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Integrated management to reduce rodent damage to lowland rice crops in Indonesia

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Abstract

Benefits and costs of an integrated management system coordinated at the community level to reduce rodent damage to lowland irrigated rice were measured in West Java, Indonesia, from 1999 to 2002. Four villages, each of 120 ha (70–80 families per village), were involved in the study, two being allocated as treatments and two as controls following a randomised block design. The emphasis was on integrated rodent management with the overall aim of reducing the need for toxic chemicals in rice fields.

Rodent damage to rice can be measured at several stages of crop growth. In West Java, monocultures of lowland irrigated rice, cumulative damage to rice during the dry season was 54% at the primordial stage, 32% at the booting stage, but only 16% at the ripening stage. If measured at the ripening stage, the measured value ought to be multiplied by approximately 6.5 to obtain cumulative damage to the rice crop or by 4.2 for an estimate of yield loss.

Rice yield can be estimated by farmers directly or by quadrat samples, the former being on average 20% lower than the actual yield. Integrated rodent management increased rice yields more when rats were common, in both dry and wet season crops. For every 1% increase in tiller damage by rats, there was a decrease of 58 kg/ha in rice yield. Wet season crops benefited more from a trap-barrier system (TBS) than dry season crops at the same rat abundance index. The benefit-to-cost ratio for all seasons and years averaged 25:1 but varied considerably from year to year between a low of −2:1 to a high of 63:1. The economic benefit of integrated rodent management was equal to or better than that achieved by conventional management based on synthetic rodenticides.

Keywords: *Rattus argentiventer*; Pest management; Irrigated rice; Indonesia; Economic; Cost–benefit analysis; Yield loss

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1. Introduction

Rodents may significantly affect crop production and livelihoods of farmers in both developed and developing countries but their impact as related to the choice and associated costs of management actions is poorly known (Stenseth et al., 2003). In Asia, pre-harvest rice losses are estimated to be between 5 and 10%. A loss of 6% of SE Asia rice production amounts to approximately 36 million t, i.e. enough to feed the population of Indonesia (215 million people) for 12 months (Singleton, 2003). Farmers often use inappropriate methods to reduce the impacts of rodents, and rely heavily on chemicals, causing risks to non-target species and to the environment, and generally providing poor return on investment (Singleton, 2003). Nevertheless, rodenticides are likely to remain the central management tool for controlling rodent damage in tropical agriculture (Buckle, 1999; Wood and Fee, 2003).

Integrated management methods based on the ecology of the principal rodent pests have been promoted for developing countries (Singleton et al., 1999a; Wood and Fee, 2003). Liau and Wood (1978), Buckle and Rowe (1981), Buckle (1988), Lam (1999), Stenseth et al. (2001) and Singleton et al. (1998, 2003) have considered the economics of particular rat-control methods or strategies in developing countries. There has been no study of integrated management of rodents at a village scale under replicated conditions, whereas it is essential to quantify its economic value compared to conventional management based on rodenticides.

A 3.5-year study designed to measure the impact of ecologically based management of the rice field rat, *Rattus argentiventer*, Robinson and Kloss, was conducted at a village scale in lowland irrigated rice monocultures in West Java, Indonesia (Jacob et al., 2003), where *R. argentiventer* is the dominant species, making up more than 95% of the rodent fauna (Leung et al., 1999). Rats cut rice tillers at their base at any stage of the crop. Some damaged tillers decay but many re-grow and produce viable seed (Buckle and Smith, 1994). However, rice is unable to compensate for rodent damage after the maximum tillering stage because growth is largely vegetative (Buckle et al., 1979; Cuong et al., 2003; Islam and Hossain, 2003). Damage assessment is time consuming and generally done only once during a growing season, which provides a relative measure of rat activity between seasons. It would be valuable for economic studies to use a standardized damage assessment at a particular crop stage to estimate yield loss, but the association between crop damage and yield loss is unclear and needs to be determined (Buckle and Smith, 1994).

