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Rodent Control in Practice: Tropical Field Crops

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Introduction

Examples of long-term successes in reducing rodent damage to tropical crops are few. More than two decades ago this situation was blamed on insufficient information that prevented specific recommendations from being made. Since then, several research projects, primarily in Asia, have not only investigated important crop loss situations, but also demonstrated several effective control methods. Moreover, these findings and some specific control recommendations have been published and are widely available. Despite this progress, adoption of new rodent control methods by farmers has been slow, even in areas where intensive efforts were made to introduce new procedures (Quick, 1991). Problems associated with changing traditional rodent control practices parallel those encountered with the introduction of other new crop production technologies to tropical agriculture.

Practical rodent pest management methods are still lacking in most of the tropics. Published work on rodent pests, a reflection of the research effort, has been minimal in Central and South America, the Caribbean, the Middle East and the Far East (Kaukeinen, 1987). Though relatively more publications on African rodent damage problems have appeared, there are still a number of important African crop damage situations for which no general accepted rodent control methods are available.

Rodent Problems

Annual chronic losses

Rodent damage situations can be highly variable, often seasonal, unevenly distributed and difficult to predict (Fiedler *et al.*, 1991). Many rodent species are inactive during the day and are therefore not readily observed by farmers, extension workers, or researchers. Damage can be concentrated and obvious, such as the 1–2 m diameter circles of cut wheat tillers surrounding burrow openings of bandicoot rats (*Bandicota bengalensis*); or it can be widely dispersed and cryptic, such as in rice fields in Southeast Asia with less than 10% damage. The latter damage pattern is frequently unobserved by both farmers and crop protection specialists who do not examine plants closely.

The perception of a problem and the actual damage or loss occurring can be very different, erring in either direction. For example, farmers in Indonesia appeared satisfied with their harvest prior to learning that their rice fields actually had more than 7.5% cut tiller damage and 0.64 t ha^{-1} lower yields than fields baited with rodenticides (Buckle, 1988). Also, without the benefit of actual damage assessments, crop protection specialists and Filipino farmers disagreed on the pest status of rodents in rice fields (Litzinger *et al.*, 1980). These examples demonstrate the importance of physical examination of individual plants to assess rodent damage and the need to examine yield losses.

Estimating crop damage and relating the results to yield loss is often confounded by variations caused by plant compensation and different fertilizer inputs, insect pest and weed problems, and inadequate damage assessment techniques (Chapter 10). Nevertheless, chronic losses occurring annually in tropical field crops from rodent damage are probably 5% or more (Hopf *et al.*, 1976), even when traditional rodent control methods are practised. Locally, chronic losses can be much higher (Jackson, 1977), particularly when crops are grown in areas highly susceptible to rodent damage. When these chronic losses occur continually over large areas, they are more significant than the more obvious outbreak losses that receive national and sometimes international attention (Buckle *et al.*, 1985).

Periodic acute losses

Outbreak losses in agricultural areas resulting from unusual rodent population increases can be dramatic and extremely visible and can occasionally result in food shortages over large areas. There are two primary types of rodent population outbreaks. One type occurs after new areas are opened to agricultural production, whereas the second type results from major climatic changes involving a period of either excessive rainfall or, more commonly, abnormal drought followed by normal rainfall. Lengthy drought not only reduces rodent populations but also changes the influence of factors which normally limit their numbers – predation, competition, and disease. Resumption of rainfall provides an immediate abundance of food, shelter and water for surviving rodents; thus increased reproduction, survival and dispersal occur. Outbreaks in Australia and Hawaii involving *Mus musculus* occur after lengthy droughts are ended by normal rainfall (Tomich, 1986). Australian wheat crops have been seriously affected during these mouse plagues (Chapter 13).

Reports of rodent outbreaks in Africa have been more frequent, extreme, and widespread than in other tropical areas. Two or more periods of favourable rains after a period of low rodent population density resulting from drought characterized outbreaks in Senegal (Hubert and Adam, 1985). Similarly, the 1986–1987 outbreak in Sudan and some other Sahelian countries occurred after a 4–7-year drought was interrupted by normal rainfall in 1985 and 1986 (Fiedler, 1988a). Over a 12–18-month period, high rodent populations developed but went unnoticed by authorities until complaints from farmers reached a peak. In remote areas, subsistence farmers were forced to replant fields several times before any assistance was begun.

Common characteristics of tropical rodent problems

Although each tropical rodent damage situation deserves individual attention, there are some general characteristics which are shared. Most rodent pest populations express seasonal trends in activity, reproduction, and abundance which are related to crop phenology and climate. Alternating dry and wet seasons influence not only crop planting schedules but also rodent breeding, mortality and mobility. Successful research programmes have identified these seasonal trends and used the information to help determine when rodent pests are most susceptible to control.

When habitats are disrupted, resident rodents may move to more favourable surroundings. Disruptions may be caused by fire, flooding, drought, or agricultural practices such as land preparation and harvesting. During dry seasons, irrigated croplands attract rodents from surrounding, less favourable habitats. Knowing how adjacent habitats influence rodent damage in susceptible crops is essential for effectively managing rodent pest problems.

Control Methods

The primary objective in any agricultural rodent pest management programme should be cost-effective crop protection – lower damage and higher yields. Using numbers of rodents or indices of rodent abundance before and after control operations is only useful for determining changes of populations. Unless it has been adequately demonstrated that reduced populations result in reduced damage in a particular situation, changes in rodent numbers should not be relied on to estimate the degree of crop protection achieved. Although reducing local populations may achieve higher yields in many situations, in some, the yield increase may be relatively costly. For example, crown-baiting in Philippine coconut plantations is more cost-effective than ground-baiting methods (Fiedler *et al.*, 1982). Targeting those rodents which are actually doing the damage increases efficiency and raises the economic benefits of control by lowering costs. Effective control programmes have been based on ecological research that identified the vulnerable factors in the behaviour and life cycles of rodent species and have used this information in developing materials, methods, and procedures to protect crops.

Many rodent control problems involve only a single pest species. However, in multiple species situations it is possible for a minor rodent species to assume a greater role in crop damage when populations of a primary species are reduced or when seasonal habitat changes no longer favour the primary species. For a situation involving rodents and larger mammals, such as bandicoot rats and golden jackals inhabiting Bangladesh sugarcane fields, a systems management approach may be helpful. However, systems approaches are expensive and time-consuming to develop and without widespread adoption, development costs would probably not be recovered (Hygnstrom, 1990).

Chemical

Rodenticides are generally an integral part of successful rodent pest management and, in some tropical habitats, are the only practical method available. Unfortunately, farmers and extension personnel are often confused or uninformed as to how a particular product may be effectively used. Local labels typically lack adequate use directions and provide only generic instructions that leave users guessing or improperly improvising untested application methods. Fortunately, a number of companies that service international rodenticide markets are now providing better information and technical assistance for tropical countries.

There are two basic field methods currently recommended for applying rodenticide baits. Both the sustained baiting method with multiple-dose anticoagulants and the pulsed-baiting method with single-dose anticoagulants or acute rodenticides are cost-effective in specific crop situations. Sustained baiting, developed in the early 1970s (Fall, 1977), is still recommended for reducing rodent losses to rice-field rats, even when damage levels are low (Reissig *et al.*, 1985). The technique initially requires a low-level input of bait which is monitored and supplemented as rodent consumption increases during the crop season. Costs are therefore related to the actual risk of damage and unnecessary use of rodenticide is avoided. The approach has been even more profitable to farmers in areas susceptible to significant losses.

Pulsed baiting promotes the application of second-generation anticoagulant rodenticides at intervals designed to reduce the amounts of labour and bait material used. Because of the greater toxicity of second-generation anticoagulants, they are generally sold to farmers as end-use products rather than concentrates. Acute rodenticides, such as zinc phosphide, can also be applied at intervals, but often require prebaiting or other tactics to achieve a similar effect. The interval between baiting pulses may be as short as one week (Dubock, 1982) or as long as six months (Advani and Mathur, 1988) depending on the rodent problem and the control objectives.

Non-chemical

Non-chemical methods can be used alone or integrated with rodenticide use when practical and cost-effective. Continuing research efforts are clearly needed so that effective rodent damage control is less dependent on the use of rodenticides as a primary method. However, continuous availability of food (crops), water (irrigation in dry seasons) and shelter (proliferation of vegetation) maintains rodent populations in and around tropical agricultural fields and often limits the apparent effectiveness of physical and biological approaches to controlling crop damage.

