◆ EPPO Standards ◆

GUIDELINES ON GOOD PLANT PROTECTION PRACTICE

RODENT CONTROL FOR CROP PROTECTION AND ON FARMS

PP 2/5(1) English

oepp
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APPROVAL

EPPO Standards are approved by EPPO Council. The date of approval appears in each individual standard.

REVIEW

EPPO Standards are subject to periodic review and amendment. The next review date for this set of EPPO Standards is decided by the EPPO Working Party on Plant Protection Products.

AMENDMENT RECORD

Amendments will be issued as necessary, numbered and dated. The dates of amendment appear in each individual standard (as appropriate).

DISTRIBUTION

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SCOPE

EPPO guidelines on good plant protection practice (GPP) are intended to be used by National Plant Protection Organizations, in their capacity as authorities responsible for regulation of, and advisory services related to, the use of plant protection products.

REFERENCES

All EPPO guidelines on good plant protection practice refer to the following general guideline:

OEPP/EPPO (1994) EPPO Standard PP 2/1(1) Guideline on good plant protection practice: principles of good plant protection practice. *Bulletin OEPP/EPPO Bulletin* **24**, 233-240.

OUTLINE OF REQUIREMENTS

For each major crop of the EPPO region, EPPO guidelines on good plant protection practice (GPP) cover methods for controlling pests (including pathogens and weeds). The main pests of the crop in all parts of the EPPO region are considered. For each, details are given on biology and development, appropriate control strategies are described, and, if relevant, examples of active substances which can be used for chemical control are mentioned.

EUROPEAN AND MEDITERRANEAN PLANT PROTECTION ORGANIZATION
ORGANISATION EUROPEENNE ET MEDITERRANEENNE POUR LA PROTECTION DES PLANTES

PP 2/5(1) English

Guidelines on good plant protection practice

RODENT CONTROL FOR CROP PROTECTION AND ON FARMS

Specific scope

This standard describes good plant protection practice for the control of field and commensal rodents on arable crops, meadows, fruit trees, ornamentals, forest trees, products stored after harvest, and on farms.

Specific approval and amendment

First approved in September 1995.
Edited as an EPPO Standard in 1998.

This guideline on good rodent control practice contributes to the overall EPPO programme for the preparation of guidelines for optimal plant protection practices in all major crops of the EPPO region. It should be read in conjunction with GPP Guideline no. 1 (Principles of good plant protection practice) (*Bulletin OEPP/Bulletin OEPP* **24**, 233-240, 1994). As most rodent pests are polyphagous and control measures against a given pest species do not vary much from crop to crop, it seems reasonable to avoid undue repetition crop by crop, and divide this guideline into two major sections. The first section deals with the aspects common to all rodent control, i.e. the rodenticides, their toxicological properties, registration and use patterns, as well as consideration of potential non-target hazards and alternative means of controlling rodent pests. At the same time, this guideline stresses the features that make rodent control specific and different from other sectors of plant protection. The second section, in turn, specifies good practices for the three principal areas of rodenticide use: (1) arable crops (cereals, legumes, vegetables, etc.) and meadows; (2) fruit trees, ornamentals and forest trees; (3) post-harvest damage control in farm stores and, generally, control of commensal rodents on farms. Urban rat control and control programmes primarily for hygienic and health reasons are not included.

For practical reasons, rodent pests are conventionally divided into two groups: the field rodents, i.e. species damaging growing crops (herbivorous *Microtus* spp., *Cricetus cricetus*, etc.) and the commensal rodents (*Rattus norvegicus*, *R. rattus*, *Mus musculus*). Ecologically, the borderline between the two groups is not clear; commensal species may occur as pests in growing crops, and some of the field rodents enter human habitations, particularly during the winter or dry season. In these cases, the instructions below refer primarily to the type of habitat where the control operation takes place.

1. General aspects common to all rodent control

Cultural measures, crop resistance and mechanical control

Good agricultural practice in an everyday sense may contribute to reduction of rodent damage in certain instances, but is not normally alone sufficient to prevent damage. This is because the incidence of damage does not depend on the *in situ* infestation in the crop only, as in the case of most insect and microbial pests, but as much on the general level of the pest population in the whole landscape mosaic of which the target crop forms a part.

Historically, the creation of mechanically cultivated large-scale monocultures with effective weed control and a minimum of edges has considerably decreased rodent damage to field crops such as cereals. Now that the current trend is towards increased heterogeneity (habitat diversity) of the agricultural landscape, on the basis for example of the "set-aside" programmes, creation of shelter belts, use of green manure, etc., it can be predicted that rodent damage to field crops will increase again. Consequently, the overall need for active control of pest rodents by means of rodenticides will probably not markedly diminish in the foreseeable future.

As to the chance of developing rodent-resistant cultivars, there has been some interesting and preliminarily promising results in the area of forest-tree breeding. However, the threshold for practical application of these findings is still high due to the fact that rodent-resistant provenances may not be resistant to other major pests at the same time. In the case of arable crops, there has been little serious interest among plant breeders in developing rodent-resistant cultivars.

Use of mechanical guards round the stems of cultivated trees can also be included among cultural means of controlling rodent damage; this approach will be discussed in detail in section 2.2. Correspondingly, mechanical proofing against commensal pests is discussed in section 2.3. Further, trapping is an old professional activity that will be given due attention in section 2. The utility of a modern challenge, the ultrasound generators, is also discussed.

Biological control and IPM

By definition, IPM (Integrated Pest Management) is always GPP (see Principles of GPP), but practices that do not include the biological control component, or habitat manipulation, can as well be GPP. In the field of rodent control, there are theoretically two options for biological control: improving the life conditions and hence effectiveness of rodent predators, and use of microbial control agents.

New research findings on the cycle of microtines have given rise to some optimism for the development of integrated control programmes where the natural predators of these rodent pests play a role. There is, however, a great difference between the fact that predators can contribute to population crashes and their being able to prevent a new population peak. There is evidence that predator numbers can be influenced, e.g. by installation of nest boxes, but there is virtually no evidence that this leads to significantly increased predation pressure during the increase phase of the microtine cycle. As a consequence, it seems that rodent control problems are not likely to be solved in the foreseeable future by a strategy based on the use of predators as control agents.

