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Effective Management of Roof Rats in Nut and Fruit Orchards in California

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Invasive nonnative vertebrate animals cause an estimated $39 billion in damage annually in the United States (Pimentel 2010). Rats (*Rattus* spp.) are common invasive pests found throughout most of the United States in both urban and agricultural areas and are thought to be one of the main contributors to these damages. In fact, one projection of annual costs of damage caused by rats is estimated at $19 billion (Pimentel et al. 2005).

More specifically, roof rats (*Rattus rattus;* plate A) are known to be large contributors to damage of nut and fruit trees in the United States (Kern Jr. 2012; Pearson et al. 2000; Tobin et al. 1997). Common types of damage include direct consumption of fruit and nuts (plates B and C), removal of bark and associated cambium layers on trees (called girdling; plate D), chewing damage to irrigation infrastructure (plate E), burrowing that may lead to increased soil erosion and instability of trees (plate F), and risks to food safety through fecal contamination of fruit and nuts. For example, in macadamia nut crops in Hawaii, invasive rat damages have been estimated to be between 5 and 10 percent of crop production values (Tobin et al. 1997), whereas in almond orchards in California, roof rat damage was estimated between $109 and $311 million during autumn 2024 (Goodhue et al. 2025). Clearly, effective rat control is critical for preventing damage to agricultural crops. In this publication, we will discuss identification of roof rat damage, strategies for monitoring roof rat abundance, and the potential utility of various management approaches. We conclude by detailing options for how to construct an integrated pest management (IPM) program.

Plate A. Roof rat (*Rattus rattus*) in tree canopy. Note the pointed nose, large ears, and tail that is equal to or longer than the length of the body of the rat, which separates it from the Norway rat (*Rattus norvegicus*). *Source*: Jack Kelly Clark, UC IPM.

Plate B. Hollowed out orange that is indicative of roof rat damage to citrus. *Source*: Roger Baldwin, UC Davis.

Plate C. Roof rat chewing damage to almonds. *Source*: Niamh Quinn, UC ANR.

Plate D. Roof rat girdling damage to lemon tree. *Source*: Roger Baldwin, UC Davis.

Plate E. Roof rat chewing damage to irrigation tubing. *Source*: Juan Ayala Cruz, California Department of Food and Agriculture.

Plate F. Roof rat burrows at base of tree exposing roots and causing instability for the tree. *Source*: Niamh Quinn, UC ANR.

Identifying damage

Accurate identification of the pest species causing damage is essential for developing an effective management program. If a management plan is derived for the wrong species, it is likely to be ineffective, may result in hazards to nontarget species, and may be illegal based on the rodenticide label. Fortunately, a few options are available to help determine if roof rats are present. Roof rats often burrow at the bottom of trees; these burrows are very distinctive (plate G). Distinguishing between the presence of deer mice (*Peromyscus* spp.) and roof rats is easiest by looking at the size of burrow entrances. Roof rat burrow entrances are often in the range of 1.5 to 3 inches in diameter while deer mouse burrow entrances are generally less than or equal to 1 inch in diameter. Additionally, roof rats often create leaf nests in tree canopies that can be used to determine their presence (plate H).

Feeding activity can also be used to identify roof rat activity. For example, in nut orchards, discarded shells at the entrance of the burrow can be examined to determine tooth marks from rodents. In most citrus varieties, the hollowed-out rind of the fruit is a tell-tale sign of rat consumption; although, in Meyer lemons, rats generally eat the rind and leave the fruit. Deer mice do not generally girdle branches of trees, so the presence of such damage is a good indicator of roof rat presence. Consider, however, that other rodents can cause similar damage in some settings, including various tree squirrel (*Sciurus* spp.) and ground squirrel species (*Otospermophilus* spp.) as well as wood rats (*Neotoma* spp.). If you are uncertain as to which species is responsible for causing damage, rat- and mouse-size snap traps can be placed around areas showing damage. Alternatively, remote-triggered game cameras can also be used to assess the presence of damaging species. The identification of the captured or photographed individual will help you decide upon the appropriate management plan. Further information on identifying roof rat and deer mouse species can be found at the University of California (UC) IPM Pest Note website (ipm.ucanr.edu).

Plate G. Roof rat burrow found in citrus orchard. Roof rats often use old pocket gopher (*Thomomys bottae*) burrow systems, as illustrated in this photo. *Source*: Roger Baldwin, UC Davis.

Plate H. Roof rats often create nests of leaves in the canopy of citrus trees. *Source*: Roger Baldwin, UC Davis.

Plate I. Tracking tunnel attached to a 3-foot section of a 2-inch-by-4-inch wooden board. Tracking tunnels are used to monitor roof rat presence. *Source*: Roger Baldwin, UC Davis.