Artificially increasing predation has been periodically promoted as a method of rodent control, the most well-known attempt being introductions of the mongoose (*Herpestes auropunctatus*) to sugarcane-producing areas in the tropics during the late 1800s. Although these introductions were not successful in reducing rodent damage, they had long-lasting and unfortunate impacts on ground-nesting birds and provided a continuing reservoir of wildlife rabies. The excellent cover provided by field crops and the long intervals between crops preclude effective establishment of predator populations in many crop areas. However, the approach continues to be investigated. Recent efforts have included provision of artificial raptor perches or nesting structures and attempts to increase predator abundance, but field trial data to establish effectiveness in increasing crop yields are lacking (Howard *et al.*, 1985; Askham, 1990; Smal *et al.*, 1990). Nonetheless, locally active rodent predators in farming areas should be maintained and control programmes should be designed to minimize impact on predators and other desirable wildlife.

Barriers or fences have been effective in local situations. Inchaurraga (1973) used galvanized sheet barriers in South American rice fields to obtain a 5 ton ha^{-1} yield compared to only 2 ton ha^{-1} in unprotected plots. Barriers are commonly used to protect more valuable crops, such as seed beds or research plots. Unfortunately, some methods are hazardous and have killed humans, livestock and other non-target species. Quick and Manaligod (1991) reported 11 human fatalities in one area of the Philippines resulting from the use of 220 V electric wires strung from main lines to protect rice fields.

Research on barrier methods continues and may yet result in more broadly useful techniques.

Trapping is usually not practical if rodents are numerous, affected areas too large, traps costly, or reinvasion rapid. However, Lam (1988) combined drift barriers and traps to prevent invasions of Asian rice-field rats (*Rattus argentiventer*) into a substantial area of susceptible rice. If traps are used, the intensity of effort needs to be related to the numbers and activity of rodents and compared to the level of crop damage. Usually, trapping has proven to be so labour-intensive that little benefit is achieved or efforts cannot be maintained.

Habitat manipulation appears to have more potential in temperate, urban areas than in tropical crops (Colvin, 1991). However, for some tropical crops, changing certain portions of agricultural habitats could be beneficial. Wood (1991) noticed two distinct cultural practices in Malaysia that could account for major differences in rice yield and rodent damage. Large northern paddies with smaller and fewer bunds provided fewer nesting sites and less weedy shelter for Asian rice-field rats than did southern paddies with larger, more numerous bunds. Wood speculated that modifying the bunds in the south might result in lower damage. Weeding within and adjacent to field crops can also reduce cover and rodent damage (Hoque and Olvida, 1986), a concept understood by farmers using very traditional crop production methods (Litzinger *et al.*, 1982).

Synchronous planting shortens the period that crops remain susceptible to damage and reduces the chance of early- or late-maturing fields becoming focal points of rodent activity. However, labour shortages during the brief transplanting and harvest periods and the progressive availability of water in areas with gravity irrigation may preclude synchronous planting.

Control Programme Organization

In any rodent damage control effort there are three basic strategies to choose from – tolerance of the damage, management of the damage, or eradication or exclusion of rodents. Tolerance is practised by both farmers and government officials. It is usually selected because of apathy, a lack of awareness of crop damage, unfamiliarity with other options, or because of religious, social, or legal taboos against harming animals. Tolerance may be useful when control may require more effort and cost than simply accepting crop losses. Permanent or temporary eradication of rodents from a given area generally is not practical or ecologically sound. Large-scale rodent control campaigns have often been based on the false assumption that rodent eradication was possible. Eradication has only been accomplished on smaller islands where rodent immigration is negligible.

The most practical strategy is management of crop damage. Whether for a large commercial grower, a research farm, or an individual farmer, a management strategy should determine a minimum amount of damage or loss that can be accepted (Fall, 1991). Drummond (1991) presented a four-part management concept consisting of: (i) an objective leading to (ii) a plan for implementing (iii) actions or activities which are subject to (iv) evaluation to determine the level of success. The objective should not be merely to reduce rodent populations, but rather to reduce damage, increase yield, or lower rodent-borne disease to some predetermined, acceptable level.

Two general approaches to organizing rodent damage control programmes have been used. The area-wide or community-based approach, with its origins in the urban rodent control programmes of temperate countries, is clearly difficult to organize and maintain for tropical field crop situations due to small farm sizes and high human populations. Such programmes (frequently built around external donor assistance) tend to foster bureaucracies that are more responsive to the vagaries of local politics than to protection of crops. However, area-wide programmes can be effectively organized when governments have the authority to demand, or the influence to attract, farmer participation. Rural communities, farmer cooperatives or other farmer organizations often provide an existing framework within which rodent control activities can be introduced and implemented. The pulsed-baiting method for rodenticide use which relies on area-wide participation has been used effectively in these situations. Smaller quantities of rodenticide bait applied at more locations but at longer time intervals provide adequate protection with less effort compared to sustained baiting or other farm-based programmes. However, the technique loses some advantage when adjacent farms do not participate or when immigration of rodents is rapid. When large-scale programmes are appropriate, careful attention to early warning and surveillance procedures, timing of treatments, full participation of the affected community, and monitoring of crop damage are essential elements for effectiveness.

The second approach places responsibility for rodent control with individual farmers. This requires that each farmer must obtain materials needed and carry out rodent control in his own fields. Extension workers may assist by providing specific information and recommendations, but government personnel need not become directly involved in rodent control operations except during major population outbreaks. Individual responsibility is a relatively new approach in many tropical countries. Farmers who have relied on government programmes in the past are reluctant to take individual initiatives. This constraint will probably continue until methods and materials are developed and are widely available for individual use and until effective methods are available to inform and train farmers.

