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RODENTS IN TROPICAL RICE

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Introduction

Rodents of many species damage rice throughout its growing period and cause waste and contamination in storage. They cut or pull recently transplanted seedlings from the ground, and cut or open growing stems (tillers) to reach the developing heads. When the grain heads have developed, rats cut or pull down plants to eat the grain, much of which drops on the ground and is thus lost from the harvest. Some species accumulate extensive grain stores in their burrows.

Often, rat damage during the early crop stages is undetected. Damage to green plants is virtually invisible from a few feet away. Failure to examine plants closely can easily mislead anyone into unawareness of damage. By the time grain heads develop and damaged plants become more conspicuous, it is usually too late to initiate effective rat control.

Farmers and technicians throughout the world employ a variety of methods for control of field rats, usually with limited success. Most of the methods discussed in technical papers or reported in popular accounts have been devised for rat control in the suburban or urban environments of temperate countries. This report will provide agricultural technicians in the tropics with a summary of information on rodent problems in rice and provide brief discussions of all the major rat control methods that have been used or proposed for these situations. Because much of the evaluation of rat control methods in rice fields in recent years has been centered in Southeast Asia, particularly in the Philippines, many of the examples used here are drawn from that region. Application of these general discussions to areas involving other agricultural environments or other rodent species may be helpful, but this should be qualified by the need to approach each pest situation without preconceptions. Field trials should always be conducted in each situation before technical recommendations are made.

Characteristics of Rodents

There are more than 6,000 different kinds of rodents; nearly 600 of these belong to the genus *Rattus* and are called "rats," although many other rodent species are also commonly referred to as rats. The term "mouse" is often applied to smaller rodents in a particular country. However, a "mouse" in one country may be larger than a closely related species of "rat" in another. Local common names may be equally confusing; several different rodent species are commonly called "rice field rats" in different rice-growing countries. I have avoided the use of common names throughout the paper, except for the general terms "rat" and "rodent."

Most rodents are mainly nocturnal in their activity and somewhat secretive in their habits. One of the common characteristics of all rodents are the sharp upper and lower incisor teeth. These protruding front teeth are continuously growing. They are used for gnawing, digging, obtaining food, and fighting.

Another obvious character of many species of rodents is their long, slender tail. A tail may be helpful in balancing, but it is not used for grasping. Most rats are good climbers. They are also good swimmers. Rodents range in size from the small harvest mice, *Micromys minutus*, which weigh from 5 to 7 g, to the South American capybaras, *Hydrochoerus hydrochoerus,* which weigh more than 50 kg (Walker, 1968). Most rats weigh less than 500 g and have total lengths (head, body, and tail) of less than 0.5 m.

Like many other nocturnal mammals, rodents have relatively poor eyesight and apparently cannot distinguish colors. Their other senses more than make up for this deficiency. Hearing, touch, smell, and taste are well developed. The upper range of sound detection is somewhat higher than in man. Some attempts have been made to use this sensitivity to high-frequency sound to repel rodents from storage areas. The long whiskers or vibrissae around a rat's muzzle are highly sensitive to touch and are probably useful in following runways or burrows. Excellent senses of taste and smell probably account for many of the stories of rat intelligence. Rats can detect chemicals at low concentrations, and because of the arrangement of their teeth, can carefully investigate and even nibble unfamiliar materials without actually taking them inside the mouth.

Species and Distribution

Several species of rats are known to be pests of rice in the Philippines. Recent collections throughout the country indicate that *Rattus argentiventer, Rattus rattus mindanensis, Rattus exulans,* and *Rattus norvegicus* are the major species inhabiting rice lands (Barbehenn *et al.*, 1972; 1973). Taxonomic designation of many of the Philippine *Rattus* groups has not been clarified. For example, the names *R.r. umbriventer, R.r. mindanensis,* and *R.r. argentiventer* have at various times been used synonymously for rats found in rice fields. Recently, the synonymy between *umbriventer* and *argentiventer* was recognized (Barbehenn *et al.*, 1972). By convention, the names *R. argentiventer* and *R.r. mindanensis* are now used by many biologists in the region to designate the most important Philippine crop pests.

R. argentiventer occurs as a major rice pest in most of the countries of Southeast Asia. In the Philippines, populations of this species have been found only in the islands of Mindanao and Mindoro where they are the predominant rice field species (Barbehenn *et al.*, 1972). Although the distribution of *R.r. mindanensis* is apparently restricted to the Philippines, additional collections may show otherwise. This is a highly adaptable rat that occurs in most types of habitats and damages a variety of crops; it is also a common occupant of houses and storage areas and is the major rice field rodent pest in Luzon and the Visayas.

R. exulans and *R. norvegicus* are widely distributed in Southeast Asia and are found throughout the Philippines. They often occur in small numbers in rice fields together with *R.r. mindanensis* or *R. argentiventer. R. exulans* is a major rice field pest in Palawan, while *R. norvegicus* occurs sometimes as a field pest in Cebu.

Of the more than 30 kinds of rodents in the Philippines, most live in forested or mountainous areas and are only rarely found in lowland fields. In other Southeast Asian countries, however, several other species of rodents in addition to *R. argentiventer* are recognized rice pests. Often several species of rodents may inhabit the same field simultaneously, raising the possibility that control methods which are too selective could lead to population increases of one or more of the competing species.

Ecology

Like all other animals, rats require food, water, and shelter to survive. However, they are very adaptable in their behavior patterns and can survive and reproduce successfully under a variety of environmental conditions. When conditions change, they may modify their behavior to suit the new situation. *R.r. mindanensis* is a good example of a highly adaptable rodent. It has been found in the Philippines from mountain tops to the seashore. It thrives in agricultural field crops, as well as in tree plantations, and is commonly found in towns or in storage areas.

The carrying capacity of an environment refers to the number of animals it can support. The number of rats that can populate a particular habitat depends upon the combination of resources that are available. If one factor is in short supply, fewer rats can survive. The condition that is most important in establishing the carrying capacity in any particular area (food or nesting sights could be examples) is called a limiting factor. As an animal population begins to use up the available resources, behavioral and physiological stress may occur and population growth begins to level off. Under different conditions, this adjustment may take place by increased mortality, decreased reproduction, emigration, or some combination of these forces. If the environment remains stable, a rat population may fluctuate about the carrying capacity indefinitely.

In lowland agricultural areas in the tropics, rat populations rarely, if ever, reach the carrying capacity of an environment while a crop is growing. This is largely due to the relatively short growing period of many crops and the seasonal nature of agriculture. The carrying capacity of such an area as a rice field is continuously changing - first increasing rapidly as the crops grow then decreasing sharply when the crop is harvested. The interacting forces of birth, death, and movement provide means for rat populations to adjust rapidly to these changing conditions. When non-agricultural areas supply adequate food, water, and shelter near an area of harvested fields, many animals can survive the period between crops.

In irrigated areas where farmers often choose widely differing planting dates or where rice varieties mature at different times, animals can easily move to nearby fields when those where they have lived are harvested, and can move on to still others after that. Because the patterns of lowland rice agriculture in Southeast Asia produce continuously changing micro-environments, the local density of the rat population may fluctuate greatly. The time and magnitude of population peaks may be largely determined by the rate of immigration of rats from surrounding areas, the reproductive rate of resident animals, and the growing period of the crop (i.e., the length of time that the increase from immigration and reproduction can accumulate). Similarly, population lows may be determined by the length of time between crops and the quantity and quality of non-agricultural habitats which act as population reservoirs.

Reproduction

Within the genus *Rattus*, a variety of factors have been suggested as controlling or influencing reproduction. Some tropical rodents have been reported to be seasonal breeders. In rainfed rice areas in the Philippines, where only one crop is grown, *R.r. mindanensis* breeds only during one season - the crop period. In irrigated areas, where two rice crops are grown, there are two peaks of reproduction both coinciding with the two crop periods (Uhler, 1966; Sanchez *et al.*, 1971; Marges, 1972). However, populations of *R.r. mindanensis* with high pregnancy rates have been found every month of the year in maturing rice or other favorable habitats in the Philippines. Since rainfall directly or indirectly determines the general condition of habitat at a particular season (except in areas with deep wells, reservoirs, or stable natural irrigation), rodent reproduction often appears to follow a seasonal pattern. *R.r. mindanensis* and probably other species of field rats breed whenever adequate food, water, and shelter are available, and when there is freedom from disturbance. In many instances, the apparent seasonal reproductive cycles in tropical rats probably relate to the seasonal changes in the quantity and quality of cover and food.

Breeding frequency, litter size, and survival of young animals vary considerably from place to place and from one part of the year to another. These variations probably relate to weather and habitat conditions, diet, and to population density itself. The inhibiting effect of population stress on the reproductive capacity of several species of rodents, including *R. norvegicus*, has been well documented (Christian and Davis, 1964). Many studies indicate that habitat quality can have an important influence on reproduction and growth of rodents. In one comparative study, *R.r mindanensis* in lowland irrigated areas bred more times per year, produced more young per litter, and grew to larger adult size than the same species in rainfed areas (Sanchez *et al.*, 1971). The biological factors involved in these differences are not yet understood. However, similar observations on *R. norvegicus* in different habitats have shown growth to be closely related to the quality of food in the diet (Davis, 1949).

Population Levels

Although it is not necessarily important to know the number of animals present in designing rat control programs, many technicians are asked by farmers, "How many rats do I have in my fields?".

Rough measurements of rat populations in Philippine rice fields made with trap grids have indicated that numbers in mature rice usually range from about 20 to 200 per hectare. Before planting, when food and shelter are limited, attempts to count the animals present in burrows or other shelters in the fields have resulted in estimates of 0 to 12 per hectare depending perhaps on the amount of shelter present in the fields. After harvest, when most shelter has been removed, rats are much more conspicuous. Great numbers of them may concentrate in small areas of sheltering weeds or stubble. It is often at this time that farmers become concerned about rat control because they see many animals. When food and habitat are favorable in adjacent, non-agricultural habitats, rat populations may reach spectacular numbers. Libay and Fall (1976), for example, reported breeding rat populations of more than 10,000 animals per hectare in marshes bordering agricultural lands in the Philippines.

Feeding Patterns

Numerous studies with wild *R. norvegicus* indicate that rats sample most food materials within their home range. Even where favored food is abundant, they tend to choose a varied diet (Barnett, 1963). In some situations, rats may be initially shy of new objects or unfamiliar foods. Preliminary studies on bait acceptance show that *R.r. mindanensis* consumes little food from newly placed bait stations for the first one or two days.

A detailed study of the stomach contents of *R.r. mindanensis* from rice fields in Central Luzon (Tigner, 1972) showed that rice and several kinds of weeds and insects were the items most frequently eaten. Of course, the types of foods found in a rice field may change considerably during a season. One might speculate that the amount of rice damage is inversely related to the availability of preferred alternative foods in a paddy.

Feeding behavior of individual animals also varies considerably. Measurements of rice tiller cutting by *R.r. mindanensis* were made in field cages in six different ages of rice under both wet-season and dry-season crop conditions (West *et al.*, 1975a). Cutting was heaviest during earlier growth stages when rats were damaging the developing tillers.

After the panicles had matured, feeding activity shifted to the grains, and tiller cutting decreased significantly. Cutting rates for individual rats ranged from 1 to 309 tillers per night. Average cutting rates during the wet season were nearly twice those during the dry season. Variation in the behavior of individual animals may be an important factor in understanding the unpredictable occurrence of rat damage.

Harborage

The presence of shelter and nesting sites in the area is another important factor that permits the survival of rat populations. In rice fields, the quantity and quality of the available harborage usually varies considerably from place to place and season to season. Sumangil (1972) reported short-range seasonal movements among *R. argentiventer* in Cotabato, Philippines. The animals retreated from the fields to nearby wastelands after harvest, then returned to the planted fields during the wet season and occupied burrows in paddy dikes.

Paddy dikes, however, are only one of many kinds of harborage provided by rice fields. Canal banks, sheds, threshing sites, and small inter-field waste areas or groves all provide areas of rat harborage. These may be particularly important in helping maintain rat populations between crops.

