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Published by the Department for Environment, Food and Rural Affairs. Printed in the UK, February 2004, on 100% recycled paper.

Product code PB9158

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Executive summary

1. In preparation for the likely withdrawal of strychnine from the market in 2006, alternative methods to control the European mole, *Talpa europaea*, were reviewed. Techniques currently used within EU states were assessed for effectiveness and humaneness, although some involve the use of active ingredients that do not have UK approval. The reasons for controlling moles have also been summarised in order to judge the economic viability of the replacement methods.

2. There is currently no substitute poison to use in baits. Alphachloralose, which is registered for the control of house mice and birds here, is available in France for mole control. While apparently more humane than strychnine, it was relatively ineffective when tested under field conditions in the UK. No other EU state permits the use of poison bait to control moles.

3. Fumigation with aluminium phosphide preparations that liberate phosphine gas on contact with soil moisture is a common control method, being used in Denmark, France and Germany as well as the UK, but independent data on efficacy under UK conditions are limited. Soil temperature, porosity and moisture levels, largely uncontrollable by operators, can affect the concentration of gas in tunnel systems. Unless a high concentration can be maintained, affected moles may show prolonged symptoms of poisoning making the humaneness of the method questionable. No other fumigant is approved for mole control in the UK. Limited trials with carbon monoxide and carbon dioxide suggested that these were ineffective as fumigants, although further studies of novel formulations might be warranted.

4. Trapping is carried out in Denmark, France, Germany, Holland and the UK using both live- and kill-traps. Proposals to set humaneness standards for kill-traps are under consideration and it is likely that in the future mole traps, such as the scissor, Duffus half-barrel and any new design, will have to meet appropriate criteria. As a pest control measure, at least 1 well-placed trap per animal in the population should be set on the first day of operations to maximise the speed of control, but each trap must be carefully set to prevent moles taking evasive action. If carried out by skilled operators, trapping is probably the best method to remove small numbers of moles, but against large diffuse populations, the effort required to prevent rapid reinvasion into a target area necessitates extensive trapping and may be impractical. In Germany, where the mole is a protected species, live-trapped moles are relocated, but there are no data on the subsequent fate of such animals. Thus, relocation is not recommended in the UK.

5. Non-lethal approaches to control, such as the use of repellents (chemical, sonic/ultrasonic), fencing and habitat modification are either ineffective or not cost-effective, or have not been fully evaluated. The repellent Renardine (bone-oil) has UK approval and limited short-term efficacy has been demonstrated. In Germany, wire-mesh fences dug into the ground up to 1 m deep have been recommended as a means of preventing moles reinvading cleared areas, but installation and maintenance costs will likely make them more suited to protecting small high-value amenity areas in the UK. Habitat modification measures range from simple harrowing and rolling (to flatten

molehills and prevent soil contamination of silage) to altering soil pH to reduce earthworm populations and hence mole numbers. The latter, while effective, is generally viewed as undesirable as it affects long-term soil fertility. The general approach of forcing/encouraging moles to move elsewhere has been criticised on welfare grounds, as resident moles defending their territories may attack such ‘forced’ migrants. Moreover, moles establishing new territories may create more molehills than in their original home range, thus potentially aggravating the problem.

6. From the available data, all alternative methods to strychnine use would appear to be less cost-effective and are not unequivocally more humane. Implementing these methods will incur extra costs that may be up to 7 times greater for fumigation and up to 10 times greater for trapping in order to achieve equivalent levels of control. However, in the long-term, the option to re-use traps and fumigation applicators and the administrative costs associated with obtaining authorisation to use strychnine erode, to some extent, the cost differences between these two methods and use of strychnine.

7. Past surveys have suggested that, nationally, mole damage is relatively insignificant although individual holdings may suffer disproportionately greater losses. Thus, the relatively low cost of carrying out strychnine treatments has probably led to more control of moles than was really necessary. Therefore, the cost-benefit ratio of mole control will undoubtedly be re-appraised by landowners and occupiers when strychnine is finally withdrawn and the option to do nothing may become the best choice. In the absence of a significant breakthrough in the development of more effective deterrents/repellents, improved methods of trapping may be preferred to fumigation. The use of traps would be promoted if modifications to existing types increased humaneness, or new designs are developed, but the skill and ingenuity of the trapper will remain the most important factor.

1. Introduction

Under the EC's review of currently approved pesticides following the 91/414/EEC Directive, the continued registration of strychnine hydrochloride as a 'plant protection product' was not supported by any manufacturer/supplier. Thus, in July 2003, a revocation notice was issued that prohibits the sale of the poison after the end of 2003, but allows operators who hold stocks after that date to use strychnine, subject to authorisation, until the end of 2004. However, under the biocidal products review following the 98/8/EC Directive, strychnine has been 'identified' as an existing active substance, which means that it or products containing it may remain on the market until September 2006. Hence, with permission from Defra, strychnine can be purchased and used to control moles to prevent damage to machinery when cutting silage or harvesting crops, to prevent injury to cattle on pastures and to horses on racecourses and gallops, to prevent soil contamination of silage to protect animals (principally sheep) from listeriosis, to prevent accidents on aircraft grass landing strips, and to maintain the playing surface on golf courses.

The humaneness of strychnine poisoning and the potential for misuse of the compound have been live issues for many years and the issuing of strychnine permits incurs significant administrative costs for Defra. However, no alternative method that is comparably effective has been discovered. An experimental formulation of bromoform has shown promise in preliminary trials, but it has not been field-tested primarily due to the very substantial data collection and registration costs required for a new active substance under pesticide regulations. A shortage of strychnine in early 2003 highlighted the need to re-evaluate alternative means of control. If supplies of the poison are to be withdrawn permanently in the near future, landowners seeking to control the animal will have no choice but to use other approved measures.

The purpose of this review is to assess the range of mole control methods that exist across the EU and provide guidance to UK interests on the most humane and effective means available. We reviewed the reasons why moles are controlled, as it is likely that the loss of strychnine will alter significantly the cost-benefit analysis for control. Sources of information for this review were published and unpublished scientific papers, annual reports from research laboratories, the Pesticides Safety Directorate and personal communications. Most research on the control of moles has been carried out in the UK and Denmark, but references to work in Germany, Holland and France were found. As the range of the European mole extends into Eastern Europe, we also reviewed work carried out in the former Czechoslovakia, Poland and Russia.

The European mole, *Talpa europaea*, is found in most parts of Europe except Norway, Ireland, most of Sweden, regions close to the Mediterranean Sea and most small islands (Mitchell-Jones *et al.,* 1999). It prefers lowland forests, plains and pastures without heavy or sandy soils. Soils that are very acid or stony are also avoided, as these are likely to have a poor invertebrate fauna. The population of moles in Britain has been estimated to be 31 million (Harris *et al.,* 1995). Other species of moles are present in southern Europe, including *T. caeca* (Italy, the Balkans), *T. occidentalis* (Portugal, Spain), *T. romana* (Italy) and *T. stankovici* (the Balkans) but not all of them are regarded as pests.

