8. Physical Control of Rats in Developing Countries

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Abstract

Digging, trapping, flooding, netting, rat drives and physical barriers are the norm for rodent control in rice fields in most developing countries. We provide a brief overview of physical methods of control aimed at reducing pre-harvest damage by rodents, then consider in detail the use of trap–barrier systems. An important catalyst for adoption of physical control in Southeast Asia is the use of bounties for each rat captured. In Australia, uses of bounties to control vertebrate pests have been singularly unsuccessful. Differing socioeconomics and more intense trapping may provide better results in developing countries. There is a scarcity of good data to assess whether bounties based on physical actions of control are effective. In contrast, experimental field studies support the strategic use of trap–barrier systems (TBS) using early crops ('trap crops') as a lure to rodents. Experimental studies in West Java, Indonesia, and the Mekong and Red River Deltas of Vietnam, indicate that TBS plus trap crops (TBS+TC) are cost-effective in most seasons. Yield increases of up to 1 t/ha have been recorded up to 200 m from a TBS+TC. The need to invest money into traps and fences, which protect neighbouring crops, requires a community-based approach for rodent management. An untested recommendation is that one TBS+TC (25 × 25 m) would be sufficient for every 15 ha of rice crop. Although we require more detailed knowledge of the population ecology and biology of rodent pest species, what we already know has had an important influence on the development of management strategies incorporating physical methods.

Keywords

Rice-field rat, physical control, trap–barrier system, bounty, rodent management

Introduction

In developing countries, physical methods of control are probably the most commonly used approaches by farmers to combat rodent pests. This is simply because they generally cannot afford, or do not have ready access to, chemical rodenticides, fumigants, nest boxes for birds of prey, or other forms of rodent control.

Physical methods have been long recognised as effective for reducing the impact of rodents in post-harvest stores and in intensive animal production units where they damage structures and foul foods (Jenson 1965; Brooks and Rowe 1979; Meehan 1984). Actions include mechanical proofing inside and outside buildings or ships, physical barriers preventing access to an area and various means of trapping. Nevertheless, post-harvest food loss to rodents remains a substantial problem in tropical and sub-tropical regions (Morley and Humphries 1976; Elias and Fall 1988; Prakash and Mathur 1988). Post-harvest losses and impacts on livestock production will not be considered further in this chapter. Instead we refer interested readers to review articles and leaflets on rodent management in large food stores (Meyer 1994), pig production units (Brown and Singleton 1997), and small to medium-sized food stores and food processing units in developing countries (Posamentier and van Elsen 1984; Bell 1998).

This chapter will focus on physical methods aimed at reducing pre-harvest damage by rodent pests. We will provide a brief overview of physical methods of control used in developing countries, then consider in detail the use of trap–barrier systems. The latter will cover historical innovations in the use of the technique, its efficacy across different rice agro-ecosytems, benefit–cost analyses, strengths and weaknesses of the approach, research needs, and its likely role in ecological and sustainable management of rodent pests at a village and district level.

Physical Methods—General

Many inventive techniques have been developed by farmers in developing countries to catch or kill rats or to deflect them from their crops. These include the methods outlined in Box 1.

Other methods are more peculiar to particular regions and countries. These range from placing offerings in the corner of crops to a particular god, to catching large male rats, sewing their anus closed and letting them go again. Farmers believe that 'sewn rats' will become aggressive through an inability to use their bowels and therefore scare neighbouring rats away. This latter technique is inhumane and there is no evidence that it is effective.

The efficacy of the above techniques for controlling rodent populations is rarely assessed. Many are inappropriate given the risk they present to humans. For example, in their desperation to protect their crops from rodents, some farmers redirect mains-power so that it flows through wire suspended centimetres above a flood-irrigated rice crop. The wire is strung around the margins of the crop, killing any rat that comes in contact with it.

Box 1.
Methods promoted by farmers in developing countries to catch or kill rats or to deflect them from their crops

- Various snare and live-traps, usually made of bamboo, that garrotte a rat or break its back (see Mathur 1997; Schiller et al., Chapter 18).
- Bamboo tubes—simply offer cover for rats and either they get stuck or they are caught alive and emptied into a bag.
- Digging of burrows to kill rats in situ; occasionally dogs are used to locate burrows or to help hunt rats flushed from burrows (e.g. Posamentier and van Elsen 1984).
- Rat drives or battues—where rats are driven from cover and herded towards nets (Singleton and Petch 1994).
- Stalking at night with a kerosene light and a net at the end of a long handle—in Co Dung village of Hai Duong province in Vietnam, farmers apply this method from 1900–2200 hrs at specific times of the year and each farmer catches from 5–15 kg of rats per night.
- Electrocution—electrical wire is strung the length of a rice crop about 10–50 mm above a flooded paddy; wet rats that make contact with the wire are quickly killed. As indicated below, this method presents an unacceptably high risk to human health.
- Physical barriers—these usually consist of plastic or metal sheeting and are placed around or along the borders of crops or around areas where grain is stored (e.g. Lam 1988).
- Physical barriers plus traps—live-multiple-capture traps are inserted intermittently at the base of a physical barrier. The traps are placed against small holes in the barrier. Rats enter the traps, attracted to the developing crop or stored food that is on the other side of the barrier (e.g. Lam et al. 1990; Singleton et al. 1998).
- Metal rat guards—sheets of metal are wrapped around the trunk of a tree, higher than 1 m from the ground, to prevent rodents from climbing trees to access fruits. The design of the guards depends on the climbing habits of the rodent species; some are flat against the tree, whilst others are conical or circular metal sleeves, flush with the trunk of the tree but projecting outwards at, or less than, 90° from the trunk (e.g. Posamentier and van Elsen 1984).
- Scaring devices — white cloth or plastic is attached to a bamboo pole approximately 1.2 to 1.5 m high. The white material flapping in the wind supposedly mimics the flight of owls and therefore frightens rats away from the immediate vicinity. These ‘scare-owls’ are erected in ripening crops where rat damage is evident.