Examination of a number of straw piles in Laguna, Philippines, during the period before planting of the dry-season rice crop by Sanchez *et al.* (1972) revealed an average density of two rats per pile, with some of the females pregnant. In the areas examined, the density of piles was about six per hectare (about one in each paddy). Farmers generally try to burn the piles left at the threshing sites, but rain often prevents complete burning. Observations during subsequent crops suggest that partial burning of such piles makes little difference in their suitability for rats, and that animals continue to use them for burrowing and as food sources until the next crop is well developed.

When rice is several weeks old, it provides excellent shelter, and many animals stop using burrows. Sanchez *et al.* (1971) used miniature radio transmitters to follow the movements of 11 *R. argentiventer* in maturing rice in Cotabato, Philippines. Over several days of periodic observations, only 13 of 33 rats located during daylight were using burrows; the other 20 were apparently resting in standing rice or in nearby uncultivated areas. At night, the animals were active, presumably feeding in the rice fields.

R.r. mindanensis commonly builds field nests after the rice is several weeks old. The nests are ball-shaped structures made by weaving together leaves and stems of a rice hill. Unlike the obvious burrows in paddy dikes, they are rather difficult to find except by very careful examination of the paddy. Survival of the young produced in field nests may be greatly reduced because the nests are destroyed at harvest, and any animals not yet independent of the mother, probably die.

Floods

Field areas in many parts of the Philippines and other Southeast Asian countries are subject to severe floods during the monsoon season. Many farmers wonder what effects these floods have on rat populations.

When the area occupied by rats is flooded, the animals climb higher into the vegetation or move to higher ground. (Poisoning operations are sometimes carried out while rats are crowded this way in isolated high areas). When flood waters cover a wide area with few high spots, rats may move considerable distances to escape, but many may perish. Surprisingly, rats return rapidly to fields when the water recedes. However, no studies have been carried out to determine whether animals displaced by floods return to the same location they have left.

Population pressure, lack of suitable shelter, and food shortage may be reasons why rats rapidly redistribute over available habitat after floods. J. P. Sumangil (personal communication), who observed known field areas in Central Luzon after the serious flash-flooding in July 1972, found that wide areas covered by several feet of water (and presumably cleared of rats) were repopulated within 2 weeks after the waters receded. In areas that remain flooded for longer periods, rats often build nests in floating vegetation and maintain active breeding populations.

Economic Losses

It is generally agreed that rat damage can be an extremely serious agricultural problem. However, crop losses caused by rats and other vertebrate pests are difficult to estimate in economic terms and cannot usually be determined on experiment station plots. This common inability to express rodent damage in economic terms is probably one of the principal reasons why control of rat damage has been given much less attention than that caused by insects and plant diseases.

Rat damage to rice appears to occur in two basic patterns, one superimposed upon the other. The first is chronic damage, which occurs every year in every area and may be highly variable, even from field to field. The second pattern, which is poorly understood, is that of exceptionally heavy damage associated with rapid increases in the numbers of rats over wide areas.

Little information on actual losses caused by rodents is available. Pre-harvest damage surveys conducted in nearly 1,600 rice fields distributed throughout the Philippines revealed some rat damage in about 90 per cent of the fields (Sanchez *et al.*, 1971). Counts in these fields showed that cut stems averaged about 4 per cent of the total stems at harvest, but much early damage is missed in such surveys because early cuts are no longer visible at harvest. Stem cutting in the survey paddies reached as high as 58 per cent. Considerable variation in the extent of damage is common, even from paddy to paddy.

Crops in fields near unfarmed areas and those bordering roads or irrigation canals are often more heavily damaged than others, presumably because of the additional rat harborage provided nearby. It is commonly observed that rice maturing much earlier or later than that in surrounding fields receives especially heavy damage because of local movements of rats. Recent estimates in the Philippines (Sanchez *et al.*, 1974) indicate that more than 600,000 hectares in major rice-producing provinces were potentially susceptible to heavy rat damage.

Few studies have been made of the relationship between the stem cutting that is usually taken as an indication of damage and the actual yield reduction caused by rats. Tillers suffering early damage may regenerate, and may show no physical damage by the time of harvest. On the other hand, heavy early cutting may delay maturation of panicles and drastically reduce yields. When portions of the tillers in a rice hill are cut, the remaining panicles tend to compensate partially by producing more grains or by increased filling of the remaining grains, depending on the stage at which damage occurs. However, when regenerating tillers are at different stages of development, the grains that are not fully developed or those that are too dry may be lost at harvest, thus greatly reducing yield.

Sanchez *et al.* (1972) reported an experiment in which 45 per cent of the tillers of a late-maturing variety (120-day growing period) were mechanically cut at different crop stages. All tillers cut 4 weeks after transplanting regenerated by harvest, but yield was reduced by about 7 per cent. When 45 per cent of the tillers were cut 9 weeks after transplanting, only 37 per cent could be detected at harvest and yield was reduced by 27 per cent. In another experiment (Rodent Research Center, unpublished), yields were compared between hills that had been totally cut by rats 4 to 7 weeks after transplanting and hills that had received no damage at all. Although no cut stems were detected in either group at harvest, yields from the hills that received early damage were reduced by more than 50 per cent.

In controlled field experiments where rice crops have been substantially protected from rat damage, great differences in yield are often noted. Wood (1971) carried out baiting programs using a chronic rodenticide on two large rice field areas and compared yields with those of reference areas where a baiting program was not followed. He estimated that the yield reduction due to rats was greater than 60 per cent. In some areas of the Philippines, rat damage acts as a limiting factor on rice production, sometimes precluding successful production of crops during some parts of the year. In such situations, effective rat control can produce huge returns on investment.

Serious rodent outbreaks have occurred periodically in the Philippines and other parts of Southeast Asia. In the early 1950's for example, rat outbreaks on the island of Mindanao caused such extensive damage to rice and corn that the Philippine government undertook relief measures and massive control programs (Clark, 1958). The reasons for such outbreaks are not clearly established. One possible explanation may be the coincidence of planting schedules with weather patterns or other factors that favor heightened production of rodents in non-crop areas such as marshlands or second-growth forests (Libay and Fall, 1976). When the availability of alternative foods declines, or conditions become unfavorable, large numbers of rats may invade adjacent croplands. Another possible explanation may be that some rodent populations, when subjected to disorganizing influences such as major changes in habitat, may go through a period when the reproductive rate is excessively high. Others have suggested that such "rat outbreaks" are cyclic. Evidence to support any of these explanations, however, is lacking.

Heavy rat infestations tend to develop quickly and are somewhat unpredictable. Many factors may affect the degree of damage in a rice field; it is not uncommon to find apparently similar adjacent paddies with widely different amounts of rat damage. This variability, coupled with the small farm size in Southeast Asia, can result in tragic economic losses for individual farmers. On a national or global scale, the crop losses caused by rodents are matters of serious concern.

Signs of Infestation

It is frustrating for a farmer to realize when his crop has nearly matured, that undetected rat damage has reached significant proportions, for at that stage, little can be done. Since some control methods are costly in either materials or effort, farmers often do not look with favor on the idea of carrying out rat control programs before crop damage becomes evident (Anonymous, 1971). The intensity of damage seems to vary considerably, even from paddy to paddy, and farmers have no reliable ways of predicting probable losses except, perhaps, from the damage to previous crops.

Although tracks, burrows, trapping, or actual observation of animals may be of some help in assessing potential rodent problems, the most reliable means of detecting damage is probably periodic examination of the fields during the growing season by the farmer himself. Rat damage is rather distinctive and is not likely to be confused with that of other rice pests or diseases. Farmers must conduct such examinations by walking through the paddies and examining hills for cut tillers. If the damaged and undamaged tillers in a number of hills are counted, the calculated percentage can provide a useful index to the intensity of damage. Patterns of yield reduction tend to parallel the percentages of cut tillers, but under various conditions of damage and at different ages, actual losses may vary considerably. Yield losses appear to be greatly underestimated by cut-tiller indices obtained at harvest.

The occasional massive outbreaks of heavy rat damage that have been reported as occurring over wide areas or sometimes entire countries (Crucillo *et al.*, 1954; Clark, 1958; Madsen, 1966) are difficult for biologists to understand, and, given the existing techniques for assessing rodent populations, virtually impossible to predict. Unquestionably, such rodent outbreaks do occur. Reliable reports of heavy damage over wide areas of a country should signal priority attention by extension workers and biologists. It is, of course, equally important that distinctions be drawn, as early as possible, between large-scale outbreaks, localized heavy damage, and chronic damage situations of which farmers or extension workers suddenly become aware.

Protecting Crops

Whenever a pest control program of any size is contemplated, the problem should be defined, biological and ecological aspects assessed, and objectives of the program established. In rodent control programs for cities, villages, or houses, the primary objective is generally to reduce rodent populations to a low level and maintain that level for an extended period. This objective can often be accomplished by a combination of rat population reduction, improved sanitation (reduction of harborage and food sources) and ratproofing (structural repair or modification).

In contrast, the primary objective for most agricultural rodent control programs is protection of crops. Killing animals may or may not be necessary, depending on the situation and the control strategy chosen, but reduction of food supply and harborage may be difficult or impractical during the growing seasons, particularly in the tropics. Even effective population reduction programs can contribute little to crop protection if applied at a time which permits rat populations to recover before crops are susceptible to damage. While the choice of control methods for a particular situation is often a matter of debate, it is important that methods and programs be evaluated by their contribution to the prevention of crop damage, not by the number of dead rats that can be found or the amount of poison used.

Farmers' Attitudes

In vertebrate pest control as in other agricultural processes, an understanding of farmers' attitudes is just as important as technical knowledge in making control programs successful. Farmers throughout the world often tend to be reluctant to accept proposed changes in their agricultural practices. Among rice farmers in Southeast Asia, this trait has had some obvious advantages since stable agricultural practices developed over several centuries have been passed on from father to son. Over this long period, trial and error have shaped agricultural patterns that are well integrated with the local environmental conditions.

Farmers are not usually indifferent to obvious crop losses. Many farmers show considerable interest and exert considerable effort in controlling vertebrate pests even without the encouragement of extension agents. Their activities seem to fit a few common patterns. In general, action is taken only when damage or the pest animals become visible to the farmer. The methods chosen generally cost little or nothing but — and perhaps more important — tend to produce visible results. When control approaches that do not produce visible results are used, they generally require only one application, such as rat flags or coconut husks treated with strong smelling materials. These local methods are always logical, although they are sometimes based on false assumptions, and the animals do not always respond as anticipated.

Crop protection methods that produce immediate, visible results appear to have the best chance of rapid acceptance by farmers. It is fair to say, however, that poor results can be expected from a rat control program unless a farmer has a sincere interest in protecting his crop from pest damage and is willing to work for this goal with the same intensity that he pursues other agricultural activities.

Helping the farmer decide on the methods that are best for his problem may be difficult. But it is sometimes also important to help him decide when not to engage in rat control. Since catching rats or chasing birds from a field produces an immediate sense of accomplishment, these activities are sometimes pursued without regard to potential crop damage. Under some conditions, weed control or insect control may be better choices for the application of farm labor. It is always important to remind farmers to attend to all phases of agricultural production and crop protection to ensure good harvest.

Politics and Rat Control

Most Asian countries have long histories of severe rat damage to agricultural crops, particularly rice. At various times, local governments, national agencies, international organizations, and military units have tried in various ways to help farmers with this problem.

Rat control programs are sometimes geared for maximum political impact without enough attention to crop protection needs. Since rats are highly visible during post-harvest or inter-crop periods, these are often the times when political attention focuses on rat control. Massive campaigns during such periods can result in tremendous numbers of dead rats visible evidence of the campaign's "success." Although such approaches rarely contribute to the reduction of crop damage, the farmers may be placated until the next crop when a new cycle begins again. Such politically based rat campaigns have been used throughout the world, even in urban rat control. Particularly in situations where farmers visit their fields only occasionally (or not at all) between planting and harvest, everyone (farmers, technicians, and government officials) may be sincerely pleased with the results of the large campaign because no one is aware of crop damage during the growing season.