2. Overview of reasons to control moles

Throughout Britain and mainland Europe, tunnelling and the production of molehills frequently bring the mole into conflict with humans and it is widely perceived to be a pest. However, this pest status is not universally recognised with the species being protected in Germany and moles can, in some contexts, offer biodiversity benefits, for instance, as providers of regeneration niches for plant species in species-rich grasslands. Nevertheless, the majority of potential problems are common to all countries where moles are present and can be divided into two broad categories: (1) damage to amenity areas that is often relatively trivial, but can occasionally have serious consequences; (2) potentially economically significant damage to agriculture and flood defences.

2.1 Damage to amenity areas

The damage caused by moles to gardens, golf courses, bowling greens and cricket pitches is well documented (e.g. MacDougall, 1942; Lund, 1976; Neville, 1985; Stone, 1989; Lodal, 1999). Most of the problems occur as moles tunnel across grassed areas throwing up molehills as they dig. In most cases, the resultant damage is considered to be aesthetically unattractive and regarded simply as an inconvenience. The cost of this type of damage is generally difficult to assess (Gorman and Stone, 1989), but while some people may find it distressing, the economic loss is rarely significant (Lund, 1976). Of greater importance, is the presence of molehills on racecourses (Farndale, 1993; Neville, 1985), grass airstrips (Bollaerts and Tahon, 1968) and sports fields, where horses, riders, pilots and players, including school children, risk injury.

2.2 Damage to agriculture

2.2.1 Contamination of silage

Arguably, the most important single problem associated with moles is the pollution of silage (Lund, 1976; MAFF, 1975; Atkinson *et al*., 1994). In a 1970 survey conducted by the Pest Infestation Control Laboratory (MAFF), participating farmers listed the deleterious effects of moles on silage as a major concern (Mead-Briggs and Woods, 1970). The problem occurs when soil from molehills is collected with grass cut for silage. Bacteria present in the soil, especially *Clostridium* spp., lead to the formation of butyric acid, which can adversely effect the fermentation and preservation of silage (Neville, 1985; Stone, 1989; Atkinson *et al*., 1994; Guedon, 1998). This in turn can reduce the nutritional value of silage or, in some cases, render it unpalatable, thereby affecting both milk (Guedon, 1998) and beef (Stone, 1989) production. A less common problem occurs when *Listeria monocytogenes* in the soil contaminates silage resulting in listeriosis in sheep and cattle (Barlow, 1971; Farndale, 1993). Up to 10% of animals in a flock/herd may be affected (Atkinson *et al*., 1994).

2.2.2 Covering of pasture

In a survey of Welsh farmers in the late 1970's, the reduction of grazing areas by molehills was regarded as the most serious and widespread of all types of mole damage (Hill and Jones, 1978). In subsequent field trials, it was observed that the loss of grazing area was up to 18%. Goszcynska and Goszcynski (1977) calculated the amount of soil deposited on a meadow by moles to be 32 tons/ha (dry weight) with a volume of 21 m^3/ha, covering an area of almost 400 m^2. Similarly, Grulich (1959) found that in parts of Czechoslovakia 8-10% of permanent grass fields were taken up by molehills each year, and that the loss in grass yield amounted to about 15% due to the effect of the molehills on the grass cover. In one example, 1 ha of pasture was covered with 7,380 molehills weighing 64,500 kg with a volume of 40 m^3. In Poland, Skoczen *et al.* (1976) recorded 21,063 molehills on 1 ha of pasture, 11.2% of which was consequently unavailable for grazing. Clearly, this amount of surface soil will appreciably reduce the amount of feed available to livestock and thus represents a considerable loss of milk and meat to the farmer if no action is taken (Gunston, 1953).

2.2.3 Damage to agricultural machinery

Molehills may interfere with harvesting and cause considerable damage to farm machinery (Adams, 1920; Macdougall, 1942; Neville, 1985; Stone, 1989). Indeed, the blunting of machine blades is one of the main concerns of farmers (Mead-Briggs and Woods, 1970), when clover and grass are cut very close to the ground to produce silage (Lund, 1976); similar damage has been noted when corn, peas and soya beans have been harvested (Neville, 1985; Guedon, 1998). The tendency for moles to bring stones to the surface (Jewell, 1958; Farndale, 1993) can lead to increased machine damage, as can the consolidation and enlargement of molehills by invading ants (Bennet *et al*., 1942; Vonorov, 1968).

2.2.4 Damage to young plants

On arable farms, the uprooting of seedlings and young plants is considered one of the most serious types of damage attributed to moles (Mead-Briggs and Woods, 1970). The problem is well documented (Macdougall, 1942; Oates, 1956; Lund, 1976; Guedon; 1998) and damage usually occurs as a result of animals raising the roofs of their tunnels, either killing plants directly as they are pushed up onto the surface or by depriving their rooting systems of soil and water which may also lead to the exposure of roots to frost (Stone, 1989). In Czechoslovakia, Grulich (1959) reported up to 25% of young sugar beet plants being thrown up onto the surface at one site. In Britain, root and ground fruit crops are susceptible to similar types of damage (Neville, 1985).

2.2.5 Weed invasion and degeneration of pasture

The exposed soil of newly formed molehills is often the first area of fields to be colonised, invariably by volunteer weed species, which may further invade the pasture and dilute the sward (Neville, 1985; Stone, 1989). This has the effect of steadily reducing pasture quality and consequently production. In a quantitative study, Davies (1966) found *Agrostis* spp. to be the most frequent colonisers of molehills regardless of sward use. Within two years, most molehills in the study were covered by almost pure stands of *Agrostis* spp. at which point the vegetation appeared to stabilise. Davies also noted an association between the presence of molehills and the spread of thistles (*Circium arvensie*), which, at one site, accounted for 8% of the ground cover. Ford (1935) discovered a similar connection reporting that the number of thistles per square yard of mole infested ground was 6.9 compared with 0.7 in an adjoining mole-free area. In a later study, Jalloq (1975), collected and germinated seeds from molehills and found that only a very small proportion of the seedlings that emerged were high-quality fodder grasses. Weed species contributed most to the emerging sward. Thus, grass species are more likely to colonise a molehill by vegetative means, but they have to compete with weed species better adapted to colonise bare soil.

2.2.6 Wilting of seedling crops

The burrows of small mammals are known to influence the humidity of soil (Popova, 1962), which can have deleterious effects on plants growing nearby. In Poland, in an area of grassland heavily populated by moles, Skoczen *et al*. (1976) demonstrated that the presence of mole tunnels had a drying effect on the adherent soil layers. The effect around some burrow systems was found to reach the point at which permanent wilting could be induced in plants and over a period of years a maze of surface tunnels could therefore markedly reduce the quality and quantity of grass, particularly in times of drought (Bennet *et al*., 1942; Hoogerkamp and Hoogerbrugge, 1975).