As to the chances of microbial control of rodents, *Salmonella*-based preparations have been used for this purpose until recently in some EPPO countries. However, the Joint FAO/WHO Expert Committee on Zoonoses (WHO Technical Report Series no. 378, 1974) has strongly recommended against all use, or even experimentation, with microbial preparations against vertebrate pests. It is not GPP to register or use any microbial preparation for rodent control.

Two decades ago, there was some interest in rodent chemosterilants. However, no practicable solution was found, and there were serious doubts about the environmental safety of these unspecific compounds. So this interest slowly died off. As the idea is still brought up from time to time, it is worth stating that it is not GPP to register or use chemosterilants for rodent control, unless there is full scientific documentation on the efficacy and safety of these chemicals.

Conditions for registered use of rodenticides

To go beyond the limits fixed by registered use is, by definition, never GPP (See GPP Guideline no. 1). However, in view of the whole array of rodenticides registered today in EPPO countries, it seems necessary to subject the prevailing registration conditions to thorough scrutiny. This concerns both the selection of active ingredients (a.i.) available, their label instructions and their use patterns. Broad definitions of use conditions (e.g. "all noxious animals", "all species" or "against injurious rodents") are not acceptable and, hence, not GPP. The minimum requirement to be met when defining the use conditions of a rodenticide preparation is to separate use against field rodents in growing crops from the use against commensal species on farms, or human settlements in general. Particularly in the case of field rodents, the target groups of pests should ideally be more closely defined.

Currently, it is not considered GPP to encourage use of rodenticide compounds like endrin, lindane, endosulfan (or any other organochlorine compound), thallium sulphate, fluorine compounds (fluoroacetamide, sodium monofluoroacetate, glycerine trifluoride), strychnine or scilliroside. The use of these compounds is discouraged on the basis of their high toxicity and/or persistence and biomagnification capacity, or lack of humaneness, or subsequent non-target and environmental risks. Use of the traditional fast-acting rodenticide zinc phosphide is regarded as GPP, if the actual formulation complies with the basic performance requirements, and necessary safety precautions are followed. However, it is not GPP to distribute technical-grade zinc phosphide (about 80% a.i.) to end users, unless these are specifically trained. The same condition applies to phosphine-producing tablets or granules and cyanide-producing powders that are used for fumigating rodent burrows. Smoke cartridges based on the production of sulphurous fumes or carbon monoxide are, unless shown otherwise, often ineffective and as such not recommendable. The same applies to calcium carbide and carbon bisulphide as rodent fumigants.

By far the dominant rodenticides in EPPO countries are the anticoagulants. These, in turn, are conventionally divided into two groups: the traditional multiple-dose first-generation compounds (chlorophacinone, coumachlor, coumatetralyl, pindone and warfarin), and the second-generation anticoagulants (brodifacoum, bromadiolone, difenacoum, difethialone and flocoumafen). The prerequisite for good effectiveness of the first-generation compounds is repeated take of the a.i. over several consecutive days, whereas second-generation compounds (e.g. brodifacoum, difethialone and flocoumafen) can act on single-dose take with a few days' latent period between the take and appearance of the symptoms.

First-generation anticoagulants are normally supplied in the form of ready-to-use baits (including liquid baits, powder or liquid concentrates) or contact powders (sometimes the same product can be used both as concentrate and contact powder). Broadly speaking, it is GPP to use these products against *R. norvegicus*; see below, however, the reservations due to anticoagulant resistance. Against *M. musculus*, most first-generation compounds are not fully effective. Further, first-generation anticoagulants are not generally considered suitable (effective) against microtine rodents and most other pest species damaging field crops. Their main disadvantage is the prerequisite for multiple feeding that is hard to ensure when treatments cover large areas. However, one first-generation compound, chlorophacinone, is widely used against some microtine species in EPPO countries. Whether or not this use is GPP depends on the performance of the actual bait formulation in use. Sometimes (e.g. for curative treatments when damage to the crop has already started), it may be acceptable to compromise in favour of safety and apply chlorophacinone bait, even if the percentage kill expected is not fully satisfactory.

Most second-generation anticoagulants are effective against field rodents as well as commensal species. On the other hand, there is no general agreement about the safety criteria for GPP in using these compounds, particularly against field rodents. There is a trend among the registration authorities in some EPPO countries to restrict the use of some second-generation compounds within buildings, i.e. to exclude their use for protecting growing crops. However, as the second-generation anticoagulants are the only effective rodenticides against several species of crop pests, their use in the field should also be accepted as GPP, provided that the application technique used minimizes primary non-target hazards. Neither in the case of treatments in and around buildings nor in connection with treating rodent burrows in the field are there means of completely eliminating secondary hazards to predators and scavengers.

Second-generation anticoagulants are mostly provided to the end user in the form of ready-to-use baits, which is certainly GPP. Distributing these compounds in the form of concentrates should be restricted to persons who are specifically trained for their use. As such training is currently not organized in the majority of EPPO countries, it is strongly recommended that appropriate training programmes be instituted for rodent-control operators.

The only non-anticoagulant multiple-dose rodenticide registered in EPPO countries is calciferol. It is good practice to use ready-to-use calciferol bait against commensal rodents inside buildings. Calciferol is important as a "standby" rodenticide, in so far as it can be used when resistance to second-generation anticoagulants has appeared in target populations of rats or mice. It is also acceptable practice to use alphachloralose against mice, inside buildings, provided that ambient temperature during the treatment period is below 16°C.

Generally, it is not GPP to use combinations of anticoagulants and antibiotics, or anticoagulants and calciferol in rodent baits, unless there is full experimental evidence of the advantages of the effect due to combined action, and no contra-indications about increased non-target risks.