This method has been observed by one of us (G. Singleton) in the Philippines and Vietnam.

In southern Luzon, Philippines, 11 human fatalities were reported in the late 1980s (Quick and Manaligod 1990). In Thai Binh province in the Mekong River Delta, three people were killed in 1997.

Bounty Systems

Bounty schemes in general

In developing countries, management actions are often poorly coordinated. This results in rats quickly reinvading areas where control has been conducted. Sometimes governments introduce a bounty system as an incentive for widespread concurrent control. Inherent weaknesses of bounty systems are that they require rats to be caught and they are generally invoked once densities are already high. This leads to two major problems. The first is that bounties promote inefficient reliance on physical methods of rodent control such as live-trapping, digging and rat drives, replacing management programs based on the use of rodenticides, better farm hygiene, habitat manipulation and/or changes in farm management practices. The second is that bounties encourage a crisis management mentality—acting when rat numbers are high, rather than the more appropriate use of early tactical management (see Redhead and Singleton 1988; Brown et al. 1998). Often the rationale for invoking a bounty system is more to do with political expediency rather than developing an effective, community-based management strategy. Governments have to be seen to be doing something to help farmers in their fight to save their crops from the ravages of high density rodent populations. The collection of tens of thousands of rat bodies has a strong visual effect, providing a sense of satisfaction to farming communities that they have waged a good fight against their perennial enemy.

Bounty schemes have been around for hundreds of years and have been adopted in many countries. In Australia, bounties were first introduced in 1830 for the tails of unregistered dogs in metropolitan Sydney. Since then, bounties have been used for both introduced (e.g. foxes and wild horses) and native species (e.g. dingoes, species of wallaby, Tasmanian tiger) (Breckwoldt 1988). In Australia, as elsewhere, there is no compelling evidence that bounty schemes have been successful in achieving their management aim.

A recent review of bounty schemes by Hassall and Associates (1998) identified the following reasons for their failure.

- Fraud—schemes are abused by people they are supposed to serve.
- Harvesting mentality—bounties are seen as an ongoing source of income rather than a control measure.
- Inefficiency of control—financial incentives promote management systems which provide bodies of animals; as discussed above, there are generally more efficient methods for control.
- Compensatory growth by pest populations—unless more than 50% of a pest population is removed by a bounty, then at best, the pest population will maintain numbers through enhanced survival, higher rates of immigration from uncontrolled areas and better reproductive performance (Caughley 1977; Hone et al. 1980).
- Inadequate benchmarks for success—few programs have appropriate success criteria and so they continue from one campaign to the next with the sole criteria being that they caught many animals last time through imposing a bounty.

This review primarily considered the appropriateness of bounties in Australia. It concluded that bounties were not a cost-effective system for managing vertebrate pests.

Bounty schemes for rodents

Rodents have all the life history characteristics that suggest they would not be the appropriate target for a bounty scheme. They are highly fecund, can produce a litter every three weeks, are extremely mobile and are widely distributed across a landscape. Moreover, most rat drives or bounty systems are conducted once rats have already become a significant problem. Often then it is too late to protect the ripening crop.

The issue of compensatory growth of populations, therefore, is particularly important when considering the potential effectiveness of bounties for controlling populations of rodent pests. In the case of Norway rats, *Rattus norvegicus*, in urban environments in the United States of America, populations which have been reduced to 10–25% of their pre-treatment level, double their population size within 2–4 months and are back to >75% of pre-treatment level by 6–8 months (Emlem et al. 1948). Similarly, trapping high numbers of muskrats (*Ondatra zibethicus*) in Germany, had little impact on the dynamics of their abundance. Indeed, it was estimated that annual loss due to trapping was less than the number of naturally surplus individuals in a population (Halle and Pelz 1990).

Perhaps the implementation of bounty schemes in developing countries may hold greater promise. In these countries, the density of people per hectare is up to two orders of magnitude higher and individual holdings are measured in fractions of a hectare rather than thousands of hectares.

In Lao People's Democratic Republic (PDR), the rat bounty is around 70 kip per rat tail (4,000 kip to US$1). In Indonesia, in West Java, the rat bounty is 50 rupiah for the head of a rat (9,000 rupiah to US$1). In Vietnam, in the Red River Delta, the going price during a bounty season (bounties are not available in all years) is 200 dong for a rat tail (14,000 dong to US$1). Bounty schemes have been also implemented in Cambodia and the Philippines.

In 1991 in Luang Prabang province in northern Lao PDR, a sparsely populated region by Asian standards, over 600,000 rat tails were collected in just 2–3 months (see Singleton and Petch 1994 for details). The bounty scheme stopped because the money ran out. These figures are impressive and it may have been a successful campaign. The officials that one of us (G. Singleton) spoke to were certainly impressed by the number of rats they caught and had little doubt about its success. However, there was no quantitative assessment of whether there was a substantial impact on pre-harvest losses caused by rats. In that year it was still common for growers to report losses of greater than 50% to their crops (Walter Roder, pers. comm.).

In August 1998, a rat bounty of 50 rupiah per rat was instigated in four adjoining villages in West Java, Indonesia. Over 164,000 rats were collected from 1,790 ha in less than a month. In one village of 230 ha, an average of 222 rats were caught per ha. The bounty was instigated during the land preparation for a third rice crop for 1998. A third crop is unusual for West Java and the mass action against rats was activated to guard against rat damage to the newly sown crop. The action seemed to be successful, although there was no control site for comparison and no quantification of crop damage. Nevertheless farmers were satisfied with the outcome.

