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Ecologically-Based Management of Pest Rodents in Rice-Based Agro-Ecosystems in Southeast Asia

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Abstract: About 70% of the current energy intake of the human population in southeast Asia is met by rice. Rats, especially the ricefield rat, *Rattus argentiventer*, cause significant pre- and post-harvest losses in rice-based agro-ecosystems of southeast Asia and therefore require appropriate management. Current management practices focus on culling animals when populations are high and after significant damage has already occurred. The use of legal and illegal poisons poses a considerable threat to non-target species and humans. This is of particular concern in regions where rats are often consumed by humans to provide an important protein supplement to their diet. During the last seven years, CSIRO's rodent research group has tested and refined several methods aimed at decreasing pre-harvest rodent damage in cooperation with the Indonesian Research Institute for Rice and the Vietnamese National Institute for Plant Protection. These methods include exclusion of rats by fencing and physical control by trap-barrier systems with lure crops. The effects of these technologies were investigated regarding the regulation of rat numbers (physical control), damage (exclusion, physical control) and yield (physical control). The results are promising, indicating yield increase, of up to 20% in some cases. Integration of these methods with improved field sanitation, crop synchronisation and more efficient timing of other physical methods of control should result in pronounced increases in yield and improved cost effectiveness. Our approach is contingent on a strong understanding of the ecology of specific rodent pests. Measures of success besides decrease in rat numbers and damage are an increase in farmers' net income through yield increase and a decrease in the use of chemicals. Pros and cons of these methods in different economic and cultural environments are discussed.

Key Words: pest rodent, *Rattus argentiventer*, southeast Asia, trap barrier system

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IMPACT OF PEST RODENTS IN SOUTHEAST ASIA

Rodents, insect pests and weeds are the main causes for pre-harvest losses in southeast Asian rice crops (Singleton and Petch 1994). In Indonesia, rodent pests are the most important pre-harvest pests, causing on average 17% losses in rice crops (Geddes 1992). In Vietnam, where rodent damage to rice has increased from 63,000 ha affected in 1995 to 600,000 ha in 1999, rodents are one of the three main problems faced by farmers, the other two being insects and weeds (Huynh 1987). In Asia a loss of 5% of rice production amounts to 30 million tonnes, enough to feed 180 million people for one year (Singleton 2001). In irrigated lowland rice agro-ecosystems, rodents are generally a chronic problem whereas in rain-fed upland cropping systems in the Lao People's Democrat Republic, chronic rodent problems are compounded by episodic local to regional irruptions. Moreover, farmers in the uplands of the Lao PDR regard rodents as the constraint to production they have the least control over (Schiller et al. 1999). A general feature of pre-harvest rodent damage is its patchy nature with localized damage causing crop losses of 70% or even 100% in particular fields (Table 1). Although few recent data are available it seems post-harvest damage in southeast Asia can reach proportions similar to pre-harvest losses (Mustaq-Ul-Hassan 1992, Singleton 2001 for review).

In lowland flood irrigated rice systems of Java, Indonesia, the ricefield rat (*Rattus argentiventer*) is the

only species of rodent that causes significant damage (Leung et al. 1999). Ricefield rats and other species including black rats (*R. rattus*) and Norway rats (*R. norvegicus*) invade facilities for processing and storing rice. In Vietnam, the ricefield rat is the predominant species found in rice crops and presumably causes the most damage, but the lesser ricefield rat (*Rattus losea*), the black rat, bandicoot rats (*Bandicota indica* and *B. savilei*), and mice (*Mus* spp.) are present also (Brown et al. 1999). For the Lao PDR, less is known regarding the identity and distribution of major pest species and even less about their activity patterns in relation to cropping cycles (Schiller et al. 1999). Studies conducted in several upland regions of Laos indicate that one or more members of the *R. rattus* complex are probably the major pest species in rice crops, with other significant pests such as *R. nitidus*, *R. exulans*, *B. indica*, and *Mus cervicolor*. Almost nothing is known about rodents of lowland rice in the Lao PDR, though *R. argentiventer* and *R. losea* are both recorded from owl pellet deposits near paddy habitat in the Khammouan region of Savannakhet province (Robinson and Webber 1981). Besides their marked impacts on crop production, rats and mice can harm people by transmitting diseases through direct contact (e.g., leptospirosis) as well as inhalation of contaminated particles (e.g., hantavirus, tularaemia) or via infected arthropods that feed on rodents and humans (e.g., rickettsiosis, Lyme disease, bubonic plague) (Gratz 1994).