Criteria of bait performance and choice of formulations

As the predominant type of formulation used for rodent control is preformulated bait, the performance of the product is determined by the reaction of target pest species to the formulation. However effective the a.i. may be, performance is poor if the target rodent does not find the carrier attractive and consume the bait. Good palatability is, therefore, the first criterion of acceptable performance. Consequently, use of poorly palatable baits for rodent control is not GPP. There is great variability among EPPO countries as to how the performance of rodent baits is tested and evaluated before registration. In some countries, the product must undergo mandatory palatability and no-choice efficacy tests in the laboratory (Guideline for the Efficacy Evaluation of Plant Protection Products no. 113 - Laboratory tests for evaluation of the toxicity and acceptability of rodenticides and rodenticide preparations, *Bulletin OEPP/EPPO Bulletin* **12**, supplement, 1982), if intended for use against commensal rodents, and additional field performance tests in the case of products for field rodent control (Guideline for the Efficacy Evaluation of Plant Protection Products no. 169 - Field rodents, *Bulletin OEPP/EPPO Bulletin* ***22***, 181-202, 1992). Experience has shown that results of laboratory tests predict fairly well the practical performance of baits for commensal-rodent control, but tend to overestimate palatability and, hence, performance of baits used for field-rodent control.

If palatability testing and other criteria of bait performance are not built into the registration procedure, it is GPP to seek information about the performance of the product from other sources before making the choice of product for any extensive field operation. Information from field tests is particularly important in the case of wax-block baits that are often advocated as a solution to the non-target risk problem associated with second-generation anticoagulants. It is good practice to consider the safety aspect, but it is not GPP to sacrifice good performance for minor gains in safety. The main advantage of the use of wax blocks instead of pelleted bait is reduction of primary hazard to birds, whereas the risk to non-target mammals (dogs, foxes, pigs, goats) is not essentially reduced, nor is the risk of secondary poisoning of predators or scavengers. There are nevertheless situations where the use of wax blocks should be considered GPP. This is the case for control of rats in sewers and other wet places, where some other types of bait decay and disintegrate sooner than wax blocks. However, the blocks intended for sewer-rat control also show differences in palatability, and it is good practice to request, or conduct, pilot tests before proceeding to large-scale treatments.

Choice of carrier is the most important factor determining bait palatability. For commercial preparations, it is important that the carrier material should remain stable for a long time. There is experimental evidence that, of the cereals used for bait carriers, oats is more stable than barley, wheat or maize. Opinions differ concerning taste enhancers;

addition of sugar (5-10%) is the only case on which there is general agreement. Addition of anti-mould compounds or bird repellents generally lowers palatability of the bait for rodents.

Dosage levels, application rates and application techniques

It is not GPP to use dosages of a.i. in the end products (in practice, baits) which are too low (leading to decreased effectiveness) or too high (causing repellency or increased environmental risks). The following list may be regarded as a tentative recommendation for permissible dosage levels in ready-to-use rodent baits:

Compound (a.i.)	*% of dry matter in bait*
Zinc phosphide	1.0-2.5
Alphachloralose	2.5-4.0
Warfarin, coumachlor, coumatetralyl	0.025-0.05
Pindone, chlorophacinone	0.005-0.01
Difenacoum, bromadiolone	0.005-0.01
Brodifacoum, flocoumafen, difethialone	0.001-0.005
Calciferol	0.1

Liquid baits present a certain problem: the possible repellent properties of the a.i. are likely to affect the take at lower concentrations in liquids than in dry baits, but liquid baits are seldom fully effective alone, which leads one to suggest higher concentrations than in dry baits. A plausible compromise may be to keep to the same range as suggested for dry baits.

Where experimental evidence for the maintenance of effectiveness exists, it is always GPP to lower the dosage level below the lower limits suggested above.

As said above, it is generally not GPP to allow rodenticide concentrates to enter the hands of end users unless they are specifically trained in handling such products. The only exception may be powder concentrates of first-generation anticoagulants that are, at the same time, used as contact powders. If contact powders of second-generation single-dose anticoagulants appear on the market, their use should be limited to specifically trained personnel.

As to the application rates, it is more difficult to fix recommended levels in the case of rodent control than in the case of other plant protection measures. What is GPP depends on the type of a.i. and carrier used, the application technique, the population level of the target species, etc. In general terms, it is GPP to ensure that as high a proportion of the product as possible reaches its target and a minimum is wasted or, in the case of bait, consumed by non-target animals. This prerequisite is readily met when distribution of bait is done manually, straight into rodent burrows, or by means of equipment that places the bait underneath the soil surface. According to the above definition, aerial distribution of rodent bait or broadcasting the bait by means of fertilizer spreader is not GPP, although mechanical broadcasting may be unavoidably necessary because of the extent of the area to be treated. In such conditions it is highly recommendable that a follow-up survey to detect non-target hazards be made and reported by a competent independent authority.

Control strategies: timing of control operations

GPP is conditioned by control needs and seeks to establish whether a pest needs to be controlled at all. Consequently, it is GPP to achieve adequate control by making as few treatments as necessary for avoidance of damage. Whereas in other types of plant protection, it may be GPP to apply products to growing crops according to a fixed schedule, this is never so for rodenticides. Occurrence of the pest and the threat of damage should have been corroborated. However well the population trends of the pest rodent are known, there are still a number of options in timing treatments in relation to the population trends of the pest, the type and time of damage expected, and the likelihood for non-target incidents. Several alternative strategies have been developed.

Calendar treatments. This strategy is practically never applied in connection with rodent control in growing crops. It is traditionally used for commensal rodent control, but with variable results in some countries.

Prophylactic treatments. The idea of this strategy is to influence population development of the pest rodent, usually several months before the expected period of damage. The main weakness of the strategy is that it does not take into account either compensatory reproduction or the dispersal capacity of the target rodent population.

Preventive treatments. This strategy aims to slow the local pest population down temporarily, shortly before the expected period of damage. This strategy is most effective during the non-breeding season, when the burrowing species are confined to their underground galleries and hence easy to locate.

Symptomatic (or curative) treatments. This strategy reacts to damage that has already taken place, or at least started. The treatment is mostly late, but in certain circumstances this may be the only applicable strategy.

Permanent baiting. This strategy is widely practiced in urban rodent control, but rarely against field rodents in Europe. It is labour- and cost-intensive.

Supervised treatments. This strategy implies intensive follow-up of bait consumption and rodent signs till these signs disappear. It applies to commensal rodent control, particularly on farms.

