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An experimental field study to evaluate a trap-barrier system and fumigation for controlling the rice field rat, *Rattus argentiventer*, in rice crops in West Java

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The effectiveness of a trap-barrier system (TBS), which enclosed a crop planted 2–3 weeks early (trap-crop), and fumigation (sulfur dioxide) was assessed for managing pre-harvest damage by the rice field rat, *Rattus argentiventer*, to rice crops in West Java, Indonesia. The TBS was a 50 × 50 m plastic fence with live-multiple-capture traps inserted intermittently at its base. Damage to tillers and yield loss were assessed within the trap-crop and at 5, 50, 100, 150 and 200 m from the TBS. Two crops were monitored: dry season crop when rat densities were high and 20–55% of rice tillers were cut by rats; wet season crop when rat densities were low and 0–4% of rice tillers were cut. Over the two crops, rats caused a 20% annual loss in potential rice production. The benefit-cost ratios for using a TBS were in the range of 20:1 to 7:1 for the dry season and 7:1 to 2:1 for the wet season. Fumigation was not effective in reducing rat losses. Damage assessment provided a phenology of rat damage for the two crops but, unlike the yield data, differences were not significant between treatments. The benefits of the TBS need to be weighed against high labour input, initial cost, logistics of growing a trap-crop, and whether the technology can be transferred to growers. Research on how rats respond to a TBS-plus-trap-crop is required before it can be recommended to manage rats.

Keywords: rodent control; Indonesia; economics; physical control; fumigation

Rodents are a major pre-harvest pest in Southeast Asia (see Singleton and Petch, 1994 for review). The most common rodent pest in rice fields is the rice field rat, *Rattus argentiventer*, which, in Indonesia, is the single most important pre-harvest pest to rice crops, causing annual losses of around 17% (Geddes, 1992). These losses occur despite a reasonable knowledge of the general field biology of *R. argentiventer* (Lam, 1983) and the potential to control this species using various rodenticides (Wood, 1971; Buckle *et al.*, 1984; Lam, 1990).

A promising method of rodent control is the use of a physical barrier (made from plastic sheeting; recycled metal sheeting, etc.) with live-multiple-capture traps inserted intermittently at its base. This trap-barrier system (TBS) was developed in Malaysia to control populations of *R. argentiventer* in rice crops (Lam, 1988). Briefly, a rectangular TBS is erected around the crop to be protected or a linear TBS is erected between an area that contains high rat densities (e.g. abandoned fields and early planted crops) and the crop to be protected. The TBS works on the principle that after rats make contact with the barrier, they take the line of least resistance by following it along until they come to the opening of a trap which they then enter. To protect a crop, the TBS needs to be erected soon after transplanting and maintained until harvest.

In Malaysia, the TBS approach first found favour with farmers who had acute rat problems or were trying to reclaim abandoned rice fields. Under such circumstances, as many as 6872 rats were caught in one night and 44,101 rats in 9 weeks (Lam *et al.*, 1990). These are extreme cases where the subsequent reduction in rat damage to crops, more than compensated for the monetary outlay for the TBS, daily checking of traps and maintenance of the fence. Subsequent studies in the Philippines and Malaysia

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indicate that rats need to be causing crop losses of > 30% for the method to be cost-effective (Singleton *et al.*, 1994; Lam Yuet Ming, pers. commun.). Although it is not uncommon for rats to cause > 30% loss to rice crops, damage by rats is typically patchy, and generally there is insufficient knowledge to be able to predict which fields are likely to be badly damaged by rats in a particular season. Coupled with the fact that most growers in Southeast Asia have little disposable income, the benefits would need to be substantially better than a break-even point at 30% loss for the TBS to be widely adopted for rodent control.

The current study examines the efficacy of a new method that may be cost effective in West Java, a region that typically has crop losses attributed to rats of 17% (Singleton and Petch, 1994). The approach is based on a suggestion by Lam (1988) that the rice crop within the TBS could provide an effective lure for rats if it was at a different, but more attractive, stage than the surrounding crop. The rice crop within the TBS would be acting as a 'trap-crop' for rats.

The simple concept of the TBS has led to its use in many shapes and forms in Southeast Asia. Out of desperation to manage their rat problem, many farmers have used a TBS, but the success rate has not been high. This reflects not only a poor extension of the technology, but also a paucity of well-designed field trials for testing efficacy. There have been various claims that the efficacy of a TBS was enhanced with a trap-crop containing an earlier stage of rice, a later stage of rice, an aromatic variety of rice, or seedlings of rice planted on a 2-week rotation. Unfortunately, none of these studies had sufficient controls, replication, scale, or economic assessment for a quantitative appraisal of the respective claims (Singleton, 1997).

This paper reports on a large scale field study, with appropriate controls and two replicates of each treatment, which assesses the economic effectiveness of an early trap-crop (planted 2–3 weeks prior to the surrounding rice crops) in association with a TBS, for managing pre-harvest damage by *R. argentiventer* to rice crops in West Java. The study was conducted over 10 months. This region has two crops per year; a wet season crop followed closely by a dry season crop, then a fallow period of 3 months before the next wet season crop. Given this timing of cropping and that breeding of *R. argentiventer* is linked to the crop cycle resulting in two breeding seasons per year (Lam, 1983; Murakami *et al.*, 1990), then generally there are more rats in the fields during the dry than the wet season crop. We therefore predict seasonal differences in the efficacy of the TBS-plus-trap-crop; the benefit–cost ratio is expected to be higher during the dry season.

In this study, rat damage and yield losses were assessed to a distance of 200 m from a TBS because rats can move hundreds of metres in a night, especially once the crop reaches the booting stage (Singleton *et al.*, 1994; unpublished data).

