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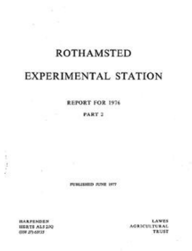
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Slugs in Agriculture

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Slugs in Agriculture

J. W. STEPHENSON and R. BARDNER

Introduction

An animal recognisable as a slug was used as a hieroglyph by the ancient Egyptians so it is likely that the Egyptian farmers were familiar with the depredations of these pests. Though their distribution is world wide, slugs as agricultural pests are particularly important in moist temperate climates. Many methods of controlling them have been advocated including the use of physical barriers of sand, ashes, soot, lime or tar oils or the use of poisons, such as copper sulphate or copper aceto-arsenite, but it was not until the discovery in 1936 of the molluscicidal properties of metaldehyde that a more systematic approach to slug control began. Despite many studies of the biology and control of slugs during the past 40 years, present methods of control are unsatisfactory largely because of the protection afforded to the animals by their mucus film, and because there is always a proportion of the population that is concealed, inactive and inaccessible.

The sporadic and localised nature of severe outbreaks of slug damage has discouraged coordinated research but improvements in the methods of controlling other pests have emphasised the damage that is still being caused by slugs, particularly to cereals and potatoes.

Slug biology

The slug fauna and pest species. There are 26 species of slugs in Britain (Quick, 1960). MAFF summaries of insect and allied pest reports show that *Agriolimax reticulatus* (Müll.), *Arion hortensis* (Fér.) and *Milax budapestensis* (Haz.), are the most important pests and that *Arion fasciatus* (Nils.) and *Milax sowerbyi* (Fér.) damage crops less often. The large black *Arion ater* (Linn.), though frequently associated with horticultural crops is not common on farm land, except perhaps on pastures and leys.

Life-cycles. Slugs are hermaphrodite and protandrous and although pairing is usual, self fertilisation can occur. In some species sexually mature pairs indulge in courtship before mating and this may be followed by a variable pre-oviposition period. Clusters of eggs are laid in sheltered places, or in the soil; the number of eggs per cluster varies from 10 or 15 to 40 or 50 depending on the species. Most species lay two or three clusters usually between autumn and the early spring; *A. reticulatus* can lay at any time, although it lays most of its eggs during the cooler months. There is no free-living larval stage and the embryo completes development within the egg; the duration of development varies, and is largely governed by the ambient temperature. After hatching the young slugs stay near the egg remains and although they disperse after a time there is no evidence that-they migrate over great distances. Dependent upon the species and the weather, there may be one, two or more generations per year.

Temperature and humidity relationships. Slugs thrive in a cool, moist environment. In experimental conditions, slugs are active at near-freezing temperatures that render most other invertebrates comatose. The temperatures that induce chill-coma vary with the species but are unchanged whether slugs are acclimatised for 1–10 days at 5, 20, or at

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temperatures fluctuating between 0 and 10°C (Mellanby, 1961). Thus, although slugs are usually most active in more clement conditions, they are well adapted to remain active at low temperatures and they do not readily lose this adaptation. In a temperature gradient *A. reticulatus* settles at 17–18°C (Dainton, 1954).

In contrast to the effects of low temperature, *A. reticulatus* survives for only 1 h at 35°C (Carrick, 1942) but within the range 20–30°C slugs are activated by rising temperatures (Dainton, 1954). This positive response to temperature change has important survival value in hot weather because the slugs move and may find cooler resting places.

The amount of water vapour in the atmosphere affects feeding activity (Stephenson, 1973). When *A. reticulatus* and *A. hortensis* were fed for ten days on clover leaf discs kept at different humidities, *A. reticulatus* showed no significant diminution in feeding activity in deficits of 0·8, 2·6 or 3·8 mm Hg^{-1}, whereas *A. hortensis* fed progressively less as humidity decreased. These results imply that in the field, *A. reticulatus* may continue to feed on a crop or slug baits, in an environment that is too dry to allow feeding by *A. hortensis*.