Monitoring strategies

Effective management of pest species relies not only on proper identification, but also on the ability to determine relative abundance of the target species, as well as changes in relative abundance over time. Unfortunately, no action thresholds for implementation of management actions have been developed for roof rats. As such, it is up to the grower to determine what an acceptable level of abundance is. Several strategies can be used to monitor changes in rat abundance.

Tracking tunnels

Baldwin and Meinerz (2022) have verified the effectiveness of tracking tunnels for monitoring roof rat abundance in orchards. This approach relies on placing inked tracking cards in a plastic tunnel (plate I). Place an attractant at the center of an inked card (plate J) located within the tunnel to entice the rat to step on the ink. When the rat exits the tunnel, it leaves footprints on the card that can be used to verify presence (plate K). A simple comparison of the number of tunnels visited by rats over time provides a quick and easy assessment of changes in relative abundance. We recommend tying tracking tunnels to 3-foot sections of 2-by-4-inch wooden boards (plastic cable ties work well for this) and placing the boards in a relatively flat position in tree canopies (often 3 to 5 feet aboveground). A variety of attractants can work, including peanut butter and various commercial products such as nontoxic wax blocks (for example, NoTox Monitoring Blocks, Liphatech, Inc., Milwaukee, WI; DETEX Blox, Bell Laboratories, Inc., Windsor, WI) and soft baits (for example, NoTox Soft Bait Attractant, Liphatech, Inc.; DETEX Soft Bait, Bell Laboratories, Inc.; Wales et al. 2021). Placing the tracking tunnels in a grid pattern allows for continuous coverage throughout the orchard. We found that 230-foot spacing between tracking tunnels works well for periodic monitoring (Baldwin and Meinerz 2022). Several commercial tracking tunnel options are available including Black Trakka (Gotcha Traps, Warkworth, NZ) and Pest Control Solutions (Christchurch, NZ). Tunnels can be operated for two to four nights depending on the abundance of activity in the area. However, once you decide on a duration, you should keep it the same throughout all monitoring sessions thereafter, as the longer you keep the tunnels out, the more likely it is that a rat will visit them (for example, if 20 tunnels are placed, 4 may be visited after 2 nights, but perhaps 7 will be visited after 4 nights).

Remote-triggered cameras

Remote-triggered cameras, also known as trail or game cameras, are a tool often used to track wildlife populations and have proven to be a reliable approach for monitoring roof rat populations in orchards (Baldwin et al. 2014, 2022). Target the camera on an attractant such as nontoxic wax blocks or soft baits. The camera will take photos or videos when the animal walks in front of it (plate L). Set up for remote-triggered cameras is similar to that for tracking tunnels. The cameras can be placed 3 to 5 feet aboveground in the tree canopy, with the camera targeted at an attractant generally located 2 to 5 feet from the camera. Care must be taken to ensure the attractant is properly centered in the camera's field of view. Cameras can be placed in a grid pattern separated by 230 feet. They should be operated for two to four consecutive nights to detect rodents in the orchards. Be sure to read the operational logistics of each camera to ensure that you are using them properly.

The use of remote-triggered cameras has an advantage over tracking tunnels in that you can identify when the animal visited the site (both date and time). Remote-triggered cameras could also potentially identify rats that would not enter a tracking tunnel given a neophobic response (fear of something new in their environment). That said, remote-triggered cameras are more expensive

Plate J. Tracking card with inked center. An attractant was placed at the center to draw roof rats into the tracking tunnel. *Source*: Ryan Meinerz, UC Davis.

Plate K. A tracking card with roof rat foot prints left behind when the rat exited the tracking tunnel. *Source*: Ryan Meinerz, UC Davis.

Plate L. Photo of roof rat taken at night with a remote-triggered camera. *Source*: Niamh Quinn, UC Davis.

to operate than tracking tunnels, and they require substantial time to scroll through photos to identify if a rat was present. As such, tracking tunnels may be the more practical tool for long-term monitoring strategies, but both options are effective.

Other monitoring strategies

Placing a series of snap traps throughout an orchard is sometimes used to track changes in rat abundance over time. This approach generally entails placing rat-sized snap traps (often 50 to 100 traps per site) up in tree canopies by tying the traps to branches and baiting with an attractant such as peanut butter (plate M). The user then determines the number of captures over two to four trap nights, thereby allowing comparisons across time. This approach has not been officially tested but should provide at least some idea of changes in rat numbers over time, although it's important to note that visitation to traps may be lower than that to tracking tunnels or remote-triggered cameras given occasional avoidance of traps by cautious rats.

Plate M. Rat-sized snap trap baited with peanut butter and attached to a branch of an almond tree. This approach can be used to monitor roof rat activity. *Source*: Adam Chang, California Department of Food and Agriculture.