Table 1. Summary of damage to rice caused by rodents in selected countries of Asia and possible reasons for increase in rodent problems (as at 1998).

Country	Area of rice (000 ha) ^a	Rice prod. (000 t) ^a	Rodent species	Level of damage to rice	Reason for increase in damage	Source
Bangladesh	10,470	29,857	<i>Rattus rattus</i> ^b , <i>Bandicota indica</i> , <i>B. bengalensis</i>	Varies, > 50% regionally	Not stated	1,2,3
Cambodia	1,961	3,800	<i>R. argentiventer</i> , <i>B. indica</i> , <i>R. exulans</i> ^c	Varies	New varieties, more dry season rice	4
China	31,720	200,499	<i>R. nitidus</i> , <i>R. norvegicus</i> , <i>R. turkestanicus</i> (formerly <i>R. rattoides</i>), <i>Microtus fortis</i> , <i>B. indica</i>	0.6 – 5.3%	Climate change, increase in rice production	5
India	44,800	131,200	<i>B. bengalensis</i> , <i>Mus booguda</i> , <i>R. rattus</i> , <i>R. nitidus</i>	Varies (outbreaks 30-100%)	Asynchronous planting (? flowering of bamboo)	6
Indonesia	11,624	49,534	<i>R. argentiventer</i> , <i>R. exulans</i> , <i>R. rattus</i> ^b , <i>R. nitidus</i>	17%	Increase in rice production, asynchronous planting	7,8
Laos	718	2,103	<u>Lowland</u> ^c <i>R. argentiventer</i> , <i>R. norvegicus</i> , <i>R. exulans</i> , <i>B. indica</i> <u>Upland</u> ^c <i>R. rattus</i> ^b , <i>R. nitidus</i> , <i>R. exulans</i> , <i>Mus spp.</i> , <i>B. indica</i>	Significant, 15% (?) Outbreaks 30-100%	Unusually dry years, flowering of particular bamboo species	9,10
Malaysia	674	1,934	<i>R. argentiventer</i> , <i>R. exulans</i>	5% (1-11%)	Losses in abandoned fields	9,11,12
Philippines	3,978	11,388	<i>R. rattus</i> ^b , <i>R. argentiventer</i> , <i>R. exulans</i> , <i>R. norvegicus</i>	2-5%, Reports of >50% loss regionally	Level of damage believed to be low	11
Thailand	10,000	23,272	<i>B. indica</i> , <i>B. savilei</i> , <i>R. argentiventer</i> , <i>R. losea</i> , <i>R. rattus</i> ^b , <i>M. caroli</i> , <i>M. cervicolor</i>	6-7%, up to 18% in 1977, 1.5% in 1993	Reduction due to more coordinated control methods	9,13
Vietnam	7,648	31,394	<i>R. argentiventer</i> , <i>R. losea</i> , <i>R. rattus</i> ^b , <i>R. exulans</i> , <i>B. indica</i> , <i>B. savilei</i>	10-30%, but up to 100%	Increased area and intensity of production	9,14

^a Source of data - IRRI (1997)

^b *Rattus rattus* is used here to include all members of the Black rat 'complex' (e.g., including *R. tanezumi*). This complex probably includes 3-4 species.

^c Taxonomic data are sparse; further studies of which species are the major pests to crops in these regions are urgently needed.