2.2.7 Damage to drainage systems and watercourses

The extensive tunnelling of moles into the raised banks of drainage systems can weaken and undermine their structure by allowing water to wash away substantial quantities of soil (Bennet *et al*., 1942). Macdougall (1942) reported on an artificial embankment, built to protect a low-lying stretch of meadowland from flooding, being substantially weakened by the presence of extensive burrow systems. Farndale (1993) also reported that mole activity undermined raised floodbanks. Although not common, this potential for water defences to give way, on increased pressure from flood, could have serious economic consequences.

2.2.8 Use of mole tunnels by other species

Occasionally, secondary use is made of existing mole tunnels by other mammal species that may subsequently cause problems. For example, gamekeepers claim that weasels (*mustela nivalis*) use mole tunnels to gain access to game-bird rearing pens (farndale, 1993). Voles (*microtus and pitymys* spp., the latter not present in Britain) are also believed to use the extensive burrow systems of moles to move from place to place, causing damage to plants and trees by eating exposed roots and bulbs (stone, 1989; guedon, 1998).

2.3 Cost of damage and control

It is notoriously difficult to obtain even approximate figures on the economic importance of moles (Lund, 1976; Gorman and Lamb, 1994; Lodal, 1999) though some attempts have been made to estimate the extent of the problem and the national costs of mole damage and control.

MAFF (1970) surveyed 5776 holdings in England and Wales between January and March 1970 and found 78% had signs of moles with 680 (11.8%) infested seriously enough to justify the issue of a permit to use strychnine. Moles were regarded as a pest by 55% of all occupiers. Arable farms were significantly less likely to have moles than grassland and mixed farms. In 1992, responses to a questionnaire returned by

157 occupiers of farms in England, Scotland and Wales showed that 97% of farms had moles and 64% of farmers regarded them as pests (Atkinson *et al*., 1994). Although these two surveys differed most notably in sample size, there was no evidence that the attitude amongst farmers towards moles had changed markedly in the intervening years.

In the early 1990’s, the Danish Agricultural Advisory Centre made a crude estimate of costs based on information gathered by a network of local advisors. The annual cost of damage and the associated extra labour to minimise it was estimated to be £3 million (Lodal, 1999). In Britain, the annual cost of damage and control measures to the agricultural industry in the late 1980’s was estimated by MAFF to be £2.5 million (Gorman and Lamb, 1994). More recently, Gorman, (1999) speculated that this cost was less than £5 million per annum. At the farm level, Atkinson *et al*. (1994) reported that the mean annual cost to farmers who considered moles as pests was £126 with a maximum of £800. Farms consisting primarily of pasture with some silage production suffered the greatest losses. Although these figures may appear insignificant to an industry with a turnover of billions of pounds per annum, the presence of moles can have a serious impact at the local level, particularly in marginal areas where farmers may already be struggling to maintain economic viability (Gorman and Lamb, 1994). There is no quantitative information available on the economic costs of the mole to non-agricultural interests.

Where mole damage is on a small scale, in areas such as private gardens, sports fields etc, one option may be to flatten molehills and tolerate the continued presence of moles. However, for large-scale or acute problems some form of control may be necessary, as without it mole populations can spread and the losses attributable to them may become correspondingly greater. Arguably, the relatively low cost of carrying out strychnine treatments has probably led to more control of moles than was really justified by the amount of damage caused.

3. Control methods

Table 1. Methods used in EU states to control the European Mole

	Poison Baits	Fumigants	Traps	Repellents	Fences	Earthworm Control
Belgium		■				
Denmark		■	■			
France	■	■	■			
Germany		■	■	■	■	
Holland		■	■			■
UK	■	■	■	■		■

3.1 Poison baits

No poison, other than strychnine hydrochloride, is approved for the control of moles in the UK, but before a strychnine treatment can be carried out, a specific authority from Defra is required. This administrative requirement under the Poisons Rules 1982 and Control of Pesticides Regulations 1986 does not apply to other methods of control. For each treatment, strychnine baits (1 g poison/50 worms) are normally applied during one day at the rate of up to 25/ha (10/acre) with one treated worm per mole run. Operators should be able to treat 2 ha in 2-4 hours. Re-treatment is sometimes necessary if mole activity persists after 2-3 days, but the expected final outcome is ~75% control (Mead-Briggs, 1974; Mead-Briggs and Trout, 1975). The most common problem affecting the efficiency of strychnine treatments is that excessive time may be spent collecting a sufficient number of earthworms of optimal size (1 g each), especially during dry periods when the worms burrow deeper into the soil.

When strychnine is withdrawn, owner/occupiers will have to use one of the alternative methods mentioned below. However, we give a brief review of the properties required for a potential alternative poison bait to be an effective method of control. A poison already approved for use against a different species may be relatively easier to register as a mole control agent than an entirely novel compound.

For any poison to be effective, the preparation that is mixed with bait has to withstand the natural 'cleaning' action that the mole carries out whenever it eats its principal food, earthworms. Each worm is consumed progressively from one end to the other and, as it does so, the mole's large front feet wipe particles off the surface and by simultaneously squeezing the body of the worm, the earthy contents in the gut are extruded (Bennet *et al.,* 1942). This behaviour probably evolved to minimise tooth wear caused by gritty soil particles. Hence insoluble poisons, applied as a powder, are largely removed, or the bait is rejected as unpalatable. In contrast, it was thought that strychnine was dissolved in the body fluid emitted by earthworms and was then reabsorbed, thereby avoiding removal by the worm-cleaning behaviour of the mole. In practice, reliance on this effect led to inefficient use of the poison and by dipping worms individually (rather than in bulk) into a formulation of coragum mixed with a concentrate of powdered strychnine in talc, the intake of poison was increased and the time to death was reduced (Redfern *et al.,* 1984). Moles apparently prefer live worms to those dead or moribund (MAFF, 1968), thus the toxicant should not also be lethal to the bait carrier. In order to maximise the chance that moles will find fresh baits, baits should be placed in tunnels about 4 hours before dusk (Trout, 1982). Poison treatments are more effective when carried out during October to April.