The systematic placement of nontoxic wax blocks or soft baits throughout a field are sometimes used to serve as a chewing index for rodent activity. However, this approach does not strongly correlate to rat abundance in orchards. Furthermore, this approach does not allow the user to differentiate chewing damage from rats versus other rodent species. Therefore, other listed approaches likely have more utility for rat control in orchards.

Regardless of the strategy used, it is important to keep good records of rat visitation during each monitoring period. This will allow you to evaluate your management program, document where rat activity has occurred within an orchard over the course of several to many years, and allow you to identify when rat outbreaks are occurring. For example, you may find rat activity most commonly along a particular field edge, indicating extra effort is needed to slow reinvasion along that perimeter. Likewise, a change in adjacent habitat may lead to a change in where rat activity is most likely to occur, suggesting control efforts may need to be shifted to another part of the orchard. Without good records, you may not be able to identify these changes over time.

Management strategies

Several potential management strategies could be considered for roof rats in orchards including habitat modification, biocontrol, fertility control, burrow fumigation, rodenticide application, and trapping. The following sections outline some of the strengths and limitations of each of these approaches and provide details on how they may be implemented to reduce roof rat abundance in orchards. It should also be noted that it is the responsibility of the grower to be aware of the presence of threatened or endangered species in orchards where management programs are to be executed, as the use of pesticides or traps detailed in the following section may prove hazardous to nontarget species. Killing an endangered species may result in a fine and imprisonment under the Endangered Species Act of 1973. Growers and their associated agents must consult and follow the California Department of Pesticide Regulation's PRESCRIBE website for any endangered species restrictions associated with pesticide application.

Habitat modification

Habitat modification involves altering the desirability of a particular area for roof rats. For example, roof rats require harborage for protection. Brush or pruning piles found within or adjacent to orchards provide excellent protection for roof rats, and as such could be used for shelter. Getting rid of this preferred harborage could help reduce roof rat abundance in an orchard and should always be considered when developing an IPM plan. Additionally, abandoned orchards likely serve as sources for roof rat populations. Removal of these abandoned orchards would greatly increase the ability to manage roof rats. However, this may not be an option in many situations. If their removal is not an option, these abandoned orchards should be acknowledged as a potential source population for roof rats; monitoring and management actions should be particularly robust along field perimeters that are adjacent to these abandoned orchards to minimize invasion of production orchards.

Biocontrol

Natural predation of roof rats may potentially provide some control at no cost or reduced cost (when compared to other management options). The primary predator considered for rodent control in agricultural systems is the barn owl (*Tyto furcata*). The barn owl is known to remove a large number of rodents. In fact, the number of rodents removed annually by a breeding pair and chicks has been reported up to 3,466 (St. George and Johnson 2021). One may also artificially inflate barn owl numbers in an area by using barn owl nest boxes (plate N; Labuschagne et al. 2016). Barn owls have been reported to reduce deer mouse and pocket gopher (*Thomomys* *bottae*) abundance in California vineyards (Hansen and Johnson 2022; Larson 2024), and they've been shown to reduce roof rat populations in oil palm plantations in Southeast Asia (Primananda et al. 2024). However, no data exists on their effectiveness against roof rats nor for any rodent species in California orchards. Orchard settings may be more challenging for barn owls given the dense canopy cover, which may impede their flight. Still, in almond and pistachio orchards, there likely is enough room for barn owls to maneuver, so they could possibly be considered as part of an IPM program. That said, growers need to be realistic about their ability to manage roof rat populations; they won't be able to eradicate roof rats from orchards, but they may be able to reduce numbers. There appears to be less utility for barn owls in citrus given thick vegetative cover, although their presence could still be encouraged by the placement of barn owl boxes.

Plate N. Barn owl nest box placed in an almond orchard to help control rodent pests including roof rats. *Source*: Roger Baldwin, UC Davis.

Fertility control

Much research has gone into developing fertility control options for rodents over the last few years. There is at least one product with the active ingredient cottonseed oil that is available as a fertility control option for roof rats in orchards (Evolve, SenesTech, Inc., Phoenix, AZ). Although this product has not been tested in a field setting, implementation would likely involve placement in bait stations. It is important to note that fertility control relies on the disruption of reproduction in the rodent population, but it does not lead to mortality of the target animal. Therefore, rapid knockdown of rodent populations will not be possible with fertility control. Rather, the most likely scenario where it might be used is as a tool to slow reinvasion of areas where rat populations have already been depopulated through other techniques (such as rodenticides, trapping, etc.). Furthermore, fertility control methods require continued use to intercept reinvading roof rats, and as such would likely be far more costly to implement than other approaches such as trapping. The added costs, combined with unknown efficacy of this product, suggests that there are better options for inclusion in an IPM program for roof rat control in orchards. That said, future testing on fertility control of roof rats in agricultural fields is warranted to assess its effectiveness.