Sources:

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|---------------------------|--------------------------------|-----------------------------|
| 1 - Catling et al. (1988) | 6 - Parshad (1999) | 11 - Hoque et al. (1988) |
| 2 - Islam et al. (1993) | 7 - Geddes (1992) | 12 - Lam et al. (1990) |
| 3 - Karim et al. (1987) | 8 - Leung et al. (1999) | 13 - Boonsong et al. (1999) |
| 4 - Jahn et al. (1999) | 9 - Singleton and Petch (1994) | 14 - Brown et al. (1999) |
| 5 - Zhang et al. (1999) | 10 - Schiller et al. (1999) | |

CONVENTIONAL CONTROL METHODS

Rat control in southeast Asia traditionally comprises physical (Buckle et al. 1984, Singleton et al. 1998) and chemical methods (Buckle et al. 1984, Wood 1971). Physical methods include: trapping with a variety of traps (snares, wire cage traps, break-back traps); digging or flooding of burrows; hunting by shooting or with trained dogs; fumigation of burrows with sulphur gas; rat drives organized at a community level; electrocution (an electrified wire about 20-75 mm above and along the perimeter of an irrigated rice crop); and plastic fence plus traps (multiple live-capture traps are placed intermittently adjacent to holes along a fence that is protecting a crop or stored grain) (Fiedler and Fall 1994, Singleton 2001).

Rodents are controlled chemically by the use of acute and anticoagulant poisons. Substances used for rodent control in southeast Asia include zinc phosphide (Buckle 1994), 1080 (sodium fluoroacetate) (H. Leirs pers. comm.), Biorat (a combination of *Salmonella enteritidis* and coumarin), and Temik (a combination of aldicarb and dichloromethane). In extreme efforts to control rats, insecticides are sometimes mixed with sump oil, which is then dispersed into irrigated rice paddies. The rats contact the mixture when swimming in the water and ingest it through preening. Bounty systems are also used and most are funded by government institutions. In Vietnam in 1998, 47 provinces applied a rat bounty scheme for specific times of the year and 179 million rats were collected. The cost of the bounty scheme was approximately 18.5 billion dong (US\$1.5 million) (Source: Plant Protection Division, Ministry of Agriculture and Rural Development, Vietnam). Bounty systems are also used widely in the Lao PDR and occasionally in Indonesia (Singleton et al. 1999b). Rat drives in 2 villages in the Subang province of west Java yielded ca. 14,000 dead rats in a period of about two weeks at land preparation stage for the dry season crop in 2001 (Source: Research Institute for Rice, Ministry of Agriculture and Rural Development, Indonesia).

ECOLOGICALLY-BASED RODENT MANAGEMENT

Ecologically-based rodent management is built on the biological and ecological understanding of the target species, coupled with management at a farming systems level (Singleton et al. 1999a). Sound knowledge of natural factors that regulate pest rodent populations, such as food availability, breeding, and habitat use helps to manipulate key features in the agro-ecosystem to limit rodent numbers and crop damage. This philosophy focuses control on the target species and reduces non-target impacts.

Affordable management options that can be easily applied include habitat modification to reduce key resources such as food (controlling the growth of grasses along the banks of irrigation channels, synchronising planting and harvesting) and nesting sites (minimising the height and width of irrigation levee banks) (Leung et al.

1999). Another option is the identification of source habitats and the tactical culling of rodents by physical and chemical methods at these locations and at specific times of the year. In addition, a sound knowledge of the seasonal dynamics of populations of rodent pests will enable strategic culling of rodents in and around crops at critical times. A range of different control methods applied at key times of the year, is most likely to yield maximum success with minimum impact on the environment (Singleton 1997). Elements of ecologically-based rodent management could include exclusion or harvesting of rodents (using a trap barrier system) as well as biological and fertility control.