The following two key questions for this cropping system are being addressed:

(i) What is the relationship between tiller damage by rats and yield loss?
(ii) What is the economic benefit at a village scale of integrated rat management in terms of yields?

2. Methods

The study was conducted near Cilamaya (06°14′51″S, 107°34′05″E), Subang province, West Java, from 1999 to 2002. The region has a wet and dry season, and the main land use consists of a monoculture of lowland irrigated rice. The wet season of 2001–2002 had considerably higher rainfall than average, followed by late rains in July 2002 during the dry season. The average farm size for a family was 1–1.5 ha with one crop grown at the beginning of the wet season (December–April) and a second in the dry season (May–September), with a 2–3 month fallow at the end of the dry season.

Four villages, each approximately 2000 m × 600 m (120 ha), at least 0.75–1 km apart, were selected for the study. In each village, about 20 ha were not cropped and were used for housing, gardens and industry. Rodent densities and damage to crops were monitored at each village for 10 months until October 1999.

The study was set up as a randomised block design, with one village with the highest and one with the lowest rodent damage being allocated at random to both treatments. In treated villages, farmers adopted the following integrated management: synchrony of planting within 2 weeks; use of eight trap-barrier systems (TBS), each 20 m × 20 m with a crop planted inside 3 weeks early (see Singleton et al., 1999b); a 2-week rat campaign 1 week prior to transplanting or within 2 weeks of crop initiation around source habitats (village gardens and irrigation channels (Jacob et al., 2003)); reduction of secondary irrigation banks to less than 30 cm to prevent nesting by rats; and general hygiene around villages and gardens. Farmers in the treated villages who wished to use rodenticides were encouraged to apply them before maximum tillering. During the 2001 dry season in the treated villages, a 17-day bounty system was instigated to encourage farmers to work together to control rats in their gardens and along irrigation channels within 2 weeks of transplanting. The farmers were paid US$ 0.015 per rat tail (150 Rupiah). In the untreated villages, farmers conducted their usual control methods for managing rats, i.e. poisoning, fumigation and hunting, with most activities conducted by individuals and rarely coordinated with their neighbors. No bounty system was utilized in the control villages during this study.

Eight TBS were used per treatment village because the early crop attracts rats from up to 200 m away resulting in a halo of protection of 10–15 ha (Singleton et al., 1998; Brown et al., 2003). In each treated village, the eight trap-barrier systems were erected approximately 400 m from each other. Four multiple-catch cage traps along the plastic walls of the 20 m × 20 m TBS intercepted rats trying to enter the TBS to gain access to the early rice crop inside. The multiple-catch traps were cleared every morning for 105 consecutive days and the numbers and species were recorded for each TBS.

Damage to rice tillers was assessed at tillering or primordial stage (50–55 days after planting), booting (70–75 d.a.p.), or a week prior to harvest (105 d.a.p.). From the 2001/2002 wet season, damage was assessed at booting stage, milky stage (85–90 d.a.p.) and a week prior to harvest. In each village, five line transects to assess damage were established and sampling was conducted at five positions along each transect (5, 25, 50, 75 and 100 m from the edge of the rice crop). The number of freshly cut tillers, tillers recovering from damage and undamaged tillers per hill were counted at every fifth hill at 90° to each transect (for a total sample of 10 hills in each transect). The five line transects were at least 100 m apart.

At each village, yield was assessed by two methods. First, at 105 d.a.p., rice was reaped from five 2.5 m × 4 m quadrats and the unhulled rice was weighed at 14% moisture content (Singleton et al., 1998). Each replicate was near one of the five transects. Second, farmers were asked within a week of harvest to estimate the yield from the one ha of crop closest to each quadrat.

2.1. Statistical analysis

All statistical analyses were carried out in Number Crunching Statistical System (NCSS) 2004 (Kaysville, Utah; http://www.ncss.com). Functional regressions were computed according to Krebs (1999).

3. Results

One important question is how damage by rats to rice tillers measured at several crop stages relates to total cumulative damage. Cumulative damage during one season was calculated from the sum of three measurements (Table 1). Values for one site at the dry season 2001 were omitted from subsequent analysis because it was a strong outlier with almost all damage during the ripening stage.