The pros and cons of these strategies should be weighed separately for each type of pest, crop and damage, as is actually attempted in the various parts of section 2.

Anticoagulant resistance

The introduction of anticoagulants in rodent control in the early 1950s was first considered a panacea that solved the problems connected with use of the earlier generation of acute rodenticides (poor take, bait shyness, tedious prebaiting procedure, non-target incidents, lack of antidotes). However, detection of the first verified cases of warfarin resistance about 10 years later led to a new type of problem, and today it is evident that resistance develops sooner or later to all known anticoagulant rodenticides. Therefore, it is necessary to accept resistance as one of the factors that determine what is good practice at least in commensal rodent control. On the other hand, there are no rational reasons for evoking dramatic scenarios about "superrats". The existing rodenticides still work in the vast majority of cases, and it is still possible to keep any resistant population under control.

Resistance is a heritable trait of an individual. At least in *R. norvegicus*, it is most probably of additive character, with potentiation of effect from warfarin to the most potent anticoagulants. The genetic and biochemical bases of anticoagulant resistance are not elaborated further in this guideline, nor will the methods of resistance detection be discussed here, because an EPPO guideline for this purpose exists (Testing rodents for resistance to anticoagulant rodenticides, *Bulletin OEPP/EPPO Bulletin* **25**, 575-593, 1995).

Resistance is most likely to appear in a population that is under continuous but not fully effective control pressure. In the case of *R. norvegicus*, conditions are suitable particularly on farms where there is excessive supply of staple food, particularly cereals, available to the rats, and the anticoagulant baits used for rat control are poorly competitive in palatability with cereal. From the resistance point of view, it may be questioned whether the permanent baiting advocated in some countries is GPP at all. Generally speaking, there is currently no agreement among specialists on the most effective resistance-avoiding strategy and how to treat populations found to be resistant to one or more anticoagulants.

The whole picture of resistance is confused by the fact that behavioural patterns may also influence the outcome of rodenticide treatments. Also, it is well known that susceptibility to a given anticoagulant rodenticide varies considerably from species to species. It is not GPP to solve poor effectiveness of a given compound simply by increasing the content of a.i. in the bait, because this may lead to increased incidence of non-target hazards. A preferable alternative is to choose another active ingredient that works at "normal" concentration, and/or to develop a more palatable bait for the species in question.

Non-target effects and other safety aspects

None of the rodenticides registered in EPPO countries are specific to target species; most are highly poisonous to non-target mammals and birds. Primary poisoning hazard can often be minimized by selecting safe application techniques that render the bait inaccessible to non-target animals. On the other hand, not much can be done to prevent secondary hazards to predators and scavengers. The risk can be lowered by keeping the dose levels and application rates at minimal level, thus avoiding "overkill" of the prey.

In some EPPO countries, there are established surveillance systems for detecting wildlife poisoning accidents by plant protection products. Reports based on these surveys reveal that accidents due to rodenticides are relatively frequent compared with the share of rodenticides in total use of plant protection products. It is therefore a special challenge to rodent-control experts and registration authorities to study potential hazard to the local spectrum of non-target vertebrates. This is most feasibly and economically done in conjunction with field efficacy tests of rodenticide products. Also, it is strongly recommended, and GPP, to conduct wildlife accident surveys in connection with any large-scale rodent control campaign. For the methods of non-target surveys, see Guideline for Evaluation of the Non-Target Effects of Rodenticides (*Bulletin OEPP/EPPO Bulletin* **25**, 553-574, 1995).

Concerning other safety aspects, operator safety is seldom a problem in connection with rodenticide use (note, however, the remarks above concerning availability of concentrates to end users). A special warning should be added concerning the phosphine-producing fumigants: large-scale applications should be avoided when the soil is dry. Heavy rain after a dry period may cause explosive release of phosphine and formation of a highly poisonous cloud of fumes over a large area. It could also be GPP to use a human taste deterrent, if developed.

2. Specific instructions for the main crop types and for farms

2.1 Arable crops and meadows

Principal pests and types of damage

The principal rodent pests in arable crops within the EPPO region are the following:

- *Microtus arvalis* and its sibling species *M. epiroticus*, *M. socialis* and *M. guentheri* (land voles). These are polyphagous herbivorous pests of fodder legumes, cereals, vegetables, meadows, etc.;
- *Arvicola terrestris* (water vole), particularly the fossorial form of the species; *Pitymys* spp. These are important pests in mountain meadows;
- *Cricetus cricetus* (hamster), *Citellus* spp. (susliks). These are polyphagous pests in a multitude of crops.

In addition to these species listed, there are others of regional interest, like *Spalax* spp. (fossorial rodents damaging roots of crops) or the gerbils (*Gerbillidae*) that are pests to various crops south of the Mediterranean. These species are certainly important pests but little is known about the control strategies applicable to them. This is the only reason why they are not specifically treated in this Guideline. Control of *Apodemus sylvaticus* and related species that consume seeds of crops like sugarbeet is similarly not discussed.

Practically all the important pests of field crops are characterized by burrowing habits. However, the activity of the majority of these species (e.g. *Microtus* spp.) is predominantly above the ground and the animals normally keep their burrow entrances open to the surface. Only *Spalax* spp., the fossorial form of *A. terrestris* and some species *of Pitymys* are truly subterranean throughout the year. Particularly the fossorial species and the hamster (*C. cricetus*) hoard various plant parts in underground caches.

Many of the species listed above (e.g. *Microtus* spp.) exhibit marked variation in population numbers from year to year. In the case of *M. arvalis*, the population peaks most often recur at about 3-year intervals and are usually synchronized over relatively large areas, though practically never over the entire range of the species. In certain types of agricultural system (e.g. irrigated areas), the fluctuations may be levelled off and the pest may be numerous from year to year. For other species (*A. terrestris, C. cricetus*), the population build-up takes longer than in *Microtus* spp.; for instance, the actual outbreaks of the fossorial form of *A. terrestris* mostly occur at 6-year intervals. *C. cricetus* is more irregular than the microtines, and its abundance is probably more directly dependent on weather (ground-water level).