Exclusion

Physical exclusion of pest rodents is widely used in Indonesia and Vietnam where the property to be protected is small, easily fenced off, or particularly valuable (e.g., hybrid varieties for plant breeding). Farmers sometimes use plastic fences to exclude rats from freshly planted seedbeds and from rice paddies. Occasionally, the seedbeds are fully enclosed in wire mesh cages.

Trap Barrier Systems

Trap barrier systems with trap crop (TBS) are simple, affordable structures used in some southeast Asian countries to control rats. These systems were first introduced in Malaysia 15 years ago (Lam 1988) and the concept has been refined since then (Singleton et al. 1998, Singleton et al. 1999b). A TBS consists of multiple-capture cage traps associated with a rectangular plastic fence, typically 25 × 25 m, with an early planted 'lure crop' inside. These systems are installed within the rice crop that needs to be protected (Singleton et al. 1999b). The lure crop is planted 2-3 weeks earlier than the surrounding crop (Figure 1) and therefore more nutritious and more attractive to the rats than the surrounding crop. Captures of rats are usually highest around the maximum tillering stage of the surrounding crop, with a decline in captures after that.

TBSs are ideal means for ecologically-based rodent management because they can be applied at key times, they allow the release of any non-target animals and, in contrast to poisoning and fumigating, they allow potential for human consumption or animal consumption of captured rodents. Furthermore, no residues remain in the system after the structures are removed at the ripening stage of the rice crop. However, the use of TBSs entails a large maintenance effort, because they need to be checked daily to remove rats and to monitor the condition of the fence. Rats entering a TBS via holes in the fence or by jumping the fence can feed protected from terrestrial predators and may cause high damage to the trap crop. This risk could be reduced by the use of high fences (60 cm) and frequent checking of fences for signs of rats entering. Placement of snap traps inside the TBS fence may also provide protection against intruders.

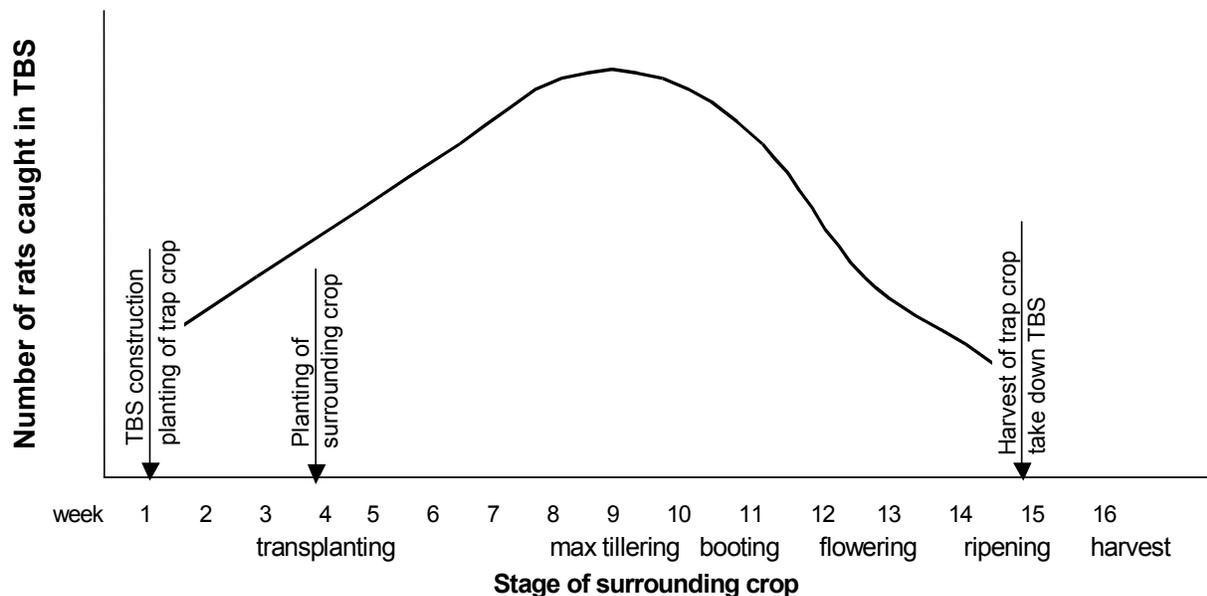


Figure 1. Schematic trapping efficiency of a trap barrier system (TBS) for ricefield rats (*Rattus argentiventer*) in relation to crop stages in low land irrigated rice fields (after Singleton et al. 2001).