The study also assessed the effectiveness of sulfur dioxide gas for fumigating rat burrows. Fumigation is extensively used by growers to manage rat populations in this region, but there is no published information on its effectiveness.

Materials and methods

Study site

The study was conducted at the Research Institute for Rice (RIR), Sukamandi, West Java, Indonesia (6°20′S, 107°39′E) between April 1995 and February 1996. The RIR has 440 ha of rice crops grown in a plain 15 m above sea level. The region has a dry (May to October) and wet (November to April) season; > 75% of the rainfall occurs during the wet season. The average annual rainfall (1986–1996) is 1448 mm. There are two rice crops grown per year. In 1995, the dry season crop was transplanted in mid-April and harvested in mid-July; the wet season crop was transplanted in mid-October and harvested in mid-February 1996. From 1 April to 31 July 1995, rainfall was 301 mm (83% of the 1986–1996 average for that period). From 1 October 1995 to 29 February 1996, rainfall was 1093 mm (128% of the 1986–1996 average for that period).

The rice crops (variety IR64) were flood-irrigated and sown by transplanting 3-week old rice seedlings at a rate of 16 hills per m^2. For this study, TBS refers to a rectangular trap-barrier system that encloses a trap-crop (variety IR64) transplanted 15 and 21 days prior to the surrounding crops for the dry and wet seasons, respectively. At sites without a TBS, similar areas of trap-crop were planted at the same time, but they were not fenced. The TBS were dismantled 97 and 102 days after the respective dry and wet season crops had been transplanted.

The growth stages of rice referred to in this paper are based on those used by Reissig *et al.* (1986) for a 120-day variety of rice. The stages are: seedling (days 1–20); tillering (days 20–40); maximum tillering (days 40–50); panicle initiation (days 50–60); booting (days 60–70); flowering (days 70–80); milky ripe grain (days 80–90); ripening (days 90–120). These stages combine into three general growth phases: vegetative (days 0–55); reproductive (days 55–90) and ripening (days 90–120).

Trap barrier system and fumigation

Each TBS enclosed an area of 50 × 50 m and consisted of 0.7 m wide plastic supported by bamboo poles (1.2 m) spaced 1 m apart and interconnected by string. The bottom 50–100 mm of the fence was buried. A live-multiple-capture cage trap (600 × 240 × 240 mm) was placed every 25 m ($n = 8$ per TBS), flush with, and opening to a hole in the fence. The rats enter a wire cone (240 mm long, 100 mm diameter at the base, tapering to 50 mm with the ends of the wire facing inwards), squeeze through the wire ends and then cannot return. The traps are made from open wire mesh (12 × 12 mm, 1-mm gauge). Because the crops were flood-irrigated (maximum water depth of approximately 200 mm), at each opening of a trap, there was a mound of earth protruding above the water level to facilitate access by rats, and each trap was mounted on a bamboo platform raised 100–200 mm above the water level. Straw was placed on the top of each trap to provide shade.

The traps were checked daily prior to 1100 h. Rats were killed using carbon monoxide from the exhaust of motor cycles or were drowned. The former appears to be more humane and was the recommended method. Each rat was weighed (± 2 g), sexed and examined for breeding condition.

There are three sizes of levee banks (= bunds) in the study area. The largest two are banks of primary and secondary irrigation channels; the smallest banks separate individual rice crops (= paddi). The latter are too small for rats to use as burrows. The fumigation treatment consisted of fumigating rat burrows along the larger banks near the perimeter of a 5-ha area (100×500 m). The respective trap crops were near the centre of this 5-ha area (*Figure 1*). Fumigation was conducted by burning sulphur granules (15 g of sulphur to 200 g of straw) to generate sulphur dioxide gas. The gas was delivered by a hand-operated fumigator which forced air (1 min per burrow) over smouldering straw containing the granules. Fumigation was conducted every 1–2 weeks after the rice crop was at maximum tillering stage. This is when farmers generally begin their fumigation activities.