To minimise the number of visits to treat an area, the poison should be toxic enough so that the mole ingests a lethal dose after eating relatively few baits. First-generation anticoagulants, such as warfarin and chlorophacinone, were tested, but they made baits unpalatable as well as being insufficiently potent and the need to re-bait caused too much disturbance to moles (Mead-Briggs, 1974; Neville, 1985). Baits containing the rodenticides warfarin, chlorophacinone and zinc phosphide are marketed in the US for mole control, but it should be noted that North American moles are different species to those found in Europe; specifically, they will eat vegetable-based baits, unlike the European mole which is strictly carnivorous. Nevertheless, a French product, Tanataupe, containing chlorophacinone, was available, but [alpha]chloralose appears to be the only poison currently approved for mole control in France (Guedon, 1998). It is presented at a concentration of 10% in baits and 2-3 treated worms are necessary to deliver a lethal dose. Field tests carried out in the UK about 20 years ago showed that a mole eating a single worm appeared to become temporarily narcotised, followed by full recovery after 48 hours (UFAW, 1983). Also, alphachloralose made baits unpalatable to moles, necessitating a formulation that would disguise its taste. It is available in the UK in products for the control of mice and birds, but, as with strychnine, the potential for misuse is well known. In this context, the need to use live-worm baits invariably means that any poison to control moles will need to be available undiluted or at a high concentration.

A novel toxicant, bromoform, has been tested experimentally against captive moles in studies funded by Defra. This compound (chemically related to chloroform) was used as an animal anaesthetic in the early 20th century and large doses result in sedation followed by unconsciousness and death. This mode of action is considered relatively humane and moles appear particularly susceptible to this family of molecules. Being volatile, bromoform had to be microencapsulated and the main thrust of the research was to develop a capsule coating that, firstly, prevented moles detecting its presence in bait and, secondly, ensured its release into the gut after ingestion, so that a lethal dose was absorbed rapidly. In tests of various formulations, sufficient microcapsules were added to a chopped worm bait to give approximately 20 lethal doses of bromoform, as it was impossible to predict how much bait an individual mole would eat, or how many capsules would be swallowed. However, none of the test formulations has been given a full efficacy test against either captive or free-living moles. Further development of the formulation would require commercial support to take a product through the pesticide approval process as a new active ingredient under the Plant Protection Products Regulations of European Directive 91/414/EEC or the Biocidal Products Regulations under the 98/8/EC Directive.

We found no other reports that present the use of poison baits as a current option for controlling moles within the EU.

3.2 Fumigants

Fumigation appears to be the most widespread method of mole control among those EU states (Belgium, Denmark, France, Germany and UK) that have at some time treated moles as pests. In all cases, phosphine-gas, generated when aluminium phosphide contacts soil moisture, is the main fumigant, but the formulation from which the gas evolves differs. In the UK, aluminium phosphide is formulated as a 3 g tablet (‘Phostoxin’), which releases 1 g of phosphine, or a 0.6 g pellet (‘Talunex’), which releases 0.2 g. A cartridge (‘Arrex’) that on ignition rapidly produces a high concentration of phosphine is not currently registered for use here, although it has been tested in southern England and in France (Mead-Briggs and Trout, 1975; Grill, 1972). No other fumigant is approved for mole control in the UK.

Early trials (e.g. those reported by Mead-Briggs, 1974) quickly established the higher cost of materials for fumigation compared with strychnine treatments, without the benefit of improved efficacy. Subsequent trials using different methods of application increased the level of control, but required more labour and still fell short of the level achieved with strychnine (MAFF, 1981).

A general approach to control is that because moles occupy individual territories and cannot be attracted to a few points, the control procedure has to be applied throughout the problem area and at a sufficient density to ensure that all animals are potentially exposed. Where a mole population has existed for some time, many tunnels might be unused or used irregularly and therefore many individual applications would be wasted. To reduce such wastage, pre-treatment visits to find active runs would be necessary, but would of course incur additional operator costs. To maximise the effectiveness and humaneness of fumigation, the gas must be widely distributed throughout a burrow system and maintained at a high enough concentration to cause rapid death. The latter is dependent on the porosity and dampness of soil, while the former is to some extent controlled by the operator: 2-3 pellets every 2-3 m of active burrow (Lodal, 1981) or 1 tablet every 4 m (Lund, 1973) have been recommended. After testing different application rates for tablets, 150 insertion points/ha (1 tablet per insertion point) gave the best results, although still less effective than strychnine baits at 25/ha (MAFF, 1982). A rate of 300 insertion points/ha (2 pellets per point), with points concentrated around fresh mole heaps only, as used in Denmark, gave slightly less good results than an even application rate of 150 paired pellets (MAFF, 1983). In a limited series of trials, Lodal (1981) found that reducing the number of pellets to 1 per application point or increasing it to 5 did not affect efficacy, but the clay soil might have helped maintain a relatively high concentration of gas. Higher application rates have been suggested for porous sandy soils, so that the generation rate balances the diffusion rate to maintain a lethal concentration. Also, soil temperature should be above 6 ^{o}C (Lodal, 1981).

Moles exposed continuously to a phosphine concentration 130 ppm in a fumigation chamber died within 30 min (MAFF, unpublished), but exposure to sub-optimal concentration-time doses resulted in prolonged symptoms of poisoning before recovery or death. Symptoms reported included uncoordinated movements, rapid respiration and mild convulsions. One animal displayed these symptoms for 3-4 days before dying.

Experimentally, the results of efficacy trials are often assessed by pre- and post-treatment counts of new molehills and/or sealed prod-holes, with the latter a more reliable measure (Mead-Briggs and Woods, 1973). In Denmark, ~100% control has been reported after test treatments with aluminium phosphide pellets (Lodal, 1977 & 1981), but only after a second (limited) application of pellets 3-6 days later. Earlier trials involving one application had resulted in an average 48% control (n=7; Lund, 1975). In two trials of 1 tablet/insert with 150 inserts/ha, 50% and 60% reduction in the mole population was achieved (MAFF, 1981). Replacing the tablet with 2 pellets/insert in another two trials resulted in reductions of 55% and 65%. The best result of 78% reduction was obtained in a single trial by using 1 pellet/insert with 300 inserts/ha, but it took 2 staff-days to insert the pellets on a 2 ha site; to treat the same site with strychnine would have taken one person 2 hours. For comparison, test treatments of Arrex cartridges gave poor levels of control (~30%), as it was thought that the rapid build-up of gas was followed by a relatively quick dispersal, so that moles not in the immediate vicinity when cartridges were ignited remained unaffected (Mead-Briggs and Trout, 1975). Slightly greater control (~50%) was achieved by sealing aluminium phosphide tablets inside a tube with a plug of cotton wool (Mead-Briggs, 1974). Just before insertion, the tube was punctured to produce a small hole through which water vapour present in the burrow entered and then phosphine slowly diffused out. The aim was to maintain a low concentration of gas over many days. The tubes were applied at the rate of 100/ha. This procedure would seem to be the least humane way of fumigating tunnel systems, but if moles can detect low levels of gas, they might block off affected tunnels or dig new ones.

Overall, the lack of replication during UK trials to compare different application rates gives little statistical validity to the results, thus the levels of control achieved in individual trials should be treated cautiously as a general guide to the expected outcome of treatments. Moreover, although fumigation appears less effective than strychnine use, the latter has been known to fail totally (CSL, unpubl.).