Table 1
Damaged rice tillers (%) clipped by rats at Cilimaya, Indonesia, 2000–2002

Season	Village	Stage of rice plants				
		Tillering	Booting	Milky	Ripening	Total
Wet 1999/2000	1	–	7.37	–	3.41	10.78
	2	–	2.60	–	3.22	5.82
	3	–	7.60	–	0.00	7.60
	4	–	2.90	–	1.36	4.26
Dry 2000	1	1.09	0.72	–	0.00	1.81
	2	4.44	2.20	–	0.18	6.82
	3	10.54	4.98	–	0.38	15.81
	4	4.16	2.03	–	1.96	8.15
Wet 2000/2001	1	1.38	0.92	–	0.16	2.46
	2	9.47	0.39	–	0.18	10.04
	3	4.79	1.42	–	5.97	12.18
	4	6.74	2.05	–	0.36	9.41
Dry 2001	1	1.76	4.32	–	0.67	6.75
	2	10.60	11.09	–	2.02	24.52
	3	3.30	4.65	–	1.60	9.55
	4	5.54	1.74	–	23.50	30.78
Wet 2001/2002	1	–	2.70	1.40	1.70	5.80
	2	–	20.1	3.00	3.30	26.40
	3	–	1.60	4.40	1.20	7.20
	4	–	10.10	6.20	2.10	18.40
Dry 2002	1	–	0.02	0.18	0.08	0.28
	2	–	0	1.32	0.61	1.93
	3	–	0.86	0.41	0.22	1.50
	4	–	5.12	2.91	1.36	9.40

Means per village from a total of 250 hills, representing 140–260 rice tillers per 10 hills. Villages 1 and 3 are the treatment villages.

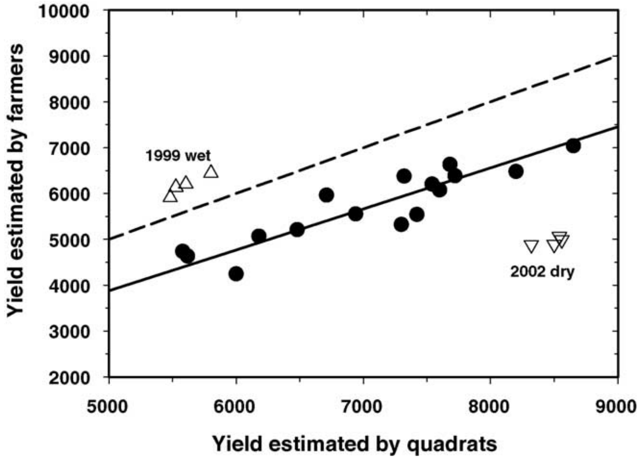

Fig. 1. Rice yield (kg/ha) estimated by quadrat sampling and by 10 farmers. Dashed line: expected relationship if estimates were equal; solid line: fitted functional regression. △ and ▽: outliers, not used for the regression line. $N = 16$ sites, $r^2 = 0.82$, $Y = 0.8944X - 594.1$.

Damage during the dry season, measured at tillering represented 54% (95% confidence limits, 40–68%), at booting 32% (20–45%), and at ripening 16% (9–22%) of the cumulative damage. Damage measured only at ripening, however, ought to be multiplied by 6.5 to obtain an estimate of cumulative damage.

Data attained for crops during the wet season (Table 1), are less complete. The wet season was statistically similar to the dry season, with 19% of the total damage occurring at ripening (confidence limits 8–30%). Farmers estimates of yield for the 1999–2000 wet season data were 10% higher than quadrat estimates, but 42% lower for the 2002 dry season. Based on all other data, farmers tended to under-evaluate yield by about 20% on average (Fig. 1). Quadrat samples were assumed to be more accurate estimates of rice yield.