Bounty payments for carcasses or parts (such as tails or heads) of dead rats have often been instituted for agricultural rat control because of their political popularity. Bounty systems as a control method are discussed later. It should be noted, however, that they are hard to manage honestly, and can often result in concentrating rat control efforts away from the farmers' fields. Frequently, dead rats may be brought from outside the political district where payments are made.

Another political difficulty that may sometimes involve rat control technicians is the problem of refinancing crop loans. Often, rat damage severely reduces farm profits and may justify the delay of loan payments. Occasionally, particularly if technicians or bank officers are uninformed on damage problems, delay of loan payments is allowed on the basis of false, exaggerated, or unchecked reports of rat damage. Obviously, the agricultural technician or bank officer must play a key role in avoiding these difficulties by checking reports of severe damage before harvest.

In the long run, sound information and effective programs are nearly always more politically acceptable than "arm-chair" reports and contrived "success." Rat control technicians often provide the only communication channel between farmers and program administrators. They must take responsibility for providing biologically sound advice to both groups.

Environmental Impact

All types of crop protection cause changes in the environment – ideally, positive changes that result in reduced crop damage. It is important for biologists studying rodent control and technicians managing operational programs to consider the environmental effects of the methods they use or recommend.

One of the most common concerns with animal control programs in which poisons are used is their potential for affecting other (non-target) animals. The effects may be direct (for example, if ducks are killed by consuming zinc phosphide bait) or indirect (for example, if hawks are killed by residual 1080 in the carcasses of rats that had eaten treated bait). Often, such problems can be avoided by careful placement of bait, collection of dead animals, or selection of toxicants or concentrations that are not highly toxic to other animals.

More subtle, long term effects might be expected from control methods that involve major ecological changes, such as rearrangement of paddies, land contouring, or removal of trees, shrubs, or grasses adjacent to agricultural areas. Introduction of predatory animals has been tried in some areas as a means of rodent control, but such introductions may have far-reaching effects on other species of animals – for example, ground-nesting birds or domestic chickens – if the introduced predators find these animals easier prey than rats.

A relatively small number of species of vertebrate animals other than rodents inhabit rice fields when crops are growing. These species are principally marsh birds (rails and gallinules), seed-eating birds (weavers and sparrows, which may often cause crop losses themselves), several species of snakes (cobras, for example), lizards, frogs, toads, and sometimes fish. Hawks, civet cats, and other predators often forage in rice field areas, but such foraging is more common before planting or after harvest when prey animals are more visible and have less protective cover available than during the growing season when rat damage occurs. Wide rice field areas generally present so little cover and such an irregular food supply that populations of the larger predators cannot become established. In addition to wild vertebrates, a variety of domestic or semi-domestic animals – dogs, cats, water buffalo, goats, ducks, and chickens – may follow field dikes or be allowed to forage or glean in harvested fields. Some rat control methods, particularly if they are carried on haphazardly or practiced intensively after harvest, may present serious hazards to these animals.

In some situations, control methods that work well against one species of rodent may be less effective against others. To the extent that competition by a dominant species acts to depress the number of associated species, selective control programs may result in changes in the predominant kinds of rodents even during the maturation of a single crop. Few observations have been made of this occurrence, but it may be an important consideration where several different kinds of rodents occupy the same field areas.

The technicians should help farmers recognize the unique ecological aspects of their farms and choose effective crop protection methods that minimize hazard and undesirable environmental changes.

Control Strategies

A suitable strategy or plan of approach for dealing with a crop damage problem must be devised before any decision regarding the methods or materials to use is made. Before choosing a rodent control strategy, one should know, ideally, the species present, the species causing or likely to cause damage, value of the crop, value of the potential damage, possible control methods to be employed, cost and technical performance of each method, and the interaction of potential methods in a particular cultural-ecological setting. Although it is not always possible to make decisions under ideal conditions, each extension worker should recognize that sound recommendations depend on a thorough knowledge of the situation.

Crop protection strategies can be divided into two categories - those intended to stop damage and those intended to prevent it. The choice of strategy is largely independent of the particular control methods chosen. It may depend to a large extent upon the predictability of recurring rat damage and the attitude of the farmers toward investing labor and capital before a problem is evident (or on the ability of extension workers to change the farmers' attitudes). Without knowledge of the factors affecting a particular problem area, it is difficult to suggest that one approach will be better than the other. Damage-stopping strategies are the most widely applied, whereas preventive strategies are usually mentioned as ideal improvements upon which little research has been done (Davis, 1972).

One factor that may be helpful in deciding between these two basic approaches is the stability of pest populations (or of the agricultural environment itself) in a particular area. In situations where the rodent population is relatively stable or where the environment changes slowly (for example, a grove of coconuts or a grain warehouse), it may be practical to initiate control when damage or the pest population reaches a certain level or economic threshold. If the pest population recovers slowly, this approach may be very effective.

Rice fields generally present a much different environment - one that is dynamic and constantly undergoing improvement in terms of available food and harborage until harvest. Repopulation occurs rapidly through the movement of animals from outside areas. When the treatment unit is particularly small such as a farm, repopulation occurs so quickly that simple population reduction methods may have a negligible effect in stopping damage (Sanchez *et al.*, 1973; West *et al.*, 1972). Preventive strategies seem to hold more promise for managing rat damage in rice fields.

Another aspect of strategy that is partially independent of the particular method chosen is the size of the target area. Control programs may be designed to cover a wide area or they may be directed at individual occurrences of damage. When the average farm size is small, as in many of the countries of Southeast Asia, the effectiveness of area-wide methods may depend on considerable organization, cooperation, and coordination among many individual farmers. However, area-wide programs may result in overall cost reductions and may delay the return of animals into target areas. The argument that area-wide programs are the only way that agricultural rat control can be approached is prevalent among farmers (and some technicians and administrators). This point of view often provides a convenient way for farmers to shift responsibility for their problems to government agencies and for agencies to plead lack of resources. There is evidence, however, (for example, Sanchez, *et al.* 1973, 1974) that this belief is untrue, and that rice damage on small-farm units can be prevented or greatly reduced by localized approaches. In agriculturally diverse rice-growing regions, with year-round cropping, area-wide approaches may actually result in a waste of resources if rat control efforts are concentrated at particular times of the year without regard to crop stages.

Control Methods

No single method of rodent control fits all rice field situations, and even under ideal conditions, the results of most control methods are somewhat variable. For these reasons, it may sometimes be necessary to use several approaches to reduce or prevent crop damage. Extension workers should be familiar with the major alternatives, but should also recognize that results may differ among different agricultural situations and with different rat species.

The topic of rat control is a popular one among farmers, professional agriculturists, and laymen alike. Nearly everyone has a favorite theory or a story about a new method that should work without fail in any situation. It can be disconcerting for the technician, in the midst of explaining a proposed control program, to find that he lacks a good answer to a casual question, "Why don't we do it this way instead? ".

Proposed control methods must be reasonably effective in reducing crop damage in a particular situation, but they must also be evaluated from several other viewpoints, including safety for human and animals, cost, practicality, short-term and long-term side effects on the environment, and acceptability to farmers to name a few. Unfortunately even the effectiveness of most potential control methods is not well established for agricultural situations. Although it is not possible or necessary to provide the details of all of the proposed, potential, and existing methods of rodent control, the following sections discuss most of the methods that are now in use or have been seriously suggested as having application in rodent control.

The status and potential application in rice field situations are briefly discussed for representative methods in four categories: physical, chemical, biological, and others. It may be readily seen that several of the methods considered under this simple classification have considerable overlap and often require similar application. From the standpoint of population reduction, however, it makes no difference if a rat is killed by a trap, a poison, or a predator. Any of the basic approaches for protecting crops (killing or excluding animals or making the habitat unsuitable) could, theoretically, be accomplished by physical, chemical, or biological means. Decisions about which method to employ should be made on the basis of effectiveness, cost, practicality, potential side effects, and acceptability in the culture where it will be used.

Physical Methods

Physical approaches to rodent control are those involving direct killing or exclusion by human or mechanical means. The approaches that have been tried or suggested range from the farmer digging animals from a burrow with his hands to high-cost methods requiring extensive technology that may be impractical or uneconomical in tropical rice fields. Only a few of these approaches are discussed.

Digging or flooding burrows

These are old but commonly used methods of removing animals from burrows. They are popular because there is virtually no direct material cost and the results are evident to everyone involved. When carried out during the early to mid-term stages of the rice crop, intensive removal of animals through this method reduces damage by resident rats. Efficiency is reduced as the field habitat improves through crop maturation because many animals remain among the rice plants during the day. Breeding females, however, make considerable use of burrows during the latter half of the crop period (Sumangil, 1972).

Removing a few rats from a field after the damage is evident is generally of little help. Intensity and frequency are important considerations in applying the simple removal methods.

Trapping

Trapping can be a useful way of capturing rats causing localized damage, but it is usually too costly and laborious for effective use in large areas. A large variety of traps are available, ranging from primitive snares to multiple-catch cage traps. The most common type used in rice fields is the break-back or snap trap.

The two basic approaches to trapping are: setting the trap in the path of an unwary animal, or setting the trap with bait to attract an animal's investigation. The first approach requires a knowledge of the paths that animals are likely to follow while the second requires the ability to make attractive trap sets. Rice grains, coconut, and sweet potatoes are among the bait materials generally suitable for attracting rats in rice fields.

If the plots being damaged are small and valuable (such as seed beds) and if enough traps and laborers are available, intensive trapping can be used to reduce a local rat population quickly. By using up to several hundred traps per hectare set throughout the rice fields (not just along dikes or edges), rapid population reduction is possible within a few days (Sanchez *et al.*, 1973). Presumably, fewer traps and slightly longer time intervals would also cause rapid depletion of the rat population. However, reduction of the local population in rice fields usually stimulates immigration of animals from surrounding areas. Unless the period of potential damage is short, or animal removal is extended to cover a surrounding buffer area, operations might need to be repeated many times between planting and harvest (possibly without much reduction in crop damage).

Drives

Drives have been used extensively for moving or concentrating animal pests in many parts of the world. In Southeast Asia, including the Philippines (where the process is sometimes called "blanketing"), drives are frequently used as a means of killing field rats. Except by very specialized techniques, drives cannot be adapted for practical use in fields of growing rice, but they can be useful in reducing reservoir populations between crops, before planting, or from localized waste areas adjacent to croplands. Drives require the cooperative activity of a group of people and, considering the frantic efforts involved in chasing rats, they often appear to be done more for sport than as an agricultural chore. Nevertheless, if efficiently done at the proper time and on a sufficiently large scale, drives may provide a useful, low-cost means of reducing the potential crop damage in local areas.

There are, of course, a variety of ways of conducting drives, all of which can work well. Several people (usually 10 or more) may surround a small section of grassland and remove a strip of vegetation around the outside edge to isolate the animals. If more people are available, beating the grass with sticks may be quicker than cutting. If hand tractors with cage-wheels are available to roll down wide swaths of vegetation, larger areas can be covered in one operation. Vegetation is then disturbed or cleared toward the center to force the rats into a smaller and smaller central area of standing vegetation where they can be captured or killed.

Another approach involves driving rats toward a section of netting or fence by cutting vegetation, then closing the fence to capture them. Participants in drives must be warned against swinging knives among groups of people and must avoid being bitten by rats.

Frightening devices

Frightening devices are occasionally used against rats with probably little effect. Shyness towards new objects exists in some rat populations, but this response is usually short-lived. Rats adapt to new situations quickly; even noisy areas such as a rice mill operating 24 hours a day may have losses from rat feeding and contamination.

Various types of rat flags or "scarecrows" that are sometimes placed at vegetation level in rice fields appear to be of no use in frightening rats. Not only can rats adapt to such objects, they are unlikely to be aware of flags since most rat activity occurs at night beneath the shelter of vegetation.

Barriers

In theory, barriers could be used to completely isolate crops from rats. In practice, however, barriers are usually troublesome to install, difficult to maintain, and expensive. Because rats can climb, swim, dig holes, and gnaw through fences, many barriers installed in rice fields are completely ineffective.