Other than the UK and Denmark, we found little information on the effectiveness of fumigation across the EU. Carbon monoxide is apparently used in Germany (J. Pelz, pers. comm.) and gave limited success in trials in Denmark (Lodal, 1997). However, this was found to be ineffective in the UK in small-scale trials (Mead-Briggs, 1974; Woods, 1970), although a novel formulation has subsequently been developed that might offer greater effectiveness (Ross *et al.,* 1998). Carbon dioxide also appeared to be ineffective during small-scale trials (Lodal, 1997).

3.3 Trapping

Trapping has long been recognised as a method of controlling moles and the technique is used widely in Britain, Denmark and France (Atkinson *et al*., 1994; Lund and Lodal, 1976; Guedon, 1998) and to a lesser extent in Holland and Germany (Bool and Garritsen, 1953; J. Pelz, pers. comm.). Many different traps have been used in the past but today there are two main types in common use, the scissor (pincer) trap or metal half-barrel trap (Duffus). Both are spring traps designed to catch moles around the body when a trigger plate is pushed releasing the killing mechanism.

Trapping appears to be one of the most effective methods of mole control when conducted by an experienced operator (Macdougall, 1942; Stone, 1990; Guedon, 1998), but there are few quantitative data to support this assertion. For the best results, it is recommended that traps be placed in active tunnels taking care to avoid bends and junctions and to ensure that tunnels are unblocked and clear before trap placement (Guedon, 1998). New traps should be buried prior to use to 'age' them and once set it is best practice to monitor all traps at least once every 24 h, although this is not a legal requirement. However, moles often avoid being caught by filling traps with earth, by-passing by a new run, blocking runs or pushing traps out of the ground (Rudge, 1963). To maximise efficiency, the general approach is to set the maximum number of traps on the first day at an optimal rate of 1 trap per animal, but trapping trials (unpublished) by MAFF staff between 1967-71 indicated that about 80 traps was the maximum number that could be set by one person in a day. As the mole appears to be very sensitive to changes in its tunnel system, flawed techniques will increase the chance of avoidance and prolong the treatment. Hence, the initial placement of traps is necessarily labour intensive, but thereafter the input depends on the success rate and the need to re-position traps until all activity ceases or is reduced to an acceptable level. Also, the maximum benefit from a trapping programme will be obtained by co-ordinating simultaneous control on adjacent fields.

An alternative approach is to engage in sustained trapping over a long period using, initially, relatively few traps in relation to the numbers of moles present. Rudge (1963) trained a worker, with no previous experience, to trap moles on 33 ha of a 254-ha grassland research site. Using a total of 54 traps of 3 types, but mainly pincer and Duffus, 170 moles were trapped over 2 years of continuous trapping and the area affected by mole activity was reduced to 11 ha after the first year and to 5 ha after the second. Significant immigration occurred each year and the conclusion was that a resident, but not full-time, trapper was needed to prevent population recovery. Potential immigrants might be intercepted by placing traps along peripheral reinvasion routes associated with boundary hedgerows (Mead-Briggs, 1974; Mead-Briggs and Trout, 1975). MAFF staff carried out an annual trap-out of moles occupying about 45 ha of farmland between January and March each year for 5 years (1967-71) and the results showed that to trap all the animals that re-occupied a cleared area of 30-40 ha a trapper would take at least one week.

From the above examples, it is unlikely that many landowners will view trapping as cost-effective in eradicating large populations. However, where damage is confined to specific areas, eliminating all moles may be unnecessary and trapping can be a useful means of targeting control measures against specific problem individuals. For controlling small populations that are causing damage to horticultural enterprises or spoiling private gardens, trapping is likely to be the best method of control.

Atkinson *et al*. (1994) examined a sample of 22 trapped moles (20 in scissor traps and 2 in Duffus traps) all of which were dead on inspection 24 h after being set. The two caught in the Duffus traps were both held across the lower abdomen. By contrast, of the 20 moles in scissor traps, 17 were caught across the shoulders, one across the abdomen, one by the hip and one by the skin of the flank. Some of the moles caught across the shoulders appeared to have died instantaneously from massive internal haemorrhage and circulatory failure, or from asphyxia after the animal became unconscious due to shock induced by the sudden immense pressure from the trap mechanism. The authors argued that some of the animals might have asphyxiated whilst still conscious or died later of starvation or hypothermia. In an earlier study to compare different types of trap, Rudge (1963) found that six of 26 Duffus-trapped moles were caught by one or both forelimbs. Two of these six animals were alive on inspection, although no information was given on the length of time that each animal had been held in the trap. Thus, the performance of existing kill-traps (or the way they are used) is questionable as a more humane alternative to the use of strychnine.

The issue of humaneness during kill-trapping operations is being addressed internationally. In relation to the capture of fur-bearing species, proposals have been put forward aimed at setting criteria for each type of trap: for example, 80% of trapped animals should die within a specified time limit. The proposals contained in the Agreement on International Humane Trapping Standards do not currently apply to mole traps. At present, these traps are exempt from testing and approval under the Spring Traps Approval Order (made under the Pests Act 1954), as the Small Ground Vermin Traps Order 1958 permits their use. Nevertheless, the EU has declared its intention to extend the standards established in the Agreement to other trapped species in due course, and it is possible that in the future mole traps will have to meet an appropriate standard.

Kill-traps are used occasionally in Germany where the authorities will only grant permission to control moles on a very restricted scale and only where the damage poses a risk to human health (e.g. to secure traffic signal cables, to prevent damage to flood prevention structures). Live-traps are also used to clear moles from sites and the captured animals are then relocated to areas where their presence is tolerated (J. Pelz, pers. comm.). This approach may appear to be humane and can work well where ecological conditions are appropriate for mole colonisation. However, intra-specific aggression, inherent in many territorial species such as the mole, contraindicates on humaneness grounds moving individual animals into areas already occupied by an existing population. As the fate of relocated moles has yet to be investigated, this option is not recommended in the UK. Live-capture traps are also used in the UK, but we found no data on effectiveness, except in relation to the effect of predator odours on capture rates (see below).

3.4 Repellents

Repellents used against moles fall into three main categories: physical, auditory/vibrating and olfactory. At the most basic level, physical repellents rely crudely upon the sensitivity of the moles' snout to sharp objects placed in their tunnels. Physical repellents used in the past include; pieces of bramble, holly leaves, corks studded with pins, barbed wire and broken glass (Godfrey and Crowcroft, 1960; Farndale, 1993; Atkinson and Macdonald, 1994; Guedon, 1998). The efficacy of these impractical measures is highly questionable, as the moles' usual reaction is to bury the offending object and to tunnel around it (Godfrey and Crowcroft, 1960). Physical repellents are no longer in common use and have been replaced, to some extent, by auditory/vibrating devices.