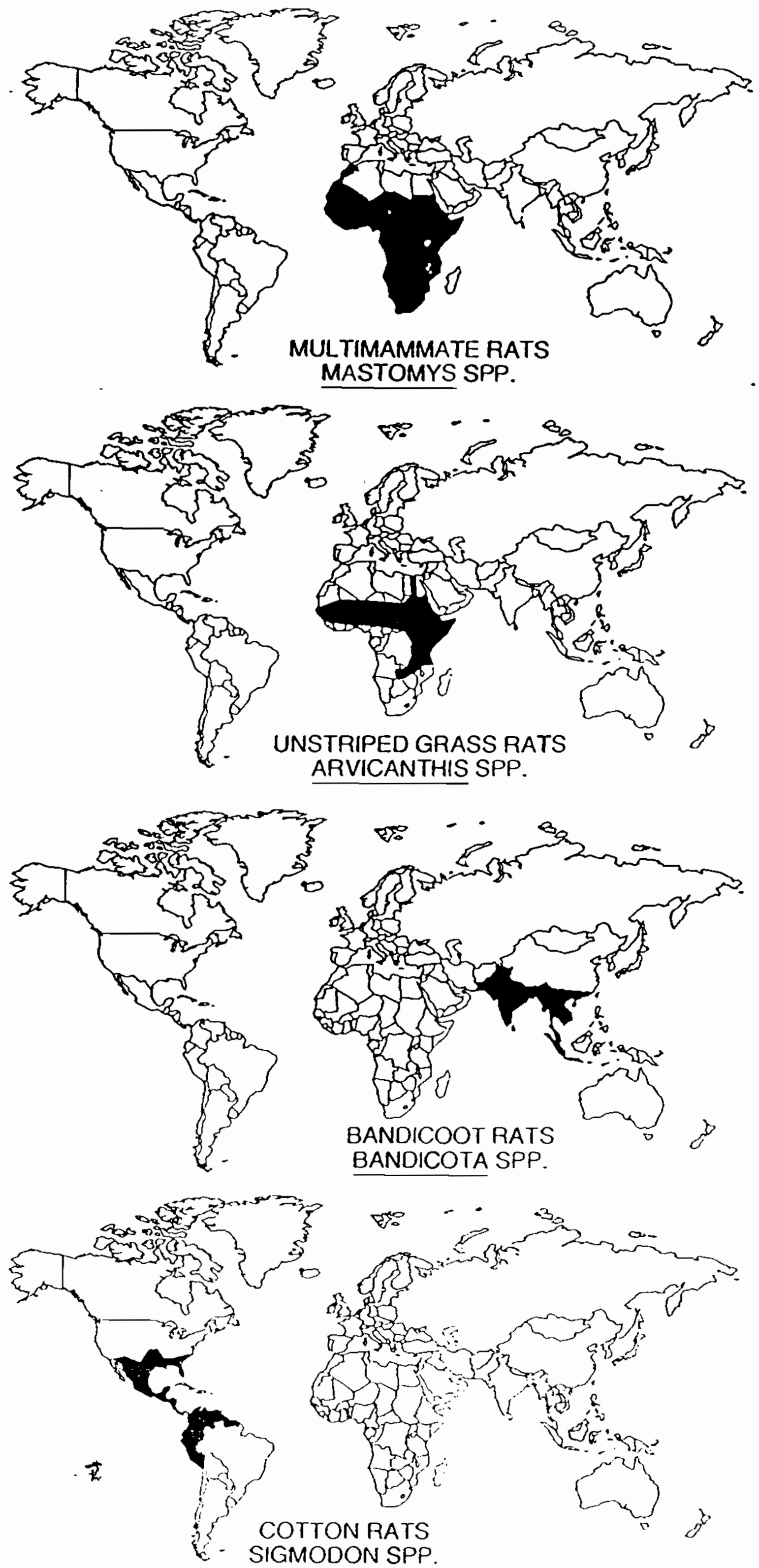
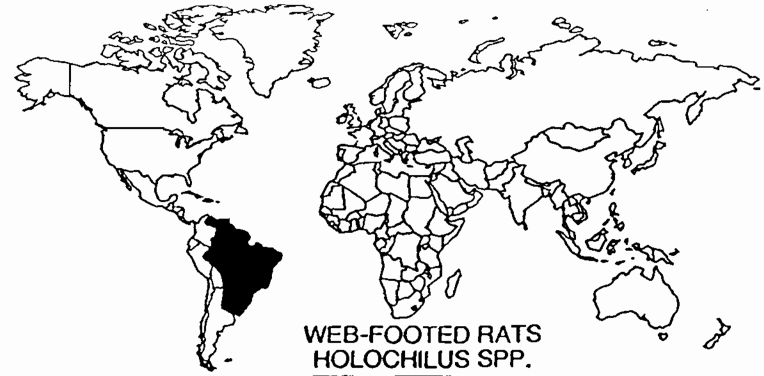
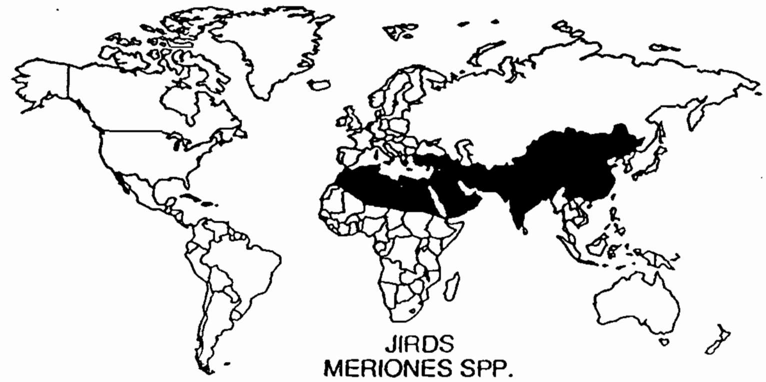


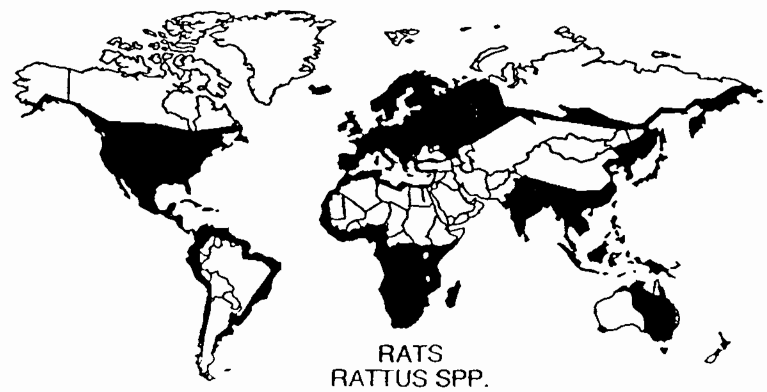
Fig 14.1. Ranges of eight rodent species or groups which are responsible for major crop damage in tropical agriculture.



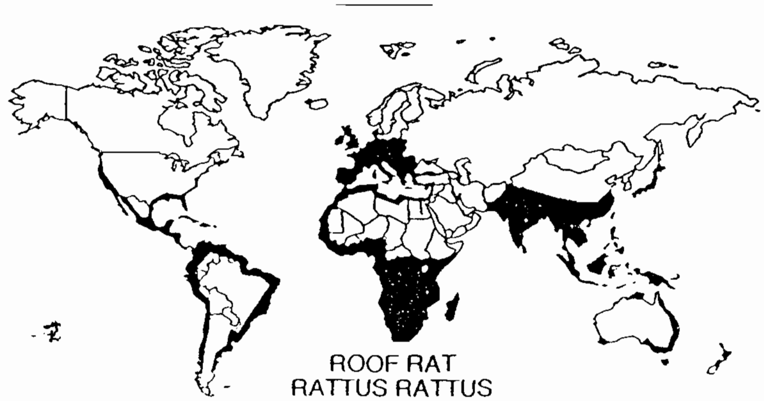
WEB-FOOTED RATS
HOLOCHILUS SPP.



JIRDS
MERIONES SPP.



RATS
RATTUS SPP.



ROOF RAT
RATTUS RATTUS

Primary Rodent Pests

Seven genera of rodents are responsible for most crop damage in tropical situations (Fig. 14.1). These genera range over wide areas with some overlapping of continents. Consequently they have received the most attention by international and national research and development programmes.

Rattus spp. (rats)

The genus *Rattus* ranges worldwide and includes about 56 species, although only a few adversely impact man (Chapters 2 and 3). These rodents typically are generalists, exhibiting broad food and habitat preferences. They are the most abundant mammal as well as the most economically important rodents present in many countries. The most familiar are the Norway rat (*R. norvegicus*) and the roof rat (*R. rattus*), which cohabit with humans nearly everywhere. Occasionally they have adapted to living in agricultural fields (for example in sugarcane in Hawaii), but crop damage is usually ascribed to other, less commensal species. Some subspecies of *R. rattus*, such as the Philippine rice-field rat (*R. r. mindanensis*), are true field pests and, although they may be an opportunistic commensal, they thrive in the absence of dwellings. Introduced commensals have disrupted the biodiversity on many islands throughout the tropics (Atkinson, 1985) and attempts to eradicate *Rattus*, even on small islands, have required massive, labour-intensive efforts (Moors, 1985).

In addition to *R. rattus*, other species (*R. argentiventer*, *R. exulans*, *R. nitidus*, *R. losea*, and *R. tiomanicus*) are present in various parts of Asia and the Pacific Basin where they damage rice, oil palm, coconut, maize and a wide variety of other crops (Williams, 1985; Hoque, *et al.*, 1988). *R. tiomanicus* has been a chronic pest of ripening oil palm fruit in Malaysia where resistance to warfarin has required use of second-generation anticoagulants in control operations. *R. r. diardii*, a commensal species, has recently become common in some oil palm plantations far removed from dwellings (Wood and Chung, 1990). *R. villosissimus* periodically irrupts and causes extensive crop damage in Australia.

Since Wood (1971) realized Malaysian rice yields could be experimentally increased threefold with rodenticide baiting, equally dramatic results have been achieved in Indonesia and Philippine rice fields. Costs of control efforts can usually be economically justified if yield losses exceed 0.5% (Buckle *et al.*, 1984), but without effective control, average losses from rodent damage in field crops are usually much higher. Research has identified rodenticide formulation, bait placement, and timing of bait applications as key factors which determine the effectiveness of crop damage control. Timing proved to be most important when two formulations of warfarin were compared for controlling *R. argentiventer* damage to Malaysian rice (Buckle *et al.*, 1980).

Baiting, begun shortly after transplanting and continuing for at least 4–8 weeks, was more effective than other baiting schedules tested. Research in Philippine rice fields on *R. r. mindanensis* and *R. argentiventer* showed that it was critical to begin baiting early in the crop cycle and to distribute bait points within paddies instead of at central locations on dikes (Fall, 1977).