More impressive still were the numbers of rats caught under a bounty system in Vietnam. In 1997, 22 provinces applied a rat bounty scheme for specific times of the year and 55 million rats were killed. The combined cost for the provincial governments involved was approximately 62 billiion dong (see Table 1).

In 1988, in the first two months of the year, 8.5 million rats were killed throughout Vietnam under the bounty system. In the one province of Vinh Phuc, over 5 million rat tails were returned from January–September 1998—the bounty season closed in October. This is in a province where the human population is around 1.1 million.

Regardless of the theoretical evidence that suggests bounties may be an inefficient means of controlling rat populations, digging, trapping, flooding, fumigation, and rat drives are the norm for rodent control in rice fields in most developing countries (see Jahn et al., Chapter 17 and Schiller et al., Chapter 18). Unfortunately, there is a scarcity of good data to assess whether these physical actions of control are effective or not. In regions such as West Java, the intensity of physical activities directed at controlling rats is high. There, some people get paid a levy on the number of rats they catch, however most are locked into conducting nightly control campaigns during the generative stage of the rice crop because they can ill afford to lose much of their potential harvest to rats. These intensive physical activities and bounty schemes elsewhere need to be assessed against specific criteria of success. Apart from a simple benefit–cost analysis, it is important also to take into account whether the time, effort and resources could have been more effectively marshalled for an alternative strategy of rodent control. Such a strategy that may even centre on a coordinated, restricted, bounty season that shifts focus to earlier tactical intervention.

Physical Control as an Adjunct to Rodenticide Baits

Knowledge from both the population ecology and feeding behaviour of rats indicates that the best time to use rodenticide baits in and around rice crops is at maximum tillering. This coincides with the onset of breeding and with the final weeks of a 2–6 month fallow period when food quality and quantity have been low.

Table 1.
Number of rats returned for bounty payments in three northern and three southern provinces of Vietnam for the first five months of 1997. (Source: Ministry of Agriculture and Rural Development, Vietnam.)

Province	Area rice damaged (ha)	Number of rat tails	Vietnamese dong paid for bounty
Red River Delta (North)			
Hai Duong	4 139	3 363 257	672 651 400
Hanoi	10 000	650 000	130 000 000
Vinh Phuc	6 729	9 008 700	1 801 740 000
Mekong River Delta (South)			
Long An	3 500	4 600 000	100 000 000
Quang Ngai	4 752	180 225	36 015 000
Bac Lieu	2 990	550 000	9 000 000

Hence the rat population would be at a relatively low density and bait acceptance would be high. Once panicle initiation begins, rats show low acceptance of baits (Buckle 1988). In India, local traps then become a useful control measure together with fumigation and weed control (Mathur 1997).

TRAP–BARRIER SYSTEMS

In developing countries, a common method for protecting a crop from invading rodents is to use plastic fences to deflect rats and mice away from the crop. If the rats are successfully kept out they are generally deflected into neighbouring crops. The net effect is that crop losses in a village are rarely reduced. In the 1980s, Lam (1988) developed a variation of the drift fence and pitfall method commonly used for trapping small mammals. The variation consisted of placing a plastic fence along the margin of a rice crop and placing small holes in the fence just above the irrigation water. Adjacent to each hole is a multiple-capture cage trap suspended on bamboo above the water level (on the crop side of the fence). A mud mound provides access to the hole and thence to the trap. The dimensions of the fence and trap are shown in Figure 1.

This fence plus trap method has been variably described as the 'environmentally friendly system', the 'active barrier system', the 'plastic fences and multi-capture trap' and the 'trap–barrier system' (TBS). The trap–barrier system or TBS is now the commonly accepted description used in most Southeast Asian countries and is what we will use in this chapter.

The TBS was first developed to protect crops in areas where rat damage was high (e.g. crops adjacent to abandoned agricultural land, early planted crops). In Malaysia, a TBS that extended for 5 km was used successfully to protect reclaimed cropping lands that were planted out of synchrony. The most rats caught in one night was 6,872, with 44,101 rats caught in nine weeks. Subsequent studies in Malaysia (Lam et al. 1990) and the Philippines (Singleton et al. 1994) focused on the use of small rectangular TBSs (0.25 ha to 4 ha). Again, promising results were obtained when rat densities and crop losses in surrounding areas were high. However, benefit–cost analyses indicated that losses would have to be greater than 30% for the TBS method to be cost-effective on a regular basis (Singleton et al. 1994; Lam Yuet Ming, pers. comm.).

More promising results were obtained when the TBS was used to protect a crop that was locally attractive to rats, e.g. late-harvested rice crops or vegetable crops maturing after the rice crops had been harvested (see Lam and Mooi 1994). This led to the development of a second generation TBS, consisting of an early or late planted 'trap crop' within the TBS which lures rodents to the traps. The expectation was that rats from the surrounding areas would be drawn to the trap crop and then enter the traps. The TBS plus trap crop (TBS+TC) would then provide a halo of protection to the neighbouring rice crops.