An early example of an auditory measure to deter moles was the burying of empty bottles up to their necks in the ground where moles were a problem. The wind whistling across the open mouths of the bottles was thought to produce low frequency vibrations that disturbed the moles causing them to leave the area (Godfrey and Crowcroft, 1960; Atkinson and Macdonald, 1994; Gorman and Lamb, 1994). More recent variations on this theme include 'windmills', the whirring action of which moles are said to dislike (Mellanby, 1971; Willock, 1992), and various mechanical devices, which produce vibrations in the soil (Gorman and Lamb, 1990; Defra, 2003).

There are an increasing number of commercially available devices, which, their manufacturers claim, are of value in resolving problems associated with moles. However, the available information suggests that these devices are not effective and are unlikely to provide a long-term solution. In a recent British study, Gorman and Lamb (1994) tested the efficacy of three such devices to expel moles. The movements of two free-living moles were recorded before and after each scarer was introduced and the animals' responses determined by radio telemetry. There was no shift in the range used by the animals beyond what would be expected due to short-term changes in foraging patterns and moles did not abandon the areas around the scarers. The authors proposed that moles were not deterred because the vibrations produced by the devices were rapidly attenuated when passing through soil and could not therefore be detected beyond a few centimetres away. Sonic/ultrasonic repellent devices have disappeared from the Danish market (J Lodal, pers. comm.), although they are occasionally advertised for sale in the UK.

Olfactory repellents have been used for many years to discourage moles and it is still a regularly held belief that the animals can be driven away by simply placing distasteful substances, such as mothballs, carbide, bad fish, tar or creosote into their runs (Armsby, 1952). Naphthalene, formalin, bisulphide of carbon and sump oil have also been used at one time or another to drive moles away from areas where they are causing problems (Macdougall, 1942; Mellanby, 1971). Most of the claims made regarding the effectiveness of these substances are questionable and based primarily on hearsay. Their use now as mole repellents would be illegal, as these materials are not approved under the Control of Pesticides Regulations (1986). However, a few scientific studies have been conducted into the efficacy of olfactory repellents.

In a Danish study, Lodal (1985) assessed the effectiveness of a non-toxic (unspecified) repellent from Sweden in both a garden and grassland area. Activity was assessed before and after the treatment by levelling all molehills and making prodholes into the tunnel system. After three days, the number of fresh molehills and closed prodholes were counted. The activity assessment showed no significant difference between the treated and control areas and the compound had no effect in repelling moles from the treated areas. At a few treated sites, however, the compound was pressed up onto the surface showing a reaction to avoid the substance.

As part of a programme to find non-lethal approaches to the control of moles, Gorman and Stone (1989) looked at the possibility of repelling moles by means of mammalian chemical odours. Experiments were conducted using social odours produced by mustelid carnivores and social odours produced by moles. Initially, the effectiveness of clean Frisian live-traps was compared with those treated with anal sac secretions of weasels (*Mustela nivalis*), synthetic 2,2-dimethylthietane (a major component of the anal gland secretions of mink, *Mustela vison*) and with peppermint oil (a novel control odour). The traps tainted with weasel odour and 2,2-dimethylthietane were less efficient at catching moles than were clean traps. The peppermint oil had no effect. A single field trial was also conducted to determine whether moles would avoid tunnels treated with predator odours by monitoring mole activity before and after the introduction of 2,2-dimethylthietane-treated filters into a tunnel system. The presence of the predator odour was shown to have a repellent effect and the test mole ceased foraging in the treated area for eight days and began to extend the network of tunnels elsewhere in its range.

In a second series of field trials, clean cotton buds and cotton buds treated with mole preputial gland secretions were placed into the tunnels of radio-tagged moles. The responses were very marked with moles almost always retreating when they encountered a treated cotton bud. This reaction occurred regardless of the sex of the donor or whether it had been a neighbour or an unknown animal. Animals usually passed by the control stimuli.

Despite the fact that moles were found to avoid these two classes of compound, the authors suggest that it is unlikely that they will be of any use in a large-scale control operation. This is primarily because the material and labour costs would be too high, the compounds are highly volatile and would therefore need frequent renewal and also because moles would quickly habituate to the chemicals or simply block off the treated tunnels.

In Britain, Renardine (a bone-oil formulation marketed as a general repellent of problem mammals) is the only commercially available repellent approved for use to deter moles (Defra, 2003). Methods of application include inserting tissues, soaked in the product, through prod holes into mole tunnels at the rate of 1-2 per sq m, or pouring the product into a trench 3-5 cm wide and 36-51 cm deep at the rate of 0.5 l per m. In a test of the repellent’s efficacy, Atkinson and Macdonald (1994) conducted a series of trials to determine whether its use could evict moles from part or all of their home ranges and also whether it could delay the recolonisation of previously cleared areas. Mole activity was monitored before and after treatment by means of radio tracking. The results showed that moles appeared to avoid treated areas, which were also invaded significantly later than controls. Reinvasion was prevented for about four weeks. The authors concluded that on a small scale, and over a period of about a month, Renardine was an effective means of control, albeit labour-intensive and thus precluding its use in the majority of agricultural situations. Several manufacturers across the EU have indicated that they intend to support the continued registration of bone-oil under the Plant Protection Products Regulations.

In Germany, one of the recommended methods of mole control is the use of a repellent gas. Mueller (1998) suggests the application of a calcium carbide preparation at a rate of 20 g/burrow. The compound, which generates acetylene gas and small amounts of phosphine on contact with moisture, is said to deter moles though no information is available on its efficacy. It is usually used in association with mole-proof fencing which is erected to prevent reinvasion into areas from which moles have previously been driven away (J. Pelz, pers. comm.).

Repellents are useful only where the presence of moles is tolerated in areas adjacent to treated plots, as moles driven out of one field or garden will simply move to the nearest unoccupied territory. As the animals occupy more or less contiguous ranges below ground (Gorman and Lamb, 1994), neighbouring moles will soon reoccupy cleared areas (Gorman and Stone, 1989). For this reason, mole control must be conducted over a sufficiently large area to prevent rapid recolonisation. The use of repellents in a population limited by territoriality also raises a question about humaneness. The eviction of a mole from its own home range into that of a neighbour could be unacceptably stressful to the individual concerned and, at worst, could result in the death of the displaced animal (Atkinson and Macdonald, 1994).

3.5 Habitat modification

One non-lethal alternative to direct population control is habitat modification. This technique aims to reduce mole numbers in specific locations by manipulating the local environment in such a way as to make the area less attractive to moles. Farndale (1993) and Guedon (1998) suggested landowners and occupiers plant the caper spurge (*Euphorbia* spp.), as moles apparently dislike its presence. More usually, modification involves manipulating the soil type and soil conditions to reduce the distribution and abundance of earthworms and hence indirectly reduce the abundance of moles (Funmilayo, 1977; Edwards *et al*., 1999).

