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Strategies to Attain Ecologically Sustainable Pest Management in Rice Systems

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The Lucerne Declaration and Action Program, adopted at a ministerial-level meeting on 9-10 February 1995, called for renewal and reinforcement of work toward meeting multiple challenges of increasing and protecting agricultural productivity, safeguarding natural resources, and helping to achieve people-centered policies for environmentally sustainable development. To meet these challenges, there is need for a revolution that is more productive and “green” than the Green Revolution—a Doubly Green Revolution that will repeat the successes of the Green Revolution on a global scale, in more diverse environments, and will be more equitable, sustainable, and environment-friendly. This paper examines the ecological strategies that will contribute toward meeting these challenges in attaining sustainable and environment-friendly pest management in rice systems. An important contribution from ecological research of pests is discovering the unique natural stability and resilience in arthropod communities in tropical rice ecosystems. Habitats, both rice and nonrice, occur in a mosaic of patches where communities of herbivores, predators, parasitoids, and “neutrals” move actively, complementing each other’s actions spatially and temporally. Noncrop areas, for instance, may be important refuge for the less mobile predators, like spiders. Thus, an important approach is to better understand the role of biodiversity, both in spatial and temporal dimensions, and use such discoveries to develop strategies that keep pest populations below economic injury levels. For instance, crickets living in *Brachiaria* habitats are important egg predators of pests and they make nocturnal trips into rice fields in search of food. Ecological research has also shown that insecticides sprayed in the early-crop-season stages disrupt normal food web development and favor pest species, often doing more harm.

In most cases, the early-season sprays are directed at leaf-feeding insects that inflict highly visible damage symptoms, but little effect on yields since many modern rice varieties have high compensatory abilities. One strategy is thus to identify such unnecessary sprays and reduce or eliminate them. A common insect farmers tend to control by spraying is the leaffolder, yet most research has shown that under normal rates of attack, yield loss is negligible. In Vietnam, through the use of media communication to motivate farmers to stop early insecticide applications, farmers reduced their sprays by 53% without compromising yields. Outbreaks of insecticide-induced secondary pests, such as the brown planthopper, were drastically reduced in subsequent years. Habitat management is a strategy to conserve natural biological control by improving the availability of resources for predators. For instance, *Brachiaria* habitats near rice fields are often breeding sites for crickets, which are important egg predators. Another example is the use of rock piles beside rice fields to serve as spider refuge. Spiders can also be encouraged into rice fields by spraying sugar solutions that attract flies. *Zizania*, a vegetable often intercropped with rice, harbors a planthopper and its eggs are parasitized by the same parasitoid that attacks brown planthopper eggs. Research has shown that simultaneous operation of more than one mechanism often works better. High-nutrient inputs tend to favor pest and disease development and reduce searching efficiencies of some predators, resulting in a net increase in ecological fitness of pests. For instance, high plant N increases the pest's egg hatchability, nymphal survival, female longevity, and number of eggs laid, and reduces searching efficiencies of the predator *Cyrtorhinus*. An important strategy is thus to avoid excessive seed and N use. In the Three Reductions Program (*Ba Giam Ba Tang*) in Vietnam, farmers were motivated through media and drama to reduce seed and fertilizer rates so as to reduce pesticide use. Since pesticides had higher costs than seeds and fertilizers, their reduction served as incentives. Farmers reduced their input costs by as much as US\$58/ha per season and the practice is spreading through mass media. A similar impact of high N on leaffolder populations had been observed, further reducing farmers' unnecessary sprays.

Strategies for sustainable pest management in rice production will depend on understanding of ecological processes and developing methods to harness their effects to maximize natural biological control, which might be seen as enhancing the "immune system" in human health. A "healthy" rice ecosystem can be more resilient to pertur-

bations from weather changes, such as drought and flood, which can trigger pest problems. Another form of perturbation is pesticide spraying, often in the early season, which compromises the “immune system” and favors secondary pest development. Since this practice is widespread among farmers, innovative communication strategies are needed to motivate change. Attaining ecologically sustainable pest management will thus require not only ecological research but sociological research as well. New strategies will need to be people-centered and implemented through participatory mechanisms to cultivate quality partnerships among local stakeholders.