The water content of the soil can affect oviposition. Carrick (1942) found that *A. reticulatus* did not lay eggs in excessively dry or wet soils, i.e. < 10 or 100% of field capacity, though oviposition did occur in soils with intermediate water contents. For development, the optimum water content of soil was 70–80% of field capacity. Embryos did not develop when the soil was waterlogged, or when it was < 25% of field capacity.

Adult *A. reticulatus* can lose body-water either by evaporation, or by excessive production of mucus. In either case the loss can be made good by the absorption of water through the epidermis. Locomotor activity is not decreased by small evaporative losses but if larger amounts of water are lost as a result of excessive mucus production, the animal may be immobilised and die (Dainton, 1954).

The importance of water in the slug environment has also been the subject of several field observations. Barnes and Weil (1942) found that as long as the soil did not dry out completely, slugs inactivated by a short dry spell would become fully active after only a small but undefined amount of rain. In contrast, if the soil dried out, considerable rainfall was necessary to re-activate them although there was little activity while the rain was actually falling.

The effect of prolonged rainfall on known numbers of *A. reticulatus*, *A. hortensis* and *A. ater* which were confined by electric fences in outdoor enclosures was examined by Stephenson (1976). The enclosures were flooded during the winter for a total of 34 days; on one occasion, the vegetation was completely submerged for 14 days. Soil sampling showed that populations of *A. ater* and *A. reticulatus* had been depleted: these are both species that live mainly near the soil surface. No adults were found and the numbers of immature slugs had been halved. In contrast, *A. hortensis*, a species that spends most of its life deeper in the soil, had been less seriously affected, although their numbers had decreased. Evidently this species can survive some water-logging such as may occur on heavy land in a wet winter.

The intense sensitivity of slugs to moisture is reflected in the size of populations that develop in moist cultural conditions. Irrigation of Redskin or Majestic potatoes in the second half of the growing season increases slug damage, whereas irrigation in the first half of the season has no effect (Stephenson, 1965a). Unripe tubers are not damaged by slugs (Thomas, 1947) so that irrigation regimes that keep the soil moist towards the end of the growing season favour slug activity and feeding. Sugar-beet seedlings were most severely damaged at the lower and wetter end of a steeply sloping field, presumably because the slugs were either more active or more numerous in moist conditions (Stephenson, 1968a). In potato crops, *A. hortensis* and *M. budapestensis* are active below ground throughout the growing season. This activity is greatest in the soil below furrows where

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rain running off the ridges keeps them moist, particularly before the leaf canopy is fully developed. Later, the rain running off the leaves maintains the moist conditions in the furrows (Stephenson, 1967b).

Weather and slug activity. No detailed field study has been made of the effects of drought on slugs but it is clear that long periods of dry weather adversely affect both slugs and their eggs. In dry weather, surface living species such as *A. reticulatus* seek sheltered places; for example, under stones, clods of earth, surface litter, or in cracks and crevices in the soil. In prolonged dry weather mortality may be high amongst those slugs that fail to find moist hiding places. However, as Barnes and Weil (1945) pointed out, the remnants of the population resume full activity after prolonged rain. Subterranean species such as *A. hortensis* and *M. budapestensis*, descend to lower levels in the soil in dry weather. Indeed, *M. budapestensis* can actually ingest soil and so burrow its way through heavy clay; it can also excavate cavities in the clay in which to lay eggs (Stephenson, 1966).

In their nocturnal movements on the soil surface or on low growing vegetation, slugs enjoy a moist, cool microclimate but changes in the weather can affect this, so attempts have been made to correlate these environmental changes near the ground with slug activity. In field experiments, Barnes and Weil (1945) could find no single weather factors or combination of factors that were associated with changes in slug activity except for falling rain (see p. 170) and freezing temperatures. They found no slugs active while the temperature remained below freezing for a short time, nor when the ground remained frozen from January to mid-March, but activity was quickly resumed when the temperature rose above freezing point irrespective of the duration of the cold period. Webley (1964) studied slugs in market garden plots catching them with baits of various types. The catches were naturally dependent upon the slugs being active and this in turn depended on the weather. The effects on catch of the age of the bait used, the mean night air temperature, the grass minimum temperature, the relative humidity, the wind speed and the rainfall, were investigated by multiple regression analysis. Each of the factors was responsible for some of the variance but the two most important were the age of the baits, which decreased in efficiency with time, and the mean night air temperature. By counting the numbers of slugs seen during night-time searches lasting for 30 min, Crawford-Sidebotham (1972) measured the slug activity in a single habitat in different weather conditions. The effects of temperature, vapour pressure and vapour pressure deficit on slug activity were analysed by multiple regression. The activity of *A. hortensis* and *M. budapestensis* were most closely correlated with the air temperature and the vapour pressure deficit but the relationships in respect of *A. reticulatus* were not clear. Further investigations are necessary to identify and explain the complex relationships between slug activity and weather.