In a test of biological habitat manipulation in Holland, Ennik (1967) compared mole activity under varying nitrogen application regimes. The addition of a nitrogen-based fertiliser (ammonium nitrate limestone) to the soil was effective in reducing the number of molehills. The reduction in mole activity was greatest in areas with the highest nitrogen application. The rationale behind the study was that a reduced soil pH level would result in a corresponding reduction in earthworm numbers and biomass leading indirectly to a decrease in mole activity. In a more comprehensive study, Schaefer (1981) also found that elevated nitrogen levels reduced both soil pH and earthworm biomass. However, the associated reduction in mole* activity was only small and the increased soil acidity was found to be detrimental to crops. In a more recent study, Edwards *et al*. (1999) reported that in acid grassland half as many molehills were formed in unlimed as limed plots. Significantly fewer molehills were also formed in grazed and herb-rich areas. Evidence from the study suggested that the reduced mole activity was due to the indirect effects of these treatments on earthworm abundance.

In Russia, Shilova *et al*. (1971) experimented with the application of insecticides, primarily Sevin (carbaryl – no UK approval) but also aldrin, dieldrin and chlordane (all banned throughout the EU). Earthworms in treated areas were found to accumulate large doses of Sevin in their bodies and this led to a considerable reduction in the number of earthworms present in the soil. This in turn led to a corresponding reduction in mole numbers and activity. The disruption to animal numbers was also attributed in part to the direct loss of some animals as a result of Sevin accumulation in the liver, reproductive organs and muscle tissue of affected moles. By contrast, Edwards *et al*. (1999) detected no significant effects of chemical pesticides (dimethoate, pyrethroid and metaldehyde) on molehill numbers, probably because the pesticides appeared to have no effect on earthworm abundance. In Britain, carbendazim, carbendazim+chlorothalonil and thiophanate-methyl are occasionally used to reduce the number of earthworm castings on lawns, golf courses and sports turf areas (Baker, 2002). On agricultural land, they are not approved for use on rotational or permanent grassland or to control earthworms, but are normally applied as fungicides to treat crops. In the long-term, the beneficial effect of earthworms on soil fertility (e.g. Edwards and Lofty, 1972) probably outweighs any damage mole activity is likely to cause.

Habitat manipulation can also be used to reduce damage to silage and a number of practical measures are available to aid the farmer in this respect. Firstly, fields inhabited by moles should be harrowed and rolled early in the season and rolled as necessary thereafter. This not only reduces contamination with soil at harvest to a negligible level (MAFF, 1986), but it also reduces the risk of damage to machinery (Berryman, 1977). Secondly, mowing height should be set as high as possible to avoid the majority of molehills, thereby lowering the risk of soil contamination and protecting the cutting blades from damage. An added advantage of raising the cutting height is that the grass recovers more quickly for re-cutting (Atkinson *et al*., 1994). Finally, silage will benefit if the grass is first cut and then allowed to dry out for 24 h. In this way, soil from molehills in the grass has more chance of drying and falling out either as the crop is still lying or as it is cut and gathered the second time (MAFF, 1977 and 1986).

The contamination of silage with soil from molehills can also be treated post-harvest using additives that destroy harmful bacteria. As there are several different strains of the soil bacteria and each additive tends to be strain-specific (Carson and Kennedy, 1991), the development of broad-spectrum additives may improve the cost-effectiveness of treatments. However, the use of complex antibiotics in the wider context of preventing aerobic spoilage has been rare because of the extremely high cost compared with other additives (Rees, 1997). Additionally, the use of other additives, such as organic acids to control bacteria and fungi, has declined in recent years due to the hazardous nature of the materials and the safety precautions necessary during applications. It is thus uncertain that a cost-effective ‘chemical solution’ will be found to the problem of soil contamination.

* *The study was conducted in Canada on the coast mole (Scapanus spp.) – the appearance, biology and associated problems of which are very similar to those of the European mole.*

3.6 Fencing

Fencing is used in Germany, where the mole is legally protected, to ‘mole-proof’ gardens that border heavily populated pastureland. The fence consists of zinc-plated wire netting with a 15 mm mesh. The netting is placed vertically in an 80 – 100 cm deep trench with 20 cm, at both the top and bottom, bent over in order to make it more difficult for moles to dig under or climb over it. A fence can prevent re-invasion into an area where moles have previously been driven away with repellents (Mueller, 1998).

There is no information available on the efficacy of the design but given that the tunnels of moles are often found deeper than 1 m below ground (Stone and Gorman, 1991), it can be reasonably assumed that moles are capable of bypassing the system. When combined with the major cost of fence construction, this suggests that fencing is not a viable management option in most cases.

Table 2. Summary of information on methods of controlling the European Mole across the EU

Method		Approved In UK	Efficacy	Humaneness
Poison Baits	Alphachloralose	No	Ineffective in UK trials	-
	Strychnine hydrochloride	Yes (until 2006)	~75% reduction	Lethal dose kills in <15 min
Fumigants	Aluminium phosphide	Yes	Variable – 30-100% Average 60% in UK (n=6)	>130ppm phosphine lethal in<30 min
	Carbon monoxide	No	Ineffective in UK trials	-
Traps	Live-traps	Yes	Unknown	Humane if traps checked more than once/day
	Kill-traps	Yes	~70%	May not always kill quickly – check at least once/day
Repellents	Calcium carbide	No	Unknown	-
	Renardine (bone-oil) £30/5 l, 1-2 inserts/m^2	Yes	Short-term only (1 month)	?
Fences	Wire-mesh: (13 mm 22 gauge mesh 1200mm width £35/10 m)	No tests carried out in UK	Unknown	-
Earthworm Control (Habitat Modification)	Carbendazim, Carbendazim + chlorothalonil Thiophanate-methyl	Yes (to control casting on amenity turf – may lead to indirect control of moles)	Unknown (in relation to mole control)	-

4. Conclusions

In 1992, the status of the mole as an agricultural pest was assessed from responses obtained from a questionnaire sent to farmers (Atkinson *et al.,* 1994). Nearly half the respondents carried out some form of control, but the cost of the damage that the control was meant to reduce appeared to be, on average, insignificant. Undoubtedly, the relative cheapness of carrying out strychnine baiting has always tilted the balance in favour of control, but most of the reports about damage are not recent and the current economic significance of any damage that does occur is unknown. Nevertheless, it will remain likely that, due to local factors, individual farmers may suffer disproportionately greater losses from mole activity.

Our review has not found any other lethal-control method that is as cost-effective as strychnine baiting and it is uncertain that those methods that are available to UK landowners are unequivocally more humane. When control seems necessary, Table 3 should help landowners/occupiers compare the expected costs of carrying out poisoning with strychnine (until deregistration), trapping, or fumigating. There are, however, several caveats that apply to the total cost calculated for each method:

1) Once the decision to use strychnine has been made, there is likely to be a delay in carrying out the treatment, as Defra approval is required and a site visit by an advisor may be necessary. The cost of 2 g of strychnine may vary, depending on the supplier: wholesale prices in November 2003 varied from £2.59-£4.90, but the figure used in the table is a quoted retail price of £6.45 (all prices excl VAT). The cost of collecting earthworms will also vary depending on their abundance, but usually 100 baits can be collected in about 30 min by pouring a weak solution of an irritant over a small area of pasture (MAFF, 1981). There are additional costs determined by the conditions of use: providers of a commercial service can re-use the utensils used to mix and apply baits on other farms, but non-commercial users must dispose of them by burying at the treatment site; a secure means of storing unused strychnine must be provided.

