is now so severe that they have been cited a threat to global food security (Lou & Cheng, 2011).

Rice cropping systems are characterized by high levels of disturbance including aggressive soil tillage, seasonal wetting and drying, transplanting, and harvesting as well as high inputs of synthetic pesticides and fertilizers. Whilst the pesticides reduce populations of natural enemies resulting in impaired biological control (Heong, 2009), high rates of nitrogenous fertilizers directly promote planthopper nutrition and population growth rate (Lu & Heong, 2009). Habitat manipulation/management to enhance biological control by has been explored in a wide range of crop systems (Landis et al., 2000). This approach is intended to promote natural enemy activity by providing resources to enhance their performance. These resources include alternate foods when prey or hosts are temporarily unavailable (Gurr, 2009). The availability of resources such as nectar have been shown to improve longevity, searching efficiency and realized parasitism of many parasitoid species (Mitsunaga et al., 2004; 2006; Rivero & Casas, 1999; Shearer & Atanassov, 2004; Jervis et al., 2004; Zhu et al., 2013a; Lu et al., 2014). Ecological engineering for pest management is a targeted approach to habitat manipulation where the attributes of a number of candidate plants are assessed to determine optimal ones to introduce into a farming system (Gurr et al., 2004b). This contrasts with the 'hit and miss' approach to habitat manipulation used in the 1990s which was based on the simple premise that increased vegetation diversity would promote pest suppression.

Ecological engineering for rice pest management was led by the International Rice Research Institute (IRRI) and initiated in China, Vietnam and Thailand in 2008. Recently in Vietnamese field studies it was demonstrated that growing nectar plants on the bunds beside rice crops significantly increased the number and impact of natural enemies on rice planthopper*s* (Lan et al., 2010). In this chapter we discuss the parallel development and evaluation of ecological engineering in rice ecosystems in China.

8.2 Influence of Flowing Plants on the Biological Control

Increasing in the area of agricultural production and improving crop yields was thought to guarantee the adequate provision of food with an increasing world population. These changes have reduced the area of non-crop habitat and simplified farming landscapes. This sharp decline in farmland biodiversity reduces the number of flowering plants, which natural enemies depend on (Lu et al., 2014). In this context ecological engineering aims to protect crops from pest damage by maximizing natural mortality by strategic introduction of plant diversity (Gurr et al., 2004a; Cullen et al., 2008). A key consideration is the identification of plants that selectively favor natural enemies over pests. Ideally these are then included in agro-environmental schemes so as to provide pest suppression at the same time as delivering other ecosystem services such as pollination and biodiversity conservation.

8.2.1 Influence of Sesame Flowers and Alternative Prey on Planthopper Egg Parasitoids Anagrus spp.

Anagrus spp. are egg parasitoids that are important in the management of leaf- and plant-hoppers in Asia (Gurr et al., 2011). In China where *A. nilaparvatae* dominates, parasitism rates in rice fields are between 10% and 70% (Yu et al., 2001). The same species is also important in Cambodia, India and Philippines (Chandra, 1979; Kalode, 1983; Preap et al., 2001). Ecological engineering strategies in rice based ecosystems that target this natural enemy are two-fold. First, providing alternative hosts for the parasitoid during periods of rice planthopper unavailability. In eastern China a perennial vegetable crop *Zizania caduciflora*, which is attacked by the green slender planthopper *Saccharosydne procerus*, is often grown in fields to rice. The parasitoid *A. optabilis* attacks *S.*

procerus during the winter period, then moves to rice crops in spring to parasitise rice planthoppers (Lu, 2003; Zheng et al., 2003). A second and complementary approach is the use of flowering plants to provide nectar to parasitoids.