Rhythmic activity. Slugs are usually nocturnal but on dull, warm, humid days, *A. reticulatus* and *A. hortensis* sometimes feed on low growing vegetation during daylight hours. Most species are active between 2 h after sunset and 2 h before sunrise and the time of peak activity varies with the species (Barnes & Weil, 1945). They are well adapted to their nocturnal habit and can adjust to seasonal changes in day length thereby confining their periods of activity to the hours of darkness when the basic requirements for 'normal' activity are best satisfied. For most of the year, night air temperatures fall within the range 5–20°C within which falling temperatures stimulate locomotor activity enabling slugs to forage, search for a mate or lay eggs. Their water-permeable epidermis makes slugs vulnerable to drying but the danger of desiccation is minimised by a continually replenished mucus film that envelopes them. Nocturnal activity near the moist soil surface also diminishes the risk of desiccation.

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Distribution in soil and aggregation. The behaviour, activity and survival of slugs is affected by the physical characteristics of the soil. The choice of resting places in bare moist soil of both adult and immature *A. reticulatus* has been investigated in the laboratory (Stephenson, 1975a). Very coarse 'soils' composed of aggregates retained by 10·0 or 12·5 mm mesh sieves and with a moisture content of 25% by weight were chosen by both the adults and the young in preference to 'soils' composed of smaller aggregates. Even newly hatched slugs emerging from eggs buried at the centre of a choice of 'soils', moved to the one composed of the larger aggregates. The slugs usually took up positions between the soil aggregates that ensured maximum contact with the soil. *A. reticulatus* preferred to lay their eggs in 'soils' composed of finer aggregates retained by 3·0 or 5·0 mm mesh sieves probably because they found it easier to lay eggs in them.

In his study of the vertical distribution of slugs in an arable plot, Hunter (1966) found that although *A. reticulatus*, *A. hortensis* and *M. budapestensis* descended deeper into the soil in dry or frosty weather, over the year as a whole and allowing for seasonal effects, these three species had a different pattern of vertical distribution. In a 30 cm deep section of the soil, the top 8 cm contained 82·5% of the *A. reticulatus*, 61·6% of the *A. hortensis* and 49·5% of the *M. budapestensis.*

South's (1965) study of the horizontal distribution of slugs in arable and grass plots, provided little evidence for the aggregation of slugs in the arable plot but in the grass plot, the distribution of *A. reticulatus* was correlated with the distribution of tufts of cocksfoot, *Dactylis glomerata L.*, which were about 30 cm apart. This grass is one of the first to commence growth in spring and the semi-recumbent tufts provide shelter for both the slugs and their eggs. Although no strong association was found with other components of the habitat, slugs were aggregated in patches 9·0–25·8 cm across; this distribution seemed to arise from individuals resting near to one another in sheltered places, e.g. hoof prints or under clods of soil. No positive relationship has been established between the aggregation of slugs and such obvious factors as soil pH, soil organic-matter content or the availability of food plants. Some other possibilities are that small areas of soil in a field may maintain a high moisture content and restrict slug movement; shelter and oviposition sites may be limited, or that slugs may form close groups so that their combined mucus output maintains a moist atmosphere.

When slugs were released from a central point, South (1965) found that in the first two to five days they dispersed fairly evenly; they then established a 'territory' in which they remained. In both field and laboratory studies Duval (1970), Moens, Francois & Riga (1966) and Newell (1966) established by more sophisticated techniques that slugs on release from shelter move in a circuitous path that tends to return them near to the point of release. These restricted movements tend to perpetuate established aggregations.