Burrow fumigation

In nut orchards, roof rats live primarily in ground burrows. As such, the application of toxic gases (burrow fumigation) within burrow systems may provide effective control, although the efficacy of these fumigants has yet to be tested against roof rats. Note that in citrus orchards, roof rats do sometimes use ground burrows, but they regularly nest in tree canopies as well; therefore, burrow fumigation is likely a more viable option in nut orchards than in citrus. When using burrow fumigation, a key requirement is high soil moisture; this is generally defined as soil that is moist enough to form a ball in your hand when making a fist with a handful of burrow-depth soil. If soil is too dry, gases will dissipate through cracks and pores in the soil at a high enough rate to render the fumigant ineffective. When soils are moist, the cracks and pores swell shut, thereby holding the toxic gases in at a much greater rate. Because of this, burrow fumigants should only be used after sufficient rainfall has been received or after a heavy irrigation event. It is also important to note that each burrow fumigant generally has restrictions regarding how close to a building you can be to make an application. This pertains to buildings or related structures that are or may potentially be occupied by humans or domestic animals. It is important to fully understand these restrictions before using burrow fumigants.

A common burrow fumigant that is sometimes used for roof rat control is aluminum phosphide. For application, tablets or pellets are placed into the burrow system where they react with soil moisture to slowly emit phosphine gas over a 24-hour period. The burrow opening is then plugged with a material such as newspaper or grass and covered with soil to hold the toxic gases within the burrow system. It is important to plug the burrow entrance with a barrier material before covering with soil, as simply covering with soil will bury the tablets, rendering them ineffective. Please note that aluminum phosphide is a restricted-use material. The applicator must be certified or under the direct supervision of someone who is certified to use the product, including for a new burrow fumigation category that is now required (for individuals with a Qualified Applicator Certificate [QAC] or Qualified Applicator License [QAL], Category M; for individuals with a Private Applicator Certificate [PAC], Burrowing Vertebrate Pest Fumigation [BVPF] certificate). In addition to filing a Notice of Intent to apply and a Pesticide Use Report, the applicator will also need to file a Fumigation Management Plan, which will include items such as contact details for the orchard manager, local emergency response phone numbers, and potential endangered species impacts, among other details. The site will also need to be posted for 48 hours following application. Please contact your local Agricultural Commissioner's office for additional details on the application of aluminum phosphide and associated Fumigation Management Plan in your county.

Carbon dioxide injection devices (such as IGI CO_2, Liphatech, Inc.) can also be used to fumigate roof rats in burrow systems. This approach involves injecting pesticide-labeled carbon dioxide into the burrow system through a specifically designed injection probe. It is important to note that only carbon dioxide that is specifically labeled for use against burrowing rodents can be used, and places that sell this product are quite limited. We recommend potential users to seek the closest location where they can purchase this gas to determine the practicality of using this device before making a purchase. Three-minute injection times per burrow system are recommended for carbon dioxide. Be sure that burrow entrances are plugged with soil while injecting the gas. Carbon dioxide is not considered a restricted-use pesticide so a grower would not need a QAC, QAL, or a PAC to use it. They also do not need a Category M or a BVPF certification. However, a private (for hire) pest control company would need to be appropriately licensed, and a Pest Control Advisor (PCA) would require a PCA license for recommendations associated with this product.

Pressurized exhaust machines that inject carbon monoxide-laden exhaust into burrow systems can also be used to control roof rats within burrow systems (for example, Pressurized Exhaust Rodent Controller, H&M Gopher Control, Tulelake, CA; CO-Jack, Jackrabbit, Ripon, CA; BurrowRx Carbon Monoxide Sprayer, BurrowRx, San Diego, CA). As with carbon dioxide injection devices, probes are inserted into active burrow systems and exhaust is injected for 3 minutes per burrow system. Burrow entrances should be covered with loose soil while the exhaust is injected. The California Department of Pesticide Regulation (CDPR) considers these machines as devices rather than pesticides. Therefore, a permit from your county agricultural commissioner or CDPR is not needed to use this device for rodent control.

Rodenticides

Rodenticide baits are historically the preferred technique used to control rat populations given their low cost and high efficacy (Baldwin et al. 2014). Many rodenticides have been developed to control roof rat populations. Some of these rodenticides can be used to manage roof rats in and around agricultural buildings (such as brodifacoum, bromadiolone, difethialone, zinc phosphide, cholecalciferol, and bromethalin), while others are used in field settings (such as chlorophacinone and diphacinone). This publication aims to manage roof rats within orchards, so we will focus exclusively on field rodenticides. Furthermore, although some chlorophacinone and diphacinone products may be applied during the dormant season or on orchard perimeters, we will focus our discussion in this section on the use of the California Department of Food and Agriculture's Rodent Bait Diphacinone Treated Grain (0.005%) product (CDFA diphacinone bait), as it is the only product that allows for application within an orchard during the bearing season. This is a rolled oat product that is sold in select county agricultural commissioner's offices. Although the CDFA diphacinone bait is the only rodenticide that can be applied for roof rat control during the bearing season, there are potential chlorophacinone products that can be applied via bait station application at the ground level during the dormant season. However, it should be noted that although chlorophacinone has worked well against roof rats in other settings (Whisson et al. 2004), it did not test well against roof rats in almond (Baldwin et al. 2014) or citrus (Baldwin, unpublished data) orchards. As such, diphacinone products may yield better or more consistent results.