Laboratory screening experiments were conducted to select plant flowers that best enhance *Anagrus* spp. parasitoids (Zhu et al., 2013a). Findings indicated that *A. optabilis* is attracted by volatiles of *Sesamum indicum*, *Impatiens balsamen*, *Emilia sonchifolia*, *Hibiscus coccineus*, *Trida procumbens* and *Hibiscus esulentus* (Table 8.1). Of these, *S. indicum*, *E. sonchifolia*, and *I. balsamena* were also attractive to *A. nilaparvatae*. Sesame was selected for further study that discovered that *A. nilaparvatae* and *A. optabilis* female life span was enhanced by sesame flowers. Realised parasitism by *A. nilaparvatae* was also enhanced by sesame flowers as was that of *A. optabilis* (Table 8.1). This indicated that sesame promotes key aspects of *Anagrus* spp. performance and justified its use in field studies. Field experiments also indicated that egg parasitisms by *A. nilaparvatae* and *A. optabilis* could be significantly enhanced by sesame flowers in field conditions (Fig. 8.1).

Table 8.1 Percentage of food-deprived parasitoid adults choosing flower odors or clean air in a Y-tube olfactometer (Zhu et al., 2013a)

Plant flowers	*Anagrus nilaparvatae*		*Anagrus optabilis*	
	Choicing flower odor (%)	Choicing clear air (%)	Choicing flower odor (%)	Choicing clear air (%)
Sesamum indicum	70.0*	30.0	67.5*	32.5
Impatiens balsamena	72.5*	27.5	77.5*	22.5
Emilia sonchifolia	67.5*	32.5	70.0*	30.0
Hibiscus coccineus	45.0	55.0	77.5*	22.5
Tagetes patula	30.0	70.0	70.0*	25.0
Hibiscus esulentus	55.0	45.0	70.0*	27.5
Vernonia cinerea	85.0*	15.0	50.0	50.0
Luffa cylindrica	70.0*	30.0	/	/
Tagetes erecta	65.0	35.0	/	/
Rosa chinensis	72.5*	25.0	/	/
Largeleaf Hydrangea	42.5	55.0	/	/
Gazania rigens	37.5	62.5	/	/
Glycine max	60.0	40.0	/	/
Canna indica	37.5	60.0	/	/
Ageratum conyzoides	55.0	40.0	/	/
Trida procumbens	60.0	37.5	/	/
Mazus japonicus	80.0*	17.5	/	/
Erigeron annuus	45.0	52.5	/	/
Portulaca grandiflora	47.5	52.5	/	/
Cosmos sulphureus	37.5	52.5	/	/
Ipomoea nil	65.0	35.0	/	/
Herba Ecliptae Eclipta prostrala	50.0		/	/

*A significant deviation from random choice (preference or repellency) (test on two-tail binomial distribution; p<0.05)

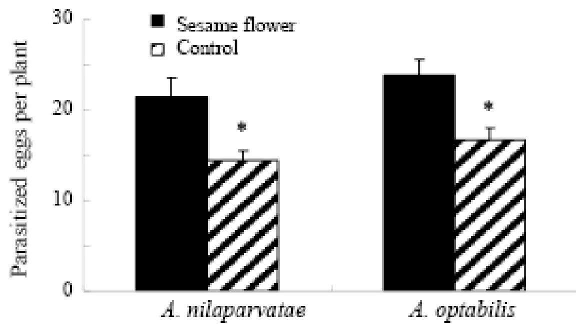

Fig. 8.1 Effects of sesame flowers on realized parasitism of *Anagrus* spp. Asterisks indicate a significant at $p<0.05$ (Zhu et al., 2013a)

8.2.2 Influence of Flowering Plants on Planthopper Predator Cyrtorhinus Lividipennis

The mirid bug, *Cyrtorhinus lividipennis* (Heteroptera: Miridae) is an important zoophytophagous predator, preferring leaf- and planthopper eggs and young nymphs (Zhu & Chen, 1981; Chen et al., 1985; Katti et al., 2007; Shepard et al., 1987). It tends to be highly correlated with planthopper density and plays a key role in suppressing planthopper populations (Heong et al., 1991; Laba & Heong, 1996). Predation of *N. lugens* eggs by *C. lividipennis* in the field can average 30% and reach up to 70% (Zhou & Chen, 1986). Laboratory studies have shown that individual *C. lividipennis* nymphs and adults can consume up to 7.5 and 10.2 *N. lugens* daily (Reyes & Gabriel 1975). Whether the life history parameters and predation performance of *C. lividipennis* could be improved by access to nectar was uncertain until recently. It had been suggested that *C. lividipennis* may benefit from plant foods (Shepard et al., 1987) and can survive in the crop even when prey is scarce or totally absent (Ingegno et al., 2011).