Estimation of slug populations. Field experiments and advisory work have been hindered by the difficulty of obtaining accurate estimates of slug populations. Population estimates based on trap catches are criticised on the grounds that the catch depends on the unknown proportion of the total population active at the time of trapping, which is affected by the weather. Marking and recapture methods using dyes or radioactive tracers have not proved practicable for extended periods of observation. Methods of extracting of slugs and their eggs from soil samples have been investigated. The optimum size of sampling unit was found to be a 30 cm cube (Hunter, 1968). Although this is much larger than the sampling units normally used for soil invertebrates, the size ensured that few units contained no slugs. Each unit was broken into 7·5 cm layers that were treated separately in a soil-washing machine (Salt & Hollick, 1944), the slugs being floated free of plant debris on concentrated magnesium sulphate solution. Some of the young slugs and the more delicate eggs are destroyed by the water jet but large slugs are relatively undamaged.

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South (1964) allowed water to rise very slowly from the bottom of a similar-sized but intact sample unit, driving the slugs but not eggs out of the sample and depositing them on the soil surface. The 'Bristol' soil-washing machine speedily and effectively extracts tipulid larvae from large amounts of soil (Mayor & Browne, 1964), so the possibility of using it to extract slugs from soil samples was tested (Stephenson, 1976). The soil samples, each 30 × 30 × 15 cm, have to be subsampled; the whole sample took about 1 h to wash and a very large volume of water was required.

All slugs except newly hatched ones were recovered by the Salt and Hollick apparatus but the method was laborious and slow. The flooding method took less time but only 88–92% of the slugs were recovered. The 'Bristol' apparatus gave only 78–81% recovery of slugs from heavy clay with flints but 90% of the *A. reticulatus* and 100% of the *A. hortensis* were recovered from light garden loam. Because of the aggregated distribution of slugs all the methods require that a large number of soil samples should be examined. None gives a 100% recovery of slugs and while the Salt and Hollick method is the best if labour is available, it is impracticable for use in advisory work.

For advisory purposes, the possibility of predicting slug-damage to cereals and potatoes has been examined. Duthoit (1961) exposed batches of ten wheat seeds on the soil surface prior to drilling; the numbers of seeds found damaged after seven days were considered to be related to the numbers of slugs present and an indication of whether or not control measures were needed. Similarly, damage to maincrop potato tubers planted 80–100 cm deep, about one month before drilling and examined after seven days, may indicate the need for control measures in this crop (Hunter, 1969a). A recommended method to confirm the need for treatment and fix the time of pellet application in the potato crop (Terrington E.H.F., 1973) is to place a teaspoonful of methiocarb pellets covered by a piece of wood or a tile between the ridges. The trap should be examined two to three times a week when the number of slugs caught will be indicative of the population and activity levels.

A drawback to the use of these methods of predicting damage and timing control measures is that they reflect both slug activity and slug numbers. At present it is difficult to allow for the factors which cause variations in slug activity.

Control methods

Cultural control. Several cultural practices decrease the risk of crop damage by slugs. The numbers of *A. reticulatus*, *A. hortensis* and *M. budapestensis* were reduced when soil was broken down to a fine tilth, compacted, and sown with grass that was then kept short for three months (Hunter, 1967). This method of compacting grassland might be of use in wet summers when winter wheat is to follow the grass. *A. reticulatus* can be prevented from reaching wheat seeds by ensuring that they are properly covered by soil. In the laboratory, this was done in a simulated cloddy seed-bed, by compacting the soil immediately after sowing (Stephenson, 1975b). The larger soil aggregates were broken down and the fine soil so produced, was firmly packed over the seed, and the slugs, that are unable to burrow, could not reach it. In practice, the seed can be protected in this way by rolling immediately after drilling provided that the soil and weather conditions permit.