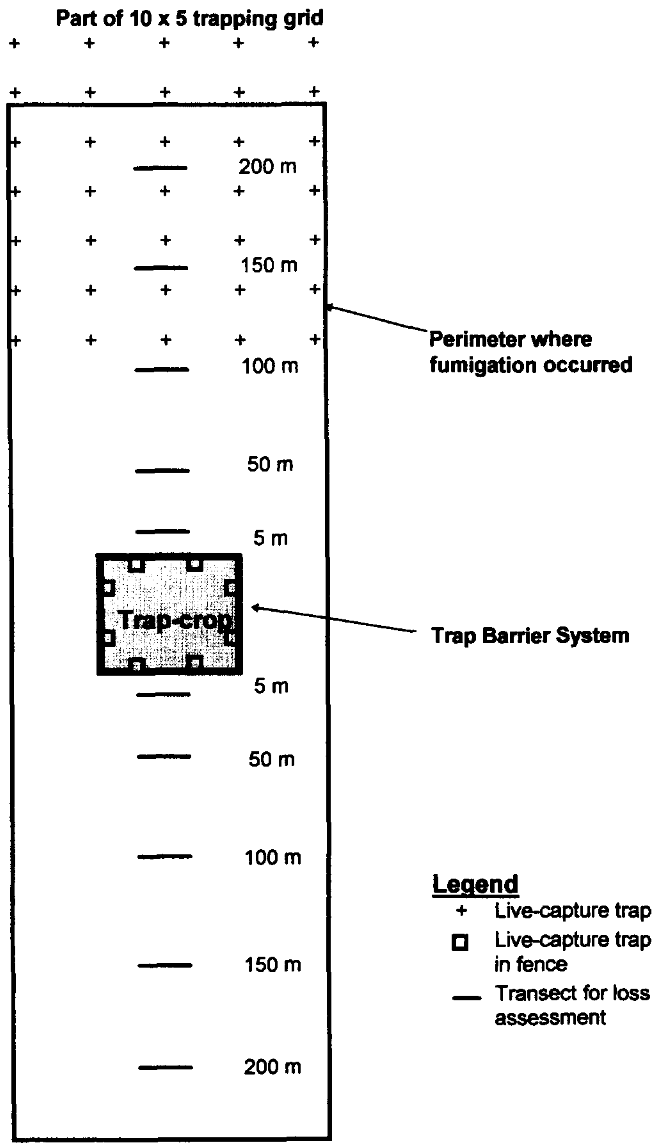

Figure 1. Layout of a TBS, trap-crop, transects for damage assessment, and live-trapping grids at the Research Institute for Rice, Sukamandi. Note that in the dry season, there was no transect 5 m from the TBS.

Experimental design

During both the dry and wet season, there were four treatments with two replicates per treatment: TBS with fumigation of rat burrows; TBS with no fumigation; fumigation only; no imposed method of rat control. Farmers occasionally conducted rodent control at each of the sites; they were encouraged to follow their normal control practices.

The treatments were randomly assigned to one of eight blocks of rice, each measuring approximately 200×500 m. The blocks were a minimum of 500 m apart. The TBS trap-crop was situated in paddies near the middle of a block. Rats were not expected to be within a trap crop when the barrier was erected because of the high level of disturbance during crop preparation.

Assessment of crop damage

Assessment of crop damage was conducted at the unit of a hill — a group of adjoining seedlings planted in a clump. During the dry season, fresh rat damage was assessed along five parallel transects to the north and south of each trap-crop, every 2 weeks (10 transects per trap-crop). These were within the trap-crop (0 m) and 50, 100, 150 and 200 m from the trap-crop. Each transect was 11.2 m wide. Every fifth hill ($n = 10$) along each transect was assessed for total number of tillers and number freshly cut by rats. During the week prior to harvest, yields were assessed from the weight (14% moisture content) of unhulled rice reaped from 2.5×4 m quadrats taken at transects on one side only of each trap-crop (*Figure 1*).

During the wet season, damage was assessed also at 5 m from each trap-crop, and yields were estimated from quadrats taken on both sides (north and south) of each trap-crop. In addition, because rat damage was generally patchy and there were few cut tillers during the wet season, yields of individual farmers (each farmed 1 ha) were compared to those obtained on the closest 2.5×4 m quadrats (*Figure 1*).

Dynamics of rat populations

In the dry season, live-capture traps were set 25 m apart in a 10×5 grid to the south of each trap crop for four consecutive nights every 3 weeks. The closest line of traps was 150–200 m from each TBS (*Figure 1*). The traps were similar to those used with the barrier and were baited with freshly roasted crab. At first capture, rats were ear-tagged, sexed and weighed. Rats recaught in a session simply had their tag number recorded. All rats were released at site of capture. This trapping was not repeated in the wet season because too few rats were caught.

Analyses

The effects of the various treatments on rat damage were analysed using a split-plot analysis of variance and generalised linear modelling (GENSTAT — Rothamstead Experimental Station). Each period was analysed separately because each time of sampling represented a different stage of crop development. If time was included, interaction effects could complicate the interpretation of the data.

Results

In both seasons, there were no rats within the TBS at the commencement of the study based on the absence of cut tillers and rat tracks.

Dry season

There were 506 rats caught in the four TBS. Rats were caught throughout the growing cycle of the rice crop. However, 40% ($n = 202$) of captures occurred over 2 weeks, when the trap-crop was at the booting stage (*Table 1*).

Only seven rats were caught from 6400 trap nights on the grids adjacent to the eight trap-crops. This result highlights the importance of a barrier to direct *R. argentiventer* into traps.

Fumigation of neighbouring banks had little effect on the number of rats caught, except during the booting stage when there were significantly more rats caught ($\chi^2 = 13.4$, $P<0.001$, df = 1) on the two sites where fumigation was not conducted (> 40% increase) (*Table 1*). Although there were consistently more females than male rats caught in the traps, this difference was only significant at the booting stage ($\chi^2 = 27.1$, $P<0.001$, df = 1) when the ratio of males to females was 1:2.1.

Rats caused substantial damage to the dry season crop from the maximum tillering stage on the control sites and from the booting stage on the TBS sites. Although the rice plants compensated for some of the damage by rats up to the booting stage by growing additional tillers, the percentage of damaged tillers just prior to harvest was generally in the range of 20–55% (*Figure 2*a and b).

There was significantly higher damage to tillers within the trap-crop than elsewhere (split-plot ANOVA, $F_{4,47} = 4.82$, $P = 0.002$). However, there were no significant between-treatment effects because the damage to the trap-crops within the TBS sites was similar to that of the unfenced plots (*Figure 2*a and b). This is consistent with observations that rats had burrowed under the fences at various times. When the analysis was restricted to damage by rats outside the trap-crops, differences were not significant for treatment or distance effects (*Table 2*). During ripening of the crop, the mean level of tillers damaged by rats was lowest on the TBS-plus-fumigation sites (6.7%), followed by the control sites (25.0%), TBS sites (30.0%) and fumigation sites (51.9%). The control plots, however, had few tillers remaining following high damage during the tillering and booting stages (*Figure 2*b). During ripening, the variation in mean damage estimates between replicates was high, indicating that rat damage was patchy (*Table 3*).

When the treatment and distance effects were analysed at the different stages of crop development, rat damage to tillers was significantly lower from the booting stage onwards on the TBS-plus-fumigation sites. These differences were maintained through to 200 m from the trap-crop (*Figure 2*c).