Electric fences (Ramos, 1967; Srinivasalu *et al.*, 1971) are in use at several agricultural experiment stations in the Philippines and in other parts of Asia. The fence described by Ramos operates on a heavy-duty 6-volt or 12-volt battery and might injure humans, cattle, dogs, or other animals if they were wet or standing in water or mud. Rats or other small animals may hang on the charged wire after they are electrocuted, grounding the fence and allowing other rats to pass into the plots. Thus the fence sections must be continuously patrolled to keep them in operation. A well-maintained electric fence with the base in water or flooded soil can be quite effective in protective small field plots, but on dry soil, animals readily burrow under the base. After rice reaches mid-term, the animals that find their way into fenced plots have sufficient food and cover to live there for the remainder of the crop period. The cracks that develop rapidly in drying soils may also provide ready access routes under fencing when water is drained from paddies nearing harvest.

Metal sheet barriers are sometimes used for protecting seed beds, small upland plots, and on occasion, wet paddies. These barriers are expensive and suffer the same maintenance difficulties as fences. To be effective, such barriers should be deeply inserted in the soil to reduce the number of animals that gain access by burrowing. These barriers can be further improved by bending the bottom edges outward and burying them under the soil. The sections of sheeting used to construct such barriers must be securely fastened together at the edges to present a smooth surface that is difficult for rats to climb. Much labor and expense might be warranted for permanent installations, but in rice fields, barriers must generally be disassembled after each crop to permit land preparation.

Chemical Methods*

A great diversity of chemicals and chemical approaches have been tried or suggested for rat control in different situations around the world. Such methods have, in fact, been the major focus of man's efforts to reduce rodent problems for many years. While there are no methods that are ideal from all standpoints, chemicals can be useful to provide short-term protection for crops, and according to some reports, for long-term suppression of rat populations.

***Reference to commercial materials is for identification only and does not imply endorsement by United States or Philippine government agencies.**

Many chemicals once used for rodent control are no longer considered suitable – some because of ineffectiveness, some because of high cost, and others because of hazards associated with their use. Research to discover new chemical rodenticides is conducted in many of the developed countries. As new materials become available, it is essential that they be tested against local problem species before being accepted for use. For example, some materials that are effective for certain species of pest rodents prove to be of little use against others, or may present unanticipated hazards when used in new areas.

In the use of chemicals in agricultural areas, safety for humans and domestic livestock is a major consideration. People in the area where such materials will be used should be warned of the possible hazards and appropriate steps, such as penning, should be taken to keep stock and poultry away from the area.

Anyone handling a pesticide must be careful to avoid accidental poisoning. Materials should be securely stored in well-marked containers labelled "poison" (in the appropriate language). Mixing should take place in a well-ventilated area, preferably outdoors. Gloves should be worn and precautions taken against breathing dust or fumes. Empty containers should be burned, or crushed and buried. Smoking or eating should be avoided when pesticides are being used, and thorough washing and cleaning after the operations are completed is essential.

Materials should be prepared and used according to directions on the label, never at higher concentrations. Increasing the amount of toxicant almost never improves results but significantly increases hazards and cost. When possible, formulation of technical materials, fumigation, area-wide baiting, and other operations involving quantities of toxic materials should be supervised by trained extension workers.

Acute toxicants

A variety of acute toxicants – fast-acting poisons that kill with one dose – have been developed for use as rodenticides. Unfortunately, very few of the existing materials are of practical use for solving agricultural rodent problems in the tropics, either because of reduced (or unknown) effectiveness against local species (compared with the urban Norway rats for which most rodenticides have been developed and tested), or because of hazards associated with widespread agricultural use.

Perhaps the best known and the most available of the acute toxicants used throughout the world is zinc phosphide. This gray powdery material is used in most of the government plant protection programs in Southeast Asia and is, for most rice farmers, the only rodenticide readily available at little or no cost. Zinc phosphide is generally prepared in 1 or 2 per cent concentrations with grain baits (Marsh, 1965). Vegetable or mineral oils at about 0.5 to 1 per cent (by weight) are often added to help hold the toxic particles to the bait carrier. Other acute toxicants, such as sodium flouracetate, fluoracetamide, and thallium sulphate, are sometimes available, but because of the hazards frequently ascribed to these compounds, many authorities maintain that their use should be avoided entirely. Several newer acute rodenticides, such as Norbormide, Gophacide, and Vacor, are generally untested and unavailable where rats damage rice.

In growing rice, baits treated with acute toxicants are often placed in small piles along paddy dikes. A study in the Philippines by West *et al.* (1972) has indicated that such applications are of little use in protecting rice crops from damage by *R.r. mindanensis.*

They found that three applications in each of six 20-hectare areas showed no significant reduction in damage compared with that in adjacent reference areas. More recent work (Sanchez *et al.*, 1972) suggested that a much greater proportion of animals can be reached if bait stations are placed inside the paddies and maintained for three or four days with untreated bait before poison bait is introduced. In an experiment with tracer-labeled bait, they found that this approach contacted about 80 per cent of a *R.r mindanensis* population when station density was about 25 per hectare. At present, one apparently should not expect acute rodenticides to reduce populations effectively in growing crops without "pre-baiting" (first exposing untreated bait to train animals to use the bait stations and accept the bait carrier). This process must be carefully explained to farmers, since feeding untreated food to rats that are causing damage might seem to be wasted effort to people unfamiliar with rat behavior.

Even when baiting is successful, reduction of the population may be insufficient to protect crops if rapid recovery occurs by immigration or breeding. And unfortunately the effectiveness of acute toxicants often declines with repeated use, probably because more and more animals survive poisoning and learn to associate their illness with the bait material. The resulting avoidance is sometimes termed "bait-shyness." When acute toxicants must be used repeatedly, bait shyness can sometimes be reduced by changing the bait carrier and by continued use of pre-baiting.

The selection of bait carriers for rodent control is sometimes a controversial matter. People have definite opinions about what constitutes an attractive, palatable food for themselves, and may apply these ideas to rats. This thinking sometimes leads people to go to considerable effort to prepare relatively small amounts of "attractive" baits. Cage studies with *R.r mindanensis* and *R. argentiventer* (Sanchez, 1972) indicate that these species readily accept a wide variety of natural foods and potential bait carriers in preference to a regular laboratory ration. However, the successful bait material must remain relatively well-accepted in the field where many alternative foods are available. Because available foods and relative preferences may vary among different field situations, it is desirable to check the acceptance of untreated bait at several stations before baiting instead of speculating on what the particular rat population would find attractive.

The choice of a bait carrier should also be based on its availability to local farmers, its cost, its practicality when quantities of bait must be prepared, and its resistance to spoilage. For control situations in growing rice, low-grade polished rice or rice shorts appear to be cheap, well-accepted bait carriers. It is usually undesirable to use unmilled grains when toxic material is to be coated on the surface, because rodents generally remove the husk before consuming the grain. Any baiting operation in growing rice should be initiated before the grain begins to mature, when rats apparently become less active and begin feeding heavily on the individual grain heads. Most bait materials appear to be poorly accepted after this time.

Chronic toxicants

Chronic toxicants are materials to which animals develop toxic symptoms more slowly, usually over a period of several days. The chronic rodenticides currently available are a group of related chemicals known collectively as "anticoagulants" because they interfere with the clotting mechanisms of the blood. They are used at relatively low concentrations and usually require several days of feeding to cause death. Pre-baiting is unnecessary and bait shyness does not become a problem because the rats do not associate the slowly developing toxic symptoms with the bait material.

Several types of anticoagulants are available as rodenticides in most Asian countries. Among them are warfarin, cumatetralyl, diphacinone, coumachlor, and chlorophacinone. Prepared baits are generally sold in small quantities and are intended chiefly for dealing with household pests. Chemical concentrates are usually chosen for use against field rats. These concentrates must be mixed with a suitable bait carrier, usually in proportions of one part concentrate in 15, 20, or 40 parts carrier, depending on the type of concentrate used. Some anticoagulants are also available in soluble formulations for preparing liquid baits or as tracking powders which the animals ingest as they groom the powder from their feet and fur. Such formulations are not generally practical for use in growing rice. Relatively weatherproof, prepared baits that incorporate anticoagulants in mixtures of paraffin and broken grain are available for field use in some countries.

Effectively reducing a local rat population with anticoagulants may require several weeks and, as with acute toxicants, may result in rapid reinvasion by animals from surrounding areas. Some investigators have suggested long-term exposure to anticoagulant baits, beginning the field treatments even before damage is actually observed. One approach developed originally for town and village rodent control in Europe (Telle, 1967) involves continuous exposure of baited stations in croplands throughout the year, even during the non-crop period (Anonymous, 1971). The approach reported by Wood (1971) involved baiting with paraffin bait cubes containing an anticoagulant starting at planting or in the early vegetative period of rice growth and continuing at 4-day intervals until acceptance declined to 20 per cent. Wood noted that reinvasion of the crop areas might occur after baiting, but this would generally take place after the time when rice is most susceptible to damage.

A series of experiments using anticoagulant baits throughout the crop period (Sanchez *et al.*, 1972, 1973, 1974) indicated that rat damage to rice crops on individual small farms could be substantially reduced. Such baiting, when done on a small scale with commercial anticoagulant concentrates and low-grade polished rice, can be expected to cost less than ₱50 (about $7.00 U.S.) per hectare. It appears critical that baiting be started soon after planting, that enough bait stations be made available to avoid competition among rats, and that an excess of bait be maintained at the stations. Apparently baiting can be stopped one to two weeks before harvest, and then resumed for the next crop. This approach has been termed "sustained baiting" (Sanchez *et al.*, 1974).

Field applications of anticoagulant bait generally require fewer baiting points than acute toxicants. Having a bait in place over a longer period provides time for rats to adjust their feeding activity and use the bait for food. Two to six baiting points per hectare have provided satisfactory results under most Philippine field conditions. More important than the number of baiting points is the amount of palatable bait available. An excess of bait should be maintained to permit most of the rats in the population to feed regularly for several days. West *et al.* (1975b) believed that this could best be accomplished in dense rice field rat populations by placing several small bait containers (bait stations) at each baiting point to reduce competition among rats. The number of stations, rather than the amount of bait in a station, could then be reduced or increased to maintain an excess. During the rainy seasons, baits may need to be replenished more frequently because of spoilage, although studies by Sanchez *et al.* (1973) and personal observations suggest that spoilage is not a major problem in sustained baiting programs where fresh bait is added to stations at least once a week.

The type of station in which the bait is placed is not of great importance. However, a good station should be inexpensive and durable, should provide the bait some protection from direct rain, and should allow free access to rats. Discarded oil or kerosene cans can be cleaned and made into satisfactory, low-cost bait containers. Large-diameter sections of bamboo are also often used. Sections of coconut husk pierced by a bamboo stake have proven to be very practical paddy stations under Philippine conditions. Limited observations by West *et al.* (1975b) suggest the reluctance of some rats to use enclosed stations that must be entered to reach the bait material. Domestic animals or poultry that might encounter the stations regularly, should be kept away from the poison bait by modifying station construction, placing stations among plants within paddies, or keeping these domestic animals in pens during . baiting program.

The foregoing experiments and observations have provided a basis for the inter-agency recommendations adopted in the Philippines for rat control in rice and for the inclusion of rat control under the agricultural loan programs. The current Philippine inter-agency recommendations for rat control in rice are included in the Appendix.

Returns from anticoagulant baiting programs are difficult to assess under actual field conditions because of the great variation in each farmer's investments in his crop and in his final yields. Another difficulty is the variability in the severity of rat damage itself. Rats may limit crop production in some situations but cause only moderate or negligible losses in others. Such variations occur almost unpredictably from season to season, place to place, and even paddy to paddy.