Plant resistance. Potato tubers are mainly damaged by *A. hortensis* and *M. budapestensis*, and in Scotland damage may also be associated with *A. reticulatus*. Nevertheless there are important varietal differences in the susceptibility of maincrop varieties to attack (Thomas, 1947; Gould, 1965). The relative attractiveness to *A. hortensis* of exudates from actively growing tubers was compared (Stephenson, 1968b). Soil, watered with the diluted exudate from the susceptible variety King Edward, was more readily occupied by the

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slugs than soil watered with the exudate from the less susceptible variety Pentland Falcon. These experiments suggest that water-soluble tuber exudates may pass into the soil water adjacent to the tubers, where they could be detected by slugs and influence their behaviour.

Feeding experiments were done in which substances identified chromatographically in aqueous extracts of tubers were absorbed on filter paper and offered to *A. hortensis*. Sucrose, some amino acids and chlorogenic acid caused more of the treated filter paper to be eaten than untreated controls (Stephenson, 1969, 1970). The roles of these substances in the feeding process have yet to be identified; further work may make it possible to relate differences in the chemical composition of potato cultivars to their susceptibility to attack.

Reduction in the amount of crop damaged could be obtained by growing the less susceptible varieties in those areas where experience has shown that the crop may be at risk. Unfortunately, the least susceptible varieties do not possess so many other desirable qualities and are less widely grown; examples are Pentland Ivory and Stormont Enterprise.

Investigation of the breeding seasons of slugs by Bett (1960) showed that active mature individuals of the tuber damaging species are present at the end of the maincrop growing season. Lifting the crop as early as possible will therefore help to decrease the amount of damage.

Biological control. In a review covering relevant publications from 1921 to 1964, Stephenson and Knutson (1966) listed 46 species of invertebrates associated with 25 species of slugs, and ten species of invertebrates are known to kill 14 species of slugs. Among the insects that feed on slugs, Stephenson (1965b) found that seven common species of carabid beetles showed some interest in them. In a 1 m^2 outdoor enclosure containing 20 *Pterosticus melanaria* (Ill.) and 20 adult *A. reticulatus*, all the slugs were eaten in 24 days. Tod (unpub.) found that 18 species of carabids and three species of staphylinids fed on slugs; *Carabus*, *Pterostichus* and *Calathus* spp. were the most important predators. The larvae of *Tetanocera elata* (Meig.), Diptera : Sciomyzidae, kill slugs (Knutson, Stephenson & Berg, 1965); the first instar and part of the second were passed in a single *A. reticulatus*, thereafter the larvae were predatory. They were not host specific at this stage and attacked and killed six species of slugs. In all, four to nine slugs were killed by each larva between hatching and pupation. The influence of these predators on slug populations is at present unknown. If predators, parasites or diseases of slugs proved important it might be possible to increase their abundance by appropriate cultural practices.

Chemical control. The use of copper sulphate to kill the snail *Lymnea truncatula* (Müll.) was pioneered by Walton and Jones (1925) and it was soon established that this compound would also kill slugs (Anderson & Taylor, 1926). Ten years later the molluscicidal properties of metaldehyde were discovered, apparently by chance. Gimingham and Newton, (1937) used a 1 : 50 mixture of metaldehyde and wheat bran in a field trial and obtained an estimated kill of 20 000 slugs ha^{-1} in the centre of the field and 28 000 ha^{-1} at the margins.

The mode of action of metaldehyde is not understood but Cragg and Vincent (1952) found that both as a solid and in solution, it could act as either a stomach or a contact poison and its toxicity increased with rising temperatures. As it became more widely used some defects of metaldehyde as a slug-killer became apparent. Barnes and Weil (1942) showed that metaldehyde-bran baits exposed to the weather on six successive nights caught progressively fewer and fewer slugs, thus showing the necessity for repeated applications. Cragg and Vincent demonstrated that if slugs fed only briefly on metalde-

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hyde-bran baits, they were immobilised but recovered in a humid environment. In the field, this would mean that a proportion of the slugs that fed on baits would recover if the weather conditions were favourable. In addition, metaldehyde-bran baits exposed to heavy rain disintegrate and are washed away.