The TBS sites had significantly higher crop yields than the other sites (*Table 2*), and the yields were significantly higher in surrounding crops than in the trap-crops (*Tables 2* and *4*). Fumigation had no substantial effect on crop yields. When the analysis was restricted to crop yields outside the trap-crops, the TBS effect remained significant ($F_{1,4} = 7.80$, $P<0.05$), but distance did not ($F_{3,12} = 1.87$, $P = 0.19$). Together, these results indicate that a TBS protected the surrounding crop for a minimum radius of 200 m (*Tables 4* and *5*). At each distance, the TBS sites had mean increases in yield ranging from 50 to 85% (*Table 5*).

Fumigation led to a slight decrease in yield (*Table 5*).

Table 1. The number of male and female rats captured in the two trap barrier systems with, and the two without, fumigation of neighbouring banks during the different crop stages of the 1995 dry season and 1995/1996 wet season rice crops at Sukamandi

		Dry season				Wet season			
		TBS		TBS+Fum		TBS		TBS+Fum	
Stage of trap-crop	Rep	Nm	Nf	Nm	Nf	Nm	Nf	Nm	Nf
Tillering	1	16	25	12	10	54	32	16	5
(0–35 days)	2	4	0	16	13	29	9	21	10
Maximum tillering	1	7	15	9	12	8	2	1	2
(35–50 days)	2	13	11	9	16	2	2	2	2
Booting	1	26	56	9	26	9	2	0	0
(51–65 days)	2	17	28	12	28	2	2	2	0
Heading and Ripening	1	22	18	14	18	2	8	22	8
(65–100 days)	2	9	8	9	18	4	5	27	16
Totals		114	161	90	141	110	62	91	43

Rep: replicate; TBS: trap barrier system; Fum: fumigation; Nm: number of male rats; Nf: number of female rats.

Wet season

There were 306 rats caught in the four TBS. Most of the rats (88%) were caught early (tillering stage — 58% of rats) or late (ripening stage — 30% of rats) in the cropping season (*Table 1*).

Fumigation of neighbouring banks did not reduce the number of rats caught. Indeed, there were significantly more rats caught on the fumigation sites during the ripening stage of the crop ($\chi^2 = 31.7$, $P < 0.001$, df = 1) than where fumigation was not conducted. Contrary to the dry season, there were consistently more males than females caught in the traps, this difference was only significant at the tillering stage ($\chi^2 = 23.3$, $P < 0.001$, df = 1) when the ratio of males to females was 2.1:1.

Rats caused little damage to the wet season crop. The percentage of damaged tillers just prior to harvest was generally in the range of 0 to 4% (*Figure 3*a and b). These data were not analysed further because of the low damage levels.

The TBS sites had significantly higher crop yields than the other sites (ANOVA, $F_{3,4} = 6.81$, $P < 0.05$), and the yields were significantly higher in surrounding crops than in the trap-crops ($F_{5,60} = 21.05$, $P < 0.001$, *Table 4*). There was also a significant treatment-by-distance interaction effect ($F_{15,60} = 10.09$, $P < 0.001$). Fumigation had no substantial effect on crop yields (*Table 5*). When the analysis was restricted to crop yields outside the trap-crops, the TBS effect ($F_{1,4} = 10.12$, $P < 0.05$), distance effect ($F_{4,12} = 9.01$, $P < 0.001$) and treatment-by-distance interaction remained significant ($F_{12,48} = 3.68$, $P < 0.001$). The interaction effect was significant only when the yields at 5 m were included. Together, these results indicate that the TBS sites protected the surrounding crops but that the level of protection was significantly higher at 5 m than further from the TBS (*Tables 4* and *5*).

There was a significant correlation between the yields estimated from 10-m^2 quadrats and those obtained by farmers from 1-ha plots ($r = 0.90$, $n = 48$, $P < 0.001$).