In one controlled evaluation of sustained anticoagulant baiting in an area chronically affected by severe rat damage in the Philippines, farmers carrying out a baiting program following the inter-agency recommendations, harvested almost twice as much as those in a reference group – 42 vs. 23 cavans (about 2,100 vs. 1,150 kg) per hectare – and made more than three times the profit – ₱1,031 vs. ₱313 (about $147 vs. $45 U.S.) per hectare (Table 1). The estimated cost of baiting averaged about ₱20 (about $2.80 U.S.) per hectare. Since other production investments were similar for both areas, it appeared that the major increase in production related principally to the reduction of rat damage (Sanchez *et al.*, 1974). Other studies (Wood, 1971; Sanchez *et al.*, 1973) have shown similar degrees of protection from sustained baiting programs, but variation in production investments, and perhaps natural fertility (Wood, 1971), precluded the calculation of actual production increases that resulted from reduction of rat damage.

In spite of its apparent effectiveness, long-term anticoagulant baiting is not widely used by farmers in tropical countries. The cost, though relatively small, may sometimes be a deterrent, especially when farmers compare it with the cost of single applications of acute toxicants without reference to the degree of crop protection achieved. Similarly, the labor involved in baiting throughout the crop period may seem excessive to farmers who would hope to get the same results by one application. Some farmers complain that bait carriers are expensive or unavailable, and some are reluctant to buy rodenticides at any price, anticipating that government agencies will eventually provide free rodenticides. In many countries, token amounts of rodenticides (usually acute toxicants for single applications) are, indeed, given to farmers with sufficient frequency to encourage this reluctance to buy.

Farmers often evaluate results of toxicant applications by the number of dead rats they find. But the important question in any control situation is how many rats survived to do damage. When anticoagulants are applied during a crop period, many rats die, but few carcasses are found because the slow action of these rodenticides allows rats time to return to burrows or seek shelter among the rice plants. Extension workers can help farmers understand that they should measure the results of their rodent control efforts, not by the number of dead rats found, but by improved yields. As more farmers gain experience with anticoagulants, the use of these materials in Asia can be expected to increase rapidly.

Table 1. Comparison of mean production costs and yield for farmers using sustained baiting with anticoagulants and for those in a reference area. The study was conducted in Barrio Tagumpay, Baco, Mindoro Oriental, within the range of* **Rattus argentiventer.**

Production Factor	Program Farms (pesos/hectare)	Reference Farms (pesos/hectare)
Land Preparation	223	228
Seeds	76	73
Transplanting	118	129
Mechanical Weeding	130	93
Herbicides	25	23
Insecticides	60	62
Irrigation	7	0
Fertilizer	0	4
Harvesting	423	233
RAT CONTROL (all methods)	20	6
Total Production Cost	1,084	852
Gross Value of Crop	2,115	1,165
Profit	1,031	313
Yield (cavans/hectare)	42.3	23.3

*Modified from Sanchez *et al.*, 1974.

As the use of anticoagulant rodenticides increases, one future problem must be considered. Genetic resistance to these materials has been discovered in some rodent populations (*R. norvegicus, R. rattus* and *Mus musculus*) in Europe and the United States (Jackson *et al.*, 1971; Jackson and Kaukeinen, 1975). Bentley (1970) surmised that almost any poison used at chronic dosage levels would eventually evoke resistance in rats and mice under conditions of intensive use. As yet, no anticoagulant resistance is known in Southeast Asian rodent populations. In any case, potential resistance is not an argument against the current use of these chemicals as rodenticides, since several alternative anticoagulants may be available if resistant populations are discovered. Bentley (1970) has, however, noted that the potential for resistance to existing chemicals is a primary reason for continuing research to develop new rodenticides. Technicians who believe that the effectiveness of anticoagulants in an area has declined should notify appropriate government agencies so that the rat populations can be checked for susceptibility.

Fumigants

When rats are confined in closed spaces, fumigants or toxic gases are sometimes used for control. Fumigants have been employed in a variety of situations to kill rats occupying burrows in paddy dikes. The most widely used material is probably calcium cyanide dust, which produces hydrogen cyanide gas upon exposure to moist air or soil.

Foot-pump dusters are available for applying this material to rodent burrows. However, it is sometimes recommended that the applications be made by spooning a small amount of cyanide dust into the openings of occupied burrows so that animals have less chance to leave the burrows before lethal concentrations of gas are evolved.

Fernando *et al.*, (1967) tested commercial aluminum phospide tablets for fumigating burrows of the mole rat (*Gunomys gracilis* [= *Bandicota bengalensis*]) in Sri Lanka. To eliminate rats occupying dikes during rice growing, they made cuts in dike about every 7 or 8 feet (about 2.5 m) and inserted into the exposed rodent burrows. Among the several approaches tested, they concluded that one-half of a 3-gram tablet placed into one exposed burrow in each dike section was adequate to control resident animals. The procedure worked best in dikes that had not yet begun to dry and crack.

Burrows are sometimes fumigated by introducing into them the exhaust gases of tractor engines or smoke from burning or smoldering materials. Introduction of smoke from a burning mixture of rice straw and sulfur is a widely practiced fumigation technique in Indonesia, where cyanide fumigation is considered hazardous.

Although fumigation can be an effective means of killing burrowing rodents, it has the same limitations as some of the physical methods previously discussed for protecting rice crops. As the rice matures, many rats remain in the fields during the day, using rice plants rather than burrows for shelter. In other situations, rats may use surface nests in grassy or marshy areas adjacent to fields. Commonly, reinvasion from these areas is rapid, reducing the effectiveness of this technique from the standpoint of crop protection. Plugging old burrows with mud and examining them periodically for renewed signs of activity, or examining paddy mud for tracks, are ways of determining whether reinvasion is occurring. Because chemicals and equipment for fumigation of field burrows on a farm-wide scale may entail considerable expense, they should be used only in areas where this approach is appropriate, or in conjunction with other methods.

Great care must be taken not to inhale the gases produced by fumigants. Since dangerous levels of some gases may remain in closed burrows for several hours, the burrows should not be opened to recover dead rats. As with other chemical pesticides, gloves should be worn to handle fumigants, and precautions listed on the label for each material should be observed.

Chemosterilants

In recent years, the idea of using chemicals to inhibit the reproduction of vertebrate pests has been studied by a number of investigators. A variety of materials with different modes of action or different physiological effects, including gametocides, antifertility agents, and others have been proposed or investigated for primary effects upon rodents. Several field trials have been conducted using experimental chemosterilants against *R. norvegicus* (e.g. Marsh and Howard, 1969; Brooks and Bowerman, 1971; Bowerman and Brooks, 1971), but the results have been generally disappointing.

Knipling and McGuire (1972) have outlined the theoretical advantages to be gained by the use of sterilization techniques against equilibrium rat populations over conventional methods of population reduction. They noted that both sexes need to be sterilized to gain the full theoretical advantages of the approach, but they did not address the more practical issues. The current disparity between theory and practice relates partially to the lack of "ideal" chemicals, to the difficulties in getting effective doses of the chemical into all or most of a target population, and to the importance of immigration in maintaining some populations. Various experiments have confirmed the importance of considering all of these factors in the effort to devise ways to use chemosterilants for effective rat control. Kennelly *et al.* (1972) found, for example, that surgical sterilization of 85 per cent of the male rats in an enclosed colony of *R. norvegicus* had little or no effect on subsequent population growth over several months, in comparison with that of a similar, untreated colony. Marsh and Howard (1969), in field tests of one of the first experimental rat chemosterilants, found that repeated treatments were necessary because the effects of the chemical were only temporary. However, bait acceptance by the test populations progressively declined with each application. After 3-1/2 months of treatment, the test populations no longer showed evidence of reproductive impairment. Although bait was available for several months, Marsh and Howard (1969) suggested that the chemical probably did not inhibit reproduction after the first 30 days of baiting.

Immigration of fertile animals may be a continuing difficulty in the use of chemosterilants against field populations. Agricultural rat populations tend to be highly mobile, particularly in patchy environments where fields of rice of different ages, groves, houses and wasteland are in close proximity, and the rats damaging a farmer's rice may have been born elsewhere. At harvest, the resident population may be forced to find food and shelter in still another location. Under such conditions, effective use of chemosterilants might require treatment of large areas including both agricultural and non-agricultural habitats.

Continued development and testing of new materials hold some promise for the emergence of better chemicals and improved baiting systems (Kendle *et al.*, 1973; Garrison and Johns, 1975), and this aspect of rodent control research will continue to be important. Despite some progress, chemical sterilization techniques, alone, do not appear to hold much promise for practical use against rice field rat populations in the near future. However, chemosterilants – even those that lack some of the theoretically desirable characteristics – may ultimately find considerable use in combination with other control methods in maintaining local rat populations at economically acceptable levels during periods when crops are susceptible to damage.

Repellents

The concept of using chemicals to repel pest animals has intrigued biologists and laymen alike for many years. Good uses for area repellents (which might act at a distance) and contact repellents (which might require an animal to attempt gnawing a treated material) can easily be conceived. Unfortunately, effective chemicals suitable for use in grain fields have not been developed.

In major chemical screening programs during the past two decades, thousands of chemicals have been tested as potential contact repellents for protecting stored food, tree seedlings, crops, electric cables and other goods against damage by a variety of rodent and other mammalian species. Tigner (1968), who summarized the results of screening more than 12,000 chemicals as repellents for food packages by the Denver Wildlife Research Center from the post-World War II period onward, reported that some effective chemicals had been found, but had not come into wide use because of possible food contamination, difficulties in application, and hazards in handling. Developmental research on repellents for protecting electric cables, tarpaulins, and tree seedlings has, however, produced some materials that appear effective in reducing damage by several species of mammals (Tigner, 1966, 1968; Lindsey *et al.*, 1974). Even if there were effective contact repellents that presented little dangers from contamination and were acceptable on food crops, they would not necessarily be widely used in growing rice because the effort and expense required to maintain a treated chemical surface on the growing stems throughout a crop period might be prohibitive.

Not much work has been directed toward discovering area repellents for rodents. Mills and Munich (1942) reported that some materials such as naphthalene flakes, lime, lye, powdered sulfur, and cayenne pepper sometimes reduced rat activity in established runways. Tigner and Bowles (1964) found chloropicrin to be a potentially useful area repellent for house mice in confined spaces. As Maddock and Schoof (1972) noted, however, the search for suitable and effective area repellents has not been very fruitful.

Bull (1972) and other investigators who have tested repellents under experimental conditions have found that odors may play a relatively unimportant part in feeding behavior of rats if the animals are not able to relate the odor to the taste of food. In addition, continuous exposure to an odor may lead to sensory adaptation so that, after a short period, the odor is no longer very noticeable. Because odors dissipate quickly in circulating fresh air, technical difficulties could certainly be expected in maintaining active concentrations of area repellents in fields, even if effective materials were available.

Biological Methods

Biological control or, more appropriately for vertebrates, ecological control, encompasses a group of control approaches that have been a major topic of discussion for many years among people concerned with rodent damage. Compared with chemical control, biological control of vertebrates has received little research attention. But, because reduction of disease and predation, habitat improvement, and regulated hunting have been investigated as management tools for increasing or maintaining populations of desirable wildlife species, a considerable body of theory exists on how such approaches might be applied in reverse to reduce or eliminate pest populations. However, few critical experiments have been conducted to evaluate the real potential of most of the methods that have been suggested.

It is known to most ecologists and to increasing numbers of professional agriculturists and laymen that environmental manipulations often have unexpected, far-reaching effects, some of which may be undesirable. These negative effects have been termed "ecological backlash." Several early attempts to control rodents by introducing predators or diseases resulted in such unplanned effects. Today, most responsible biologists would recommend against major environmental manipulations to control rodents until all of the potential effects have been critically evaluated and weighed against the potential benefits. The difficulties encountered in assessing such potential effects are sometimes used to argue the need for increased research on chemical methods, since selective removal of pest animals from the restricted habitats of farms and cities might be expected to cause much less environmental and social disruption than introduction of new species or directed changes in human activity patterns. Although not all biological methods for controlling rats would result in such drastic or far-reaching changes that they should be ruled out on these grounds, most suffer from other theoretical or practical difficulties. Biological methods that have been most frequently suggested as possible approaches to rodent control are discussed below.

Predation

The introduction of new predators and the encouragement of existing predators have been among the most widely discussed biological control methods for rodents. Although these approaches should not be entirely dismissed as subjects for research, there are both practical and theoretical problems in applying them to reduce crop damage by rodents.