Bandicota spp. (bandicoot rats)

Bandicoot rats are major rodent pests in irrigated crop fields of India (Prakash and Mathur, 1988) and cause significant damage in Sri Lanka, Nepal, Burma, Bangladesh, and Pakistan. Substantial amounts of the total yield in field crops can be cached in burrows by these rodents which are also important storage pests.

Field studies in Bangladesh on the biology and behaviour of the lesser bandicoot rat (*B. bengalensis*), in combination with laboratory results, offered clues for a potential strategy to reduce damage in maturing wheat (Poché *et al.*, 1982). Results from damage surveys showed that wheat fields were not utilized by these rodents until the booting stage, after which rapid immigration, burrow formation, and wheat damage were observed. A zinc phosphide bait cake developed in Pakistan was effective in small-scale field trials and in a large-scale demonstration in wheat fields. Using this technique, a reportedly successful national campaign was carried out in 1983 and 1984 (Adhikarya and Posamentier, 1987).

Despite the minimal cost, time, and effort required by Bangladeshi wheat farmers, it is unclear how well the programme functions today. Donor assistance, now ended, played a large role in motivating government officials and programme participants. Private industry did not continue the local manufacture of high-quality zinc phosphide bait cakes thereby permitting other substandard products to dominate the marketplace, probably degrading farmer confidence. An area-wide approach is being evaluated to determine if damage in both wet season rice and dry season wheat could be reduced by single rodenticide applications at the time of the year when rodent populations are most vulnerable, after the monsoon floods recede. Preliminary results indicated that this minimal treatment may reduce major crop damage and could be more easily managed by government agencies and farmers (Sultana and Jaeger, 1992).

Arvicanthis niloticus (Nile rat, unstriped grass rat)

The Nile rat is the predominant rodent pest in field crops in eastern Africa and Egypt and is occasionally abundant in western Africa as well. Nile rats are herbivorous and normally consume grass seeds, leaves and shoots during daylight hours. They have a generally short life span; predation may help limit rodent numbers except during population peaks which occur about every four years in Senegal (Poulet, 1985). Breeding and population density generally follow seasonal trends related to rainfall and vegetation, including crops (Fiedler, 1988a). During dry seasons, when regional populations decline dramatically, relative abundance may appear to increase as survivors concentrate in restricted areas of irrigated croplands or other suitable habitats and become highly visible to farmers.

Little information has been gathered to describe crop damage or to develop effective control techniques for this species in agricultural areas. However, it is susceptible to 1% zinc phosphide on whole sorghum bait mixed with a 1% vegetable oil (Suliman *et al.*, 1984), a formulation now used in Sudan. Greaves (1989) reported that anticoagulants mixed with wheat grains were effective in the field, but Taylor (1968) observed poor bait acceptance during an outbreak in Kenya and proposed that natural vegetation may have been preferred over the cereal grain bait being used.

***Mastomys* spp. (multimammate rats)**

These small rodents are the most important agricultural rodent pest in Africa. The severe crop damage they cause is a result of their omnivorous and opportunistic feeding behaviour, extraordinary reproductive capabilities, and a propensity for close association with human settlements. Multimammate rats thrive in the presence of cultivation and readily enter homes, damage stored foods, and spread disease.

Considerable effort has reduced but not eliminated the confusion in the systematics of *Mastomys* (Robbins and van der Straeten, 1989). Within this species complex, animals display one of three chromosome numbers which differentiate *M. natalensis* in southern Africa and *M. huberti* in eastern, central and western Africa (both with 32 chromosomes) from *M. coucha* (36 chromosomes) and *M. erythroleucus* (38 chromosomes). However, all are physically and behaviourally similar and are often treated as one pest problem.

Like many other African rodents, multimammate rats generally have predictable patterns of breeding and abundance that follow seasonal precipitation patterns (Fiedler, 1988a). Telford (1989) followed *P. natalensis* population trends over a 4-year period and related breeding and rodent numbers to the amount and duration of the two annual rainy seasons occurring in Morogoro, Tanzania. Leirs *et al.* (1990) showed that this pattern of bimodal rainfall could be used to predict population densities and potential damage in subsequent crop seasons. These research findings should facilitate the development of an appropriate management strategy for control efforts in Tanzania and other African countries with similar problems.

Although multimammate rats have been involved in virtually every documented regional rodent outbreak in sub-Saharan Africa (Fiedler, 1988b), comparatively little research on damage or development of control approaches has been published. Taylor (1968) recorded observations during a major outbreak in Kenya, including an attempt to control the field damage caused by multimammate rats, Nile rats and four-striped grass mice (*Rhabdomys pumilio*). Several other studies that evaluated rodenticide formulations for multimammate rats in the field or laboratory have produced no consensus as to what materials or techniques are suitable for crop damage control (Fiedler, 1988a). Myllymaki (1987) suggested that control efforts should focus on symptomatic treatment during critical damage periods, such as in seeded maize or preharvest cotton fields, which would provide Tanzanian farmers with immediate visible results – an approach with a better chance of farmer acceptance.

Meriones spp. (jirds)

Damage to field and plantation crops by jirds is a significant problem in North Africa (Bernard, 1977) and the Near East (Greaves, 1989). Only in India has there been any major effort to examine systematically tropical crop damage problems caused by this group (Prakash and Mathur, 1988). Damage by *M. hurrianae* populations, which can average 300 or more animals ha^{-1}, occurs in grain and tree crops, grasslands, vegetables, and irrigation schemes.

Burrow treatments have been the most practical and useful technique to reduce damage. Only small amounts of bait are required and access to bait by non-target animals is restricted. Whole-grain pearl millet (*Pennisetum typhoides*) is very attractive to jirds, particularly when natural food is scarce. The hoarding behaviour of jirds would probably make multiple-dose anticoagulant baits costly to use except in low-level maintenance control programmes. Nevertheless, chlorophacinone and coumatetralyl, as well as the single-dose anticoagulant brodifacoum, each formulated in a pearl millet base, has reduced active burrows 83, 81, and 91%, respectively, after 10 days (Mathur and Prakash, 1984).

Strychnine (0.5% with mineral oil) and zinc phosphide (0.6–2.5%) on wheat grains reportedly have been successful when used in burrow applications. However, Bernard (1977) reported that tolerance to 0.5% strychnine in some populations required a change in concentration to 2.5% to achieve adequate toxicity. Strychnine tolerance has also been reported in pocket gophers (Lee *et al.*, 1990); large differences in strychnine efficacy were found within three subspecies of the California ground squirrel (Howard *et al.*, 1990).

Sigmodon spp. (cotton rats)

Cotton rats range from the southern United States, through Central America, to northwestern South America. Although cotton rats occasionally burrow, these 100–200 g herbivorous rodents generally prefer grassy habitats that provide abundant vegetation for shelter, food and nesting. Cotton rats normally are active at night, using distinct runways to traverse a home range of about 0.1–0.5 ha. Breeding can be year-round in the tropics, although peaks probably occur in favourable seasons. Population outbreaks occur occasionally over large areas, probably associated with favourable climatic conditions. Holler *et al.* (1981) noted a capability for doubling of cotton rat populations in one month in Florida sugarcane fields. Cotton rats damage maize, sugarcane, rice, cotton and a variety of other field, garden and plantation crops (Espinoza and Rowe, 1979; Elias and Fall, 1988). However, they are less damaging to flooded rice since they remain at drier edges of fields or along dikes. If populations are high, rapid and significant damage may occur when fields are drained before harvest.

Methods used for controlling damage include removing weeds in and around crop fields to reduce suitable habitat and increase exposure to predation. Rodenticides reported effective for cotton rats include the anticoagulants, diphacinone (0.005%), brodifacoum (0.005%), pival (0.025%), warfarin (0.025% on maize/groundnut oil), coumatetralyl (0.0375%) and coumachlor (1% in a paraffin/maize meal block). In addition to anticoagulants, zinc phosphide, formulated with a grain/vegetable oil or cubed sweet potato, and bromethalin have been used to reduce cotton rat numbers. Lefebvre *et al.* (1978) found that acceptance of 1.88% zinc phosphide formulated on oat groats or cracked maize was similar and that prebaiting did not increase acceptance.