Recent laboratory studies examined the growth and predatory capacity of *C. lividipennis* progeny after feeding by the parents on the flowers of four plant species *Sesamun indicum*, *Tagetes erecta*, *Trida procumbens* and *Emilia sonchifolia* (Zhu et al., 2013b). The findings indicated that the offspring nymphal period duration of *C. lividipennis* was shortened after the parent adults had feed on the four candidate flowering plants, and the male nymph duration was significantly reduced by parental adults feeding on the flower of *S. indicum*. The 4th instar nymph's predation on BPH eggs was significantly increased after parental adults feed on *T. procumbens*, *E. sonchifolia*, *T. erecta* and *S. indicum* flowering plants. Among the flowering plants treatments, *S. indicum* was the most favourable, followed by *T. erecta* and *T. procumbens* (Table 8.2). The adult's predation on BPH eggs was greatly enhanced after the parental adults fed on *E. sonchifolia*, *T. erecta* and *S. indicum* flowering plants (Table 8.2). Among the flowering plants treatments, *T. erecta* was the most favourable. These results show that suitable flowering plants can significantly improve the predation ability of offspring *C. lividipennis* and can shorten the nymph duration period in progeny.

Table 8.2 Predatory capacity of *Cyrtorhinus lividipennis* offspring after feeding the parental adults with different plant flowers (Zhu et al., 2013b)

Plant flowers fed on parental adults	*S. indicum*	*T. erecta*	*T. procumbens*	*E. sonchifolia*	Control
4th instar nymph	19.07±0.72[a]	14.23±0.80[b]	13.29±1.02[b]	10.15±0.50[c]	7.92±0.33[d]
Female adult	24.03±0.61[b]	29.71±0.86[a]	22.14±1.07[b]	23.56±0.87[b]	21.57±0.92[b]

Values are mean±*SE*. Means within a row followed by different letters differ significantly at p <0.05. Turkey test was used

8.3 Development and Demonstration of Ecological Engineering Practices in Jinhua, China

Rice is a very important crop in China with cultivation dating back for thousands of years. The Green Revolution in the 1960s was aimed at meeting the increasing demand for food with the rapid population growth. Rice production increased greatly, with the wide-scale adaptation of high-yielding varieties, extensive use of pesticides and chemical fertilizers. The resulting production system was dependent on high inputs of agrochemicals resulting in a serious threat to the ecological stability in rice, human and environmental health, as well as the rice grain quality (Heong, 2009). Although rice yields in China continuously increased in recent decades, the outbreak of rice pests has become one of the main obstacles to sustainable production. Large scale outbreaks of rice planthoppers and the viral diseases they transmit become common in the first decade of the 21st Century (Xia, 2008). Chemical control has been considered as a key measure to suppress the population of rice planthoppers. The excessive application of chemical pesticides not only led to the development of resistance to insecticides but also negatively affected natural enemies and other beneficial organisms, and resulted in unwelcome contamination to the aquatic environment and rice grain (Conway & Pretty, 1991). It consequently became essential to minimize the use of chemical pesticides and to guarantee the food safety by developing ecological pest management.

Attempts of rice insect pest management by ecological engineering in Jinhua, China, was initiated in 2008 with the funding of ADB and technical support from the IRRI Rice Planthopper Project. To explain and promote ecological engineering concepts, practices were communicated to the professional technicians, policy makers, practitioners and farmers through a national seminar in 2010 and an international field day in 2012, which was covered by the mass media such as local TV, newspaper and a farmers' information system. In 2013, rice insect pest management by ecological engineering has become the national recommended plant protection strategy (NATESC, 2013).