Plate O. Tubular bait station used to manage roof rats in orchards. Bait station is attached to a branch via a bungee cord. *Source*: Roger Baldwin, UC Davis.

During the bearing season, bait must be applied via stations elevated at least 3 feet off the ground to eliminate access to ground-dwelling species (plate O). A commercial bait station is available for purchase through select county agricultural commissioner's offices for use against roof rats in tree canopies. Conversely, if you wish to make your own bait stations, you can drill holes about 1.75 inches in diameter toward the top of 4-inch end caps. Be careful to situate bait stations in trees to prevent bait spillage out of openings.

Proper spacing of bait stations depends on how wide of an area roof rats roam within their home range; roof rats must have access to at least one bait station for the rodenticide to work, and access to multiple bait stations will likely increase efficacy. Baldwin et al. (2024) determined that the radius of an average roof rat home range in citrus orchards was 284 feet, so initial tests on the efficacy of the CDFA diphacinone bait were conducted at 250 feet to hopefully minimize the number of bait stations required for effective management. Unfortunately, this spacing was minimally effective (28% reduction in rat activity post-treatment), so they set up additional trials to test 164-foot spacing, which mimicked the radius of the smallest roof rat home range (157 feet; Baldwin et al. 2024). This spacing was successful, reducing roof rat abundance by 73 percent following an extended baiting period (leaving bait in place until further bait consumption ceases, about one month but sometimes longer, depending on the amount of rat activity in the area; Baldwin et al. 2025). A further reduction in spacing between bait stations may lead to an even greater reduction in roof rat abundance, as witnessed by the higher efficacy observed by Baldwin et al. (2014) in almond orchards, where they noted a 90 percent reduction in roof rat abundance following the completion of their baiting program that used 98-foot spacing. However, this increase in efficacy comes at a cost, with approximately double the number of bait stations required to bait a similar-sized orchard when using 98-foot spacing. Ultimately, the necessary spacing for a given orchard will mostly depend on the desired reduction in roof rat abundance while balancing the total cost of such a management program. As such, we recommend bait stations be deployed using between 98- and 164-foot spacing between bait stations depending on your goals.

The number of bait stations needed across the length (NLength.aa; the reference to .aa represents the decimal places resulting from the calculation) and width (NWidth.bb) of each orchard can be determined using the following formulas:

$$(\text{Length of orchard})/\text{Spacing} = \text{NLength.aa}$$

$$(\text{Width of orchard})/\text{Spacing} = \text{NWidth.bb}$$

Since NLength.aa and NWidth.bb will not likely be whole numbers, growers should round these numbers down to whole numbers before multiplying to determine the number of bait stations (NBS) needed for the entire orchard (note that in a square orchard, NLength = NWidth).

$$NBS = NLength \times NWidth$$

Bait stations should be evenly spaced in orchards (fig. 1). To determine the optimal placement of bait stations, growers must calculate the distance from the edge of the orchard (DE) to place the initial bait stations. For square orchards, this can be calculated by multiplying .aa by the spacing used in that orchard (164 or 98 ft.). The resulting number should be divided by 2 to account for spacing on both edges of the orchard.

$$DE = (.aa \times spacing)/2$$

If the orchard is not square, then the distance from the edge must be calculated for both the length and width of the orchard. This can be done by multiplying .aa by the spacing used and dividing by 2 to give the distance from edge lengthwise (DEL) and by multiplying .bb by the spacing used and dividing by 2 to give the distance from edge for the width of the orchard (DEW).