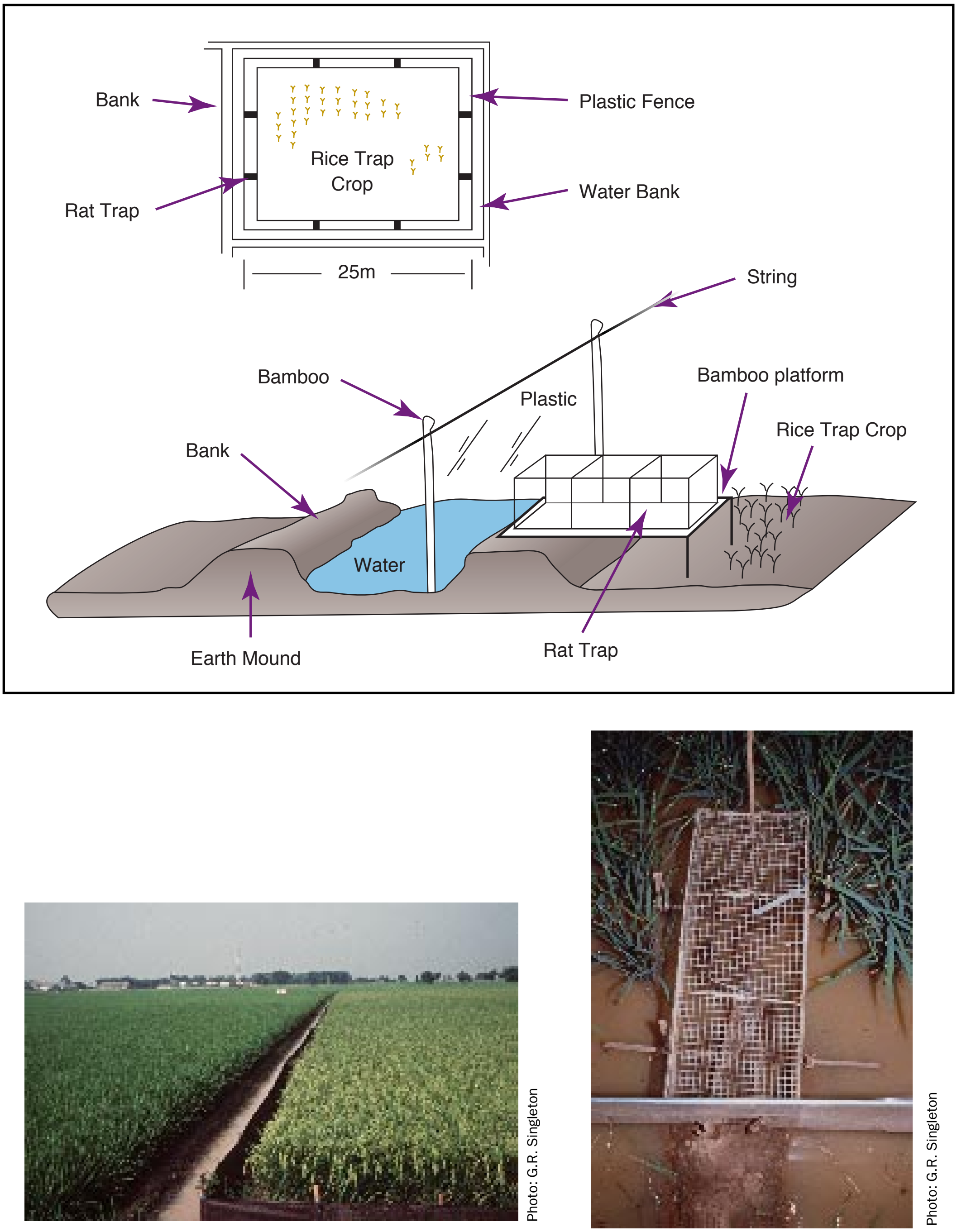

Figure 1.
Schematic diagram showing the design of the trap–barrier system plus trap crop of rice (TBS+TC) of rice. (b) TBS and TC in Sukamandi; West Java. (c) TBS in position.

Experimental field studies in different agro-ecosystems

Most of the early claims of the successful use of a TBS for controlling rats could not be substantiated because there were no appropriate control sites or replication of trials. Economic data for evaluating the benefit–cost ratio of a TBS were lacking also. It was as recent as 1993 that the first replicated and controlled study was conducted (Singleton et al. 1994). The results from that study indicated that the benefits of using a TBS were at best equivocal. These results switched the focus to the concept of a TBS+TC, first suggested by Lam (1988) but which again had not been properly evaluated.

Beginning in 1995, controlled studies of the cost-effectiveness of a TBS+TC were conducted in irrigated lowland rice crops in West Java, Indonesia. The trap crop was rice transplanted three weeks earlier than the surrounding rice crops. The results from the 1995 dry season and the 1995/96 wet season were extremely promising with benefit–cost ratios in the vicinity of 20:1 (Singleton et al. 1998). Subsequent studies conducted in different geo-climatic zones in West Java (1996–1997) and in the Mekong and Red River Deltas in Vietnam (1997–1998), have followed a similar experimental design (after Singleton et al. 1998), allowing comparisons of the robustness of the efficacy of the second generation TBS. The main variations in experimental design were the size of the TBS and lack of replicates in the Vietnamese studies (Tables 2 and 3).

The findings from these experimental studies are summarised in Tables 2–6. The main inferences that can be drawn from these studies are as follows.

- The TBS+TC generally provides a halo of protection to surrounding crops within 200 m of the fence. The protection is stronger the closer the crop is to the TBS.
- The halo of protection provided by a TBS varies markedly between seasons. In West Java, protection extended to a minumum of 200 m in two of the three dry seasons, but was less pronounced beyond 5 m in the wet seasons. In this climatic zone, the TBS+TC is generally more cost effective during the dry season rice crop when rat densities are generally at least an order of magnitude higher than in the wet season and their impact on rice crops is greatest.
- Yield increases to surrounding crops are generally 0.3 to 1.0 t/ha.
- The relative benefit–costs are higher if rat densities are higher, however the relationship between rat density and yield loss does not appear to be linear. Rice crops are able to partially compensate moderate tiller damage by rats if it occurs prior to maximum tillering (see Singleton et al. 1998 for further details).
- In West Java, the optimum size of a TBS+TC is in the range of 20 × 20 m to 50 × 50 m. When a 10 × 20 m early trap crop was employed, there was a net loss to farmers.
- The comparative performance of the TBS+TC across the different agro-climatic regions indicates that the technique is likely to be effective in a wide range of rice agro-ecosystems. The positive reports from Malaysia (e.g. Lam and Mooi 1994), where it was first trialled, adds credence to this observation.