Detailed description of the type and geographical distribution of damage to various crops due to the species listed above is beyond the scope of this Guideline. Looking retrospectively to the history of rodent outbreaks and the subsequent incidence of damage, one can detect a marked decrease in the quantity of damage to arable crops in the course of the past 50 years or so. Nevertheless, several countries within the EPPO region treat at least a few hundred thousand ha against *M. arvalis* and allied species, or *C. cricetus*, each year. During the periodic peaks of vole abundance, these figures may exceed one million ha. Hence, it is not a matter of indifference how these control operations are conducted.

Basic strategy

The basic strategy in the use of rodenticides in field crops is to concentrate efforts on preventive treatments at the very beginning of the growing season or, in the case of winter crops, late in the autumn. In spring, voles (*Microtus* spp.) are concentrated in perennial or winter crops like lucerne or wheat, or in grassy verges, road and canal banks, etc., where localization of their burrow openings is relatively easy. Also, *Cricetus* and *Citellus* spp. emerge from their winter quarters before growing vegetation has covered their burrow entrances. When baiting is done straight into burrow openings, the target population is exposed to the bait with the minimum of effort and bait consumption. It should, however, be kept in mind that only treatments that cover relatively large areas simultaneously are really useful in protecting crops over the most critical period. Later, when vegetation conceals the burrows, treatments are less effective and hence not GPP.

Attempts at attacking the target rodent population during the low phase of abundance, with the aim of prophylactically influencing population development, are seldom if ever successful in the case of microtine pests in arable crops. This is because it is difficult for laymen to localize emerging foci, and the voles are very mobile at this population phase. However, the prophylactic strategy, or the permanent control procedure, are recommended for controlling fossorial *A. terrestris* in mountain meadows. How this strategy works when left in the hands of farmers remains to be seen.

Blanket calendar-based treatments, without reference to the actual population level of the rodent pest, are never GPP. As the numbers of field rodents, particularly microtines, vary considerably from year to year, rodenticide treatments are needed once every 2-4 years, or at even longer intervals. It is therefore GPP to establish and run simple surveillance and forecasting programmes that are able to reveal regional population trends in the pest species at least a few months ahead of the normal season when damage occurs.

Rodenticides, formulations and application techniques

Although multiple-dose anticoagulants are generally less suitable for the control of field rodents than single-dose compounds, the most extensively used a.i. against *Microtus* spp. in Europe is chlorophacinone. It is hard to draw firm conclusions about the effectiveness of chlorophacinone treatments on the basis of published information. What appears clear is that the control success varies greatly and that it seldom approaches the 80% field effectiveness level that was recommended by the EPPO Panel on Rodent Control as a registration threshold. Consequently its use should not normally be GPP. However, despite this, chlorophacinone may be preferred to the second-generation anticoagulants when it is necessary to apply bait mechanically instead of by burrow-baiting, or generally in the case of large-scale treatments.

The preferable type of rodenticide to be used in arable crops is a single-dose a.i. in a highly palatable carrier (bait). Otherwise it is not cost-effective to apply the bait manually in the burrow openings, i.e. using the technique that is GPP without reservations. Active ingredients fulfilling the above prerequisite are zinc phosphide, brodifacoum, difethialone and, possibly, flocoumafen and bromadiolone. An alternative to the baiting technique is fumigation of rodent burrows with phosphine-producing tablets.

The problem with zinc-phosphide bait is often deficient palatability, that may be due both to the a.i. and to the carrier (whole grain, dried carob, etc.). The palatability problem in fact concerns all baits based on whole cereal, independently of the a.i., because this is not the preferred food of herbivorous microtines. Pelleted baits based on cereal product with sugar additives (5-10%) usually perform better but are sometimes less weather-resistant than the whole cereal baits. This is, however, no handicap if the palatability of the bait is good, because the target rodent then consumes enough bait before it starts to disintegrate and becomes harmless to non-target animals. Addition of antimould compounds, wax and other ingredients for improving durability of the bait invariably leads to decreased palatability and, subsequently, inadequate performance.

Deficient palatability of commercial (dry) baits has, in some countries, led to the recommendation to use fresh carrots or other vegetable materials as the carrier for anticoagulants. From the effectiveness point of view, this is beyond doubt a step towards improved efficacy but, on the other hand, it necessitates delivery of liquid concentrates into the hands of end users. Particularly in the case of the second-generation compounds, this solution could not be considered GPP, unless special training has been given to the end users.

In the case of the truly subterranean species, the bait should always be inserted directly into the underground galleries. This can be done manually with a metal prod 12-15 mm in diameter by making a hole through the soil to the underground tunnel of the rodent and dropping the bait through the hole, or mechanically by using burrow builders (special machines constructed for this purpose). The last-mentioned methods work well in the case of the fossorial form of *A. terrestris* and, probably, some *Microtus* spp., but not for *C. cricetus*.

Phosphine-producing tablets are applied manually in the same way as baits. When coming in contact with soil moisture, the tablets disintegrate and release phosphine into the gallery. A recommended rate of application of phosphine-producing tablets is 1-3 tablets, each of 1 g, per prod hole, with 3-5 m between the holes.

Considering all the diversity of pest species, their population densities, crops to be protected, seasons, etc., it is extremely difficult to suggest universally applicable rules for the application rates of rodenticide baits in arable crops and pastures. As a theoretical starting point, it may be calculated that about 1-2 g of bait with some second-generation anticoagulant as a.i. is enough to kill a vole. If the a.i. is chlorophacinone, the amount should be doubled, whereas in the case of zinc phosphide a smaller amount of bait may suffice. In practice, one does not know the number of animals to be killed, and some animals may consume more bait than necessary (overkill), while others do not touch the bait at all. However, where serious attempts have been made to minimize bait use, it has often been found that successful control is possible using less bait than specified by current label instructions of the product. The label instructions are mostly based on the amounts needed when bait is broadcast, manually or mechanically, onto the ground. When hand-baiting straight into rodent burrows, it is not necessary, or even desirable, to treat all the openings seen, but, say two or three holes at a spot, and then move some ten steps further and repeat the same procedure. In the case of *C. cricetus* only, it is advisable to insert about one spoonful of bait into every distinct burrow found.