8.3.1 History of the Experimental Site

In the recent past outbreaks of pests, rice stem borer, rice brown planthopper, white backed planthopper and rice leaffolder were prevalent, resulting in huge losses and great financial cost of insecticides in Jinhua. During 2005 and 2007 the population size of brown planthopper reached the highest level in the history it seriously threatened rice production. Simultaneously, rice leaffolder populations also reached at high levels. Thus, costs of insecticides used in rice field increased to about 360 US$ per hectare for one rice season. Farmers were losing interests in rice production due to the cost of production. Against this backdrop, the Zhejiang Academy of Agricultural Sciences (ZAAS) and the Jinhua Plant Protection Station (JPPS) in collaboration with the IRRI initiated a pioneering attempt to manage rice insect pests by ecological engineering in 2008. A 35-ha experimental site was established to determine and demonstrate the possibility and practicability of sustainable rice pest management by ecological engineering.

The ecological engineering site was located at Si Ping village, set in an area with nearby mountains and high quality water resources. Although the original ecosystem had not been greatly disturbed, the areas used for rice production had been impacted by intensive cultivation and overuse of chemical fertilizers and pesticides. Using ecological engineering principles and methods, various interventions were made. These included manipulation of vegetation to promote natural enemies; specifically planting nectar-rich plants, zero insecticide sprays during first 40 days after transplanting, and stopping overuse of nitrogen fertilizer. The goal was to reduce the usage of chemical pesticide by 60% – 80%, to keep yield losses by major pests to less than 3%, and to gradually recover the natural pest control function of the ecosystem.

The 35-ha site was divided into two zones. The small block (8 ha) was assigned to ecological engineering and was made up of 40 rice fields, each of which was managed as a separate crop and subject to arthropod monitoring using sweep nets, yellow sticky traps, and yellow water pan traps. Frog numbers were also monitored by counting at night. The larger block (27 ha), separated from the ecological engineering area by a sealed road, was a control treatment managed under conventional farmer practice including pest management based on repeated insecticide use. It was comprised of 10 separate rice fields in which arthropods and frogs were monitored. Data from the multiple fields in each of the two management regimes were compared by appropriate inferential statistical tests. Whilst this design does not constitute a formal, randomized, replicated design, the scale and reality of the testing conditions do provide a valuable test of the practicability of various ecological engineering methods and a broad indication of the effects on key taxa as well as the ultimate need for insecticide use.

8.3.2 Major Strategies of Ecological Engineering

8.3.2.1 Intervention: Conservation and Manipulation of Biodiversity

In the intensified rice-based agricultural production ecosystem, non-crop habitats had been greatly reduced, resulting in the simplified agricultural landscapes and farmland ecosystem. The sharp reduction of biodiversity has weakened the role of natural enemies in pest management. Our primary strategy was to conserve the native arthropod natural enemies by planting with green manure in fields at winter, leaving grasses on the bund and roadsides at other times of the year, growing sesame on the bunds during the rice cropping season, inter-planting with *Z. caduciflora* as the overwinter habitat for parasitoid hosts as well as arthropod predators and frogs (Zheng et al., 2003). Sesame was grown on the bunds of rice fields before rice transplanting (Fig. 8.2) and new plantings after one month of rice transplanting so as to ensure flowering plants were present at all rice growth stages.

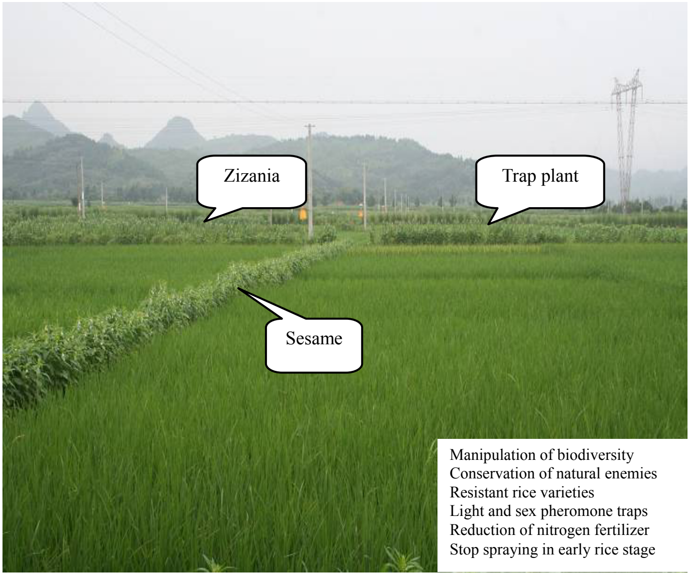

Fig. 8.2 Design of experimental demonstration of ecological engineering in Jinhua