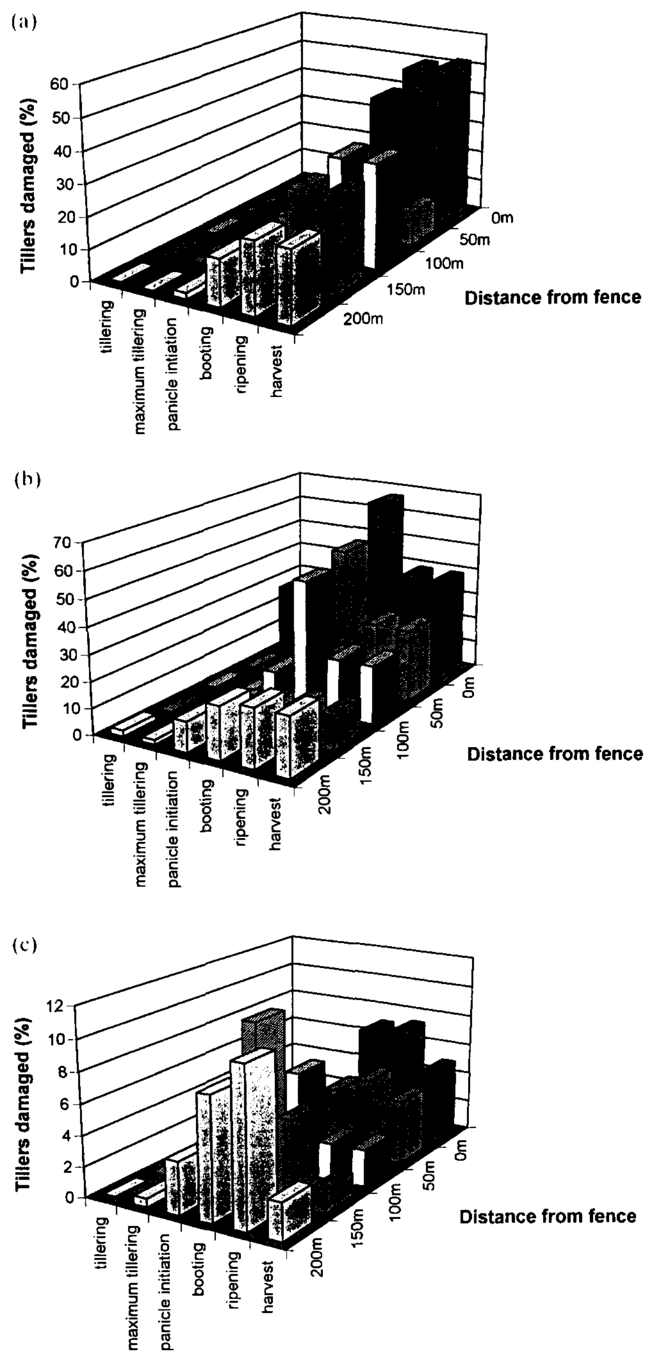

Figure 2. Mean percentage of rat damage to rice tillers during the dry season at different stages of crop development within a trap-barrier system (0 m) and 50, 100, 150 and 200 m from the barrier. (a) TBS sites, (b) control sites (no treatment) and (c) TBS plus fumigation sites. Note difference in scales used between (a), (b) and (c).

Table 2. Split-plot analyses of variance of tillers of rice damaged by rats (%) and of crop yields (kg/ha) during the dry season (analyses do not include data collected from within the trap-crops)

Factor	df	Sum of squares	Variance ratio	F-value
Damaged tillers (%)				
Site stratum				
Treatments	3	14311	0.76	0.571
Residual	4	25014	73.72	
Site × direction stratum	8	679	0.38	
Distance	3	1496	2.23	0.102
Treatment × distance	9	3220	1.60	0.154
Residual	35	7841		
Total	62	52265		
Yield (kg/ha)				
Site stratum				
TBS	1	3.99×10^7	14.78	0.018
Fumigation	1	5.78×10^5	0.21	0.668
TBS × fumigation	1	3.83×10^6	1.42	0.299
Residual	4	1.08×10^7	8.37	
Site × distance stratum				
Distance	4	4.05×10^7	31.40	<0.001
TBS × distance	4	2.51×10^6	1.95	0.152
Fumigate × distance	4	1.37×10^6	1.06	0.409
TBS × fumigate × distance	4	3.02×10^6	2.34	0.100
Residual	16	5.16×10^6		
Total	39	1.08×10^8		

Benefit–cost analyses

The cost for materials [new plastic, bamboo sticks, string, staples, traps (including two spares)] and installation of each TBS was Rp245,000 (≈US$105).

Each day it took on average 1 hr to maintain the TBS and process rats. If a fence was in place for

Table 3. Fresh damage to rice tillers by rats (%) during the ripening stage of the dry season crop

Direction and replicate	Distance from TBS (m)	Tillers damaged by rats (%)			
		Treatment			
		TBS only	TBS+Fum	Fum only	Control
South 1	0	0.6	12.8	37.2	72.0
North 1	0	5.8	3.1	27.9	57.1
South 1	50	2.6	3.1	17.5	66.5
North 1	50	6.3	7.0	20.5	37.7
South 1	100	5.4	2.6	16.9	33.0
North 1	100	17.0	0.5	18.8	50.0
South 1	150	4.0	14.8	13.6	25.9
North 1	150	16.9	1.1	13.5	15.8
South 1	200	15.3	33.0	18.7	No data
North 1	200	1.7	1.4	8.8	38.3
Total 1	Mean ± SE	7.6 ± 2.02	7.9 ± 3.20	19.3 ± 2.54	44.0 ± 6.25
South 2	0	100	3.2	100	17.7
North 2	0	100	13.4	100	12.0
South 2	50	15.9	11.9	9.3	3.9
North 2	50	24.0	0	47.4	1.5
South 2	100	72.0	9.4	94.0	8.8
North 2	100	38.4	2.4	100	5.0
South 2	150	46.8	1.5	100	10.3
North 2	150	52.9	6.0	100	8.1
South 2	200	33.3	4.0	95.5	6.1
North 2	200	40.7	3.4	98.6	4.7
Total 2	Mean ± SE	52.4 ± 9.30	5.5 ± 1.44	84.5 ± 9.80	7.8 ± 1.48
Total 1+2	Mean ± SE	30.0 ± 6.92	6.7 ± 1.73	51.9 ± 8.95	25.0 ± 5.19

The mean and standard error (SE) of overall rat damage are presented for each treatment for: (i) each replicate and (ii) the two replicates combined.
TBS: trap barrier system; Fum: fumigation.

100 days, then given an hourly rate for labour of Rp1000, the labour costs were approximately Rp 100,000 (≈US$43). Planting a trap-crop 15 days in advance of the neighbouring crop produced increased insect and bird damage to the trap-crop (generally a greater problem in the wet season). The latter occurred from the milky ripe stage and required an outlay of Rp5000 (≈US$2) per day for 21 days for bird control (constant day time vigilance). A conservative estimate of the total cost for materials, installation, maintenance and bird control for each TBS for each season was Rp450,000 (≈US$200).