The Green Revolution made unprecedented gains in world food production. Rice production in Asia doubled with the introduction of modern rice varieties in the last 3 decades. About 70% of the increase came from higher yields and cropping intensities made possible by the use of modern varieties. Food production grew at an average rate of 3%/year, surpassing population growth and, as a result, the number of poor and hungry today is lower. Thirty-five years ago, about 50% of the population in developing countries did not have enough to eat, compared with only 20% today (Conway 1997). Although there is little dispute about the impact of the Green Revolution on food production, there are questions about its effects on equitable income distribution (David and Otsuka 1994), chemical pollution (Conway and Pretty 1991), farmers' health (Rola and Pingali 1993), and environmental sustainability (Conway and Barbier 1990). Governments of many Asian countries implemented rice production programs such as the Masagana 99 in the Philippines and the BIMAS in Indonesia, providing subsidies for fertilizer and pesticide inputs. In addition, governments and foreign aid projects supported intensive pest surveillance and control programs as necessary inputs such as those in Japan (Kiritani 1979), Korea (Turner et al 1999), Indonesia (Oka 1991), and Malaysia (Triantafillou 2001), and the surveillance and early warning system (SEWS) in the Philippines (Sumangil et al 1992) and Thailand (Sri Arunotai 1988) to detect pest infestations and implement mass control programs to “protect and prevent losses.” Such an approach similar to that of the “fire brigade” service had been commonly used in the 1970s. Today, this approach is regarded as an extremely poor option because it does more harm to the pest situation, creates ecological imbalance, pollutes the environment, and lacks sustainability (Conway 1997). Often, pest outbreaks occur in small patches, and mass-spraying regimes not only have low efficacy to pests; they also have vast effects on nontarget organ-

isms. Usually, by the time the surveillance data are processed and reported and the actions planned, pest populations might be on the decline and the sprays become more detrimental to the naturally occurring biological control. Free pesticide distributions, often part of such central management schemes to pacify farmers who had suffered losses, are also poor strategic options because, in many cases, farmers might not be equipped or have the know-how to use them. In addition, such organized government actions tend to increase farmers' dependence on pesticide handouts, making them less reliant and vulnerable to pesticide misuse. For instance, in Laos, although farmers' pesticide use is low, a study showed that farmers have similar attitudes and behavioral responses to pests as those in Vietnam and the Philippines and can potentially become victims of misuse (Heong et al 2002). Current low pesticide use in Laos, as well as in Myanmar, is due mainly to farmers' lack of access and cash to buy them.

The Lucerne Declaration and Action Program, adopted at a ministerial-level meeting on 9-10 February 1995, called for renewal and reinforcement of work toward meeting multiple challenges of increasing and protecting agricultural productivity, safeguarding natural resources, and helping to achieve people-centered policies for environmentally sustainable development.¹ To meet these challenges, there is need for a revolution that is more productive and "green" than the Green Revolution—a Doubly Green Revolution (Conway 1997) that will repeat the successes of the Green Revolution on a global scale in more diverse environments and will be more equitable, sustainable, and environment-friendly.

Understanding pest ecology and the role of biodiversity

An important component to achieve the Doubly Green Revolution is adequate ecological understanding of biodiversity and biological control conservation, both at the local as well as at the landscape level to form the bases for the development of ecologically sustainable pest management. The ultimate goal is to manage rice ecosystems so that they hold pests below economic injury levels and to avoid disruptions of the naturally occurring biological control mechanisms. Rice ecosystems in the tropics have unique stability such that pest species are mostly kept at levels that do not justify insecticide use (Way and Heong 1994). Crops that encourage low ecological fitness of pests, together with ability to compensate for damages by some key pests, are fundamental to ensure reliable natural biological

¹ <http://www.worldbank.org/html/cgiar/publications/declara.html>

control. The proximity of perennial nonrice habitats is important in determining system resilience and resistance to unexpected disruptions, such as droughts, floods, and pesticide applications (Fig.1). While the occurrence of droughts and floods is beyond man's control, pesticide sprays can be managed to maximize natural biological control.