Attempts have been made to overcome these difficulties; poisonous additions such as calcium arsenate, carbaryl, zineb and dazomet have been tried in efforts to increase the kill of slugs feeding on the baits. To make the baits more weather resistant, Thomas (1948) used casein glue as a bait matrix and Webley (1966) waterproofed bran-based slug-pellets by treating them with chlorosilanes. Stephenson (1972b) used gelatin, cross-linked by treatment with formaldehyde, as a bait matrix. This formulation was resistant to weathering and showed persistent molluscicidal activity even when buried in soil.

Henderson (1969) developed a technique to measure the median lethal dose of metaldehyde necessary to kill *A. reticulatus*, for slugs within the weight range 0·3–0·6 g; it was $85{\cdot}2 \pm 4{\cdot}0$ μg per slug. On theoretical grounds pellets containing 5% metaldehyde are most effective when spaced 10–20 cm apart on the soil surface (Hunter & Symmonds, unpub.). At this spacing, slugs wandering at random are most likely to encounter haphazardly spaced pellets. Closer spacing is wasteful and wider spacing is less effective.

Large numbers of chemicals have been screened for use in the control of the snail vectors of liver fluke in man and animals. Very few of the snail-killing chemicals are effective against slugs and none are better than metaldehyde. Chlorinated hydrocarbon and organophosphate insecticides are poor molluscicides; Edwards and Stafford (1971) tested some materials in the latter group but none was toxic to slugs except phorate which seemed to have a short-term effect. In addition, they found that diazinon, chlorfenvinphos and phorate all accumulate in the bodies of slugs living in treated soils, so creating a hazard to predators that might feed on them.

Routine screening of potential molluscicides is not done at Rothamsted, but from time to time likely compounds are tested. Ten triazine herbicides were shown to be toxic to slugs (Stephenson, 1963), their toxicity was related to their solubility in water. As the most soluble compound was also the most toxic, this probably reflected the ease with which the compounds penetrated the mucus film that envelopes slugs. The herbicide ioxynil, was found to be poisonous to slugs (Wain, 1963). Stephenson (1967a) showed that although the sodium salt was repellant to slugs it was poisonous if injected directly into the stomach. The repellancy was overcome by enclosing the compound in micro-capsules in the size range 150–250 μm that could pass unbroken, directly into the slug gut, where the capsule walls of methyl cellulose were broken down by enzyme action and the poison released.

The triazines were less poisonous than metaldehyde and the sodium ioxynil capsules proved ineffective after a few weeks storage because the repellant poison leaked through the capsule walls and further work on the formulation of triazines and sodium ioxynil was discontinued. A number of cholinesterase-inhibiting carbamates that became available at this time were shown to be molluscicidal (Crowell, 1967). One compound, methiocarb, was marketed as 4% methiocarb-bran pellets. Methiocarb when introduced directly into the gut has an LD50 of 21·9 μg per slug in the 0·3–0·6 g weight range compared with a value of 45·7 μg per slug for metaldehyde (Hunter, unpub.). This higher toxicity means that few of the slugs that feed on methiocarb-bran pellets recover. It is, however, also a broad spectrum pesticide and therefore presents a hazard to beneficial soil invertebrates, though of course it will also kill cutworms whose feeding is often mistaken for slug damage.

An experimental carbamate, thiocarboxime ('Talcord') was found to be a powerful contact slug poison (Stephenson, 1971, 1972a, b). The slightly water soluble compound (14 g litre^{-1} at 20°C), was formulated in gelatin sufficiently cross-linked to ensure that

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the active ingredient was leached very slowly from the pellets under field conditions. In a small field trial, cross-linked gelatin pellets containing 1·3% 'Talcord' reduced the percentage of damaged King Edward tubers from 17·9 to 6·5% and similar pellets containing 4·0% methiocarb reduced it to 7·1%. Both formulations were applied at the rate of 5·6 kg ha^{-1} during drilling (Stephenson, 1974).

Both metaldehyde and methiocarb are currently in widespread use and are the only materials recommended for slug control in the MAFF *List of Approved Products*. Perhaps these two compounds will be superseded by more effective slug-killers in the future but at the present time their full potential is not being realised. Ideally, the carrier or matrix should be weather resistant; the active ingredient should be mixed with materials that increase the palatability and attractiveness of the pellets.