There was a linear, somewhat variable, relationship between cumulative rat damage, as measured by the percentage of cut tillers, and yield (Fig. 2). The slope of this regression was the same in the wet and dry season, and for every 1% increase in rat damage, there was a decrease of 58 kg/ha in rice yield. Damage measured only at tillering could not define this relationship because of smaller samples and scattered data, whereas damage at booting or at ripening produced similar relationships as that shown in Fig. 2.

Damage to rice tillers assessed only during the 2 weeks prior to harvest needed to be multiplied by 4.2 (95% confidence limits 2.9–7.8) to obtain an estimate of percentage cumulative yield loss.

The impact of integrated rat management was determined by the difference in rice yields between treated and untreated villages.

The extra costs and benefits of farmers using integrated rodent management were compared from 1999 to 2002 in Table 2, concentrating on the TBS management action because this required the largest input of resources. Eight TBS fences were used on 100 ha, so that Table 2 uses 100 ha as the accounting unit for these calculations. In the 2001 dry season, rat numbers were very high, and a closely coordinated bounty scheme removed 8729 rats at one site (162 farmers involved) and 5429 rats at the other (153 farmers involved), in 17 days. This cost for this bounty was approximately US$ 202, which would approximate to the labor costs if a bounty was not paid.

The average benefit–cost ratio was about 25:1 with a range from −2:1 to 63:1. There was considerable variability in the benefit–cost ratio with no statistically significant difference between wet and dry seasons. Labor costs averaged about 90% of the total cost of operating a community trap-barrier system.

Using farmer estimates of yield, there was no clear distinction between wet and dry seasons, and the slope

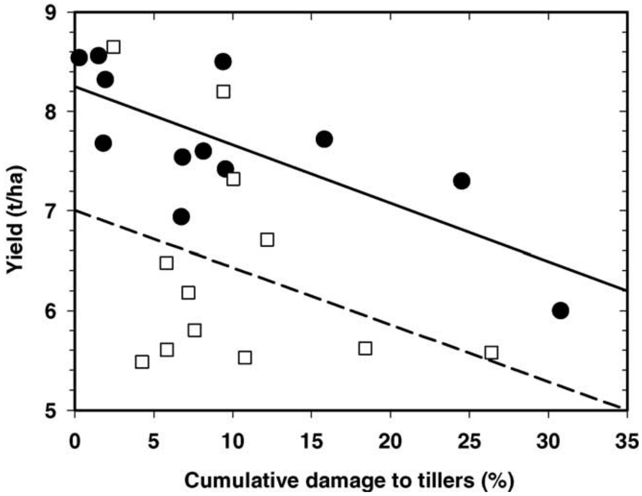

Fig. 2. Cumulative rat damage in relation to rice yield in the wet (□) and dry seasons (●). Slope for both lines = −0.0582, i.e. 1% additional damage = 58 kg/ha yield loss, predictive models being: yield = 7.014 − 0.0582 damage (%) for the wet season and yield = 8.245 − 0.0582 damage (%) for the dry season ($N = 24$ sites, $R^2 = 0.50$).

Table 2
Benefit–cost analysis for integrated rat management project in rice in Indonesia (1999–2002)

Year	Season	Village	Yield increase from management (kg/ha)	Price of 1 kg rice (US$)	Value of yield increase per 100 ha (US$)	Cost of TBS materials (US$)	Labor costs[a] for TBS (US$)	Benefit-to-cost ratio
1999–2000	Wet	1	−17	0.13	−227.50	19.75	105.00	−1.8
		3	258	0.14	3619.00	19.75	105.00	29
2000	Dry	1	110	0.11	1210.00	19.75	131.20	8
		3	150	0.11	1650.00	19.75	131.20	11
2000–2001	Wet	1	890	0.11	9790.00	20.10	157.50	55
2001	Dry	1	290	0.125	3625.00	12.10	288.43[b]	12
		3	770	0.117	9047.50	12.10	238.93[c]	36
2001–2002	Wet	1	880	0.13	11,440.00	23.00	157.50	63
		3	580	0.13	7540.00	23.00	157.50	42
2002	Dry	1	130	0.125	1625.00	19.91	210.00	7
		3	150	0.13	1950.00	16.70	210.00	9

All villages were 100 ha. The price of rice at local markets varies from year to year. Yield increase was estimated from the difference in yield measured by quadrats in treated and untreated villages. Prices and costs were converted at 10,000 Rupiah = US$ 1.00.