Table 4. Yields of rice (kg/ha) based on weight (water content 14%) of unhulled rice harvested from 10-m^2 quadrats

Season	Treatment	Weight (kg/ha)					
		0 m	5 m	50 m	100 m	150 m	200 m
Dry 1995	TBS only	3010		5600	4750	3500	4750
	TBS only	2720		5600	3900	3650	4100
	TBS+fumigation	2790		4400	5200	5250	4500
	TBS+fumigation	2380		6000	4200	5700	4950
	Fumigation only	0		2800	2950	3100	2850
	Fumigation only	0		2150	1900	1850	1600
	Control	0		2150	2250	2250	2600
	Control	0		4600	4600	4850	4500
Wet 1995/1996	TBS only	4750	6230	5930	5760	5860	5660
	TBS only	5280	5990	6070	5920	5690	5560
	TBS only	5520	6630	5620	5560	5490	5780
	TBS only	5900	6250	5590	5670	5430	5670
	TBS+fumigation	6340	6240	6140	6100	6140	6040
	TBS+fumigation	6720	6020	2300	6190	5830	5910
	TBS+fumigation	6920	5920	5880	6020	5610	5710
	TBS+fumigation	5960	6080	5850	5770	5660	5790
	Fumigation only	3950	5530	5550	5510	5360	5240
	Fumigation only	4890	5450	5390	5470	5370	5350
	Fumigation only	4080	5130	5490	5260	5090	5050
	Fumigation only	3570	5025	5290	5070	5180	5120
	Control	4180	5780	5720	5600	5820	5760
	Control	4410	5670	5490	5470	5430	5430
	Control	3880	4700	4930	4670	4680	4700
	Control	3680	5110	5300	5090	5330	5220

In the dry season, these quadrats were taken within the trap-crop and 50, 100, 150 and 200 m from the trap-crop. In the wet season, extra quadrats were sampled 5 m from the trap-crop, and a duplicate set of quadrats was sampled from the opposite side of the trap-crop.
TBS: trap barrier system.

Table 5. Mean yields of rice (kg/ha) during the 1995 dry and 1995/1996 wet season for each treatment within (0 m) and outside (5–200 m) the trap-crop (pooled data for the four TBS sites and four non-TBS sites are also provided)

Treatment	Distance from TBS					
	0 m	5 m	50 m	100 m	150 m	200 m
Dry season						
TBS only	2865		5600	4325	3575	4425
TBS and fumigate	2585		5200	4700	5475	4275
Fumigation only	0		2475	2425	2475	2225
Control	0		3375	3425	3550	3550
TBS			5400	4513	4525	4575
No TBS			2925	2925	3013	2888
Percentage yield increase			85	54	50	58
Wet season						
TBS only	5362	6275	5800	5728	5616	5666
TBS and fumigate	6484	6064	6043	6019	5809	5861
Fumigation only	4121	5283	5429	5327	5247	5188
Control	4035	5313	5360	5208	5316	5277
TBS		6169	5922	5873	5713	5764
No TBS		5298	5394	5268	5282	5233
Percentage yield increase		16	10	11	8	10

TBS: trap barrier system.

The benefits of the TBS can be calculated by comparing the direct increases in yield compared to the control sites at each of the respective distances from the fence (Benefits 1) or by only considering these differences until there was a noticeable drop in effect (Benefits 2). The latter is a conservative approach that estimates a lower limit of likely benefits. It is based on estimating a threshold distance (which is assumed at less than 200 m) at which the trap crop will have less effect on the movement patterns of rats. For the dry season, the effect of the TBS was much less pronounced at 100 m than 50 m. The threshold is estimated at 75 m, the mid-point distance. For the wet season, the effect of the TBS is much less pronounced beyond 5 m, but there is another drop at 150 m. The threshold is estimated at 125 m.

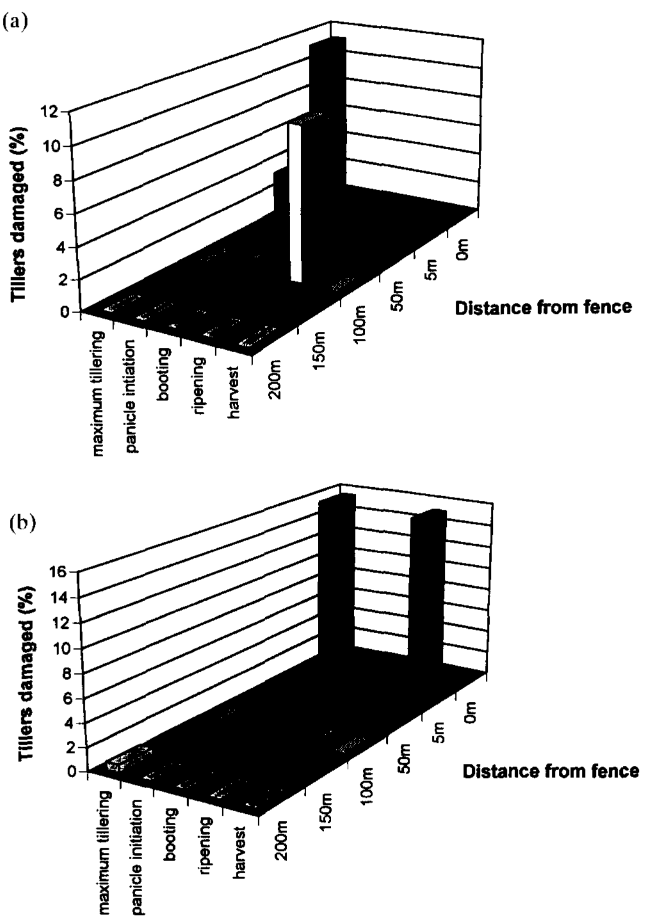

Figure 3. Mean percentage of rat damage to rice tillers during the wet season at different stages of crop development within a trap-barrier system (0 m) and 5, 50, 100, 150 and 200 m from the barrier. (a) TBS sites and (b) control sites (no treatment).