Insecticide sprays have several community-wide effects on the different functional groups of invertebrates (herbivores, predators, parasitoids, and detritivores or neutrals) in rice ecosystems. Insecticide sprays significantly reduced the species richness of herbivores and predators (Heong and Schoenly 1998) but that of herbivores recovered earlier than predators. Similarly, herbivore abundances were significantly reduced initially but recovered rapidly to levels higher than that of unsprayed fields. The total population of herbivores was reduced by 1%, while that of predators and parasitoids was reduced by 42% and 37%, respectively. Planthoppers increased by 23%, while spiders decreased by 61%, indicating that insecticide sprays favored planthopper development. Similar responses to insecticide sprays by planthoppers were also documented by other

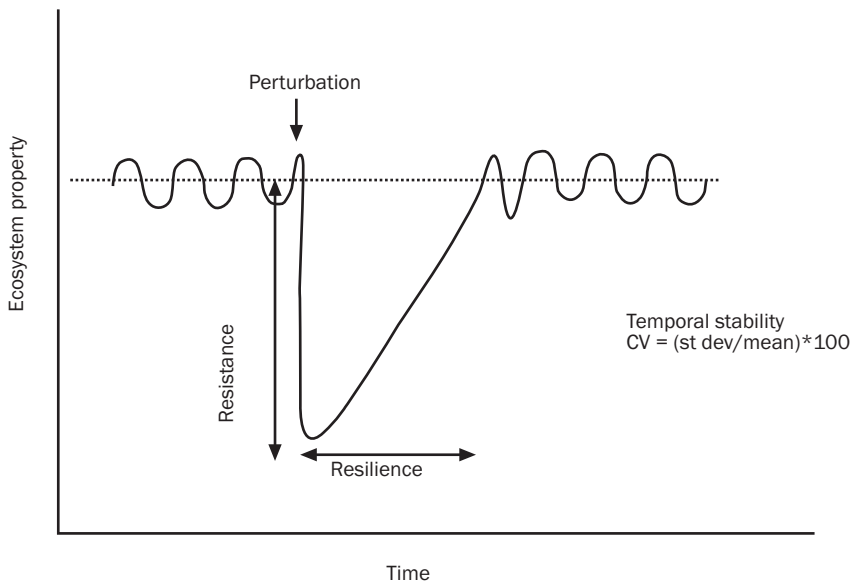


Fig. 1. Three concepts of ecological stability: resistance, resilience, and temporal stability (in this case, the coefficient of variation in time, although other measures are available). Resistance is related to the amount that the system is changed by a perturbation (resistant systems change little). Resilience refers to the speed or extent of return to the original state following the perturbation (resilient systems return quickly). A third aspect, temporal variability, is also commonly used.

scientists (Heinrichs and Mochida 1984, Kenmore et al 1984, Gallagher et al 1994, Cheng et al 1995). Food web structures of sprayed fields were found to recover to the level of unsprayed fields 22 d after the last spray (Schoenly et al 1996). However, the catastrophic asynchronization in predator-prey relationships (Perera et al 1988) created by the sprays would still tend to favor pest populations. Using multiple regression models, Cohen et al (1994) found that insecticides disorganized population dynamics and were less able to forecast fluctuations of pests in sprayed fields. When differences in pest and natural enemy abundances were translated into ecological costs, Schoenly et al (1996) found that insecticide sprays could bring about an additional 4 million pests/ha per sampling date and 1 million less natural enemies. Thus, besides hidden costs such as farmers' health and environmental pollution, insecticides can cause further burden to farmers by inducing abundances of some pest species.

Reducing unnecessary use of insecticides

Farmers' insecticide decisions are often based on perceptions and, in many cases, applied unnecessarily at the wrong targets at the wrong time (Bandong et al 2002). A study in the Philippines showed that about 80% of rice farmers' sprays were deemed unnecessary (Heong et al 1995) and this trend is widespread in Asia (Heong and Escalada 1997a). Farmers' responses to pests are often due to their biases to perceived prospects of incurring loss or loss aversion where losses loom larger than gains (Tversky and Kahnemann 1992). Rice farmers generally overestimate potential losses due to pests by more than 10-fold (Heong and Escalada 1999). Since most farmers use "heuristics" or decision rules, strategies to modify their current heuristics can be useful in changing farmers' insecticide use patterns. One such heuristic that dominates millions of Asian rice farmers is using insecticides in the early crop season to control leaf-feeders, commonly referred to as worms. Leaf damages in the early crop season caused by leaffolders, whorl maggots, and thrips are common. However, such highly visible damages often do not translate into crop loss because of plant compensation (Miyashita 1985, Fabellar et al 1994); thus, most early-season sprays reflect farmers' misperceptions. Such unnecessary sprays often cause more harm by promoting development of secondary pests such as the brown planthopper (Heong and Schoenly 1998), and their removal has had no yield consequences (Heong et al 1995, Heong and Escalada 1997b). Computer simulation studies also showed that early-season spraying is inefficient in controlling pests (Heong 1989, Cheng et al 1990).