$$DEL = (.aa \times spacing)/2 \quad DEW = (.bb \times spacing)/2$$

The following is an example of the calculations for an 80-acre square orchard (1,867 x 1,867 ft.) using 164-foot spacing:

$$(\text{Length of orchard})/\text{Spacing} = \text{NLength.aa}$$
$$1{,}867/(164\ ) = 11.38$$

$$(\text{Width of orchard})/\text{Spacing} = \text{NWidth.aa}$$
$$1{,}867/(164\ ) = 11.38$$

$$NBS = NLength \times NWidth \quad 11 \times 11 = 121 \text{ bait stations}$$

$$DE = (.aa \times spacing)/2 \quad (0.38 \times 164\ )/2 = 31 \text{ ft.}$$

These formulas will calculate the number of bait stations required for the orchard, and they will provide an approximation for the location of each bait station. However, note that different spacing between individual trees and rows of trees will require placing bait stations in the closest tree for each measurement. To attach bait stations to tree branches, we suggest using bungee cords as they provide a secure attachment in a less time-consuming manner. Cable ties or bailing wire could also be used, but they are more difficult to use and generally result in a less secure bait station. Bait stations should only be attached at angles that prevent bait spillage. Bait stations can be attached on top or to the underside of a branch, although we have generally observed greater bait consumption, and therefore a presumption of increased efficacy, for bait stations that were placed on top of branches. Crooks or forks in branches are also great places to straddle bait stations in a relatively flat orientation.

Initially, one cup (approximately 0.25 lbs.) of bait should be added to each bait station. Bait stations should

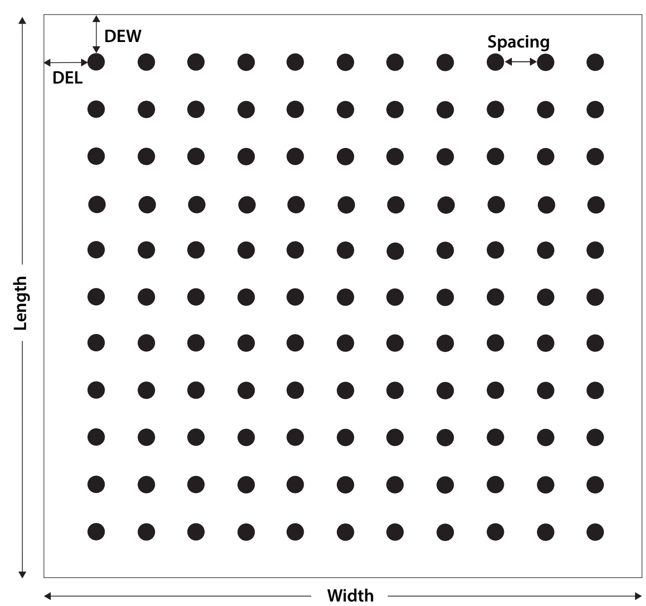

Figure 1. An example of the layout of bait stations (black-filled circles) for an 80-acre square-shaped orchard. The length and width of the orchard was 1,867 feet. In this example, we used 164-foot spacing between bait stations. Therefore, we placed initial bait stations 31 feet from the edge (DEL and DEW) of all sides of the orchard.

be checked on a regular basis to make sure that a constant bait supply is maintained; the amount of bait can be adjusted according to uptake. If necessary, up to 1 pound of bait can be applied per bait station at one time, although rarely is more than two cups of bait required at a given time. Please note that bait stations should be checked after rainfall events. If the grain gets wet, it will get moldy and will be unattractive and unpalatable to the rats. If this occurs, the bait should be replaced with fresh bait, with the wet or moldy bait properly disposed of according to label specifications. It is important to note that diphacinone is a first-generation anticoagulant that requires multiple feedings for the target species to obtain a lethal dose. As such, a constant bait supply must be maintained throughout the duration of the baiting process.

Bait stations can be deployed without bait for a few days to allow rodents to become acclimatized. Once initiated, baiting should be sustained for around 4 weeks or until consumption of grain stops. When dealing with higher-density roof rat populations, a longer baiting period may be required. If so, monitor bait consumption during checks and continue to bait until bait consumption is reduced to a minimal level. Following the completion of a baiting program, the empty bait stations could be kept in place and used again as needed.

Bait stations may also be deployed at ground level during the nonbearing season for some chlorophacinone products. However, elevated bait stations provide advantages over ground stations. For example, previous studies on roof rats have found that elevated baits are typically more effective than bait placed at ground level (Campbell et al. 1998). Additionally, bait stations placed at ground level increase the possibility of nontarget consumption of bait (for example, kangaroo rats; Burke et al. 2021). Therefore, the use of elevated bait stations is preferred.

Although concerns of secondary toxicity are lower with first-generation anticoagulants than with their second-generation counterparts (Baldwin and Salmon 2011; Lima and Salmon 2010; McMillin et al. 2008; Silberhorn et al. 2006), there is still some inherent risk. During a baiting program, most rodents die below ground (Baldwin et al. 2021). However, some may be found above ground. As such, carcasses should be searched for on a daily or semi-daily basis. If found, dead rodents can be removed and disposed of by burying or burning, if permitted. Alternatively, carcasses can be wrapped in newspaper or double-bagged and disposed of in the trash. Latex or nitrile gloves should be worn when handling dead rodents to prevent potential infection from various diseases or parasites.