Alternative control strategies and methods

The disappearance or alleviation of *M. arvalis* outbreaks in central Europe over the past few decades has been explained by increased farm and plot size, mechanization of cultivation techniques and chemical weed control, i.e. intensification of agricultural land use. Where the vole plagues have returned after a lengthy period of absence, this has been explained by subtle increase of refuge habitats, e.g. verges of newly built roads, temporary lags in the intensity of land use, or excess fertilizer application. The problem should be soluble by reversing these developments, but this is not usually easy to implement in practice. However, considering the reluctance of both experts and farmers to use rodenticides on a large scale, cultural control seems to be the only realistic strategy in the long term.

What seems plausible in mixed lowland agriculture cannot be simply transferred to the problem of fossorial *A. terrestris* in mountain meadows. The suggested use of herbicides to destroy the preferred dicotyledonous food plants of the voles has rebounded, since fertilization of pastures increases the protein content of grass enough to ensure effective propagation of the pest. As in the case of lowland *M. arvalis*, increased heterogeneity of the landscape has also played a role in enhancing population outbreaks of *A. terrestris*. Hence, it seems probable that use of rodenticides will continue to be the principal strategy against fossorial *A. terrestris* in the foreseeable future.

C. cricetus is probably the only rodent pest that has gained by the mechanization of agricultural practices. This is because its burrows are deep in the soil and cannot be destroyed by agricultural machines. Also, improved drainage has in many regions lowered the level of ground water and thus favoured the pest. As a result, the amount of rodenticides used for hamster control has exceeded that used for vole control. Nobody has been able to devise any non-chemical hamster control method other than trapping. The intensity of trapping is mostly insufficient, and this technique is more likely to ensure sustained reproductive output of the pest than effective control.

Trapping is used against the fossorial form of *A. terrestris* and sometimes to catch amphibious water voles. Though GPP as such, trapping is more suited to amateur use in gardens than to arable crops or extensive meadows. Another type of mechanical device advertised for the control of burrowing rodent species is the ultrasound generator. When these devices have been subjected to critical testing, they have been found to be useless.

2.2 Horticulture, forestry and ornamentals

Principal pests and types of damage

There are basically two main types of damage to fruit trees, woody ornamentals and forest trees, that can be attributed to the following rodent species:

- *Microtus agrestis* in the Nordic countries and forest plantations in central Europe and *M. arvalis* in central European orchards debark the trunks of trees from ground level to the height of snow cover in winter. Other species may contribute to this damage locally or less regularly. In the Mediterranean region, this type of damage is usually due to *Pitymys* spp.;

- *Arvicola terrestris*, both the fossorial and amphibious forms, damages the roots of trees. *Pitymys* spp. and *M. arvalis* may cause the same type of damage, but to a lesser extent.

The damage is by no means restricted to woody trees and bushes. Herbaceous fruit plants like strawberry, perennial ornamentals, flower bulbs and vegetables are commonly subject to the above-described types of damage. As in the case of trees, damage to the above-ground parts of the plant is generally due to *Microtus* spp., sometimes to *Clethrionomys* spp., while damage to the underground parts is due to *A. terrestris* or *Pitymys* spp.

In Nordic countries, damage by *M. agrestis* to horticultural plants reached its peak level in the 1950s and 1960s; in forestry it peaked some 15-20 years later. It has now levelled off in both fields, but the potential risk continues to exist. In central Europe, damage in forestry by *M. agrestis* was severe from the late 1940s to the 1960s, but has recently become more or less sporadic. The incidence of damage is not directly proportional to the numbers of voles, but as much dependent on the weather in winter (e.g. snow cover) during the peak phase of vole abundance. Despite high numbers of voles, damage may remain negligible if winters are mild and snow scarce.

Unlike *M. arvalis* and *Pitymys* spp., *M. agrestis* does not show significant burrowing activity and does not possess underground gallery systems. This behavioural trait makes it opportunistically vagile, and winter invasions of the species to orchards are rather the rule than the exception. Like most other microtines, *M. agrestis* fluctuates in numbers, with predominantly a 4-year cycle length in the northernmost latitudes, a 3-year interval in central Scandinavia and southern Finland, and more or less irregular fluctuations further south.

The amphibious form of *A. terrestris* often inhabits river and canal banks, lake shores and marsh areas in summer and moves to dry land when the winter sets in. It then burrows in the soil and gathers food caches in underground galleries. In winter, there is not much difference in habits between the amphibious form and the terrestrial form (see section 2.1) of the water vole. There are no clear and regular population fluctuations in the majority of the populations of amphibious *A. terrestris*. Locally, the species may maintain a high population level for a few years and then disappear for a long time. Also, the incidence of damage is mostly unpredictable.

Basic strategy

For *Microtus agrestis* and allied species, as in the case of *M. arvalis* and other microtine pests in arable crops, calendar treatments are not GPP. Due to the mobility of the species, preventive treatments with rodenticides in autumn are also of questionable usefulness, particularly in snowy regions where the voles are often not found in the orchards and nurseries where damage occurs in winter. In grass-grown forest plantations, such treatments may be more useful, especially if damage starts early in autumn. As burrow baiting cannot be applied, the treatment areas should be kept restricted. Attempts at using some types of bait stations (boxes, drainage tubes, bird feeders, etc.) have had variable success. The success was particularly poor when the stations were used prophylactically in snow-rich regions, i.e. for providing bait for winter invaders. The voles simply do not find these bait stores under the snow. In regions with scarce snow, bait stations reportedly work better.

Although *M. agrestis* is not a burrowing species, the burrow-baiting technique can be applied for controlling this species in winter. The voles make breathing holes in the snow. Due to frequent traffic in the hole, its walls become icy and the bait put in the hole readily slips down to the space below the snow where the animals live. The bait is well protected from non-target animals as long as the snow does not melt, and when it melts, cereal-based baits disintegrate and become less dangerous to non-target animals. The technique can be recommended as GPP, because it makes it possible to ensure good performance, with minimal risk, when using second-generation anticoagulants for vole control.