8.3.2.2 Intervention: Rational Fertilization

Overuse of chemical fertilizer, especially nitrogen fertilizer, has triggered the outbreak of some rice insect pests and diseases (Lu & Heong, 2009). We improved rice tolerance to adverse environmental factors and reduced population growth rate by increasing organic fertilizer and proportion of P and K fertilizers while reducing nitrogenous fertilizer. In fact, we were employing the "Three Controls" (control the amount of fertilizer, control the number of rice seedlings per hill and control the occurrence of pests) fertilizer application strategy, optimizing total nitrogen amount for improving nitrogen utilization efficiency, and minimizing pest population and pesticide usage (Zhong et al., 2012). Field experiment indicated that the population rice planthoppers can be strongly suppressed after rice booting stages by three control fertilizer application strategy (Table 8.3).

Table 8.3 Dynamics of rice planthopper population at different rice stages in fields with three controls fertilizer application strategy (per hill rice)

Treatments	Chunyou 84		Zhejing 88	
	Three control	CK (traditional)	Three controls	CK (traditional)
Seedling	0.73	0.95	0.58	0.40
Tillering	0.30	0.18	0.17	0.15
Booting	0	0.15*	0.03	0.73*
Milking	0.15	6.73*	0.65	7.98*

* indicates significantly high of rice planthopper population at $p < 0.05$

8.3.2.3 Intervention: Management of Stem Borers by Non-Pesticide Methods

Striped stem borer (*Chilo suppressalis*) regularly occurs in all rice growing stages in Jinhua, and causes dead heart at rice tiller stage and white head at booting stage. Famers spray with wide-spectrum pesticides to control stem borers in early rice stage, consequentially, spiders and other natural enemies were killed, resulting in frequent planthopper outbreaks. Reduction of pesticides in early growth stages is one of key strategies of sustainable management of rice planthoppers by enhancing biological control (Heong, 2009; Gurr, 2009). Laboratory and field experiments showed that stem borer *C. suppressalis* adults are strongly attracted to lay eggs on vetiver grass (*Vetiveria zizaniodes*) (Figs. 8.3 and 8.4), but they cannot complete their life cycle on this plant (Fig. 8.5). Accordingly, we planted vetiver grass as a trap plant on some margins of the rice fields to serve as a trap crop for stem borers. During stem borer adult flight periods, we set up 20 sex pheromone traps and 1 light trap (Fig. 8.2) per hectare to complement the trap plants.

Fig. 8.3 Trap plant on the rice bund to attracted stem borer adult to lay eggs

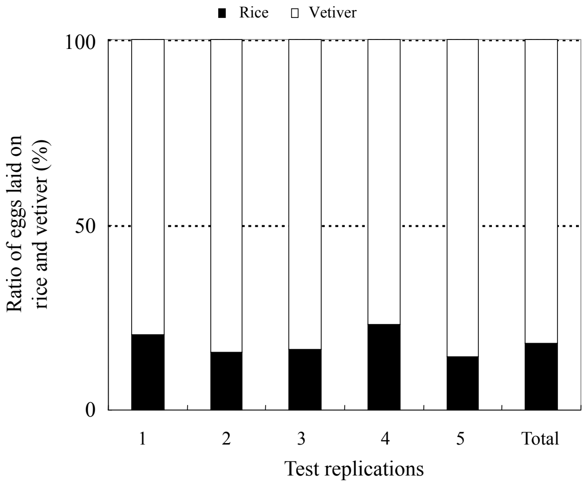

Fig. 8.4 Oviposition selection of *Chilo suppressalis* between rice and vetiver grass (Zheng et al., 2009)