In Vietnam particularly, and Indonesia in 1995–96, the yield increases at the treatment sites appeared high given the relatively low number of rats caught. Given that rats weigh around 165–200 g and consume about 20–25% of their body weight per day, then an individual rat would take about 30 days to consume 1.5 kg of rice. Yet each rat represented a reduction in damage of around 3 kg per ha or 45 kg if the halo of protection to the surrounding crop extended to 15 ha. The number of rats caught during the TBS studies in Indonesia in the dry season in 1997, and in Vietnam in the summer season in 1997, provide more convincing cases for the realised increases in yield (Table 2).

Table 2.
Overview of when rats were caught in 'trap–barrier system (TBS) plus trap crop' in Indonesia during 1995–1997. Note the different sizes of TBS. See Singleton et al. 1998 for methods.

Size TBS(m)	Season	Replicate	Timing of rat captures			Total rats caught
			Tillering–Booting	Flowering–Heading	Harvest	
Site: West Java, Sukamandi						
2 500 m^2 (50 × 50)	Dry season 1995	1	63	82	40	185
		2	28	45	17	90
		Proportion of total rats				
			33.1%	46.2%	20.7%	
	Wet Season 1995/96	1	96	11	10	117
		2	42	4	9	55
		Proportion of total rats				
			80.2%	8.7%	11.1%	
200 m^2 (10 × 20)	Dry Season 1996	1	96	11	29	136
		2	16	27	26	69
		Proportion of total rats				
			54.6%	18.5%	26.8%	
	Wet Season 1996/97	1	15	6	7	28
		2	50	4	8	62
		Proportion of total rats				
			72.2%	11.1%	16.7%	
2 500 m^2 (50 × 50)	Dry Season 1997	1	75	514	117	706
		2	43	441	364	848
900 m^2 (30 × 30)		1	65	202	66	333
		2	11	86	54	151
400 m^2 (20 × 20)		1	46	248	108	402
		2	24	85	56	165
		Proportion of total rats				
			10.1%	60.5%	29.4%	

Singleton et al. (1998) proposed three factors that together may explain the apparent disparity between the number of rats caught and the resulting increase in yield on the treatment sites. Firstly, each rat is likely to have damaged many tillers during the generative stage, compounding the loss in yield. The earlier these rats are removed the greater the resulting increase in yield. Secondly, the removal of rats leads to substantially fewer females breeding in the vicinity of each TBS—an important consideration given that breeding commences during the maximum tillering stage, the average litter size is around 10 and the first litter is weaned prior to harvest. Thirdly, rats in live-capture traps provide an early visual cue to farmers to begin other rodent control activities, leading to more effective rodent control activities on the TBS plots relative to the control plots. Typically in West Java, farmers wait until there is obvious rat damage to the maturing crop before embarking on intensive rodent control activities.

Economics of a second generation TBS

Cost of a trap–barrier system for trapping rats in rice crops

The cost of the materials for a 25 × 25 m TBS with 10 cage traps (allowing for two replacement traps during a cropping season), and the labour costs required to construct a TBS, varies markedly between countries. In April 1998, the relative costs for materials were: Indonesia—US$44.75 but should last for four seasons, therefore the cost is US$11.40 (114,250 rupiah) per season; Malaysia—US$800, should last four seasons, therefore the cost is US$200 per season; Vietnam—US$80 (1,016 million dong), the traps last for minimum of two seasons but not the fence, so the average cost over two seasons is US$50. In Vietnam, this cost can be discounted because the used plastic is adapted for other purposes and the live rats are often sold to the local market for meat.

The traps are the most expensive items of a TBS. In Indonesia, they constitute about 60% of the cost. Traps also are easily removed. It is not uncommon for traps to disappear overnight, especially when the system is trialled for the first time in a district. Generally, however, peer group pressure at the village level quickly puts a stop to traps being stolen or 'borrowed'.

Staff at the Research Institute for Rice in Indonesia have been experimenting with ways of reducing the cost of traps. The most promising development is the recycling of 18–20 litre tins which previously held cooking oil or biscuits. They are about a quarter of the price of a standard cage trap, yet they catch about 90 rats for every 100 caught in a standard trap (Table 7). These recycled traps provide the added benefit of the possible development of a village-based industry for their manufacture.

Adoption rate of TBS+TC technology

The benefit–cost ratio of a TBS+TC varies from a gain of 20 times the initial investment in a TBS to a net cost when rat densities are low (Table 6). High benefit–cost ratios are only meaningful at the village level, because they only occur if there is a halo of protection extending 150 to 200 m from the TBS.

Table 3.
Overview of when rats were caught in 'trap–barrier system (TBS) plus trap crop' in Vietnam during 1997. Note the different sizes of TBS. Methods were based on Singleton et al. 1998.

Size TBS(m)	Season	Replicate	Timing of rat captures			Total rats caught
			Tillering–Booting	Flowering–Heading	Harvest	
Site: Red River Delta						
360 m^2	Spring 1997	Ha Bac	17	34	13	64
			Proportion of total rats			
			26.6%	53.1%	20.3%	
(12 × 30)	Summer 1997	Ha Bac	40	76	18	134
			29.9%	56.7%	13.4%	
(12 × 30)	Summer 1998	Vinh Phuc	119	54	16	189
			63.0%	28.5%	8.5%	
Site: Mekong Delta — Tra Vinh						
1 000 m^2 (30 × 30 m)	Summer –Autumn 1997	1 (Chien)	184	79	40	303
		2 (Cheng)	228	88	67	383
		3	148	154	21	323
		4	182	87	42	311
		5	151	127	34	312
			Proportion of total rats			
			54.7%	32.8%	12.5%	
	Autumn–Spring 1997	1 (Cheng)	72	67	46	185
		2	106	89	50	245
		3	118	81	62	261
		4	105	112	72	289
			Proportion of total rats			
			40.9%	35.6%	23.5%	
Site: Mekong Delta — Ho Chi Minh						
1 000 m^2	Winter–Spring 1997	1	482	355	196	1 033
		2	529	194	4	727
		3	551	266	5	822
			Proportion of total rats			
			60.5%	31.6%	7.9%	

Table 4.
Effect of the trap–barrier system (TBS) plus trap crop on rice yields (kg/ha) at various distances from the TBS, in Indonesia. These estimates were based on the weight (water content approximately 14%) of unhulled rice harvested from 10 m^2 quadrats (Repl = replicate; nth = sample from north of TBS; sth = sample from south of TBS; se = standard error of mean yield estimates for the control plots).