Please note that deer mice are often observed using and nesting in bait stations. Deer mice are known reservoirs of the Sin Nombre virus, which is responsible for the potentially fatal hantavirus pulmonary syndrome (Nichol et al. 1993; Childs et al. 1994). This virus is transmitted through the inhalation or ingestion of aerosolized saliva, feces, or urine of deer mice. Therefore, it is important to ensure that the wind is blowing away from the bait applicator when opening bait stations so that any aerosolized particles are carried downwind. The use of an N95 respirator will reduce exposure risk, although only an approved respirator equipped with high-efficiency particulate air filters offers total respiratory protection against airborne viruses. Please see the UC IPM Pest Note for Deer Mice for additional information on hantaviruses and associated protective measures.

Plate P. Trapping tunnel with two captured roof rats that has been opened to expose the two snap traps housed within. *Source*: Roger Baldwin, UC Davis.

Trapping

Snap traps are the most common trap used for roof rats. Snap traps can be placed up in trees by adhering them to branches (plate M). Placing such traps out in the open can result in capturing a variety of bird species, but the use of trapping tunnels that house two traps on opposite ends of the tunnel helps to eliminate this risk (plate P). Trapping tunnels may also increase capture success over traps placed in the open given the attractive nature of tunnels (Wales et al. 2021), although it may take a few days for the rats to acclimate to the new structure located within their territory.

Trapping is often used as a follow-up approach to baiting to help keep reinvading rats from repopulating an orchard. This approach has proven very effective in citrus orchards (Baldwin et al. 2025), with results likely translating to other orchard crops as well. Close spacing between trapping tunnels may be less important when using trapping as a follow-up approach to a baiting program given that the rats have already largely been removed from the landscape. In this situation, you are trying to keep rats from repopulating the site. Baldwin et al. (2025) found that 246-foot spacing worked well for

Plate Q. Trapping tunnel attached to a wooden 2-inch-by-4-inch board and placed in the canopy of an orange tree. *Source*: Roger Baldwin, UC Davis.

Plate R. Goodnature A24 trap with a wooden platform underneath the trap to allow a roof rat easier access to the lure in the trap. Note the dead rat on the ground that was killed by the trap. *Source*: Roger Baldwin, UC Davis.

Plate S. Gophinator trap placed within a roof rat burrow entrance. *Source*: Roger Baldwin, UC Davis.

this (see the methodology provided in the "Rodenticides" section to determine how to distribute the trapping tunnels in your orchard), with a 93 percent reduction in roof rat abundance when compared to pre-treatment levels following 5 months of trapping. This reduction is higher than what was observed after the completion of a baiting program which had a 78 percent reduction in roof rat abundance when compared to pre-treatment levels. Therefore, we strongly recommend incorporating trapping into a management program to realize long-term reductions in roof rat abundance.

For trapping, we attached trapping tunnels (Tomcat Tunnel Trapping System, Motomco, Madison, WI) to 3-foot sections of wooden 2-by-4-inch boards using plastic cable ties (plate Q). Traps can be baited with a number of attractants including peanut butter or commercial lures. Peanut butter is perhaps the simplest attractant to use, but many animals, including ants, readily consume it within a day or two after baiting, thereby rendering the trap ineffective. Baldwin et al. (2025) used Goodnature Chocolate Rat & Mouse Lure (Goodnature Ltd., Wellington, NZ) given its highly attractive nature combined with the fact that it is an oil-based paste that lasts much longer in the environment than peanut butter. Other commercial lures may work in the same manner, so feel free to experiment to determine what attractant works best in your situation. If using traps as a follow-up approach to baiting, we recommend trap-check intervals of 3 to 4 weeks to remove dead rats and reset traps, as well as to rebait traps to maximize capture efficiency.

Plate T. Roof rat captured by Gophinator trap. Staking the trap into the ground with a wire flag reduces the likelihood of the rat or any scavengers from running off with the trap. *Source*: Roger Baldwin, UC Davis.

If you are an organic producer or a grower that wishes to minimize pesticide usage, trapping will likely be the primary tool to manage roof rats. We did not test the effectiveness of trapping tunnels for reducing high-density roof rat populations in orchards. However, if using trapping in this manner, we suggest reducing spacing between trapping tunnels to less than or equal to 164 feet to mimic the spacing used with bait stations. In this situation, traps will need to be checked far more frequently to remove dead rats and reset traps. This would likely require at least weekly trap checks, and at the beginning of trapping efforts, it may require daily trap checks to maximize the effectiveness of the trapping program.