Field evaluations of damage control procedures in Latin America have been very limited. Martinez-Palacios *et al.* (1978) used 0.05% warfarin with a grain-based bait in small bags selectively applied at a rate of 2 kg ha^{-1} over two 1600 ha mixed-crop areas in Mexico to reduce cotton rat populations at about 50% of the cost of zinc phosphide baiting. They attributed this success to the use of corn oil as an attractant on the bags. Kverno *et al.* (1971) made similar observations in Nicaragua where cotton rat acceptance of unoiled bags was poor. Although rodenticide baiting for cotton rat control appears to be commonly used by farmers in Latin America, particularly during population outbreaks, no research-based programme recommendations are available in the literature.

Other important rodent pests

Web-footed rats (*Holochilus* spp.) can be important rodent pests in South American sugarcane, rice and cotton (Elias and Fall, 1988; Castillo, 1990). Cartaya and Aguilera (1985) found most of the damage to rice in Venezuela occurring during the earlier vegetative growth stages and amounting to 0.9% of the biomass. These 105–255 g, nocturnal, mostly herbivorous rodents are adapted to aquatic environments, having partially webbed toes on the hind feet. They construct nests and feeding platforms above water level in flooded fields. Anticoagulant rodenticides have been field-tested, but only in limited areas and for short periods, using trap success or bait acceptance for evaluation.

Greaves (1989) cast doubt on the frequency of significant crop damage by *Tatera* and *Gerbillus* in the Near East, but elsewhere these gerbils are mentioned as important pests of dryland agriculture (Fiedler, 1988b; Prakash and Mathur, 1988). Govinda Raj and Srihari (1987) identified the reproductive patterns of gerbils (*Tatera indica*) in India and suggested that control operations should begin prior to the onset of the breeding season, which is associated with rainfall. Formulated with pearl millet, a preferred bait base, anticoagulant rodenticides reduced active burrows of this gerbil as well as those of a sympatric species, *Meriones hurrianae*, in crop fields. *Gerbillus* populations occasionally irrupt in Asia and in Africa and are occasionally involved in serious damage to planted seed.

Integrated Pest Management and Decision-making

Integrated pest management, or IPM, has been widely discussed in relation to the management of rodent damage problems, but minimal field research on the integration of methods and evaluation of programmes has been conducted. Few practical IPM programmes are in routine use for rodent damage problems in field crops. Smith and Calvert (1978) defined IPM as broad, ecologically based control systems that use and manipulate multiple plant protection tactics in an effective and coordinated way. More complex definitions have been developed, but theirs remains broadly applicable to all plant pest situations, including those involving rodents. Smith (1970) recognized two decades ago that chemical pesticides would continue to provide powerful tools in IPM programmes and that the hope for 'revolutionary' approaches to pest control should not be a basis for rejecting effective chemical techniques. Although IPM has increasingly been promoted as an 'alternative' to use of chemical pesticides, in fact and in practice, pesticides, effectively and selectively used, remain an important component of most successful IPM programmes. This will most certainly be the case for the foreseeable future for programmes to manage rodent damage to field crops. Nonetheless, in every pest situation we have described there are many opportunities to improve the effectiveness, selectivity, and environmental compatibility of rodent damage control programmes by developing, evaluating, and using IPM approaches.

Development of IPM approaches to reduce or prevent crop damage by rodents presents some special problems that require consideration (Marsh, 1981; Fall, 1991). Although the general population dynamics of rodents are well-known from studies conducted in temperate countries, few basic ecological data exist for common rodent pest species in tropical agriculture. The species are all highly responsive to changes in environmental conditions, making it essential to develop a thorough understanding of the specific ecological, phenological, and climatic factors that influence rodent population behaviour in particular crop situations. Because rodents may be relatively long-lived in comparison to crop cycles, have the capability for relatively long-range movements across different habitats, and can reproduce rapidly whenever adequate food and cover are available, most rodent damage problems must be studied and evaluated in farmers' fields rather than on small plots or experiment stations. The same rodents often damage a variety of crops in the same area, shifting from one field to another as crop cover develops or ripening progresses. Seasonal movements from crop fields to dwellings or storage structures are common for a number of problem species. In some cases, more broadly based integrated programmes addressing community problems may be more practical and sustainable than specific crop-oriented approaches.

Programmes in Malaysia, Indonesia and the Philippines have introduced IPM concepts to rodent control. The sustained baiting method, developed in the Philippines, contained a self-monitoring component in which bait consumption, a reflection of rodent activity within rice fields, was regularly checked and the baiting regimen increased or decreased accordingly to minimize rodenticide use. Based on Rennison's (1980) surveillance procedure using rat-damaged rice hills, Buckle *et al.* (1984, 1985) and Buckle (1988) established thresholds ranging from 15% to 25% damaged hills (equivalent to 1.8–3% cut tillers) for rice-field treatment with rodenticides in Malaysia and Indonesia. Recommendations called for weekly baiting with anticoagulants during the rice tillering stage and the use of tracking powder or fumigation during the maturing stages. Damage assessments at harvest were used to monitor the success of the management programme and identify where rodent control should be emphasized in the next crop season.

IPM programmes tailored to the smallest manageable unit that can be handled by a trained farmer, with guidance from IPM specialists when necessary, probably present the best prospects to be self-sustaining. Such approaches are also more likely to be compatible with other farming and pest management practices. The sustained baiting technique was designed for a single farmer to use effectively regardless of whether or not surrounding fields were being protected. This approach allowed rodent control to be included in the 'package' of new rice production technology being provided to selected Philippine farmers (Fall, 1977). Individual farmer-based programmes place the emphasis of organization on extension to provide information to farmers about rodent damage control methods and market development to assure the availability of materials. In some situations, farm-based programmes may be the preferred approach to manage chronic rodent damage problems, whereas area-wide approaches, directed by specialists, may be appropriate for managing regional rodent population outbreaks, even though both approaches might involve the same crops, rodent species and control methods.

Availability of materials for rodent damage control in rural areas is a worldwide problem that must be addressed country by country, area by area for development of self-sustaining, successful IPM programmes. Specific efforts will generally be required by public or private sector organizers whether the materials needed for a particular programme are rodenticides, bait materials, traps, fencing, or simply information. If markets for materials are undeveloped in rural areas, if distribution networks are too costly for the private sector to establish, or if the costs of providing chemical registration or other regulatory data are higher than the potential profit for private industry, then specific government involvement may be necessary. In the United States, the US Department of Agriculture is involved in the development, registration, manufacture, and distribution of minor-use vertebrate pest management materials needed in IPM programmes for which no other sources are available.

Many of the techniques, materials, and practices available for rodent damage control programmes have the potential for adversely affecting other wildlife and reducing biotic diversity. Although farmers cannot be expected to divert agricultural lands or suffer crop damage to maintain wildlife populations, one need only consider the impact of such desperate rodent control practices as burning or destroying habitat adjacent to croplands or poisoning of irrigation water to recognize that the utility and impacts of rodent control operations need careful evaluation. If other wildlife species are determined to have a measurable role in reducing crop damage, practices to encourage increased activity of predatory mammals or birds around crop fields may be a useful part of an IPM programme. Even if 'natural controls' are not demonstrated as practical components of crop damage prevention, IPM programmes should be developed with the dual objectives of minimizing crop damage and minimizing environmental effects.

An increasing number of countries are requiring that data on wildlife impacts be provided before the use of rodenticides is permitted in field crops. Most rodenticides are toxic to a variety of mammals and some birds, but toxicity data alone are an insufficient basis for regulatory decision-making (Chapter 16). Because few species of wildlife can live in the transient habitats provided by crop fields, wildlife exposure to rodenticides can often be limited by careful timing of treatments or by selective methods of application. When the costs of evaluating the wildlife impacts of pest management methods and materials outweigh the profitability of potential markets, governments may need to assist in gathering data to ensure that effective IPM programmes can be developed to replace the ineffective, hazardous, or destructive practices farmers may use when nothing else is available.

In any attempt to control crop damage, many small and large decisions must be made by each of the participants. Often, little evaluation of the outcome of these decisions is attempted and practices are simply adopted as routine. Ideally, IPM systems can help to provide feedbacks from the results of rodent damage control operations to those responsible for decision-making, ranging from individual producers to government officials. Many constraints, technical, economic, ecological, cultural, religious, and political, affect decisions about rodent damage control. It is important to recognize that much of the biological, chemical, and ecological information about rodents, rodent damage problems, and the effectiveness of techniques and materials is obtained by researchers without reference to the practical constraints or specific management objectives for any particular crop damage situation. There is a continuing challenge for both producers and pest management specialists to make careful, informed choices in translating the available technical information into safe and effective operational IPM crop protection programmes.