Like other animals, predators require suitable habitat and a stable food supply to survive in a particular area. One of the major effects of agriculture has been to reduce the areas of habitat suitable for predatory species. Another effect, particularly in field crop agriculture, has been to produce a periodically varying food supply. Rice fields, for example, may provide abundant food and good habitat for some species for several weeks, followed by total disruption during harvest and subsequent land preparation. With the rat's enormous reproductive potential, most populations are able to respond rapidly to this periodic renewal of the environmental resources which provide food and shelter. In contrast, most predator species have a relatively low reproductive potential, and the young require long periods of care and maturation before they are able to breed. Predator populations, therefore, recover slowly from food shortages and other events that cause local population depressions and respond slowly to improvements in habitat and food supply. Thus, despite the periodic abundance of prey, it appears that most potential predators of rats would not be likely to live permanently in monotypic agricultural habitats.

Introduced predators have sometimes become serious pests themselves by killing domestic chickens and ducks, by threatening the survival of desirable birds and wildlife, or by becoming disease reservoirs — particularly for rabies. Introductions of the mongoose (*Herpestes auropunctatus*) in Hawaii and the monitor lizard (*Varanus indicus*) in several Pacific islands for rodent control have been notable failures. More recent experimental introductions of weasels (*Mustela sibirica*) in small isolated islands have been studied by Uchida (1967), who provisionally concluded that such introductions would not, by themselves, provide adequate control, but that combined programs using weasels as an adjunct to rodenticides might be useful on small, scattered islands. Many authors have emphasized the need for great care in conducting and evaluating such experiments to avoid the inadvertent establishment of potential pests.

The introduction of house cats is sometimes suggested as a potentially useful way of controlling field rats. This seems doubtful if "control" is intended to mean more than killing some of the resident animals. The excellent rat habitat provided by the growing crop during the period when damage is heaviest greatly reduces the likelihood that cats patrolling dikes would have a significant effect on the growing rat population. Elton (1953) has suggested that cats, maintained around farm buildings, could help prevent reinvasion by rats if provided with supplemental food, but could not necessarily reduce an established rat population. He concluded that the cost of continuously maintaining cats might be greater than the cost of rodent control by other methods.

Disease and parasitism

To a large extent, the same principles that might limit the effects of predation apply to disease organisms and parasites as well. A disease organism that quickly eliminates all of its "prey" would have no mechanism for its own survival. However, there are usually survivors of even the most severe epizootics because of variations in natural immunity in wild populations. Although animals with low reproductive capacities require a lengthy recovery period from disease outbreaks, rats can often rebuild a decimated population quickly if suitable habitat and food are available. Since the more resistant animals that survive disease outbreaks become parents of the new generation, populations are likely to become increasingly resistant to later outbreaks of the same disease.

A variety of bacterial and viral diseases have been reported to cause mortality in wild rats, but few long-term experiments have been conducted. Davis and Jensen (1952) studied a wild population of *Rattus norvegicus* into which a disease-causing bacterium, *Salmonella enteritidis,* had been introduced. The course of infection was followed by periodically examining blood, feces, and rectal swabs from 2,000 trapped animals. The rat population increased considerably during the study, while disease incidence declined, showing that an established rat population could adapt to the introduction of highly pathogenic organisms.

The best known attempt to use a disease organism to control a vertebrate pest was the introduction of myxoma virus into rabbit populations in Australia. Rabbits (*Oryctolagus cuniculus*) had been introduced to Australia from Europe along with many other species. Their escape and rapid multiplication brought them to the status of a major pest despite a variety of attempts to control them (Myers, 1971). Introduction of the myxoma virus in about 1950 initially led to widespread reductions in populations. However, the rabbit populations later began to recover as a result of natural selection in favor of disease-resistant animals and through the elimination of those virus strains that killed the host before other animals could become infected (Fenner and Ratcliffe, 1965). From the standpoint of long-term rabbit control, Barbehenn (1969) observed that the "grand experiment must be considered a failure."

Since humans are susceptible to many of the diseases and parasites that rats might carry, and since they are often in close association with rats, great care must be taken, even in the research phases of biological control experiments, to avoid their accidental infection. This potential hazard has restricted the use of many of the disease organisms that have been suggested for rodent control. Even without such a problem, long-term reduction of rodent populations with diseases or parasitic organisms would probably be impossible without mechanisms for maintaining highly pathogenic strains and retarding the development of resistance or adaptation by rat populations.

Genetic manipulation

Interest in the use of sterilization as an approach to rodent control has also led to some experimentation on genetic mechanisms for passing deleterious traits through rodent populations. Gumbreck *et al.* (1971) reported on a mutant strain of *R. norvegicus* in which some of the male offspring were sterile. Subsequent experiments in pens and on one farm showed that rats carrying this sterility trait could be successfully introduced into wild rat populations and that the reproductive performance of such populations could be reduced (Glass, 1974). Some popular press accounts have credited these types of experiments as leading toward an ultimate solution to rat problems. In the Philippines, particular attention was paid to the speculation (Glass, 1974) that a "killer gene" might be discovered and incorporated into the "sterile male" strain. Much more research is certainly needed to evaluate the usefulness of releasing rats as practical means of population reduction.

From the standpoint of current use in controlling crop damage in the Philippines and other Asian countries, few positive comments can be made about this approach. The species studied by Glass (1974) and his associates is not one responsible for much crop damage in Asia and does not interbreed with the major pest species. If their approach were to be pursued, similar research would be needed to develop suitable mutant strains of each local pest species. Some work has been undertaken by the Philippine Atomic Energy Commission (Medina *et al.,* 1973) to seek radiation-induced mutations in *R.r. mindanensis* and *R. argentiventer* to use against these species. Fortuitous discoveries could lead to further development of genetic approaches to rodent control in the Philippines.

Beyond the problem of discovering or inducing deleterious mutations in rat species lie the same difficulties of the rice field pest situations themselves that seem to limit the usefulness of many rat control methods: dense rat populations, rapid population turnover and the adaptability of rats. Little or no attention has been devoted to devising ways to circumvent such problems in adapting to practical use genetic approaches to rodent control.

Reduction of carrying capacity and sanitation

Largely on the basis of work with *R. norvegicus* in cities (Davis, 1953), it has become almost axiomatic that long-term rodent population control can be achieved only through manipulation of environmental resources to lower the carrying capacity of an area and increase competition among the remaining rats. Davis (1972) has suggested that the application of this principle to other species of rodents constitutes a primary research need. Control measures that temporarily reduce population (while stimulating subsequent population increase) are, in this view, interim measures that must be applied repeatedly.

In agricultural areas, the reduction of carrying capacity is not a simple task, since food and habitat are often abundant and difficult or impractical to limit. In the tropics, rapid growth of vegetation further complicates efforts to keep areas cleared and may add considerable cost. Even in urban areas populated by *R. norvegicus*, permanent reduction of rat habitat and food, though biologically sound, has been difficult to accomplish because of economic, social, and political limitations of human societies (Davis, 1972).

In the Philippines, reduction of rat harborage in agricultural areas has been recommended for many years as a desirable practice for farmers (de Jesus, undated; Alfonso *et al.*, 1965; Sumangil *et al.*, 1970). Generally, such recommendations include the maintenance of weed-free fields, reduction of waste areas outside the fields, reduction in the size and number of dikes to reduce burrowing, reduction of grain waste at harvest, and disposal of straw and other waste vegetation. Although there is little firm evidence to establish that such practices actually reduce crop damage, most appear to be desirable practices, not only from the standpoint of rat control but also from other aspects of rice production as well. For example, weed control in rice has distinct benefits in increased yields. The reduction of waste grain, recently suggested by Tigner (1972) as a means of reducing rodent populations, is likewise a practice that could be recommended on its own merits.

Sumangil (1972) and others have suggested that reducing the suitability of paddy dikes for rodent burrows might provide a means of reducing breeding success. The methods most often discussed – making smaller dikes, constructing dikes with concrete, protecting dikes with metal sheeting, and leveling land to eliminate dikes entirely – would all entail considerable initial effort and expense. In addition, dike modifications might require considerable maintenance in areas with saturated soils and heavy human or animal traffic; leveling would require construction of irrigation systems, changes in cultural practices, and new systems of marking the boundaries of small farms. The preponderance of non-crop wasteland and harborage sites, coupled with the tendency of some rats to make little use of burrows once rice cover has developed, suggests that even total elimination of dikes would not necessarily eliminate the rodent damage problem in most areas.

It is evident that habitat modification would require continuous application on a rather wide scale to have impact on actual rat damage to growing crops. The rice paddies themselves, from several weeks after planting to maturity, appear to provide sufficient food and cover to sustain large rat populations, irrespective of dikes, weeds, and adjacent harborage. The mobility of animals, coupled with the fact that harvesting over a large area is usually a slow or intermittent process, gives many rats sufficient time to move and find new shelter and food. Until more convincing data are available, it would appear that farmers should consider "clean culture" and habitat modification as desirable supplements to other methods of crop protection but not measures that, in themselves, can reliably prevent or materially reduce crop damage by rats.

Resistant rice varieties

Many farmers and technicians as well as rice scientists have observed that the older rice varieties often suffer less rat damage in the field than the high-yielding varieties developed in the past decade. These observations, coupled with the successful development of rice varieties resistant to certain insect pests and plant diseases, have focused considerable popular interest on the possibility of breeding varieties resistant to rat damage. Certainly, rats do exhibit preferences among different rice varieties when a choice is available (Sanchez *et al.*, 1971, 1973). However, ecological changes in the microhabitat of rice paddies associated with the newer varieties, as well as changes in cropping patterns which lead to greater rat densities, provide parallel explanations for the damage patterns observed in rice fields. Reports of severe rat damage to growing rice were common long before the introduction of high-yielding varieties (Crucillo *et al.*, 1954).

There is a major theoretical difficulty with the attempt to develop "rat-resistant" varieties analogous to those incorporating insect and disease resistance. Whereas most insects and pathogens affecting rice are host-specific or are limited to a few alternate hosts, most rat species accept an extremely wide range of plant materials as food; the same species of rat may damage a wide variety of field, garden, and plantation crops grown in Asia. It seems most unlikely that breeders can develop rice varieties that retain the traits desired by humans but are unacceptable food for rats under no-choice conditions. Although research to identify physical and physiological differences associated with low-preference varieties may lead to a better understanding of rat food habits, it appears that truly "resistant" varieties will not be a part of rat control technology in the foreseeable future.

Other Methods

Many other potential approaches for controlling the rat populations in rice fields have been tried, recommended, discussed, or suggested (as any agriculturist involved in preventing such damage quickly discovers). Two very old approaches to control that periodically receive renewed interest deserve separate mention, although they are basically forms of predation.

Bounty systems

The idea of making cash payments or rewards for the carcasses of pest animals has been applied numerous times over the last several hundred years in many countries of the world. The results have usually been the same: the pest problems continue virtually unabated, while a small number of people (usually not those troubled by the pest) learn that they can make a reasonable living collecting bounties. In theory, rat damage could, perhaps, be greatly reduced by this method if payments were high enough to encourage people to capture animals during periods of relative scarcity or to concentrate their efforts on capturing only animals damaging crops. Usually this does not happen.

Rat catching often is pursued most enthusiastically immediately after harvest while populations are still relatively high and concentrated in smaller areas or are actively seeking shelter and food. It is unlikely that killing rats during this time can prevent much subsequent crop damage unless the dates of rice planting in the area are very irregular and neighboring fields are still being damaged. During the period when rice plants are susceptible to damage, catching rats is difficult because populations are dispersed and animals are well protected by vegetation. Because of the effort required, interest in intensive rat catching usually declines quickly.

Other problems seriously hamper the economic efficiency of bounty systems. Since rat populations probably respond to post-harvest changes in habitat with increased natural mortality, and since many farmers kill rats at every opportunity in the course of other agricultural operations, many bounties would be paid for rats which would die or be killed regardless of the payment. It is also difficult to restrict the areas from which rats are captured. Although a community making bounty payments might wish to pay only for rats that come from rice fields within its boundaries, it is difficult, in practice, to determine the source of animals presented for bounty. Often, animals are captured at considerable distances and transported to the area where payments are made. Bounty systems are based on the assumption that for each rat killed there will be less crop damage; this is not necessarily true.