For *Arvicola terrestris*, control operations against the amphibious form are normally conducted during the autumn months when the animals have settled down in their underground galleries. Basically the same strategies and methods then apply as described for the fossorial form in section 2.1. However, it is sometimes necessary to undertake control measures against animals living in canals and ditches bordering orchards, bulb fields, etc. For such situations a strategy based on the use of floating bait stations has been suggested. Promising results have been obtained on an experimental scale, but it remains to be seen whether the method will be adopted in practical use.

Rodenticides, formulations and application techniques

The list for *Microtus agrestis*, compared with the rodenticides listed in section 2.1, is much shorter: second-generation single-dose anticoagulants are those that can, from the efficacy point of view, be recommended without reservations. Even bromadiolone is not fully effective as a single-dose rodenticide and there is no published information about flocoumafen. Zinc-phosphide and chlorophacinone baits so far tested have shown variable success.

M. agrestis is probably more fastidious concerning the inert bait constituents than most other microtine species. For instance, grain baits have never performed well in critical tests, whereas some of the pelleted baits do. As a strict herbivore, *M. agrestis* would certainly accept fresh vegetable bait, but concentrates of second-generation anticoagulants for mixing such baits are not available in most countries where the species is a major problem. On the other hand, such baits could not be used in winter, when the temperature is below freezing point. As to application rates, there is enough evidence to conclude that bait consumption can be as low as 1 kg ha^{-1} (or even less), even at high vole densities (100-200 holes per ha).

Concerning *A. terrestris*, all that was said in section 2.1 about the fossorial form also applies to the amphibious form during the winter half of the year, when it has adopted the fossorial form of life.

Alternative control strategies and methods

Now and then in the course of recent decades, it has been advocated that keeping orchards clean of ground vegetation guarantees freedom from damage by *M. agrestis*. This may have been true in areas where permanent snow does not cover the ground in winter, but in snow-rich regions this doctrine has led growers badly astray. In winter, *M. agrestis* is nomadic and capable of settling down and causing damage in orchards with bare ground. Hence, as this ecological control strategy is at best conjectural, it cannot be considered GPP, particularly as growing grass between tree rows has obvious advantages over and above bare soil.

In orchards, forest nurseries and elswhere, where the unit value of the tree is high enough to warrant the investment costs, mechanical protective guards can be placed round the trunks of the trees. This is a control strategy of high priority. The material used for the protective collars may vary and there is no single choice that is clearly superior to others. Plastic-coated wire net with 10 mm mesh is probably technically the best material, but expensive. Solid materials, like aluminium foil or hard plastic, may create suitable microclimatic conditions for fungi and insect pests inside the collar that should, therefore, be removed in spring and put on again in autumn. This entails considerable labour costs. Conifers are especially sensitive to injury if solid collars are kept round the trunks the year round. More recently, a self-degradable plastic collar has become popular in many countries. However, injury to young trees that are fully inside the collar has been observed in connection with the use of this material, too. Independently of these minor problems, protective collars can be recommended as GPP against *M. agrestis*.

In forest plantations, use of mechanical guards is uneconomical. Chemical repellents would be a welcome substitute. Such products are sold in several countries, but their effectiveness has seldom been proved by critical experiments. Some candidate repellents have also been found to be phytotoxic. As a result, the status of repellents as a means of preventing damage by *M. agrestis* and allied pest species is conjectural, but is GPP if the performance of the product has been proved.

Against *A. terrestris*, in parallel to the protective collars proposed for *M. agrestis*, it has recently been recommended in some countries to plant trees in wire-net baskets. The method is probably not widely used, but it should not be too expensive, when sold along with young trees in nurseries. In contrast, surrounding old growing trees with protective fences dug into the ground is laborious, expensive and likely to damage the root system.

Traps are frequently recommended for controlling *A. terrestris*. Trapping is labour-intensive but, if it can be done economically, may be considered GPP at least for amateur use in gardens. The types of traps available vary from country to country and it is beyond the scope of this guideline to give instructions of how to use particular types of traps.

2.3 Commensal rodents on farms

Principal pests and types of damage

The following three globally important commensal species are also the dominant pests in the EPPO region:

- *Rattus norvegicus*, the Norway rat, is an important pest on farms practically all over Europe. On the African continent it inhabits ports and major cities, but can be found on poultry farms in arid regions as well;
- *Rattus rattus*, the roof rat, is absent or rare in Nordic countries, but has gained area as a farm pest in parts of central Europe. The core area of distribution is the Mediterranean region;
- *Mus musculus*, the house mouse, is actually a complex group of several subspecies (or species). It is a ubiquitous pest on farms all over the EPPO region.

There are differences in the habits of these three species but, in farm conditions, the types of damage are about the same: eating and contaminating foodstuffs and animal feed, destroying structures, and spreading diseases to domestic animals and sometimes man. Beyond any doubt, commensal rodents are important pests but the information about the quantity and economical value of damage is scattered and not easily translated into numerical terms or monetary units.

On farms, *R. norvegicus* prefers moist areas at ground level, whereas the other two species are mostly found in drier places at higher elevations. As all three species are highly dependent on food sources provided by man, there are no regular population cycles in these species as in microtine rodents. Population levels of the commensal species can also be influenced by control operations, which is seldom or practically never the case for rodent pests in growing crops.

Basic strategies

Sanitation and rat proofing are preventive measures that are regularly advocated in rodent-control textbooks and leaflets. Good housekeeping and farm hygiene include removal of refuse that the rats could use as food, shelter or nesting material. It forms a necessary prerequisite for active control measures. However, implementation of these ideas is not always easy under farm conditions. Many farm buildings are old and expensive to make rodent-proof, so that animal food and stored cereals cannot be completely sealed off from rodents. Sanitation and rodent proofing should, therefore, be seen as part of GPP, but not the sole solution to the rodent problem.

Compared with urban rat control, there are relatively few reports about successful strategies for controlling rats on farms. A traditional strategy has been to distribute rodenticide bait once a year in the form of communal campaigns, and this practice still continues in many countries. This strategy is certainly not effective alone. Without proper follow-up, a campaign-type operation invariably results in insufficient % kill and rapid recovery of the target population, if conditions, e.g. food availability, remain unchanged.