Because the trap crop is planted in advance of the surrounding surrounding crop, it may attract birds and insect pests, which can lead to damage to the trap crop and possibly to the crop adjacent to the TBS.

The TBS method has many advantages: it is environmentally benign; it is a simple technique that can be easily transferred from scientists to extension officers and farmers; and it can be applied on a large scale. In contrast to biological control or the use of poisons, there are no safety issues that could lead to objections by local or regional governments.

Biological and Fertility Control

Biological control in southeast Asia is primarily based on the introduction or encouragement of predators, mainly barn owls (Lenton 1980). Some farmers grow plants that are thought to repel rats around their crops or, alternatively, grow plants that are preferred by rats close to rice crops to supply an alternative food source. None of these methods have been tested for their effectiveness in replicated controlled field experiments. An interesting emerging approach is the use of non-toxic baits containing sporocysts of the parasite *Sarcocystis singaporensis* (Jaekel et al. 1999).

Immunocontraception in females is a form of fertility control to manage the density of overabundant species. This approach has been successfully applied for large mammals such as feral horses (*Equus caballus*) and white-tailed deer (*Odocoileus virginianus*) (Kirkpatrick et al. 1997). The concept has been tested for house mice (*Mus domesticus*) under controlled conditions where the sterilisation of 67% of female founders and their progeny

was sufficient to decrease population size (Chambers et al. 1999b).

In Indonesia, the reproductive cycle of ricefield rats is tightly linked to the stage of the rice crop. Generally, breeding lasts only for about 6-8 weeks depending on the synchronicity of planting and harvesting (Lam 1983, Leung et al. 1999) (Figure 1). The short, sharp breeding season should make ricefield rats an ideal target for fertility control. A potential advantage of using immunocontraception to manage rodent pests is that sterilised females may retain their social status in the population preventing subordinate females from breeding (Clark and Galef 2001). This approach could also minimize the problem of reinvasion that commonly occurs after culling (Krebs 1966).

EFFECTIVENESS OF RODENT MANAGEMENT

How can we best measure the effectiveness of rodent management for pre-harvest crop protection? In many studies the effectiveness of rodent control is inferred from the observed decrease in rodent abundance (or activity) (e.g., Zhang et al. 1999). However, even a 50% reduction in pest rodent density may not result in any decrease in the level of damage to the crop, and a considerable decrease in density may be required to bring damage below the economic injury level (Figure 2). The ultimate goal of rodent management in agro-ecosystems is to achieve a decrease in damage that translates into a significant increase in yield and hence net income. Nonetheless, studies on the impact of pest rodent management on damage or yield are rare. Another way of expressing this relationship is to say that the benefit-to-cost ratio of rodent management, taking all factors into