Discussion

Characteristics of successful rodent control programmes

Some initial international support to a tropical country seems to be a prerequisite for any progress in rodent control to occur. The Philippines, having one of the more successful national programmes, had major technical and financial assistance from the United Nations Food and Agriculture Organization (FAO), the German Agency for Technical Cooperation (GTZ), and the US Agency for International Development (USAID) over a 20-year period (Sumañgil, 1991). Other organizations that have provided assistance to tropical rodent control programmes are the UK Overseas Development Administration (ODA), the Danish International Development Agency (DANIDA), the Belgium Administration for Development Cooperation, the Swiss Directorate of Development Cooperation and Humanitarian Aid, the World Bank and the Asian Development Bank. Sponsored projects in Asia, Africa, Latin America and the Caribbean have contributed valuable information on key rodent problems.

Measuring success

Measuring the success of rodent control programmes has received little attention. Most managers have had no real obligation or responsibility to evaluate programmes or, if they did, lacked the skills and a budget to do so. In each situation where the application of IPM principles is being considered, specific surveillance and monitoring practices appropriate to the crop, rodent species, and farming practices should be devised to provide the essential information about management effectiveness. The common practice of counting dead animals following poisoning programmes gives no indication of programme effectiveness for protecting crops because it ignores remaining or rapidly reinvading animals and provides no information about crop damage.

Two national programmes have been subjected to independent evaluation. Dizon (1978) interviewed managers, extension workers and farmers soon after a new rodent control programme was introduced in the Philippines and found a substantial lack of knowledge among extension workers and farmers about the required materials and procedures. Despite this handicap, about 2% of farmers after one year and about 12% after two years had adopted all or portions of the new technique. The management information system developed and used by the Philippine Bureau of Plant Industry to track rodent control efforts in relation to crop damage assessments (Sumañgil, 1991) provided a mechanism to maintain a national overview during initial efforts to implement new procedures for rodent damage control.

Adhikarya and Posamentier (1987) evaluated rodent control campaigns in Bangladesh where considerable effort was expended on developing and testing extension methods designed to motivate farmers. As a result, an additional 5045 tons of wheat valued at US$857,650 were harvested in 1983 at a cost of US$23,355 for ready-made bait. In 1984, an additional 5208 tons of wheat valued at US$859,000 were realized at a bait cost of US$36,991. The gains were probably larger since only wheat fields were evaluated even though non-wheat crops were officially included in the 1984 campaign.

Keys to success

Ecological understanding of crop damage problems

The full understanding of a rodent pest problem requires considerable time for studying rodent biology and behaviour in actual field conditions. Beyond this important initial research phase, monitoring of rodent reproduction and movements, population status and condition, and crop damage patterns and relating these data to climate and vegetation over several seasons can provide the basis for models to forecast with reasonable accuracy short- and long-term rodent population and damage changes. With computers, sensitivity testing on individual components of a model can identify key factors contributing to crop damage and help to identify appropriate control strategies and methods for field evaluation (Benigno *et al.*, 1983).

Establishment of clear programme objectives

A control programme should have stated objectives that focus on effectively reducing damage to priority crops and increasing farm yields and income within a given area and period. With such a focus, a programme will be less likely to lose sight of its primary mission. Successful programmes have made extensive and creative efforts to inform farmers and rural populations about the purpose and potential benefits of effective rodent damage control.

Well-organized implementation efforts

A well-organized operational programme can reduce significant rodent damage. During the 1976 rodent outbreak in Sudan, all areas of the country (including the Gezira Scheme, an intensive irrigated agricultural production area of more than 930,000 ha located between the Blue and White Nile Rivers) were severely affected by rodent damage. A result of this outbreak was the establishment of a rodent control programme in the Gezira Scheme to research, monitor and conduct an operational rodent control programme. Ten years later, during the 1986–1987 Sudan rodent outbreak, the only area in the country not seriously affected was within the Gezira Scheme where the well-organized rodent control programme had been continued. Not only were annual yields protected from chronic losses over several years, but severe damage during one of Sudan's worst rodent outbreaks was avoided.

In too many situations there is no organization until an outbreak or some other acute problem requires it. Hastily made decisions are then usually based on limited, earlier research or information from other situations which may or may not apply. Responsibility for specific actions must be determined from the highest levels of government to the individual farmer or a programme will be ineffective. For example, at an administrative level, health and agriculture officials may not agree on who is responsible for rodent control when both public health and agricultural production are at risk from rodent infestations. At the farm level, farmers may delay action because they feel that government will take responsibility for controlling rodents.

Providing technical information to programme participants

An informed public is more cooperative and more likely to participate in rodent damage control programmes (Rampaud and Richards, 1988). Questions remain about how to inform. In this sense, the problems of improving rodent damage control parallel those of other agricultural production technologies. Effective communication methods will vary with social and cultural traditions which can pose some formidable constraints in rodent control technology transfer. For example, Adhikarya and Posamentier (1987) tested various Bangladesh extension materials for farmer acceptance and found that some symbols and pictures in extension materials had to be eliminated or changed because of adverse meanings or implications previously unknown to them. Elsewhere, radio broadcasts have been used to inform farmers and widely distributed posters have been used in control campaigns introducing new national programmes. Introduction of rodent control information through schools and local markets, training sessions involving key farmers or farmer groups, and selection of demonstration farms are other approaches that may have value in some situations.

Reasons for slow progress

Sustained adoption of improved rodent damage control methods, even those which have been properly researched, developed, demonstrated and extended to farmers, has been low. Poor adoption is frequently blamed on costs of materials, limitations on labour, the unpredictable nature of crop damage, or the lack of information and appropriate materials. Subsistence farmers may have little incentive to control rodents or to increase crop yields until available land becomes limited or markets for crops are developed. Without some type of credit programme, even progressive farmers may lack money required for preharvest investments in crop protection materials, or they may be reluctant to borrow even when credit is available.

For the most part, farmers rely on their own experience and that of their neighbours in making decisions on adopting new technology. Substantial benefits in farmers' fields create awareness, but, as many programmes have learned, creating awareness is much easier to accomplish than motivating farmers to use new technology. Of course from the farmer's standpoint, rodent damage is only one of many risk factors that can result in crop losses; similarly, crop protection is only one of many aspects of crop production that a farmer must manage (and finance) year after year. In many tropical agricultural situations, a conservative attitude by farmers in adopting and investing in new technology is to be expected. This expectation should be a part of programme development and planning.

Poor programme results can also be expected if involvement of government and rapport with farmers is lacking. However, involvement of governments should not result in farmer dependence, which can be a major hindrance to establishing rodent damage control as an on-going crop protection effort. The time and effort involved in organizing and managing effective government rodent control programmes is much more than most realize. A national programme in Taiwan took 6 months to prepare and 2 months to evaluate in addition to the actual control operation (Ku, 1984). The marketing of ineffective or adulterated rodent control products has resulted in farmers avoiding further use of similar materials, good or bad. Government involvement in quality assurance and regulation of agricultural chemicals may help prevent this lack of farmer confidence. Increasing national crop yields may prove to take decades of change – in social attitudes, agricultural policies, farmer awareness and knowledge, and in developing the necessary infrastructure and support systems in rural areas. Continued effort is needed to ensure that development of technology and programmes for controlling rodent damage is coordinated and keeps pace with other efforts in agricultural development.

The need for dynamic rodent damage control programmes

International agency support for research, training, operations, and coordination has been an initial driving force in the development of many national programmes. The publication of results of research and development activities related to rodent control has made much valuable information readily available, including crop damage estimates for several important rodent species. National priorities are influenced mostly by economic factors and without a description of the extent of losses, rodent control will likely remain a low priority (Richards, 1988). Programmes that have had more success than others have identified economic losses and used the results either to initiate programmes or strengthen existing ones.

In many surveys, farmers in the tropics rank rodents among their most significant crop pests. This view is often endorsed by government plant protection officials. However, vertebrate pests usually have been viewed as too different or unique to be considered in national crop protection programmes. Rarely have rodent damage management programmes been included with other IPM efforts. National crop production/protection packages and recommendations could easily incorporate available information on rodent control technology, thus allowing the strategies to achieve technology adoption to be developed and implemented in a coordinated manner to provide comprehensive information to farmers.