One potentially attractive option for supplementing snap trapping programs is the use of the Goodnature A24 trap (A24 traps; plate R). This trap uses an Automatic Lure Pump to attract rats up into the trap. The rat then pushes the trigger when attempting to reach the lure, releasing a carbon dioxide-fired plastic bolt that crushes the head of the rat. The rat then falls out of the trap and the trap resets itself. This trap allows for up to twenty-four captures per carbon dioxide cartridge, with the lure lasting 4 to 6 months before needing replacement. Although elegant in design, this trap has not proven effective against roof rats in citrus orchards, and it is very expensive when compared to trapping tunnels (Baldwin et al. 2022; Baldwin et al. 2025). It is an option that could be tried out within a roof rat management program, but to date, other strategies have proven more practical.

Because roof rats often reside in ground burrows, traps can also be set in these burrows to capture rats when they leave (plate S). For instance, we have noted substantial success when placing Gophinator traps (Trapline Products, Redwood City, CA) within roof rat burrow entrances in almond orchards. Other pincer-style traps may work as well. Be sure to place the entire trap within the tunnel to maximize capture success and stake the trap down with a wire flag or something similar to reduce the likelihood of a scavenger running off with the trap (plate T). Although this trapping approach is more labor intensive, it also has the potential to yield greater capture efficiency given the ability to target the rat in a location where it is highly likely to be found (where you don't have to draw the rat into a trap but simply need to intercept it when it leaves). This trapping approach may not be the most viable option when dealing with large populations of roof rats, but it could serve as a good tool to target rats that are difficult to remove through other means.

As with other methods, be sure to wear latex or nitrile gloves when handling dead rodents to prevent potential infection from various diseases or parasites. You may capture a deer mouse during trapping efforts as well. Be sure to review the cautionary material on deer mice in the "Rodenticides" section to reduce the risk of exposure to hantaviruses.

Developing a management plan

To this point, we have primarily discussed the use of various management tools. However, effective management relies on the use of multiple tools to provide more efficacious and cost-effective reductions in roof rat populations over an extended timeframe. We have previously tested multiple management plans in citrus that involved baiting and trapping, and the following example of a management program may provide long-term relief from roof rats:

1. Conduct initial monitoring using tracking tunnels separated by about 230 feet to determine a notable increase in roof rat abundance.
2. When roof rat activity is high (based on grower-defined thresholds; no official threshold yet estab lished), implement a baiting program (CDFA diphaci none bait) using elevated bait stations separated by about 160 feet. Operate bait stations until bait con sumption is minimal.
3. Place trapping tunnels in a grid pattern, with tunnels spaced approximately 245 feet apart. Check traps about every 3 weeks to rebait and reset as needed.
4. Operate tracking tunnels every 3 to 4 months to deter mine the status of the roof rat population. Additional ait applications can be used as necessary.

For management programs to be practical, they must also be cost-effective. Baldwin et al. (2025) quantified these costs in citrus orchards. In their study, they assumed the implementation of two CDFA diphacinone bait applications in year 1, with 6 months separating these bait applications. Trapping tunnels were operated between the two bait application periods, as well as after the second bait application. They calculated costs over a 2-year period and determined that a management program that mirrored the four-step approach outlined in this section would cost $79.81 per acre in the first year, largely due to the initial costs of purchasing bait stations, bait, traps, and associated materials. Costs substantially reduced during the second year of a management program ($16.21 per acre), with those costs holding relatively steady for subsequent years, although occasional replacement materials would be needed at some point. Although we have no direct quantifiable data on crop losses associated with roof rats, this management program may often be justifiable depending on damage. For example, assuming a price of $12 for a box of fancy lemons (115 lemons per box) or navel oranges (72 per box), around six and a half boxes of fruit would have to be saved per acre per year to justify management costs for the first year, but just over one box of fruit would need to be saved to justify expenditures for subsequent years. This price does not account for potential infrastructure damage nor potential food safety risks associated with their presence in orchards, further increasing the value of this management approach. We do not have similar data for nut orchards, but we expect the benefits from effective rat control to be similar.

It bears noting that Baldwin et al. (2025) only addressed bait application and trapping as management tools as those were the only options deemed practical in citrus orchards. Nut orchards provide opportunities to use additional tools such as burrow fumigation and within-burrow trapping, considering the regular use of burrows by rats in these systems. Furthermore, the use of barn owl boxes could provide some relief from roof rats in nut orchards given less vertical and horizontal obstruction present in these orchards when compared to a thick evergreen crop such as citrus. Therefore, consideration should be given as to the ability to include some of these tools into an integrated approach for managing roof rats. In general, including as many efficacious tools as possible is most likely to maximize long-term effectiveness of management programs.

Reinvasion rates can be high for many rodent species, with immigration into control areas occurring in as little as 2 months if large populations are found adjacent to treatment areas (Spurr et al. 2013; Baldwin et al. 2025). As such, it is important to consider roof rat outbreaks and invasions at the landscape level. Coordination of control programs between neighboring landowners should provide for maximum impact of management programs on damaging rat populations.

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