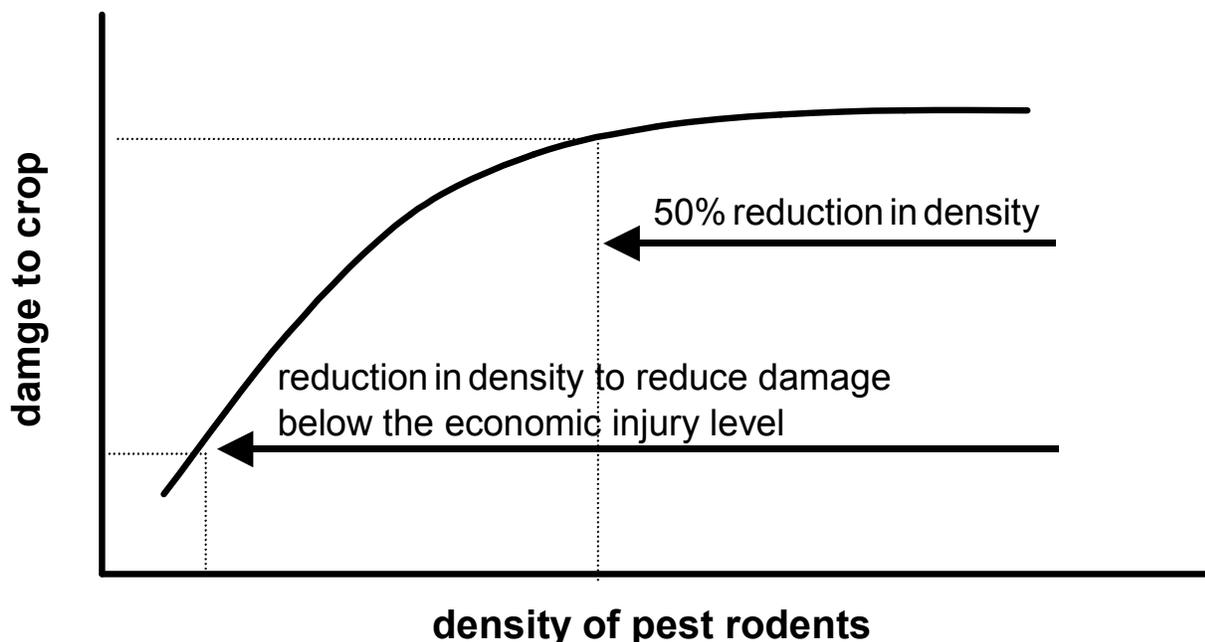


Figure 2. Hypothetical relationship of density of pest rodents and damage to rice crops (redrawn after Singleton et al. *In Press*).

account, must be positive. This may need to be judged over several seasons. If, for instance, the application of TBSs for rodent management results in a benefit-to-cost ratio of 1, but at the same time there is considerable decrease in the use of unsustainable practices, then the use of TBSs might be judged a success.

There are no published studies on the effectiveness of the exclusion of pest rodents (fences without traps) on damage and yield in rice crops. Trials conducted by the Research Institute of Rice and CSIRO Sustainable Ecosystems in 1996/97 indicate that damage in fenced seedbeds is ca. 80% lower than in unfenced controls (Sudarmaji, pers. comm.).

The impact of the application of TBSs of various sizes at various densities of rats on rice yield has been tested in Indonesia and Vietnam. There is clear evidence of the effectiveness of the TBS approach for protecting lowland flood irrigated rice at the field level, with one TBS protecting up to 16 ha (Singleton et al. 1998). Singleton et al. (1998) demonstrated that rice yields were about 20% higher in fields with TBSs than in control fields where no TBSs had been established. The benefit-to-cost ratio can reach 20:1 when rat density is high but is much lower (2:1) when only few rats are present (Singleton et al. 1998). However, these ratios would probably be higher if additional benefits from the TBS were considered, especially the decreased need for replanting before the generative stage of the rice, the

additional food source for humans and/or animals, and the decreased use of poison. A method to reliably predict rat numbers from cropping season to cropping season would be a desirable tool to avoid establishing TBSs at low rat densities when the benefit-to-cost ratio is low. Because the study by Singleton et al. (1998) was done at the field level (research farm), only limited inferences can yet be drawn about the effectiveness of the combined methods required for ecologically-based rodent management on a larger scale (e.g. village or province).