Thus, a major effort to attain sustainable pest management should be devoted to reducing farmers' early-season (first 40 d after sowing) insecticide use and any other unnecessary sprays to lessen disruptions to natural biological control. In the International Rice Research Institute experimental farm in the Philippines, insecticide use was reduced by 95% from 3.8 to 0.2 kg ai/ha/yr from 1993 to 2003 with no yield loss consequence (Fig. 2). Pest abundance had also been reduced. In Vietnam, a mass media approach to motivate farmers to stop early-season spraying motivated thousands of rice farmers to reduce insecticide use by 53% (Heong et al 1998, Escalada et al 1999), while yields remained the same (Fig. 3). The message subsequently spread to well over 2 million farmers in the Mekong Delta, and they reduced their insecticide applications by as much as 70% (Huan et al 1999). In Thailand, a similar campaign launched in Sing Buri Province reduced farmers' insecticide use by 22%. Hundreds of farmers in the Philippines who participated in farmers' experiments to stop early-season spraying reduced insecticide use by 60% (Heong and Escalada 1997b) and, in Vietnam, by 78% (Huan et al 2004).

Reducing nitrogenous fertilizers and crop densities

Rice farmers in intensively cultivated rice areas have been using high seed rates for direct seeding and high fertilizer rates. These practices might have stemmed from the perceptions that high inputs, particularly seed and fertilizer, would result in higher yields. On the other hand, the use of high seed and fertilizer rates can lead to higher pest and disease infestations, thus prompting greater use of pesticides. Research has shown that crops with enriched N can make insect pests produce more eggs, survive better, live longer, and become

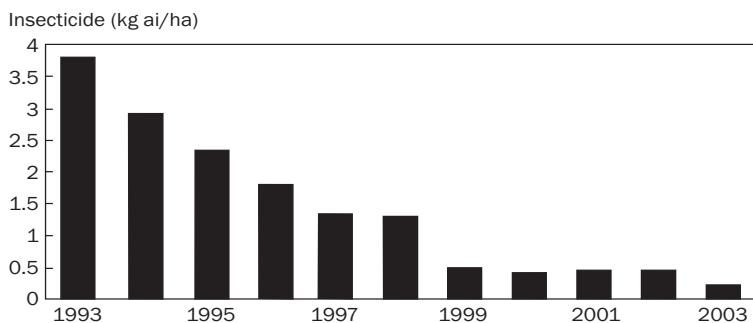


Fig. 2. Insecticide use trends from 1993 to 2003, International Rice Research Institute experimental farm, Los Baños, Philippines.

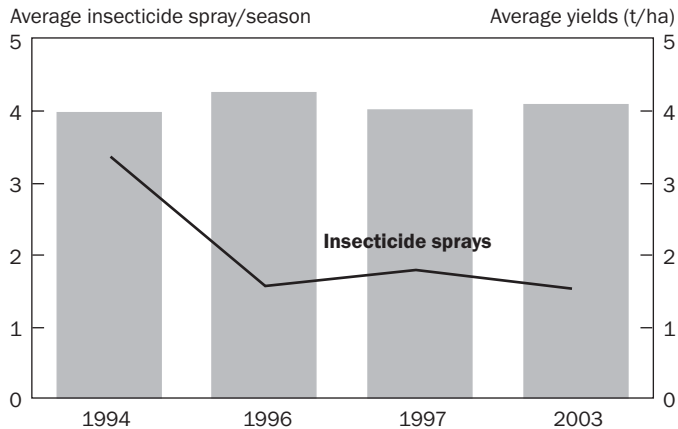


Fig. 3. Number of insecticide sprays per season that rice farmers used, and average farmers' rice yields before and after the implementation of the "No early spray" campaign in the Mekong Delta, Vietnam, August 1994.

ecologically fitter (Lu et al 2004). Searching efficiencies of predators are also reduced because prey sizes are increased. For instance, high plant N reduced the searching efficiencies of the planthopper egg predator, *Cyrtorhinus lividipennis*. Similarly, dense crops sown from high seed rates enriched with fertilizers are more disease-prone (Webster and Gunnell 1992). To further reduce pesticides, a mass media campaign was launched in Vietnam in 2002 to motivate farmers to reduce seed and fertilizer rates and stop early-season spraying. It was known as "Three Reductions" or "*Ba Giam Ba Tang*" in Vietnamese. Encouraged by the Ministry of Agriculture and Rural Development, millions of farmers in Vietnam now adopt these practices, with increased profits and no significant yield loss.

