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Abstract: Rodents occur worldwide and have adapted to most types of ecosystems. Rodents provide many important ecosystem functions and while most rodent species do not cause serious damage problems, a small number of species do. Rodent-caused damage includes crop and stored food consumption and contamination, forestry and nursery damage, rangeland damage, ornamental plant damage, property damage, cable and irrigation pipe damage, disease transmission, and, when introduced to islands, damage and even extinction of native flora and fauna. Many tools are used to reduce rodent populations and damage. Rodenticides are an especially important tool in rodent management. Many types of active ingredients and formulations are available for different species and situations. Rodenticides and their use are regulated by the United States Environmental Protection Agency (EPA) and authorized State agencies. Following regulatory review, the approved label dictates how the product must be used and who has authority to use the product. All labels contain mitigation measures to reduce the risk to workers, consumers, pets, livestock, non-target animals, and the environment. Recently, the EPA has been re-evaluating many of the major rodenticides as part of the periodic re-registration process. To reduce the number of accidental exposures by children and impacts to non-target wildlife, the EPA has proposed new mitigation measures to reduce the hazards of certain rodenticides that are used in and around homes and other buildings. If implemented as proposed, these mitigation measures may affect the availability of some of the most common rodenticides.

Key words: damage, management, pesticide regulation, risk mitigation, rodent, rodenticide

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INTRODUCTION

Over 1,400 species of rodents occur worldwide, making them the largest taxonomic group of mammals (Nowak 1999). Rodent use of habitats is extensive and varied. Most rodent species are relatively small, secretive, prolific, adaptable, and have continuously growing incisors which require continuous eroding by gnawing. All rodent species have ecological, scientific, social, and economic values. They recycle nutrients, aerate soils, distribute seeds and spores, and affect plant succession. Some provide meat and furs for people. Several species are used in large numbers in medical research. Additionally, they provide an important prey base for many species of predatory animals.

Notably, few (perhaps 5%) rodent species around the world are serious pests. Examples of genera and species of rodents considered to be serious pests around the

world were provided by Prakash (1988) and Witmer et al. (1995). A variety of economic and health problems result from rodent interactions with humans. Damage can occur to agricultural crops (both in the field and to stored foods), forests and orchards, rangelands, property (structures, cables), natural resources (both faunal and floral), and disease hazards may be posed (Marsh 1988, Witmer et al. 1995). Singleton et al. (2003) estimated that in Asia alone, the amount of grain eaten by rodents would provide enough food to feed 200 million Asians for a year. When a damage situation occurs, it is very important to determine the species causing the damage, the extent of the damage, and the abiotic-biotic-cultural factors involved before rodent population and damage management strategies are implemented (Singleton et al. 1999).

In the United States, native species causing significant damage in various regions include pocket gophers (*Thomomys* spp., *Geomys* spp.), ground squirrels (*Spermophilus* spp.), voles (*Microtus* spp.), deer mice (*Peromyscus* spp.), beaver (*Castor canadensis*), marmots (*Marmota monax*), mountain beaver (*Aplodontia rufa*), and porcupines (*Erethizon dorsaatum*). Some non-native species are widespread in the United States and cause damage as well: commensal rats (*Rattus* spp.), house mice (*Mus musculus*), and nutria (*Myocastor coypus*; Marsh 1988).

METHODS TO MANAGEMENT RODENT POPULATIONS AND DAMAGE

A variety of methods are used around the world to manage rodent populations directly or to reduce the damage caused by rodents. These methods include physical (e.g., traps, barriers), chemical (e.g., toxic baits, fumigants, repellents), biological/cultural (e.g., resistant plants, crop type, sanitation, habitat manipulation), and others (e.g., bounties, compensation; Witmer et al. 1995). Other methods are still in the developmental stages (e.g., fertility control; Nash et al. 2002). Each method has advantages and disadvantages and a site-specific assessment should be made before implementing a rodent damage management program.

Most often, an integrated pest management (IPM) strategy is developed and implemented that uses a variety of methods. This is important, in part, because a particular method of control (e.g., anticoagulant baits) may become ineffective over time. Other considerations in the resolution of rodent damage situations are rodent population monitoring and the establishment of thresholds for acceptable levels of damage and for when to implement rodent population control. Some rodent management practitioners suggest less reliance on rodenticides and a more "ecologically-based" approach to rodent damage management (Singleton et al. 1999). Nonetheless, traps and rodenticides remain very important tools in the IPM toolbox for rodent damage management.