Rodent pest management is not a temporary problem. Changes in agricultural habitats, introduction of new crop varieties and farming practices, development of improved irrigation, production of more crops per year, and the continued rapid growth of human populations will cause many ecological changes that affect rodent behaviour, population patterns, and crop damage. If control methods and management programmes are dynamic enough to account for these changes, the successes achieved thus far will be maintained and progress in rodent damage control can continue.

References

Adhikarya, R. and Posamentier, H. (1987) *Motivating Farmers for Action*. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Eschborn, Germany, 209 pp.

Advani, R.I. and Mathur, R.P. (1988) Reduction in rodent populations through intermittent control operations in the cropping ecosystem of the Indian desert. In: Crabb, A.C. and Marsh, R.E. (eds) *Proceedings 13th Vertebrate Pest Conference*. Monterey, California, 1–3 March, pp. 119–122.

Askham, L.R. (1990) Effect of artificial perches and nests in attracting raptors to orchards. In: Davis, L.R. and Marsh, R.E. (eds) *Proceedings 14th Vertebrate Pest Conference*. Sacramento, California, 6–8 March, pp. 144–148.

Atkinson, I.A.E. (1985) *The Spread of Commensal Species of* Rattus *to Oceanic Islands and*

Their Effects on Island Avifaunas. International Council for Bird Preservation, Technical Publication no. 3, pp. 35–81.

Benigno, E.A., Jackman, J.A., Fiedler, L., Hoque, M.M. and Palis, F.G. (1983) RATPOP: a population model of the ricefield rat, *Rattus rattus mindanensis* Mearns. *Philippine Agriculturist* 66, 379–396.

Bernard, J. (1977) Damage caused by the rodents Gerbillidae to agriculture in North Africa and countries of the Middle East. *EPPO Bulletin* 7, 283–296.

Buckle, A.P. (1988) Integrated management of rice rats in Indonesia. *FAO Plant Protection Bulletin* 36, 111–118.

Buckle, A.P., Rowe, F.P. and Yong, Y.C. (1980) Field trials of two warfarin baiting methods against the rice field rat (*Rattus argentiventer*) in peninsular Malaysia. *Malaysian Agricultural Journal* 52, 78–95.

Buckle, A.P., Huson, L.W. and Rowe, F.P. (1984) The frequency distribution of rat damage in rice fields and its implications for the cost–benefit of control programmes. In: Dubock, A.C. (ed.) *Proceedings of a Conference on the Organisation and Practice of Vertebrate Pest Control.* Elvetham Hall, UK, 30 August–3 September, 1982, pp. 289–296.

Buckle, A.P., Yong, Y.C. and Abdul Rahman, H. (1985) Damage by rats to rice in South-east Asia with special reference to an integrated management scheme proposed for peninsular Malaysia. *Acta Zoologica Fennica* 173, 139–144.

Cartaya, E. and Aguilera, M. (1985) Estudio de la comunidad de roedores plaga en un cultivo de arroz. *Acta Cientifica Venezuela* 36, 250–257.

Castillo, H.A. (1990) Un efectivo control de roedores en arrozales. *Agro Profesional* 2, 27–28.

Colvin, B.A. (1991) Habitat manipulation for rodent control. In: Quick, G.R. (ed.) *Rodents and Rice.* International Rice Research Institute, Los Baños, pp. 61–64.

Dizon, R.C. (1978) Diffusion of a rat control innovation among Masagana 99 farmers in Laguna, Philippines. MSc thesis, University of the Philippines, Los Baños, 69 pp.

Drummond, D. (1991) Rodent control programs to increase rice yield: the present situation and recommendations for the future. In: Quick, G.R. (ed.) *Rodents and Rice.* International Rice Research Institute, Los Baños, pp. 27–30.

Dubock, A.C. (1982) Pulsed baiting – a new technique for high potency, slow acting rodenticides. In: Marsh, R.E. (ed.) *Proceedings 10th Vertebrate Pest Conference.* Monterey, California, 23–25 February, pp. 123–136.

Elias, D.J. and Fall, M.W. (1988) The rodent problem in Latin America. In: Prakash, I. (ed.) *Rodent Pest Management.* CRC Press, Boca Raton, pp. 13–28.

Espinoza, H.R. and Rowe, F.P. (1979) Biology and control of the cotton rat *Sigmodon hispidus*. *Pest Articles and News Summaries* 25, 251–256.

Fall, M.W. (1977) *Rodents in Tropical Rice. Technical Bulletin no. 36.* College of Agriculture, University of the Philippines, Los Baños, 37 pp.

Fall, M.W. (1991) Controlling rice losses to rodents in rural communities. In: Quick, G.R. (ed.) *Rodents and Rice.* International Rice Research Institute, Los Baños, pp. 7–16.

Fiedler, L.A. (1988a) Rodent pest problems and management in eastern Africa. *FAO Plant Protection Bulletin* 36, 125–134.

Fiedler, L.A. (1988b) Rodent problems in Africa. In: Prakash, I. (ed.) *Rodent Pest Management.* CRC Press, Boca Raton, pp. 35–66.

Fiedler, L.A., Fall, M.W. and Reidinger, R.F. Jr (1982) Development and evaluation of methods to reduce rat damage to coconut in the Philippines. In: Marsh, R.E. (ed.) *Proceedings 10th Vertebrate Pest Conference.* Monterey, California, 23–25 February, pp. 73–79.

Fiedler, L.A., Fall, M.W., Bruggers, R.L. and DeGrazio, J.W. (1991) Rodent and bird problems in agriculture and their management in developing countries. In: Magallona, E.D. (ed.) *Proceedings 11th International Congress of Plant Protection.* Vol. I. Manila, Philippines, pp. 65–73.

Govinda Raj, G. and Srihari, K. (1987) Effective period for the control of gerbils – *Tatera indica cuvierii* (Waterhouse) in dry land crops. *Zeitschrift für Angewandte Zoologie* 74, 231–241.

Greaves, J.H. (1989) Rodent pests and their control in the Near East. *FAO Plant Production and Protection Paper 95.* FAO, Rome, 112 pp.

Holler, N.R., Lefebvre, L.W. and Decker, D.G. (1981) Ecology and control of rodent depredations to Florida sugar cane. In: *Proceedings Second International American Sugar Cane Seminar, Insect and Rodent Pests.* Miami, Florida, pp. 183–188.

Hopf, H.S., Morley, G.E.J. and Humphries, J.R.O. (1976) *Rodent Damage to Growing Crops and to Farm and Village Storage in Tropical and Subtropical Regions.* Centre for Overseas Pest Research and Tropical Products Institute, Ministry for Overseas Development, London, 115 pp.

Hoque, M.M. and Olvida, J.L. (1986) Rodent activity and damage in clean and weedy cropfields. *Philippine Agriculturist* 69, 329–340.

Hoque, M.M., Sanchez, F.F. and Benigno, E.A. (1988) Rodent problems in selected countries in southeast Asia and islands in the Pacific. In: Prakash, I. (ed.) *Rodent Pest Management.* CRC Press, Boca Raton, pp. 85–99.

Howard, W.E., Marsh, R.E. and Corbett, C.W. (1985) Raptor perches: their influence on crop protection. *Acta Zoologica Fennica* 173, 191–192.

Howard, W.E., Palmateer, S.D. and Marsh, R.E. (1990) Differential toxicity and taste aversion to strychnine of three subspecies of the California ground squirrel (*Spermophilus beecheyi*). In: Davis, L.R. and Marsh, R.E. (eds) *Proceedings 14th Vertebrate Pest Conference.* Sacramento, California, 6–8 March, pp. 107–112.

Hubert, B. and Adam, F. (1985) Outbreaks of *Mastomys erythroleucus* and *Taterillus gracilis* in the Sahelo-Sudanian zone in Senegal. *Acta Zoologica Fennica* 173, 113–117.

Hygnstrom, S.E. (1990) The evolution of vertebrate pest management – the species versus systems approach. In: Davis, L.R. and Marsh, R.E. (eds) *Proceedings 14th Vertebrate Pest Conference.* Sacramento, California, 6–8 March, pp. 20–24.

Inchaurraga, L. (1973) Prevencion del ataque de ratas en arroz de riego con laminas de zinc. *Bol. CIARCO* 3, 166–169.

Jackson, W.B. (1977) Evaluation of rodent depredations to crops and stored products. *EPPO Bulletin* 7, 439–458.