Increasing the density of barn owls in oil palm plantations in Malaysia generally results in a decrease in both rodent numbers (mainly *Rattus tiomanicus*) and poison use at high owl densities (Hafidzi 1998). However, the lack of replication and controls in these experiments makes it difficult to generalize these findings. The application of non-toxic baits containing high doses of sporocysts of *Sarcocystis singaporensis* led to increased mortality of several rodent species and a decrease in their activity (Jaekel et al. 1999) but nothing is known about the consequent effect on crop damage and yield. Fertility control likewise shows promise as a method to decrease rodent pest density (Chambers et al. 1999a), but enclosure and field studies are urgently needed to better understand the potential of this method to sustainably decrease the densities of relevant rodent pest species and to increase crop yields in southeast Asian countries.

SOCIOLOGICAL ISSUES

Many factors will determine whether farmers will adopt particular methods of pest rodent control and whether they can be applied effectively at a village level. These include the availability of equipment and chemicals, social and political infrastructure, associated costs including labour, local environmental factors, and a variety of religious, cultural, and ethical issues. These may be equally or even more important in the choice of management strategies than ecological aspects. Relevant examples in southeast Asia are the aversion of people in some regions to barn owls (North Vietnam; Java, Indonesia) and culturally different levels of acceptance regarding fertility control and the use of genetically modified organisms. An effective, affordable, and ecologically sustainable method of management will not be implemented by the end user (farmer) if it is not acceptable for cultural reasons.

In some southeast Asian countries, rodents are used as a protein source for human consumption. In the uplands of the Lao PDR, rats, mice, and other rodents (squirrels, porcupines) are frequently sold for human consumption at markets. In a family business the Bac Lieu province of south Vietnam, 1 tonne of rats per day (ca. 10,000 rats) are processed for human consumption during the spring/ winter season. In contrast, rodents are not eaten in the main rice bowl of Indonesia (Java) because of different cultural and religious background. In this region, even the use of rodents as feed for breeding fish or chicken is controversial and culled rats are usually dumped. One potential benefit from the use of TBSs is thus lost and the only direct pay off is an increase in yield. If there is a dietary or commercial use of rodents, benefit-to-cost ratios of >1 could be achieved more easily. Recent studies at Gadjadara University in Jogjakarta, West Java, Indonesia into possible commercial use of rats (e.g., food, handicraft) indicate possible changes in the public perception in Indonesia (S. Mangoendihardjo, pers. comm.).

The average field size for individual farmers in Indonesia, Vietnam, and Laos is 0.8-1.5 ha (IRRI 1997). Because the halo of protection around a TBS is much larger, a farmer who establishes a TBS would automatically protect the crop of the owners of adjacent crops. This altruism might seem to be an advantage at community level, but farmers in Indonesia often refrain from building a TBS because of a perceived loss of 'competitive edge.' The situation is different in Vietnam and Laos, where farmers from villages work more easily together and the workload and the benefits from TBSs can be shared. In Vinh Phuc, Red River Delta, Vietnam, farmers are well organised into groups and have a roster system to maintain and check TBSs daily. Successful broad scale implementation of the TBS technique requires a true community approach, hence the recent tendency to call it a C-TBS (community trap barrier system) rather than TBS (S. Morin, pers. comm.). To assess the likelihood of adoption of ecologically and

economically suitable rodent management tools in any particular area, it will be important to conduct studies of how local farmers perceive the benefits and costs of these management techniques.

CONCLUSIONS

Methods to control pre-harvest rodent damage to rice crops may be more effective if adapted to the biology and ecology of the target species. The most appropriate measure of success is not simply a decrease in the number of rodents, but rather a reduction in damage to the crop and a corresponding increase in yield and net income. Other factors should also be considered in judging the effectiveness of rodent control methods, such as a reduction in the rate of (mis)use of poisons. Despite positive effects on yield, some rodent control methods that are environmentally friendly may not be acceptable to farmers because of cultural, social, or religious sensitivities. Therefore, a collaborative approach including ecologists, rodent management experts, and sociologists is desirable for the successful development of pest rodent management in southeast Asia.

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