RODENTICIDE USE IN THE UNITED STATES

Rodenticides are widely used in the United States for the control of rodent populations in various settings (e.g., agricultural lands, forests, conservation lands, urban-suburban lands; Jacobs 1994). A considerable variety of rodenticides are registered for use in the United States and these can be divided into several categories depending on their mode of action and toxicity (Table 1). The characteristics of each of these materials were reviewed by Timm (1994). Many of these are available in one or more formulations: blocks, pellets, on grains or vegetables, powders, liquid formulations, and toxic gas-producing fumigants. Some chemicals used as

rodenticides in various parts of the world are either not used in the United States (e.g., compound 1080 [monosodium flouroacetate]) or have very limited use (e.g., strychnine for below ground uses only). Additionally, these materials may be applied in various ways, depending on the situation and regulations: in burrows, near burrow openings or along runways, broadcast over broad areas by hand or mechanical device, or placed in bait stations. Some rodenticides are available to the general consumer for use in and around homes and other buildings and some limited field applications, while others are restricted use materials available only to trained, certified pesticide applicators. Rodenticides are a multi-million dollar a year industry in the United States; nonetheless, these materials are considered minor-use compared to other pesticides such as insecticides and herbicides (Fagerstone 2002). It is also important to remember that while rodenticides are very labor and cost effective, they do not provide a permanent solution to rodent problems. Where abundant food and cover is available to rodents, long-term use of rodenticides is required to keep populations in check. Hence, efforts should be made to reduce the area's carrying capacity for rodents. Long-term use may lead to some negative outcomes: rodenticide resistance in the rodent population and residue accumulation of certain rodenticides (e.g., second generation anticoagulants) leading to hazards to predators and scavengers.

Table 1. The main rodenticides used in the United States by category and percent active ingredient.

Acute Rodenticides
- Cholecalciferol (0.075%)
- Strychnine (0.5%)
- Zinc phosphide (2%)
- Bromethalin (0.01%)

Fumigants
- Aluminum phosphide (56%)
- Magnesium phosphide (56%)
- Acrolein (95%)
- Gas cartridges (variable)

1st Generation Anticoagulants
- Chlorophacinone (0.005%)
- Diphacinone (0.005%)
- Warfarin (0.025%)
- Pindone (0.025%)

2nd Generation Anticoagulants
- Bromadiolone (0.005%)
- Brodifacoum (0.005%)
- Difethialone (0.0025%)

RODENTICIDE REGULATION, SAFE USE, AND HAZARD REDUCTION

Rodenticide use in the United States is regulated by the United States Environmental Protection Agency (EPA) under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA; Jacobs 1994). The EPA requires a draft product label and considerable data be submitted and reviewed prior to making a decision on a rodenticide registration. These data include product chemistry, toxicology, residue chemistry, environmental fate, ecological hazard, and both lab and field efficacy. An EPA-approved product label provides considerable information on the product and its use, including: the registrant and EPA registration number(s), active ingredient and concentration, target species and settings in which it can be used, directions for use, storage and disposal requirements, precautionary statements, safety and environmental hazards, and threatened and endangered species considerations.

Recently, the rodenticides used in the United States have been undergoing review by the EPA before renewing a registration (Silberhorn et al. 2000). A number of concerns about the safety of rodenticides have been raised, and the review will result in many changes in what is available and how these products can be used (Jacobs 2002). Recently, the EPA recommended several mitigation measures to reduce the potential hazards of a group of nine rodenticides (brodifacoum, bromadiolone, difethiolone, chlorophacinone, diphacinone, warfarin, bromethalin, zinc phosphide and cholecalciferol) to children, pets, and wildlife (EPA 2007), including:

1. Classifying all products containing the active ingredients brodifacoum, bromadiolone, and difethialone as restricted use products.
2. Requiring that all nine products available for sale to consumers and labeled for indoor residential use be sold only in refillable tamper-resistant bait stations with solid bait blocks being the only permissible bait form.
3. Requiring certain additional restrictions and labeling improvements to mitigate the risks associated with these nine rodenticides. These changes are intended to clarify label language to minimize potential exposure to children, wildlife and pets. EPA is also considering industry's suggestion to explore reductions in the amount of bait recommended for rodent control.

These measures may have a variety of effects on the production and availability of rodenticides in the United States (Thomas Schmit, LiphTech, Inc., personal communication). Sizable costs are associated with the registration or re-registration of a rodenticide product in the United States and the market and investors can be volatile (Fagerstone et al. 1990, Jacobs 1992). There is somewhat of a trend towards fewer registrations and declining use of rodenticides in the United States (Fagerstone et al. 1990, Jacobs 1992).

Both primary (direct consumption) and secondary hazards (consuming a poisoned rodent) can occur from rodenticide use. The main safeguard for the safe use of rodenticides in the United States is carefully following the EPA label instructions for the product. Other considerations include the product used: when, where, and how it is applied; cleaning up spills promptly; and not using where highly valued or protected wildlife occur (determined by scouting the area before use).

CONCLUSIONS

Rodents will continue to pose challenges to land and resource managers, commodity producers, and homeowners. Many tools are available to reduce rodent populations and associated damage. They should be used in a well thought out IPM approach. Rodenticides will continue to be

an important tool against rodents and their damage, but care must be exercised in their use. It is probably safe to assume that much of the public will continue to be leery of toxicant use. Hence, public education will be important to ensure continued availability of rodenticides. Continued technology development and transfer are essential to improve the effectiveness and safety of rodenticides.

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