2) The cost of traps can probably be reduced substantially by purchasing, for example, Far East imports that are advertised in suppliers' catalogues. This may be a false economy, if the traps are not as durable or as effective (e.g. if they have weaker springs). The success of trapping depends greatly on the skill and experience of the operator. Efficiency may be reduced by factors outside the operator's control, such as bad weather, or moles reinvading from an adjacent property where no control is carried out.

3) The wastage of fumigation materials (pellets or tablets) may be reduced by preliminary site visits, so that the insertion points are targeted on active runs. A second (limited) application of pellets a few days after the first insertions improved overall efficacy in Danish trials, whereas in UK test reports workers evaluated only a single application. The costs stated in the table for a supplementary application were determined by the minimum quantity of pellets or tablets that are commercially available and the labour required inserting all of them, regardless of how many additional insertions might actually be necessary.

4) There are economies of scale in relation to trapping and, to a lesser extent, fumigation that do not apply to strychnine treatments. Once the required numbers of traps have been purchased, each trap can be re-used on the same site or on other premises until it is no longer functional and has to be replaced. For fumigation, the pellet or tablet applicator can be re-used, so that material costs for subsequent treatments will be lower.

Fumigation with aluminium phosphide is widespread across the EU, but to gain maximum efficacy and to kill moles quickly, careful preparation is required. Even with the additional cost of fumigation, the level of control may be lower than expected due to soil conditions and when these are optimal, control may be less than that achieved with strychnine. However, there is a lack of independent data on the best strategic approach to carrying out fumigation of mole tunnels with the aluminium phosphide formulations approved for use in the UK. There is no other method of controlling large numbers of moles effectively, except perhaps trapping for which the evidence of efficacy was obtained many years ago, or appears to be mainly anecdotal. Thus, landowners will inevitably be forced to re-consider the costs against the benefits of control. Presumably, the risk of accidents to racehorses and their riders and to pilots/passengers of small aircraft will continue to outweigh the increased cost of control, in at least some circumstances, when strychnine is withdrawn.

Trapping is also common in the EU and is likely to remain the method of choice for removing small numbers of moles. The introduction of more humane kill-traps, if these can be developed, will clearly be advantageous. Trapping appears to be the only method of lethal control that is allowed in organic farming in Denmark, but here the Soil Association, while banning its members from using strychnine, does permit the use of aluminium phosphide, although subject to strict conditions. In the UK, relocation of live-trapped moles is not recommended until the full implications of doing so have been explored. The long-term cost-effectiveness of non-lethal methods, such as repellents, fencing and habitat modification, has not been proven, although repellents such as Renardine have a short-term effect. The likely cost of erecting and maintaining a mole-proof fence will surely restrict this control measure to protecting only high-value commodities/amenities or keeping moles out of a small, clearly-defined patch. Some aspects of habitat modification (e.g. reduction of soil pH) are probably undesirable in nearly all cases, but harrowing and rolling to flatten molehills would seem to be relatively benign.

This review has highlighted a lack of scientifically rigorous data on the relative efficacy of mole control methods. The potential unavailability of strychnine in the future suggests that landowners and occupiers will have to assess more carefully whether moles should be controlled or left alone in order to avoid initiating measures that are unnecessary or unlikely to reduce damage levels in the long-term. If control is necessary, then alternative methods are available, but improving their cost-effectiveness requires more comprehensive evaluations across a wider range of UK conditions.

Table 3. Comparative costs of controlling moles by fumigation, trapping or strychnine on a 2 ha field.

	Control Method			
	Fumigation		Trapping	Strychnine†
Method	Aluminium phosphide, 0.6 g pellets	Aluminium phosphide, 3 g tablets	Kill-traps Duffus/Pincer	Earthworm baits
Application Rate	1 pellet/insert, 300 inserts/ha	1 tablet/insert, 150 inserts/ha	40/ha	1 worm/insert, 25 inserts/ha
Material Costs	4 flasks (160 pellets/flask) £86 + applicator £90 = £176	10 tubes (30 tablets/tube) £176.50 + applicator £82.50 = £259	80 traps @ average cost £4.15 each = £331.60	1 g strychnine = £3.23*
Labour (Hours)	16	8	8	4.5 (including earthworm collection)
Labour Cost @ £5.15/H**	£82.40	£41.20	£41.20	£23.18
Total Cost For One Visit	£258.40	£300.20	£372.80	£26.41
Number Of Follow-Up Visits (If Required)	1	1	3	1
Additional Material Costs	1 flask = £21.50 (160 inserts, if necessary)	1 tube = £17.65 (30 inserts, if necessary)	nil	£2.58 (20 inserts/ha, if necessary)
Additional Labour Cost	4.5 h = £23.18	1 h = £5.15	4 h x 3 = £61.80	3.5 h = £18.03
Total Cost For One Treatment	£303.08	£323	£434.60	£47.02
Cost Per Treatment Allowing For Re-Use Of Equipment***				
Total Cost For One Visit	£168.40	£229.15	£57.78	£26.41
Total Cost Including Follow-Up Visits (As Above)	£213.08	£251.95	£119.58	£47.02

N.B. Mole density rarely exceeds 20/ha, but in most cases the number of moles present in a field at the start of a treatment will be unknown. Except for trapping, when at least one more visit is necessary to collect traps, follow-up visits to insert additional pellets/tablets/strychnine baits may not always be required, but they increase the likelihood that all methods will achieve the same degree of control. Material costs are based on suppliers' 2003 catalogue listings and exclude VAT. Application rates and labour inputs are derived from examples given in the literature. Eight hours is taken as one working day.

† Defra approval is required to purchase and to use strychnine hydrochloride for mole control. Individual landowners and farmers require approval for each treatment; professional pest controllers can apply for approval to carry out a programme of treatments. Applications take up to 15 working days to process and a site inspection may be required. Details of all site(s) where control is planned must be specified in the application. Such approval is not required for fumigation or trapping.
* Based on a single quoted retail price for 2 g strychnine.
** Agricultural Wages Board Minimum Wage from 1/10/03.
*** As re-treatments at the same site or treatments at different sites can re-use equipment purchased on the first occasion, costs will necessarily be lower. Therefore, for fumigation these costs exclude the price of applicators, but include a replacement tube for the tablet applicator. For trapping, the default value is that a trap can be re-used 20 times before it needs to be replaced.

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