Kaukeinen, D.E. (1987) Management of harmful rodents: published literature sources. In: Richards, C.G.J. and Ku, T.Y. (eds) *Control of Mammal Pests.* Taylor & Francis, London, pp. 387–401.

Ku, T.Y. (1984) Distribution and population fluctuations of field rodents and their control in Taiwan. In: Dubock, A.C. (ed.) *Proceedings of a Conference on the Organisation and Practice of Vertebrate Pest Control.* Elvetham Hall, UK, 30 August–3 September, 1982, pp. 487–519.

Kverno, N.B. *et al.* (1971) Exploratory studies to reduce cotton rat damage to rice in Nicaragua. Unpublished report. Denver Wildlife Research Center, 22 pp.

Lam, Y.M. (1988) Rice as a trap crop for the rice field rat in Malaysia. In: Crabb, A.C. and Marsh, R.E. (eds) *Proceedings 13th Vertebrate Pest Conference*. Monterey, California, 1–3 March, pp. 123–128.

Lee, L.L., Howard, W.E. and Marsh, R.E. (1990) Acquired strychnine tolerance by pocket gophers. In: Davis, L.R. and Marsh, R.E. (eds) *Proceedings 14th Vertebrate Pest Conference*. Sacramento, California, 6–8 March, pp. 87–90.

Lefebvre, L.W., Ingram, C.R. and Yang, M.C. (1978) Assessment of rat damage to Florida sugarcane in 1975. *Proceedings of the American Society of Sugar Cane Technologists* 7, 75–80.

Leirs, H., Verhagen, R. and Verheyen, W. (1990) The use of rainfall patterns in predicting population densities of multimammate rats, *Mastomys natalensis*. In: Davis, L.R. and Marsh, R.E. (eds) *Proceedings 14th Vertebrate Pest Conference*. Sacramento, California, 6–8 March, pp. 135–138.

Litsinger, J.A., Price, E.C. and Herrera, R.T. (1980) Small farmer pest control practices for rainfed rice, corn, and grain legumes in three Philippine provinces. *Philippine Entomologist* 4, 65–86.

Litsinger, J.A., Canapi, B. and Alviola, A. (1982) Farmer perception and control of rice pests in Solana, Cagayan Valley, a pre-green revolution area of the Philippines. *Philippine Entomologist* 5, 373–383.

Marsh, R.E. (1981) The unrealistic IPM parameters of vertebrate pest control. *Great Plains Wildlife Damage Control Workshop* 5, 109–110.

Martinez-Palacios, C., Chavez-Sanchez, C., Ituarte-Soto, R. and Marquez-Moreno, A. (1978) Warfarin baits bagging to control the population of cotton rats in field crops in Sinaloa, Mexico. In: Howard, W.E. (ed.) *Proceedings 8th Vertebrate Pest Conference*. Sacramento, California, 7–9 March, pp. 226–230.

Mathur, R.P. and Prakash, I. (1984) Field trials of brodifacoum, chlorophacinone and coumatetralyl against desert rodents in India. *Tropical Pest Management* 30, 59–61.

Moors, P.J. (1985) Eradication campaigns against *Rattus norvegicus* on the Noises Islands, New Zealand, using brodifacoum and 1080. *International Council for Bird Preservation, Technical Publication no. 3*, pp. 143–155.

Myllymaki, A. (1987) Control of rodent problems by the use of rodenticides: rationale and constraints. In: Richards, C.G.J. and Ku, T.Y. (eds) *Control of Mammal Pests*. Taylor & Francis, London, pp. 83–111.

Poché, R.M., Mian, Md.Y., Haque, Md.E. and Sultana, P. (1982) Rodent damage and burrowing characteristics in Bangladesh wheatfields. *Journal of Wildlife Management* 46, 139–147.

Poulet, R.R. (1985) The ecological basis of forecasting rodent outbreaks in a Sahelian agrosystem. *Acta Zoologica Fennica* 173, 107–111.

Prakash, I. and Mathur, R.P. (1988) Rodent problems in Asia. In: Prakash, I. (ed) *Rodent Pest Management*. CRC Press, Boca Raton, Florida, pp. 67–84.

Quick, G.R. (1991) *Rodents and Rice*. International Rice Research Institute, 132 pp.

Quick, G.R. and Manaligod, H.T. (1991) Some aspects of physical control of rice rodents. In: Quick, G.R. (ed.) *Rodents and Rice*. International Rice Research Institute, Los Baños, Philippines, pp. 31–34.

Rampaud, M. and Richards, C.G.J. (1988) Rodent pest management put into practice.

FAO Plant Protection Bulletin 36, 135–143.

Reissig, W.H., Heinrichs, E.A., Litsinger, J.A., Moody, K., Fiedler, L., Mew, T.W. and Brown, A.T. (1985) *Illustrated Guide to Integrated Pest Management in Rice in Tropical Asia.* International Rice Research Institute, Los Baños, 411 pp.

Rennison, B.D. (1980) *Monitoring Rat Damage in West Malaysia.* A consultant's report and recommendations for the Malaysian/UK Rice Rat Control Project. Overseas Development Administration, UK, 29 pp.

Richards, C.G.J. (1988) Large-scale evaluation of rodent control technologies. In: Prakash, I. (ed.) *Rodent Pest Management.* CRC Press, Boca Raton, Florida, pp. 269–284.

Robbins, C.B. and van der Straeten, E. (1989) Comments on the systematics of *Mastomys* Thomas 1915 with the description of a new West African species (Mammalia: Rodentia: Muridae). *Senckenbergiana Biologica* 69, 1–14.

Smal, C.M., Halim, A.H. and Amiruddin, M.D. (1990) Predicative modelling of rat populations in relation to use of rodenticides or predators for control. *PORIM Occasional Paper no. 25.* Oil Palm Research Institute of Malaysia, 55pp.

Smith, R. F. (1970) Pesticides: their use and limitations in pest management. In: Rabb, R.L. and Guthrie, F.E. (eds) *Concepts of Pest Management.* North Carolina State University, Raleigh, pp. 103–118.

Smith, R. F. and Calvert, D.J. (1978) Insect pest losses and dimensions of the world food problem. In: Pimentel, D. (ed.) *World Food, Pest Losses, and the Environment.* AAAS Selected Symposium 13, Westview Press, Boulder, Colorado, pp. 17–38.

Suliman, S.M., Shumake, S.A. and Jackson, W.B. (1984) Food preference in the Nile rat *Arvicanthis niloticus. Tropical Pest Management* 30, 151–158.

Sultana, P. and Jaeger, M.M. (1992) Control strategies to reduce preharvest rat damage in Bangladesh. In: Borrecco, J.E. and Marsh, R.E. (eds) *Proceedings 15th Vertebrate Pest Conference.* Newport Beach, California, 3–5 March, pp. 261–267.

Sumañgil, J.P. (1991) Control of ricefield rats in the Philippines. In: Quick, G.R. (ed.) *Rodents and Rice.* International Rice Research Institute, Los Baños, pp. 34–47.

Taylor, K.D. (1968) An outbreak of rats in agricultural areas of Kenya in 1962. *East African Agriculture and Forestry Journal* 34, 66–77.

Telford, S.R. Jr (1989) Population biology of the multimammate rat, *Praomys (Mastomys) natalensis* at Morogoro, Tanzania, 1981–1985. *Bulletin Florida State Museum, Biological Sciences* 34, 249–287.

Tomich, P.Q. (1986) *Mammals in Hawaii,* 2nd edition. Bishop Museum Press, Honolulu, 375 pp.

Williams, J.M. (1985) Interrelationship and impact on agriculture of *Rattus* species in the tropical South Pacific. *Acta Zoologica Fennica* 173, 129–134.

Wood, B.J. (1971) Investigations of rats in rice fields demonstrating an effective control method giving substantial yield increase. *Pest Articles and News Summaries* 17, 180–193.

Wood, B.J. (1991) Ricefield rats in southeast Asia. In: Quick, G.R. (ed.) *Rodents and Rice.* International Rice Research Institute, Los Baños, pp. 55–60.

Wood, B.J. and Chung, G.F. (1990) Warfarin resistance of *Rattus tiomanicus* in oil palms in Malaysia and the associated increase of *Rattus diardii.* In: Davis, L.R. and Marsh, R.E. (eds) *Proceedings 14th Vertebrate Pest Conference.* Sacramento, California, 6–8 March, pp. 129–134.