Site: West Java			Rice yield (kg/ha)					Control	
			5 m	50 m	100 m	150 m	200 m	Mean	se
Dry Season 1995									
	Replicate 1			5 600	4 750	3 500	4 750	2 313	98.7
	Replicate 2			5 600	3 900	3 650	4 100	4 638	74.7
		Mean		5 600	4 325	3 575	4 425	3 475	
	Yield relative	to control (%)		+61%	+24%	+3%	+27%		
Wet Season 1995/96									
	Repl 1 nth		6 230	5 930	5 760	5 860	5 660	5 736	37.6
	Repl 1 sth		5 990	6 070	5 920	5 690	5 560	5 498	44.5
	Repl 2 nth		6 630	5 620	5 560	5 490	5 780	4 736	48.9
	Repl 2 sth		6 250	5 590	5 670	5 430	5 670	5 210	48.5
		Mean	6 275	5 803	5 728	5 618	5 668	5 295	88.0
	Yield relative	to control (%)	+19%	+10%	+8%	+6%	+7%		
Dry Season 1996									
	Repl 1 nth		4 608	4 536	4 549	4 501	4 604	4 768	32.8
	Repl 1 sth		4 495	4 593	4 576	4 575	4 539	4 705	25.4
	Repl 2 nth		4 525	4 501	4 593	4 437	4 510	4 646	28.7
	Repl 2 sth		4 600	4 694	4 558	4 605	4 549	4 667	48.0
		Mean	4 557	4 581	4 569	4 529	4 550	4 697	19.2
	Yield relative	to control (%)	–3%	–2%	–3%	–3%	–3%		
Wet Season 1996/97									
	Repl 1 nth		7 312	7 166	7 317	7 165	7 316	7 087	12.9
	Repl 1 sth		7 301	7 201	7 112	7 135	7 165	7 148	52.5
	Repl 2 nth		6 627	6 615	6 634	6 580	6 761	7 317	35.9
	Repl 2 sth		6 580	6 782	6 622	6 611	6 639	7 273	38.4
		Mean	6 955	6 941	6 921	6 873	6 970	7 206	27.4
	Yield relative	to control (%)	–3%	–3%	–4%	–5%	–3%		
Dry Season 1997 (50 × 50 m only)									
	Repl 1 nth		5200	5400	5800	5400	5300	4100	114.0
	Repl 1 sth		5000	5000	4900	4900	5000	4000	70.7
	Repl 2 nth		4800	4700	4500	4600	4400	3920	58.3
	Repl 2 sth		4300	4200	4200	4300	4350	3980	86.0
		Mean	4825	4825	4850	4800	4762	4000	41.7
	Yield relative	to control (%)	+21%	+21%	+21%	+20%	+19%		

Table 5.
Effect of the trap–barrier system (TBS) plus trap crop on rice yields (kg/ha) at various distances from the TBS, in Vietnam. These estimates were based on the weight (water content approximately 14%) of unhulled rice harvested from 10 m^2 quadrats (se = standard error of mean yield estimates for the control plots).

		Mean Rice yield (kg/ha)[a]					Control	
		5 m	50 m	100 m	150 m	200 m	Mean	se
Site: Red River Delta								
Spring 1997	Yield relative to control (%)		5269 +8%	5236 +7%		5028 +3%	4886	
Summer 1997	Yield relative to control (%)		3941 +9%	3888 +8%		3736 +4%	3605	
Site: Mekong Delta								
Summer–Autumn 1997	Site 1 (Chien) Yield relative to control (%)	3100 +10%	3200 +14%	3000 +6%	3200 +14%	2700 –4%	2817	
	Site 2 (Cheng) Yield relative to control (%)	3200 +14%	3200 +14%	3150 +12%	3000 +6%	3600 +28%	2817	
Winter–Spring 1997/98	(Cheng) Yield relative to control (%)	4960 +17%	4640 +9%	4410 +4%	4660 +9%	4520 +6%	4256	43.9

[a] The mean rice yields for each distance from the TBS were from two measurements, except in winter–spring 1997/98 when there were six measurements.

Table 6.
The effect of a trap–barrier system (TBS) plus trap crop on mean yield increases up to 200 m from the TBS and the associated benefit–cost ratios, in the Red River and Mekong River Deltas, Vietnam, and West Java, Indonesia. Costs were calculated from material costs of the TBS and labour costs associated with building the fence and the daily clearing of rats from traps. Benefits were based simply on the increase in yield relative to an untreated site. The dimensions of the respective TBS, the rat density during the growing season and the timing of rat damage to tillers, provides context for the variation in benefit–cost ratios.