To the best of current knowledge, the only guaranteed strategy of annihilating an existing population of *R. norvegicus* on a farm is a supervised baiting programme that is continued till the last signs of rats have disappeared. The most critical factors determining control success are the density of baiting points, the frequency of check visits to these, the effectiveness of the a.i. used in the bait and the palatability of the carrier. Such an operation may commonly take several weeks under farm conditions, where alternative food is readily available to the rats. At the beginning, not less than two checks a week are recommended, but during the later phases one may suffice. In order to get full benefit in the long run, supervised control operations should be conducted on all farms of the vicinity at the same time.

Another strategy, called permanent baiting, is often recommended as an alternative to one-time supervised control. In fact, these two strategies should not be considered alternatives, but rather sequential or supplementary phases of the same operation. The control success first obtained by supervised baiting is maintained against reinvasion by continued exposure of rodenticide bait for potential immigrants.

The idea of permanent baiting usually implies use of bait boxes, i.e. containers in which the bait is placed in order to prevent access of non-target animals. It is certainly GPP to use bait containers, whenever rodenticide is left in place for a long time. On the other hand, experience shows that, during the initial supervised control operation, bait take starts sooner and final clearance is achieved earlier if open bait trays are used instead of closed containers. Once the initial infestation has disappeared, the immigrants do not show neophobic reactions to the boxes as the resident rats did, but will probably explore the containers and find the bait. The main disadvantage of the permanent baiting strategy is that the bait has to be renewed frequently in order to keep it palatable to rats. This of course makes the system expensive, especially if rat control on the farm is operated on a contract basis.

As to the other two commensal species, the strategies described above apply to *R. rattus* as well. *M. musculus* is in some respects quite different from the rats. For instance, it does not show the new object reaction (neophobia) that is characteristic of both rat species and it is thus easier to get it to accept bait. On the other hand, *M. musculus* is a sporadic feeder and its home range is very small compared with that of the rats. This means that it is necessary to use a high density of baiting points in order to clear the infestation in good time. Otherwise, basically the same strategies apply as for the rats.

Rodenticides, formulations and application techniques

The choice of a.i., their properties and formulations from the point of view of GPP were discussed in some detail in section 1. It can be briefly summarized here that the control of commensal rodents now mainly depends on anticoagulants, but other types of rodenticides, such as calciferol or alphachloralose, are also useful in specific situations.

Basically, use of all commercially available anticoagulants against commensal rodents is GPP, unless there is proof of resistance to some of these compounds in the target population. If the suspicion of resistance arises, it is wise first to check that the apparent failure of control is not due to bait palatability problems, underbaiting, hoarding of the bait by the rodent species to be controlled, or any other behavioural pattern. Hoarding behaviour is apparently released by the particle size of the bait; for instance, maize corn or pellets of similar size are frequently hoarded by *R. norvegicus*, whereas finely groundcereals, rolled oats or small grain and pellets are not. Only after all the potential behavioural reasons for failure have been excluded is it reasonable to proceed to resistance testing or, if this is not possible, switch to another a.i. higher up in the effectiveness scale.

Anticoagulants can be applied in the form of dry or liquid baits (including wax blocks) or contact powder. Liquid baits are useful in grain silos, mills, storehouses and other industrial and commercial buildings where shortage of drinking water is a problem particularly for *R. norvegicus*. *R. rattus* and *M. musculus* can survive longer periods without water, and liquid baits are less instrumental in controlling these two pest species. Contact powders are useful when applied in rodent (*R. norvegicus*) burrows or used as a supplementary method for baiting. There are examples, e.g. from the milling industry, suggesting that all three modes of application may sometimes have to be combined to obtain full clearance of rodent infestation (dry and liquid baits and contact powder can be placed simultaneously inside a bait container).

As in the case of field rodents, it is not easy to give precise advice concerning application rates for anticoagulant baits in commensal rodent control. An experienced rodent-control operator can, on the basis of signs left by the rodents, make a rough estimate of the population level and prospective bait consumption. Also, the initial take of exposed bait by *R. norvegicus*, at least, is not a good measure of subsequent bait need, because it may have been influenced by the neophobic reaction typical of the species.

A very general rule of thumb for use of first-generation anticoagulants is that there should always be a surplus of bait for the rats. An underbaiting strategy which is practically the opposite, called pulsed baiting, has been advocated for application of single-dose second-generation anticoagulants. According to this strategy, a relatively small amount of bait is exposed in the beginning, and if the exposed amount is eaten, there is no replacement for several days or a week. The philosophy behind this strategy is based on the assumption that the socially dominant individuals consume bait first, and that it is wise to let these individuals die, before exposing the second wave. It was suggested that overkill and secondary poisoning hazards could thus be avoided. Recent studies have shown that practice does not conform with theory. However, it is clear that much smaller amounts of bait are sufficient with single-dose a.i. than in the case of multiple-dose compounds. Keeping this difference in mind, it may be best to follow the instructions given above for supervised control operations as the principal GPP strategy for rat control.

When controlling *M. musculus*, the strategy for the rats also applies but, as indicated above, the density of baiting points should be much higher, in both horizontal and vertical directions, and the individual doses of bait at each point smaller, say 5-10 g each.

Alternative control strategies and methods

Trapping is a old method of rat control. However, according to current standards and compared with rodenticides, trapping is seldom cost-effective for eradication of rats on farms. When there are specific reasons for using traps instead of rodenticides, cage traps are clearly better for trapping rats than the breakback traps. *R. norvegicus* especially is extremely wary of entering breakback traps.

M. musculus is curious rather than neophobic, and therefore relatively easy to trap. Both breakback and live traps work well, but trap density should be as high as the density of baiting points. For those who have the necessary time and endurance, controlling *M. musculus* by trapping is GPP.

One of the most controversial fields in current rodent control technology is the concept of ultrasound generators. Despite the fact that critical tests have practically never confirmed the manufacturers' claims on the effects of these devices on rodents, they are still marketed and sold all over the EPPO region. The contra-indications are, however, so strong that all ultrasound equipment so far tested can be declared without reservation not to be GPP for rodent control.