Eating rats

Field rats are often used for food in rural areas of Southeast Asia. This practice is not likely to result in health problems if muscle tissues are the portions used and if the meat is well cooked. It has been frequently suggested that if the practice could be encouraged on a wide scale, rat damage to crops could be reduced.

In general, the same problems generated by bounty systems and other forms of predation apply here. "Human predation" in growing rice would probably not be intense enough to significantly reduce populations and prevent or reduce crop damage. Although killing rats during the dry season or post-harvest periods may help to increase the mortality rate, it would almost certainly leave more than enough surviving rats to rebuild the population as soon as habitat conditions became favorable.

It must also be remembered that production of rat meat at the expense of rice damage is an expensive exchange, and one for which acceptable alternatives usually exist. If rats were to be eaten on a wide scale, domestication and commercial propagation would doubtless provide a better return than subsistence hunting. Although methods of rat husbandry are well established because of the long history of using rats as laboratory animals, the raising of poultry, swine, rabbits, or other domestic stock is likely to give better returns. Rats may provide a useful supplementary source of protein, but farmers should understand that it is not an action they can rely upon to prevent crop damage.

An additional problem with the practice of eating rats caught in rice fields is the possibility of secondary hazards from chemical toxicants used in the area. Sick animals may be difficult to recognize, although they may be easier to capture. Richter (1967) believed there was little chance of human secondary poisoning from muscle tissue of field rats that have eaten zinc phosphide or anticoagulants. However, the availability and use of a variety of other rodenticides would, indeed, raise the possibility of serious secondary hazards because the consumer has no means of determining whether rats have eaten poison or not. With our present knowledge of secondary hazards from rodenticides, one could not responsibly advocate simultaneous encouragement of rat consumption and chemical control on a large scale. A few communities where rats are eaten have, at various times, prohibited the use of rodenticides to avoid such hazards. Since wise use of rodenticides currently appears to be among the most reliable means of crop protection, despite the sometimes variable results, stopping their use can be expected to increase crop losses.

Evaluation of Control Methods

It should be recognized that important differences exist between the biological, chemical, and ecological research necessary in the development of control methods and management systems, and the evaluation of a particular method or management strategy for a particular pest situation. Although research – basic, applied, or adaptive – is usually the business of scientists, evaluation is a process for which all individuals using or supervising pest control programs should take some responsibility. Simple evaluation is something that each individual extension worker and each farm can apply by repeatedly answering the basic question, "Is this control program accomplishing the real objective I had in mind when I started using it?". If the answer is negative, it is evident that other approaches are needed.

Extension technicians often want to make detailed evaluations of particular rat control methods. No standard methods are available for making these more complex evaluations, and potential control techniques are so diverse that different approaches may be needed for different methods or situations. There are, however, several common techniques that may provide useful information about the applicability of a control method for a particular situation.

The primary question must be the degree to which the method reduces rat damage or increases crop yield. Disregarding the statistical approaches used for precise comparisons, a technician may gain useful preliminary information by comparing damage or yield estimates on treated plots where the rat control method is used with those on untreated plots where conditions are similar and the same farming practices are employed. Since rats can move considerable distances, it is desirable that both kinds of plots be large (much larger than the small plots used for insect control trials) and that they be widely separated (preferably by several hundred meters). Individual farms, which average about 1 hectare in many Southeast Asian countries, are a convenient unit for many tests. For larger tests or for methods which require large areas, village units may be used.

There are several means of estimating damage and yields on treated and untreated plots. Farmers may be asked to keep separate harvest records for each paddy. These yield records may be expressed in relation to the area of the paddy (for example, as kg/hectare) and averaged to express production for each farm. Another approach is to harvest small plots (for example, 1 m x 5 m) from each paddy, measure the yield, and project these figures to arrive at a farm average. Tiller counts also provide a convenient way to compare rat damage between plots. A common approach is to randomly choose 100 plants or hills from each paddy and examine each hill about 1 week before harvest to determine how many of the total tillers (stems) have been cut by rats. These data may then be used to calculate the percentage tiller damage for each paddy.

Other important records that should be maintained for each treated and untreated test unit are the amount and cost of materials and labor used in crop production, and the costs of the control method being evaluated. These data may be helpful, for example, in determining whether higher yields on treated units were related to the rat control test or to increased use of fertilizer or some other factor. The cost data may also help determine whether the control method costs more or less than the value of rice that would be lost to rats if it were not used.

It is usually desirable also to obtain some information about rat activity on treated and untreated plots before, during, and after the test of the control method. Again, several different approaches can be used, depending on the availability of materials and the amount of time for gathering information. A common approach is to set traps in the test plots at various stages during the trials and to compare the numbers of rats captured.

Another approach is to set out plastic floor tiles having half the surface coated with printer's ink and check them daily to determine the percentage that show rat tracks. Food consumption may also be used to provide an index of rat activity. Feeding stations containing known amounts of untreated bait may be placed for short intervals in test plots and checked after one or more days to determine how much is missing.

Farmers' attitudes toward different types of control methods may be determined through informal discussions, or through the use of questionnaires. Since farmers often try to please technicians by giving the answers they think are expected, it is important to discuss their answers thoroughly or to ask the same question in several ways so that their real opinions emerge.

Examples of studies in which some of these approaches for evaluation of control methods were used may be found in reports by Swink *et al.* (1973); West *et al.* (1972); and Sanchez *et al.* (1973; 1974). Technicians can usually obtain additional advice and assistance by contacting experiment station staff members in local plant protection agencies or universities.

Summary

Throughout the rice-growing areas of the world, rats and related species have attained major pest status. Rodent damage to rice is widespread throughout the rice-growing regions of the world, but its intensity varies from place to place and season to season. Because much rice is grown on small farms, heavy damage in a few fields can be a serious economic problem for the individual farmer.

A nearly overwhelming variety of methods for controlling rodents have been suggested, discussed, recommended, or tried. Unfortunately, little distinction is usually made between killing rats and protecting crops from damage. The major criterion for evaluating agricultural rodent control methods should be the degree of crop protection they afford.

The process of protecting fields could be accomplished by killing rats, excluding them, or making the crop areas less suitable for rats to occupy. A variety of physical, chemical, and biological control methods have been suggested by various authors for each of these purposes. The choice of a method or combination of methods for each situation should be based on cost, practicality, and cultural acceptability as well as on effectiveness.

Rat control, like other forms of crop protection, should be considered as an integral part of the agricultural production process. Since the labor and capital available to each farmer are limited, extension workers have an important role in helping the farmer find efficient ways to allocate his time and resources to produce and protect his crop.

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APPENDIX

RAT CONTROL IN RICE FIELDS

Adapted from "The Philippines Recommends for Rice – 1976" and specially reproduced for the MASAGANA 99 Rice Program

Joint Recommendations of the Bureau of Plant Industry; the College of Agriculture, University of the Philippines at Los Baños; the Rodent Research Center [1]; and the Philippine-German Crop Protection Program[2].

For many years, rats have been a persistent problem of rice growers throughout the Philippines. Field damage by rats costs the nation millions of pesos every year.

Nearly all rice farmers suffer rat damage, although the extent of losses vary. Based on cut tillers at harvest, average losses are approximately four per cent. Each year some farmers suffer very heavy damage, even total losses at times. Fortunately, such occurrences are rare. A typical hectare of rice land may have an average of 20 to 200 rats, but some areas adjacent to swamps, marshes or waste areas may have as many as 10,000 rats per hectare.

Your chances of having heavy damage (over 10 per cent) on your farm are less than 1 in 10. If you plant near areas where rats can live between crops (such as in, coconut groves, wasteland, or irrigation canals), your chances of having heavy damage are usually greater. Even under these conditions, the baiting method outlined in the following pages has been consistently successful.

Rat control is an essential investment which requires money, time, and effort. Under most circumstances, only P40 to P60 which is the equivalent cost of approximately one cavan of palay per hectare is enough to protect your crop.

KINDS OF RATS

Approximately 30 kinds of rats occur in the Philippines. Only two, *Rattus rattus mindanensis* and *Rattus argentiventer*, are serious pests in major rice-growing areas. These two types are difficult to recognize separately. In some regions, *Rattus exulans* and *Rattus norvegicus* attack rice crops. It is not possible, at present, to recommend different control measures for the different species. Most rat control methods affect whatever species is living in your field.

TYPE OF DAMAGE

Most farmers are familiar with rat damage. Rats may cause extensive damage to seedbeds. The seedlings get eaten shortly after transplanting. Oftentimes adjacent seedlings in a small area may be affected. As rice becomes older, rats cut tillers and eat portions of the developing head. This damage is dispersed throughout the field and is difficult to see unless the plants are examined closely.

When rat populations are relatively low, rat damage tends to occur along the dikes. During heavy infestations, more damage occurs in the paddy interior, resulting in "eat-outs." As rice heads mature, rats feed on individual grains, often remaining at one plant

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1/ The Rodent Research Center is a cooperative research and training center supported by the Bureau of Plant Industry, the University of the Philippines at Los Baños, the National Economic and Development Authority, the National Science Development Board, the National Food and Agriculture Council, and the U.S. Agency for International Development.

2/ The Philippine-German Crop Protection Programme is an integrated crop protection program of the Bureau of Plant Industry assisted by the German Government.

for sometime. After harvest, small piles of hulls can be seen on the paddy where rats have been feeding.

RAT CONTROL

The topic of rat control is a popular one among farmers, professional agriculturists, and laymen. Nearly everyone has a favorite theory or story about a new method or procedure that will work in any situation. In fact, no single control method can be used everywhere. In evaluating different methods, it is important to remember that the objective is to reduce crop damage. The number of rats you kill is not so important; it is the number that remain in your paddies that reduce your yield. Other factors, such as cost, practicality, safety for humans and animals, and environmental side effects, are also important to consider when a particular control method is chosen.

GENERAL MEASURES

Several general agricultural practices may be helpful in reducing potential rat problems. Cutting weeds along dikes and canal banks and adjacent waste areas, particularly several weeks before transplanting and during the early stages of rice growth, removes cover which rats need to survive. Transplanting at about the same time as your neighbors may reduce your chances of heavy damage. Fields maturing much earlier or much later than the surrounding ones often have very heavy rat damage and emergency measures at this stage are usually not successful. Killing rats at any time by any method may be helpful, but for the farmer who wants to protect his crop, there is no substitute for continuous rat control through the crop period. In areas with extremely high rat populations, baiting with acute poisons before seedbedding or transplanting, is also desirable.

SUSTAINED BAITING

Chronic poisons provide a means of continuous rat control with very little cost and labor compared to some of the other methods. These bait materials are used at low concentration so the amount of chemical involved is small. Rats must eat poisoned bait every day for several days, usually less than a week, before they are killed.

Because the symptoms develop slowly over a period of days, rats usually die in their burrows or in other protected areas. Many people like to count dead rats after poison baiting. This is usually not possible with chronic poisons. If bait is being consumed and you replace it regularly, you are killing rats. Your efforts will be rewarded by reduced damage. After 10 to 12 weeks of baiting, you can expect to have reduced the rat population in and around your rice farm so that you can be assured of a good crop.

COSTS ARE LOW

The major costs of sustained baiting with chronic toxicants are for the bait carrier and for the time required to visit the bait stations regularly. Approximately 10 kilos of bait material is the most that is required under usual conditions to protect one hectare of rice for the entire crop. The labor required is approximately 1 man-hour each week through the crop. Many suitable chemicals are available. The costs of chronic toxicant enough to treat 10 kilos of bait range from ₱1.50 to ₱15.00 depending on the material used, the source of supply, and the area of the country.

MATERIALS TO USE

Chronic toxicants require bait materials, a chemical concentrate and bait containers. Most grains can be used for bait material: choose one which is available or can be obtained at lowest cost in your region. Many farmers have obtained good results using low-quality milled rice or rice shorts. Do not use rough rice (palay), because rats remove the hulls and do not ingest much of the toxicant.