Benefits 1

In the dry season, each TBS provided a minimum 225-m radius of protection from the centre of the trap-crop (halo effect), which equates to 15.9 ha. The crop inside the TBS could not be included in the calculation because there was 100% damage to the unprotected trap-crop. Therefore, the area of protected crop was 15.65 ha. The average yield in the sites without a TBS (not including the trap-crop) was 2.7 tonnes/ha (t/ha), compared to 4.2 t/ha on the TBS sites. This equates to a saving of $15.65 \times 1.5 = 23.5$ tonne of rice. The market value of 1 tonne of rice is Rp400,000. Therefore, the gross benefit of the TBS was approximately Rp9.4 million ($\approx$US\$4085). This provided a benefit–cost ratio of 20:1.

In the wet season, each TBS provided an average 16% increase in yield ($\approx$0.9 t/ha) within 5 m of the fence and 9.75% increase ($\approx$0.5 t/ha) from 50 to 200 m from the fence. Again, the protection to the crop within the TBS was ignored. The increase in production was $0.03 \times 0.9 + 15.62 \times 0.5 = 7.8$ tonnes of rice. This is a conservative estimate because a yield increase of only 0.5 tonne was assumed beyond 5 m from the TBS. Therefore, the gross benefit of the TBS was approximately Rp3.1 million ($\approx$US\$1355). This provided a benefit–cost ratio of 6.8:1.

Benefits 2

The same method of calculation was used as above, but with a radius of protection of 75 and 125 m, for the dry and wet season, respectively. The area protected for the dry season was 2.9 ha with a benefit–cost ratio of 6.8:1. The area protected for the wet season was 0.03+4.7 ha, and the savings were $0.03 \times 0.9 + 4.7 \times 0.5 = 2.4$ tonnes of rice, giving a benefit–cost ratio of 2:1.

A factor not considered in these benefit–cost analyses was the longer-term benefit of access to TBS materials from one crop to another. A new fence generally lasts two crops, and the traps last several years. A conservative estimate of the cost for a second season (string, staples, replace half of the bamboo sticks, installation, three replacement traps) is Rp75,000 (≈US$33).

Discussion

Effectiveness of trap barrier system

A TBS with a trap-crop planted 15–21 days prior to the surrounding crops provided cost-effective protection against pre-harvest rat losses to rice. As predicted, the benefit was more pronounced in the dry season when rat densities were higher.

There were no treatment differences, however, for damage by rats to rice tillers. This may be partially due to the method of assessing damage; only freshly cut tillers and those not cut were scored. The latter consisted, at harvest, of tillers that had fully formed grain and those that did not because of incomplete compensatory growth following rat damage. Therefore, the damage estimates were not additive over time, and the proportional estimates of damaged tillers were compounded by compensatory growth.

The most likely explanation for the lack of treatment differences is that rat damage is typically patchy (Fall, 1977; *Table 3*), and there were insufficient hills counted per transect and/or too few transects, to provide a representative estimate of rat damage at each of the treatment sites. If so, then the damage assessment simply provided a phenology of crop damage as background for interpreting the loss data.

If the data on rat damage are too coarse to detect treatment differences, are the yield data better? We think that they are, for three reasons. First, the number of rice tillers sampled for each yield estimate were several orders of magnitude higher than those sampled for damage estimates. Second, after analysing the dry-season data and finding little association between damage and loss estimates, in the wet season, we collected yield data from farmers (1-ha plots) at each of the transects and at each of the sites. There was a high correlation between yields from these 1-ha plots and the 10-m^2 quadrats. Third, the trends in the yield data with distance from the TBS met expectations.

What, then, did the yield and damage data indicate? The two seasons provided two distinctly different situations. In the dry season, the population density of rats was relatively high with substantial rat damage to tillers occurring after the booting stage and a mean reduction of crop yields in non-TBS sites of 1.5 tonnes. In the wet season, the population density of rats was high during tillering but low thereafter, there was little rat damage to rice tillers, and the mean reduction of yields was 0.5 tonne.

These yield reductions appeared high given the number of rats caught in the two TBS treatment sites; 275 in the dry season and 172 in the wet season. Each rat represents a reduction in damage of 3–5 kg/ha or 45–75 kg within a 15-ha halo of protection. Possible contributory factors are: firstly, that each rat damaged many tillers during the generative stage, which is highly likely, but alone would not account for the yield differences; secondly, that the removal of rats led to substantially fewer females breeding in the vicinity of each TBS, an important consideration given that the average litter size is around 10.5 (Murakami *et al.*, 1990) and that the first litter of the year is weaned prior to harvest; thirdly, the capture of rats in a TBS raised the awareness of farmers who then increase their rodent control activities, leading to an increase in rodent control activities conducted on the TBS plots relative to the control plots.

Over the two seasons, the combined mean yield was approximately 10.1 t/ha on the TBS sites and 8.1 t/ha on the non-TBS sites. In 1995/1996, therefore, rats caused an annual loss of approximately 20% in potential rice production, which is comparable to the estimated national average of 17% (Geddes, 1992).

The benefit–cost ratios for the dry and wet seasons, respectively, indicate the strong potential of a TBS with trap-crop for managing the rice field rat. This is in contrast to the use of a TBS alone, which, in Malaysia and the Philippines, requires crop losses of > 30% before there is a positive benefit–cost ratio (Singleton *et al.*, 1994; Lam Yuet Ming, pers. commun.). There has been only one report in South-east Asia of high benefit–cost ratios for a TBS alone; ratios of 19:1 and 28:1 in Malaysia in a region where 56% of rice farms had suffered complete yield losses the previous year (Lam, 1993). Murakami *et al.* (1992) also reported a TBS to be effective against *R. argentiventer* in paddies that had severe rat damage during the previous year. However, this study in West Java was restricted to 4 ha with no replicates or suitable controls. Another critical test of the importance of a trap-crop in rice fields in West Java would be a comparison of the relative efficacy of a TBS alone versus a TBS-plus-trap crop. This has not been done.