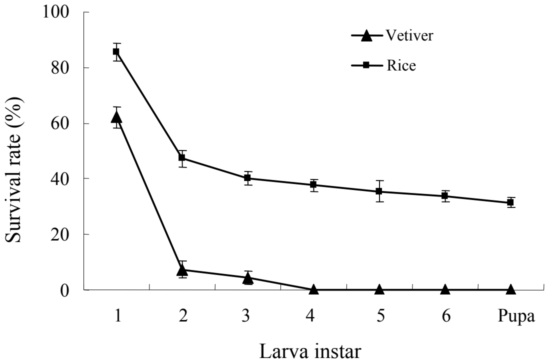

Fig. 8.5 Survival of *Chilo suppressalis* larvae on rice and vetiver grass (Zheng et al., 2009)

8.3.3 Results

Results indicated that both predators and parasitoids significantly increased in density in the ecological engineering fields (Fig. 8.6). Numbers of *Anagrus* spp. in the ecological engineering fields were four times higher than in the control fields. Differences were especially great in samples taken after pesticide application in the farmers' fields (Fig. 8.7). The number of invertebrate predators including damselfly was significantly higher in ecological engineering area than the farmers' fields (Fig. 8.8). Frogs too were much more abundant in ecological engineering area than control plots (Table 8.4). In contrast to the ecological engineering fields, conventionally managed fields required several sprays to control escalating numbers of planthoppers, when the number of planthoppers in the ecological engineering fields remained low. For example, the damage by brown planthopper was moderate in 2010, and a pesticide application was made for planthoppers in the ecological engineering fields due to the late immigration, while 4 applications were applied in the farmers' fields (Fig. 8.9). As a result, ecological engineering practices reduced the amount of insecticides by more than 75%, but the yields in both areas with ecological engineering and farmer practices were above 10 tons per ha. There was no significant yield loss in ecological engineering field (10.02 t/ha) compared with yields in farmer fields (10.27 t/ha), meanwhile famers obtained about 120 US$/ha extra income from sesame seeds harvested on the bound and saved about 150 US$/ha cost for insecticide application. Chemical pesticides were not used at all for controlling rice planthoppers in ecological engineering areas in 2009 and 2011. Similar positive results were observed also in similar sites located at Ningbo and Xiaoshan, Zhejiang province, China.

Table 8.4 Number of frogs at rice booting stage in Jinhua (per 667 m^2)

Rice stage	*Rana limnocharis*		*Rana nigromaculatta*	
	EE fields	Farmer fields	EE fields	Farmer fields
Booting	32.67±3.26[a]	6.67±2.81[b]	2.20±0.98	0.67±0.67 ns
Milky	46.33±6.28[a]	7.35±3.51[b]	5.32±2.1	2.01±1.43 ns

Values are mean±*SE*. Means within a row followed by different letters differ significantly at p <0.05. Turkey test was used

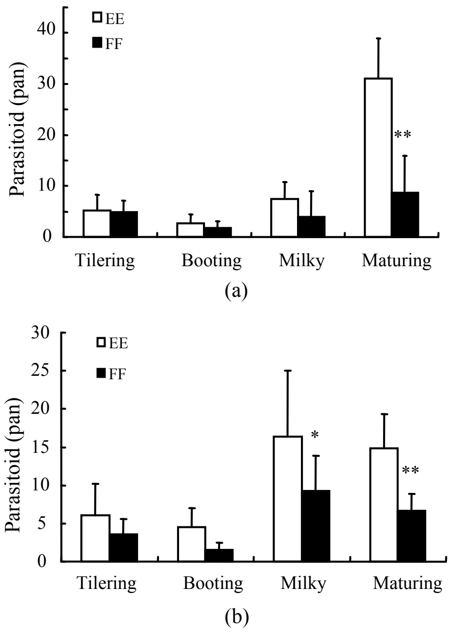

Fig. 8.6 Numbers of predators (a) and parasitoids (b), sampled by yellow pan trap (EE= ecological engineering field; FF=farmers' field)