Year and season	Dimensions of TBS	Rat density	Timing of main tiller damage	Mean yield increase (t/ha)	Benefit–cost ratio
Vietnam					
Red River Delta					
Spring 1997	12 × 30 m	Low	Flowering to harvest	0.3	
Summer 1997	12 × 30 m	Low	Flowering to harvest	0.3	
Mekong River Delta					
Summer 1997	33 × 33 m				
Site 1		Medium	No data	0.2	
Site 2		Medium	No data	0.4	
Winter 1997	33 × 33 m	Low/Med	Throughout	0.4	2.5:1

Table 6. (Cont'd)
The effect of a trap–barrier system (TBS) plus trap crop on mean yield increases up to 200 m from the TBS and the associated benefit–cost ratios, in the Red River and Mekong River Deltas, Vietnam, and West Java, Indonesia. Costs were calculated from material costs of the TBS and labour costs associated with building the fence and the daily clearing of rats from traps. Benefits were based simply on the increase in yield relative to an untreated site. The dimensions of the respective TBS, the rat density during the growing season and the timing of rat damage to tillers, provides context for the variation in benefit–cost ratios.

Year and season	Dimensions of TBS	Rat density	Timing of main tiller damage	Mean yield increase (t/ha)	Benefit–cost ratio
INDONESIA					
West Java					
1995 Dry	50 × 50 m	Very high	After booting	1.0	20:1
1995/96 Wet	50 × 50 m	Low	Maximum tillering	0.5	7:1
1996 Dry	20 × 10 m	Medium	Transplanting and tillering	–0.1	Net cost
1996/97 Wet	20 × 10 m	Low	Low damage	–0.2	Net cost
1997 Dry	50 × 50 m	Med/high	Maximum tillering to harvest (all crops)	0.8	11:1
	30 × 30 m			0.5	7:1
	20 × 20 m			0.9	13:1

Table 7.
Comparison of the efficacy of different trap designs in a trap–barrier system (TBS). See Singleton et al. (1998) for description of the 'standard trap'. Trap designs II to IV are modifications of a recycled 18 litre tin of vegetable oil (350 × 230 × 230 mm). The comparison was conducted in rice crops at Sukamandi, West Java, during the 1998 dry season. The rice crops were two weeks old and the traps were set for three weeks (May 18—June 3). There were three sample plots spaced 500 m apart. Each TBS was 50 × 100 m with eight traps per plot. One of each trap type was placed in random order along the two 100 m sides of the TBS (SE = standard error).

Trap type	Replicate	Rats captured	Total	Mean	SE	Cost (Rupiah)
I (standard trap)	1	51	317	105.7	40.18	30 000
	2	184				
	3	82				
II (wire mesh back)	1	22	193	64.3	25.46	6 000
	2	110				
	3	61				
III (wire mesh front and back)	1	50	277	92.3	32.41	8 000
	2	156				
	3	71				
IV (entrance only wire mesh)	1	24	69	23.0	7.81	4 000
	2	36				
	3	9				

In developing countries in Asia, this is well beyond the area of crop owned by an individual family. However, the results have been sufficiently promising to have the governments of both Indonesia and Vietnam express strong support for the implementation and adoption of this simple technology. For example, in the Mekong River Delta the concept of a TBS+TC was only first tested in early 1997, yet by May 1998 there were more than 100 TBSs established in five provinces. In Indonesia, the field trials on the TBS were initially conducted on a research farm (440 ha) and then on a commercial seed farm (1,000 ha with farmers share-farming areas of up to 5 ha). Following our trials, large TBS+TC (50 × 50 m or 100 × 100 m) were established and both institutions have been pleased with the returns for their outlay. At the research farm there was just one TBS+TC in 1996/97 and it caught over 26,500 rats. The next year there were three TBS+TCs and over 48,000 rats were caught. In 1998, all the plant variety trials on the research farm were conducted within a TBS, and there were more than five other large TBS+TCs.

In Malaysia, the country of its origin, the TBS is generally only used in areas that have acute rat problems (e.g. previously abandoned fields or asynchrony of cropping at borders of districts with different irrigation schedules) or high value crops (e.g. research farms).

When to use a TBS+TC?

Effective and efficient pest control strategies generally have a monitoring protocol that determines whether particular control actions need to be implemented. These protocols are based on preventing a pest population from reaching a density above which they cause unacceptable economic hardship to growers. This is referred to as the economic injury level (EIL). To prevent a species reaching its EIL, a lower population threshold is identified at which appropriate control actions are implemented.

This threshold level is relatively easy to define for actions that have a rapid impact on the pest population, such as the use of chemical rodenticides (Buckle 1988). This is not the case for the use of a TBS+TC. In this situation, the decision point is at land preparation, to enable the trap crop to be planted three weeks in advance of the main crop. By comparison, the decision of whether to use chemical rodenticides is made just before maximum tillering of the rice crop (around day 40–45 post transplanting).

An informed decision of whether or not to use a TBS+TC requires a population model that enables reasonable accurate forecasts of rodent population densities for the forthcoming cropping season. These models have been developed for some regions for mouse plague management in Australia (see Pech et al., Chapter 4), however such models in Southeast Asia are lacking, underlining the need for sound ecological studies of the principal rodent pest species in rice farming systems. Effective decision analysis on the use of TBS+TC therefore relies on the development of an ecologically-based management system for rodent pests.

Weaknesses of the TBS+TC

In weighing up the potential of the TBS+TC, an economic benefit–cost analysis is one of a number of considerations. Others include the following (see Box 2).

Whether these points are minor or major will depend on the socioeconomic context of the end-users and on the effectiveness and thoroughness of the extension campaign. Moreover, governments have shown through the implementation of bounty systems that they are prepared to invest in management of rodent pests. This raises the possibility of government subsidies for the TBS+TC at village or regional levels. Subsidising the cost of the materials for a TBS+TC would be much cheaper than funding a bounty system and grain production is likely also to be higher under a TBS+TC pest management system.

The exciting potential of the TBS+TC acting as a platform for an integrated strategy for managing rodent pests, and therefore lessening the reliance on chemical rodenticides, provides governments with another option for investing funds into rodent management.