Many chronic toxicants are available in the Philippines as concentrates. Ratoxin, Racumin, Tomorin, Diphacinone, and Liphadione are examples of commercial chemicals which are available at agricultural stores. Prices and package sizes vary considerably, but all of the materials have similar action. When comparing prices, note that some concentrates can be used to prepare more bait material than others. To determine the actual cost of chemical in a finished bait, divide the retail cost of the concentrate by the number of kilos of bait to be treated. Read the label carefully so you can follow the manufacturer's instructions.

Local materials can usually be obtained at little or no cost for making bait stations. Sections of bamboo with nodes at middle or ends, one liter cans, or discarded one quart oil cans, opened on both ends, make good containers. Under very wet conditions, it is sometimes desirable to use larger bait stations which afford maximum protection from the weather. In areas with many rats, it is important to use enough stations to allow all animals easy access to the baits.

PROCEDURES

It is important to have bait materials available to all rats occupying your field from planting until the rice grains mature. Because only a limited number of rats can feed at a single bait container, the number of containers must be provided in relation to the number of rats damaging your fields.

The following methods, tested under Philippine conditions, will help you relate the intensity of your control efforts to the potential damage to your crop. These procedures are recommended as a guide for your operations.

1. Mix the recommended concentrate with the bait material. Using more than the recommended chemical does not improve control and will only increase your expense.

2. Select five baiting locations for one hectare of riceland to be protected. For good coverage, the locations should be at least 50 meters apart. Containers can be placed on or along dikes, or supported above water level in the paddy. Other good locations to place bait containers are dike intersections, canal banks, or old threshing mounds.

3. Begin baiting as soon as your fields have been transplanted. Place one container at each location and put 6 tablespoons of bait inside. After three days, check the bait containers. If all of the bait has been eaten, at one location, place two additional containers and place 6 tablespoons of bait in all three, check again in 3 to 4 days. If the bait is gone, place 3 additional containers at the locations where this happened and maintain approximately 6 tablespoons of bait in each.

4. Continue to check the bait containers twice a week. If rats continue to consume most of the bait at some of the locations, increase the amount of bait in each of the containers. A one liter can will hold up to 18 tablespoons. Try to anticipate increases in consumption such that some of the bait will still be in the containers each time you check. Add additional full containers if necessary. This is important. If bait is not available after rats have learned to come to the stations, there may be heavy feeding on nearby plants.

5. Remove and replace bait that becomes moldy or excessively wet.

6. Because the few remaining rats which comprise less than 10 per cent of the original population, will prefer the developing grains to the bait, baiting may be stopped at least two weeks before harvest unless bait consumption remains high. When bait consumption begins to decline, some of the stations at each point may be removed.

WHAT TO EXPECT

Usually, bait consumption will increase rapidly sometime during the period 3 to 8 weeks after transplanting. This is the period when rats are moving into your paddies. Do not be alarmed by this rapid increase. Continue to replenish the bait and consumption will generally level off or decline. If your neighbors are also practicing rat control, the increase will not be as great. When rice heads mature, bait consumption usually drops off sharply because there are only a few rats remaining. Although the remaining rats concentrate their feeding on grain heads, pre-harvest damage should be minimal. Remember that chronic toxicants work differently from other materials. Do not become discouraged if you do not find dead rats; they die in their burrows.

SAFETY

All agricultural pesticides are poisons and should be used carefully. Store pesticides in clearly labelled containers out of the reach of children and pets. Do not use mixing cans or spoons to measure pesticides for any other purpose. Mix chemicals outside your house. Do not breathe the dust or vapors. Do not eat, drink, or smoke while handling chemicals. Wash your hands thoroughly each time you finish your work.

Chronic toxicants are relatively safe compared to other pesticides. They cause breakdown of the blood clotting process and animals usually die from internal bleeding. If treated bait or concentrate is accidentally eaten, take the person to a doctor or clinic immediately. Treatment for poisoning with chronic toxicants consists of oral doses of Vitamin K, and in some cases, blood transfusion.

COOPERATIVE RAT CONTROL

When a farmer uses chronic poisons, the protective effects of baiting usually extends outside his farm by as much as 200 meters in each direction. Particularly during the first 8 weeks after transplanting, rats from peripheral areas will be attracted to bait containers. If your neighbors also practice sustained baiting, your results will be improved and everyone's costs will be reduced.

TECHNICAL HELP

These recommendations have been approved for implementation beginning in mid-1975 under the national rice production program – MASAGANA 99. Farmers qualifying for MASAGANA 99 loans or supervision may contact the MASAGANA 99 rice extension technologists or participating banks for additional details.

For additional advice on rat control or for help in securing rat control materials, consult a Bureau of Plant Industry pest control officer or the MASAGANA 99 rice extension technologists.

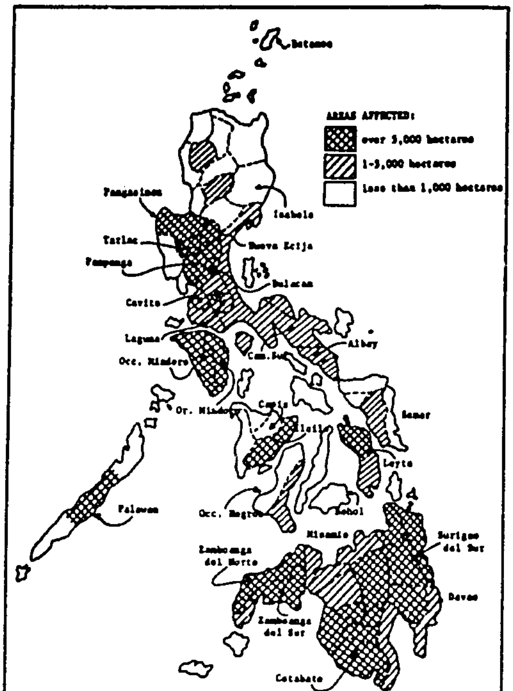

Fig. 1. Geographic distribution of provinces with high rat damage or high rat population levels.

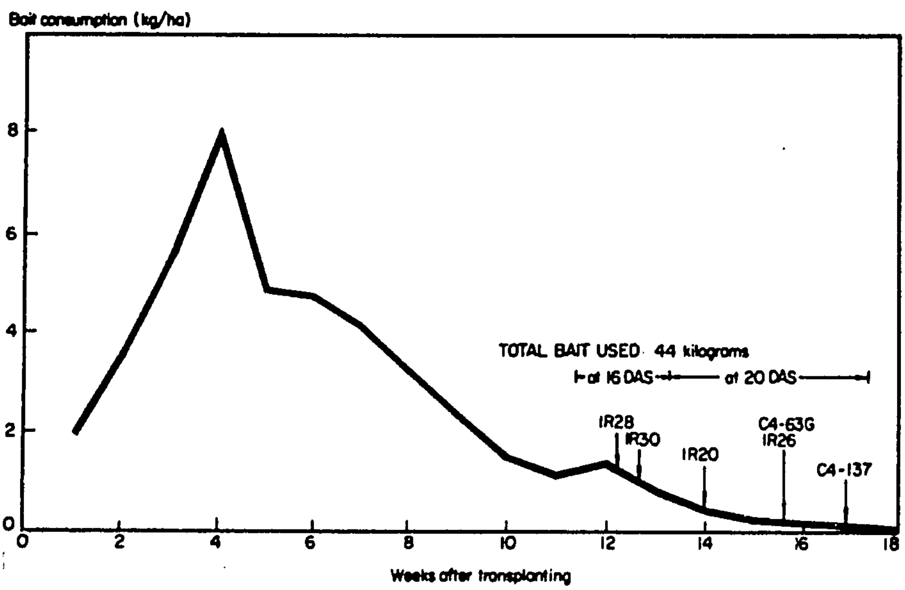

Fig. 2. Pattern of bait consumption on small farms using sustained baiting in an area with a high rat population. Most control situations should require less bait. (Low bait consumption after ten weeks of sustained baiting indicates that little or no damage is likely to the developing rice crop which usually is ready for harvest from 12 to 15 weeks after transplanting.)

DAS = days after sowing. Wetbed seedlings of rice varieties that mature in 105 to 110 days should be transplanted 16 DAS, later maturing varieties at 20 DAS.

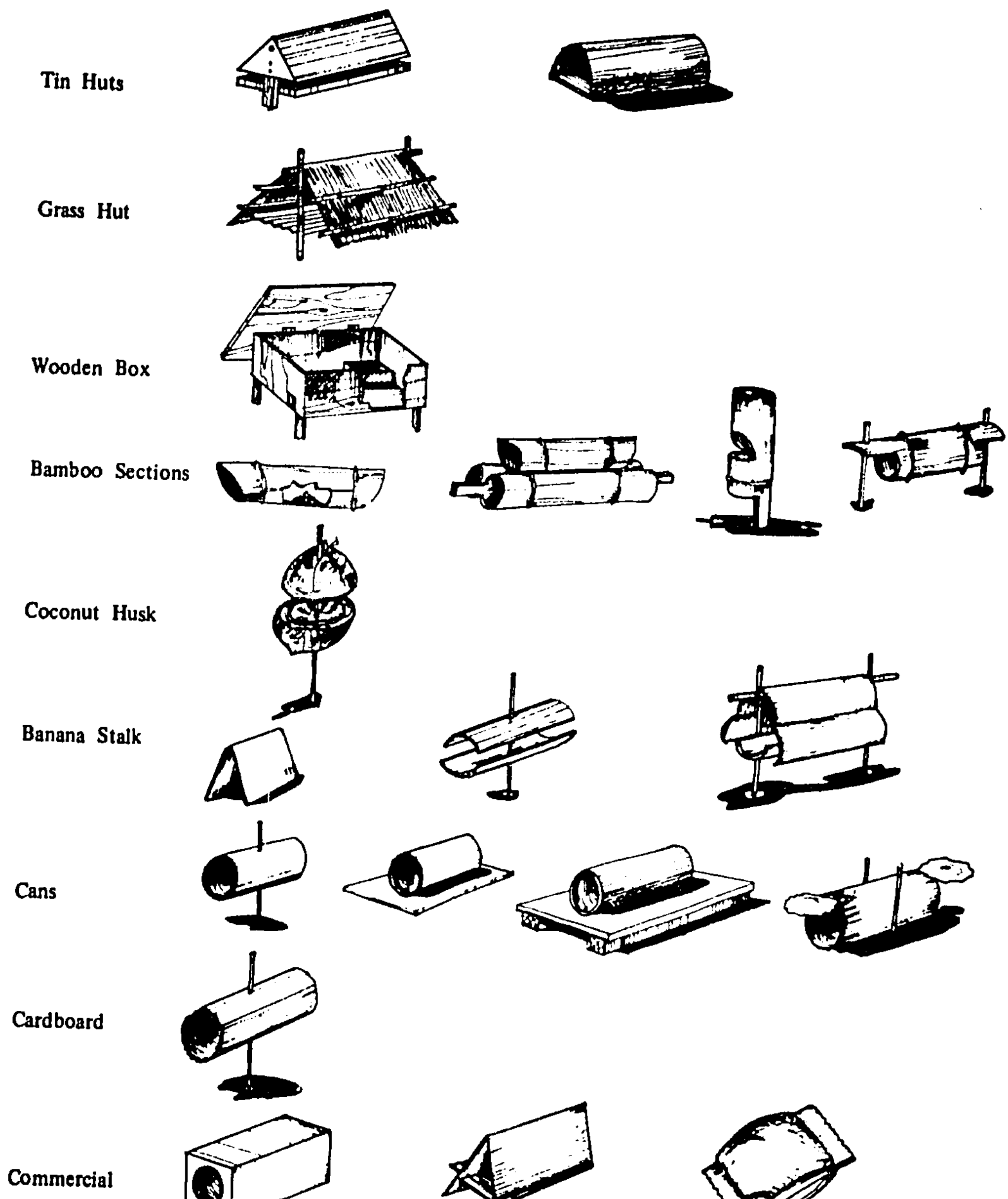

Fig. 3. Rat baiting stations for rice farms. (Local materials can usually be obtained at little or no cost for making baiting stations.)