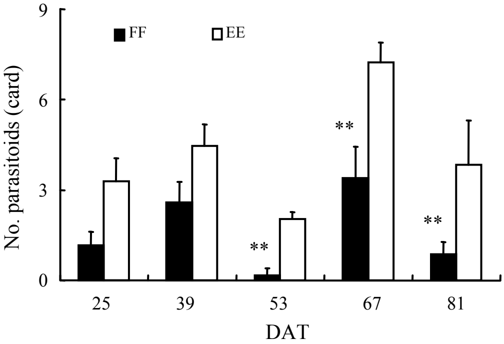

Fig. 8.7 Number of *Anagrus* spp. sampled by yellow sticky board (EE=ecological engineering field; FF=farmers' field; DAT=day after transplanting)

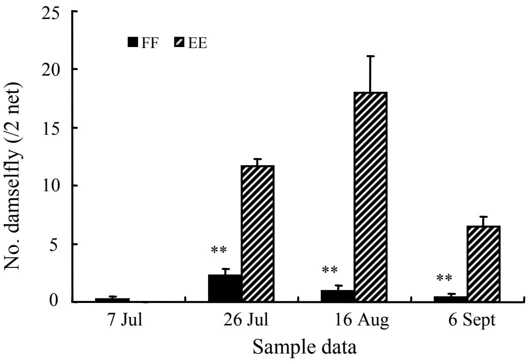

Fig. 8.8 Number of damselfly collected by sweep net (EE=ecological engineering field; FF=farmers' field)

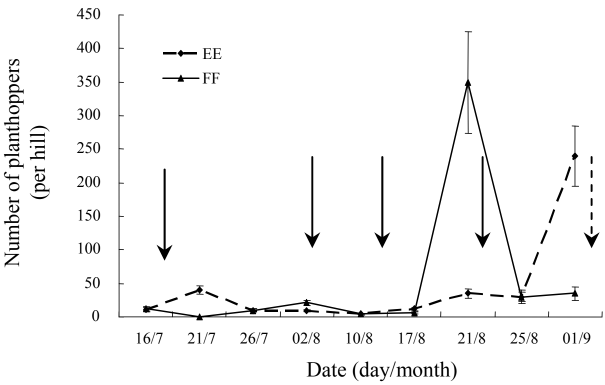

Fig. 8.9 Comparison of population dynamics of rice planthoppers between EE and FF rice fields in 2010 (EE=ecological engineering field; FF=farmers' field; Solid tips show the time spraying for rice panthoppers in farmers' fields and dotted one means spraying in ecological engineering fields)

8.4 Opportunities and Prospects for Ecological Engineering in China

Over 100 pest species cause heavy economic losses in China affecting on between 400 million and 467 million ha each year. China initiated integrated pest control in 1953 and in the mid-1970's established a national professional policy for integrated pest management (IPM) (Guo, 1998). The key strategy implemented was integrated management with an emphasis on pest prevention and more strategic use of pesticides (Xia, 2008) and this developed into the adoption in China of 'Green Plant Protection' (Fan, 2006). Since 2013, ecological engineering has been recommended as one of the key strategies for sustainable management of rice pests by the National Agriculture Technology Extension and Service Centre (NATESC) of Ministry of Agriculture. It is time to widely disseminate knowledge and further extend techniques of ecological engineering for substantially minimizing pesticide usage in rice-based ecosystem.

Pest control by ecological engineering practices developed from earlier habitat manipulation and biological control efforts into a rigorous branch of applied ecology (Gurr et al., 2004a; 2004b). Its application has advanced briskly in China, especially in rice production (Gurr et al., 2009; 2011; 2012a; 2012b; Heong, 2011; Heong et al., 2013; Zhu et al., 2013a; 2013b). The experimental demonstration of ecological engineering in Jinhua was a successful case, however, we have to be prepared to adapt the methods that have so far proven effective. Rice varieties will inevitably change, pests may adapt to phenomena like vetiver grass trap crops and new pests may emerge. Accordingly, understanding the general principles of ecological engineering and being prepared to adapt the specifics of nectar plant, trap crop species and so on are the key to the sustainability of this approach.

Finally, there is excellent scope to build on the initial successes in rice to develop ecological engineering strategies for the pest complexes of other crops such as tea plantations and vegetable gardens. We are certain that, with the support of the Chinese government by attaching greater importance to the development sustainable agriculture, ecological engineering for pest control will develop rapidly and become a prevalent pest management strategy in the future.

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