Developing and protecting habitat diversity

Sustainable pest management strategies would need to have ecosystem properties that will promote resistance and resilience of natural biological control to ecological stresses. This might be equivalent to the human body's immune system that determines good health and practices to maintain and strengthen it. Rice ecosystems have mechanisms to resist and recover from external stresses (Way and Heong 1994), and sustainable strategies will need to enhance them. One way to enhance natural biological control is by managing habitat diversity to provide alternative habitats for predators. For instance,

bunds rich in a perennial grass, *Brachiaria mutica*, are habitats for two species of crickets, *Anaxipha longipennis* and *Metioche vittaticollis*, that are important egg predators of pests, particularly leafhoppers (Kraker et al 1999). Spiders also use such habitats for shelter and breeding. In China, egg parasitoids of the brown planthopper, *Anagrus*, were found to overwinter in eggs that inhabit *Zizania*, a common vegetable (Yu et al 1996). Thus, planting *Zizania* can enhance egg parasitism of brown planthoppers. Alternatively, “predator homes” can be constructed like beetle banks in cereal fields to favor overwintering predators in the United Kingdom (Thomas et al 1992) and “spider homes” in China (Cheng 2004, pers. comm.). Wild flowers have also been found to be good sources of nectar for hymenopteran parasitoids and have positive effects on increasing parasitism (Leus 1967). In rice systems, there is a great diversity of ant species and, especially *Solenopsis geminata*, are considered important predators of pests (Way et al 2002). These are some potentially rich opportunities for research to develop options that can attain sustainability in maintaining low pest densities.

It is getting increasingly difficult for rice farmers in Asia to depend solely on rice cultivation to earn a living. By necessity, farmers are integrating cash crops into their farming systems. Often, the choice of such crops is market demand-driven, and farmers tend to spray more insecticides to protect their investments. For instance, in the Philippines, farmers spray more frequently and use more toxic insecticides on onions than on rice (Heong et al 1997). Similarly, farmers in China apply unnecessary sprays on *Zizania*, thus affecting its role as an alternate host to parasitoids. It thus seems clear that if ecologically sustainable practices are to be adopted, the practical realities are that they will need to be not only economically sustainable but well communicated as well. The motivation for adoption should be there (Heong 2004). From the experiences in implementing insecticide reduction programs, described above, the use of farmer participatory research to conduct on-farm evaluations (Heong and Escalada 1999, Huan et al 2004) and a participatory multistakeholder planning process becomes extremely valuable (Norton et al 1999, Snapp and Heong 2003). Face-to-face training programs have been traditionally employed to facilitate changes in farmers’ perceptions and practices, but these approaches are often slow and expensive (Quizon et al 2000). With millions of farmers who still need to be reached, coupled with the growing trend of reducing extension-farmer ratios and declining investments in agricultural extension, more cost-effective communication strategies will have to be explored. Thus, sustainable pest management will need to integrate communication sciences to increase efficiency in implementation.

Conclusion

Pest management dates back to the beginnings of agriculture. In the Before Christ (B.C.) years, many forms of “pesticides” or killing agents have been used by growers, like botanicals, sulfur, mercury, and arsenic compounds. Methods such as changing sowing dates have been recorded in use since 1,500 B.C., and manipulating natural enemies dates back more than 1,000 yr, like the use of *Oecophylla* ants in China and Vietnam. Genetic resistance is also one of the oldest methods used (Panda and Khush 1995). In the agricultural revolution, agriculture grew rapidly from subsistence to commercialization, and pests were seen as factors limiting efficiency and profits. Tolerance for pest damages was reduced, and the need to “eliminate” pests became a prime consideration. This provided the ideal opportunities for chemical pesticide exploration and business. Pesticides were easy to use and effective in “getting rid of pests,” thus starting the golden age of pesticide research and development (Casida and Quistad 1998). Farmers were motivated to enter the pesticide treadmill and trying other options became virtually impossible (Clunies-Ross and Hildyard 1992). Many farmers developed trust in and addiction to chemicals, a habit that continues to dominate pest management today.

To develop sustainable pest management, paradigm shifts are needed (Heong 1999). The contention that pesticides are the last resort needs to be emphasized. The paradigm that pesticides should be contemplated only when the target pest is “proven guilty” and that there is no other option (Way and Heong 1984) needs to be adopted. Thus, “Use pesticides last” should be the new slogan in promoting sustainable pest management.

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