Moving to village-level management

The impressive cost–benefit ratio for the TBC+TC needs to be viewed in the context that these were experimental studies. The challenge is to transfer this technology readily and effectively to rice farmers. An important consideration is the average size of family holdings in Southeast Asia, which is 0.5 to 1.5 ha. A TBS which encloses 0.25 ha could provide protection to neighbouring farmers without them outlaying money for materials, providing the labour required to maintain the TBS or taking the concomitant risks associated with planting an early trap crop. Therefore the TD will be most effective if it is part of a community-based approach to rodent pest management.

Box 2.
Economic benefit–cost analysis

- High initial cost—many farming families in Southeast Asia do not have the disposable income to invest in pest management methods.
- High labour involvement—the traps need to be checked every day, although stoppers (e.g. clump of straw) can be placed in the opening of the traps on days when no labour is available.
- Strong vigilance on maintenance—the fence needs to be checked daily for evidence of rats going through or under the fence; weed growth needs to be controlled near the fence.
- Early trap crop attracts avian and insect pests—this needs to be factored into a benefit–cost analysis.
- Mechanics of growing an early crop—the main difficulty is the availability of sufficient water three weeks in advance of the general irrigation schedule to maintain firstly a rice nursery and then the transplanted trap crop. An earlier maturing variety of rice may help overcome this problem.
- Non-target captures—amphibians and reptiles are caught in the traps. The experimental protocol requires these species be released. Whether farmers would release all of these species is problematical.
- Humaneness—protocols have been developed (see Singleton et al. 1998) which include the use of carbon monoxide from the exhaust of motor cycles or automobiles for killing rats. The adoption of recommended methods will depend on the operator but he/she should be encouraged to kill the rats humanely.
- Environmental contamination—proper disposal and recycling of the plastic fences are required.

We have determined the ideal size range for a TBS for farmers (G.R. Singleton and Sudarmaji, unpublished data), but not the optimum spatial distribution of these in the landscape. Although there was much variation between seasons in the extent of the halo of protection provided to crops by a TBS+TC, we recommend that a 25 × 25 m TBS would significantly reduce rat damage in the surrounding 10–20 ha of rice crop. Therefore, at a village level we suggest that one TBS+TC would be sufficient for every 15 ha of rice crop. This recommendation has not been tested.

The spatial distribution of physical methods for controlling rat numbers is an important issue given the ability rats have to re-colonise areas where their densities have been reduced. In rice fields, rats move hundreds of metres in a night, especially once the developing crop reaches the booting stage (Singleton et al. 1994; P. Brown, pers. comm.). To reduce this ability of rats to compensate for control activities, management needs to be approached initially at the village level and then at the district level. A good extension program with strong grower participation is fundamental for a community-based control campaign to be successful (FAO 1997).

At the village level, the spatial distribution and number of TBS sites will not simply be determined by the area of land under rice production. Important considerations will be how rat populations respond to:

- the heterogeneity of the habitat (the seasonal dynamics in habitats where rats can take safe refuge and/or breed);
- the degree of asynchronous planting of rice crops; and
- the variety of other crops grown in the area.

This information requires detailed population ecology and behavioural studies of *Rattus argentiventer* and good documentation of farming practices. There are some data available on points (i) and (ii). For instance, banks along the margins of rice fields and the banks of the major irrigation canals provide important habitats for rats to take refuge in during non-breeding seasons, and for rats to nest and breed in after the crop reaches the maximum tillering stage (see Leung et al., Chapter 14). Also, the breeding season of *R. argentiventer* is linked to the reproductive stage of the rice crop (Lam 1983; Murakami et al. 1990). Therefore, asynchronous planting of neighbouring crops will extend the breeding season of rats. Although we require more detailed knowledge of the population ecology and biology of *R. argentiventer*, what we already know has had an important influence on the development of management strategies for this species. Our efforts to manage this species would be considerably strengthened if we had a better understanding of the processes that influenced whether a rat did or did not enter a trap of a TBS. Towards this end, we need to develop a better awareness of the behavioural responses of rats to a TBS+TC and of the factors that may influence this response.

Concluding Remarks

In closing, the biggest hurdle facing the successful use of physical methods for managing rodent pests is the ability of rodent populations to compensate for reductions in population size through immigration, increased survival and/or better breeding performance. The early studies of Davis (1953) clearly demonstrated the ability of rat populations to recover to original levels following poisoning operations. Similarly, H. Leirs (pers. comm.) has shown that a 50% reduction in a *Mastomys natalensis* population, through the use of chemical rodenticides, has little impact on the yield loss of crops. However, sustained harvesting of rats from a population can lead to the collapse of that population, presumably because of a decline in the age structure of the breeding population (Davis and Christian 1958). Together, these studies indicate that one-off uses of physical control, especially when rodent densities are high, may have little to no impact on rat populations. In contrast, sustained use of physical control methods over an appropriate spatial scale may be both cost effective and environmentally sustainable.

Two methods which warrant further study are the use of TBS+TC and the targeting of bounty seasons at appropriate times of the year. The timing of the latter needs to be dictated by our understanding of the population biology of the rat rather than the phenology of the crop. For both methods, success will revolve around coordinated, synchronised actions at a village or district level and their ability to be adopted as part of an integrated approach to rodent management (see Singleton 1997; Leung et al., Chapter 14, for discussion of other actions).

How the use of physical barriers plus traps has evolved in our endeavours to manage the rice-field rat highlights the imperative of having sound ecological studies in progress before embarking on broad scale management programs of a rodent pest (Leirs et al. 1996; Singleton 1997). Further population studies of rodent pests are planned for Indonesia, Vietnam and Lao PDR, and they will complement our progress towards optimising the use of trap barrier systems and trap crops.

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