The main factor providing the high benefit–cost ratio is the halo of protection provided to crops outside the TBS. In the current study, this extended to a minimum of 200 m in the dry season but fell away markedly after 5 m in the wet season. Before a TBS plus trap crop can be recommended for use by growers to manage rats, more needs to be known about the biological processes that govern the size of the halo of protection. Key components are likely to be the foraging and dispersal behaviour of the rice field rat. Unfortunately, there is no published information on these behaviours for this species of rat. Therefore, conservative threshold distances for the effect of the trap-crops in each season were estimated by examining the trends in the yield data. Whether this is an appropriate model is not known.

Monitoring the movements of rats caught and radio-collared at different distances from the trap-crop would be a good place to begin.

The benefit–cost ratio decreases rapidly if the halo of protection is reduced. For example, the break-even point for an average annual increase in production of 1.0 t/ha (about 10% damage) would require a halo of protection with a radius of 60 m. Under this scenario, protection extending to 75 m would provide a benefit–cost ratio of 1.5:1; a minimum return for a grower to warrant the management effort. If the annual loss in production to rats is 17%, the halo would need to extend approximately 45 m to provide the break-even point.

Effectiveness of fumigation

The use of sulfur gas as a fumigant was not effective in reducing rat damage to rice crops. Indeed, the highest rat damage generally occurred on sites where fumigation only was conducted. It was not clear as to why this was the case.

Fumigation is a widely used method for rat control in West Java. In the current study, fumigation of rat burrows was conducted only during the reproductive stage of the rice crop. Farmers also fumigate at this stage of the crop cycle, as well as post-harvest. The latter is when rat populations are at their peak density, when breeding has finished, when many rats do not use permanent burrows and prior to a time when many will die from other causes before the next cropping season (especially during the 3-month fallow period between the dry and wet season crops). This suggests that although fumigation conducted post-harvest may lead to the death of many rats, the benefit is more likely to be psychological (farmers feel that they have been active in their fight against rats). Intuitively, fumigation is likely to be most effective when the rat populations are at their lowest density, which would be during the land preparation and tillering stage of the respective crops. Two problems then remain. One is to have concurrent control conducted over an area large enough to reduce the effect of reinvasion. Murakami *et al.* (1990) suggested a minimum area of 30 ha. The other is the problem of being able to locate a sufficiently high proportion of rat burrows present in the area being managed.

Dynamics of rat populations and crop damage

In the dry season, more rats were captured in the TBS during the booting stage than at other stages of crop development. The situation in the wet season was different: significantly more rats were caught during the tillering stage than at other stages, and few rats were caught during the booting stage. The large number of rats captured at the tillering stage was not consistent with the low level of cut tillers; half as many rats were caught during the same stage in the dry season, yet there was substantially more rat damage. The 3-month fallow period between the dry season harvest and the transplanting of the wet season crop offers a possible explanation. If the rats were nutritionally stressed, a relatively higher percentage of the nearby rat population would be attracted to the early trap-crop than at the same stage during the dry season.

Another interesting result was the female bias in rats caught during the dry season, to be replaced by a male bias during the wet season. This has not been reported previously. It will be interesting to monitor whether this trend is repeated in future years and in capture-mark-release studies.

The capture-mark-release grids were established during the dry season to compare the relative changes in the population dynamics of rats in areas adjacent to each of the treatments. Unfortunately, the results were inconclusive because only seven rats were captured across all eight sites. This low trap success is consistent with findings from previous studies of *R. argentiventer* in Malaysia (Wood, 1971) and in West Java (Leung and Sudarmaji, submitted): even at high population densities, rats rarely enter live-capture traps that are not associated with a fence.

Trap barrier system — other considerations

In weighing up the potential of the TBS plus trap-crop, an economic benefit–cost analysis is one of a number of considerations. Other considerations include:

1. Strong vigilance on maintenance — needs to check daily for evidence of rats going through or under the fence; weed growth needs to be controlled near the fence.
2. Early trap-crop attracts avian and insect pests.
3. Mechanics of growing an early crop — water is required 3 weeks in advance of the general irrigation schedule to maintain firstly a plant nursery and then the transplanted trap-crop. An earlier maturing variety of rice may help overcome these problems.
4. Non-target captures — many amphibians and reptiles are caught in the traps. Whether farmers would release all of these species is problematical.
5. Scale of operation — management needs to be at the village level because the halo of protection is likely to benefit neighbouring farmers, whilst the farmer with the TBS has the burden of initial cost, increased bird and insect pests, maintenance, etc. Apart from the concomitant extension challenges, research is needed to determine the optimum (affordable, effective and low maintenance) size and spatial distribution of TBSs in the landscape. This will depend on the ability of rats to re-colonise areas where rat densities have been reduced, the heterogeneity of the habitat (including the seasonal dynamics in habitats where rats take refuge and/or breed) and the degree of asynchronous planting of rice crops.

Concluding remarks

The high benefit–cost ratios indicate the potential of a TBS with an early planted trap-crop for the control of the rice field rat in West Java, especially when rat densities were high. In contrast, fumigation was not an effective rat management technique.

There are three important caveats to the impressive benefit–cost ratios reported for the TBS. First, there was a weak association between crop damage and crop loss. Second, little is known about the biological processes that influence the interaction between rat populations and a TBS plus trap crop. Third, the study was conducted on a 440-ha agricultural research farm; research is required to assess whether this technology can be effectively transferred to rice farmers in West Java who have an average holding of 0.75–1.5 ha.

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