[a] Labor costs for maintaining the TBS fences were assumed to operate for 105 days.

[b] Includes bounty for 8729 rats (US$ 130.93).

[c] Includes bounty for 5429 rats (US$ 81.43).

indicated a drop in yield of 38.7 kg of yield for each increase of 1% in tiller damage. The whole regression was more scattered with less good fit ($n = 24$, $R^2 = 0.24$, $p = 0.04$), and the slope was poorly determined with wide confidence limits. The mean benefit–cost ratio was 26.4:1 (range 6:1–43:1).

4. Discussion and conclusion

In West Java, integrated rat management, coordinated at the community level, provided a large benefit for farmers with small holdings, and reduced reliance on rodenticides (Singleton et al., 1999b). The current study not only showed a strong return on investment, but also led to a 50% reduction of chemical usage by farmers (Singleton et al., 2003a,b). This reduction in rodenticide usage was not included in the benefit–cost analyses, which makes our estimates of farmer benefits conservative. The magnitude of the return on outlay was comparable to that obtained for appropriate anti-coagulants using ''replacement round baiting'' in both plantation and rice crops in Malaysia (Wood and Fee, 2003), and rice crops in Indonesia (Buckle, 1988). Rodenticides are widely used by financially poor farmers in Southeast Asia, but often inappropriately (Sudarmaji et al., 2003), resulting in genetic resistance, behavioral avoidance, non-target poisoning and environmental risks (Dowding et al., 1999; Cowan et al., 2003; Jackson and van Aarde, 2003).

Measuring crop damage and yield loss is labor intensive and complicated by the ability of rice to compensate for rodent damage up to tillering (Buckle and Rowe, 1981; Islam and Hossain, 2003). Damage is measured usually only once after tillering, often in the 2 weeks prior to harvest (Buckle et al., 1985; Fieldler, 1986). When rice is mature and nutritious, to obtain sufficient food rats need to cut only 1–2 tillers instead of numerous tillers at booting. That only 16% of the cumulative damage was recorded just prior to harvest suggests that a 6.5 times multiplier of damage in the week prior to harvest would provide a simple index for estimating rat damage during the reproductive stage of lowland irrigated rice.

The cumulative tiller damage measured on control villages (13%) was 1.9 times the damage measured on treated villages (6.8%). This difference translated into an average yield increase over the 3 years of 380 kg/ha of rice per season in the treated villages. The average yield loss in this study was 4.2 times the percentage of tillers damaged at the ripening stage. In Central Java and Malaysia, yield losses in rice damaged by rats versus protected plots varied between three times (Buckle, 1988) and four to seven times the damage estimates at ripening (Wood, 1971; Greaves et al., 1977; Buckle and Rowe, 1981). Therefore, a four times multiplier of percent damage of tillers at the ripening stage would provide a conservative estimate of percent yield loss.

The economic benefits of integrated rodent management have been underestimated because we had no data on the costs associated with chemical usage. Rodenticides used in both Indonesia and Vietnam (Singleton et al., 2003a,b) reduce rodent damage and it is important for any benefits to be measured and balanced against possible opportunity costs associated with the increased labor required to implement integrated rodent management. Specific management actions, such as the trap-barrier system, require a strong community involvement through coordinated management actions and sharing the associated costs.

Morin et al. (2003) suggested that the likelihood of adoption and sustainability of integrated rodent management was associated with the severity of the rodent problem. Linked to this idea is the relationship between pest density and yield loss, which is fundamental in developing effective management strategies for rodents in field crops but is poorly understood (Hone, 1994; Brown and Singleton, 2002). The relationship between rodent abundance and crop damage in irrigated rice ecosystems needs to be defined with a view to estimate the costs and benefits of rodent density reduction.

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