The most consistent feature of field trials in slug control is the frequency with which they give inconclusive results. Obviously, some experimental control measures will not fulfil expectations when tested but more often the inconclusive results are due to factors outside the experimenter's control. The slug population on the site may prove to be less than had been indicated by pre-trial trapping; the weather may be unsuitable for slug activity during the trial and the localised distribution of slugs makes it difficult to select a suitable experimental site with confidence. Some of these difficulties have been overcome by the use of large outdoor enclosures in which slugs are retained by means of electric fences (Stephenson & Dibley, 1975). On a larger scale, it has proved possible to "manage' a field sown with grass and clover so that a large slug population has built up. Trials can be made on the site, or slugs can be trapped and used for experimental purposes (Stephenson, unpub.).

Economic importance of slugs

Slugs can attack most annual field and horticultural crops, but both the intensity of these attacks and subsequent yield losses vary greatly with weather, soil type and previous cropping. At present most of these attacks are almost unpredictable and even if control methods are used they are often ineffective and applied too late.

In the following sections an attempt is made to assess the economic importance of slugs for the few crops on which published data is available.

Potatoes and slugs

Nature of damage. Slugs bore into tubers spoiling their appearance, the damaged tubers are unsaleable for human consumption and are usually sold for stock feed at about 25% of the ware price (Baker & Waines, 1957). The Potato Marketing Board have defined standards for the ware crop that recognise 16 different defects of which pest damage, including that caused by slugs, is only one (Potato Marketing Board, 1975). As no more than 5% of damaged tubers are usually accepted, only a small percentage of slug damage can be tolerated though the actual loss in weight of individual tubers damaged by slugs is small.

Estimates of loss. Potato crops with a small proportion of defects, including slug damage, are normally 'dressed out' to ware standard; data concerning potatoes in both England and Wales are available from both the Potato Marketing Board's Annual Reports and from MAFF sources. Data from Scotland have been excluded from this paper because the maincrop area is only one-fifth of that in England and Wales and there is a negligible slug problem (Bardner & Waines, 1965). The last year for which complete figures are available is 1974 and these data have been used in this paper although the costs of production and the market price of the crop have both risen sharply since.

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The maincrop of England and Wales in 1974 occuped 146 870 ha, with an average yield of 33·9 t ha^{-1}. The average price per tonne was £24.46, making the total value of the crop £122 million. Potato growing is concentrated around the Wash, with lesser concentrations in the Yorkshire and Lancashire plains and the West Midlands, but there are some crops in all parts of England and Wales (Coppock, 1968). Thirty per cent of the maincrop potatoes in England and Wales are grown in Norfolk, Cambridgeshire and Lincolnshire. Although the total area planted has declined by about 18% in the last ten years, the relative proportions of the crop grown in different parts of England and Wales have changed very little and increased yields have compensated for the decreased area. However, the proportion of different cultivars grown has changed greatly and these may have affected the amount of slug damage, as described later.

Several different estimates of the losses caused by slugs have been made. Those of Baker and Waines (1957) and Strickland (1965) were based on Potato Marketing Board data on pre-harvest samples of potato crops; that of Hunter (1969b) on the opinions of ADAS district advisers, and that of Church, Hampson and Fox (1970) on samples of potatoes in farm stores. Baker and Waines produced a table of net losses in tons on the assumption that crops with less than 5·02 ha^{-1} of damaged tubers would normally be dressed out, whereas crops with damage greater than this would be used only for stockfeed or industrial purposes. These figures have been converted to the percentage of the crop lost.

TABLE 1

Net slug damage, England and Wales, percentage of total crop (after Baker and Waines, 1957)

	%
1954	0·29
1955	0·16
1956	0·12
Mean	0·19

Gross damage, that is crops with any noticeable slug damage, varied from 8·4 to 4·7% of the total tonnage during the same period.

Strickland (1965) suggested that on average slugs damaged about 23% of the maincrop potato area, but the net loss was small, less than 35 500t, i.e. less than 0·75%. He commented that slugs have a high nuisance value because of the dressing-out of damaged crops, though dressing-out was also done for many other reasons. Hunter (1969b) estimated that approximately 38 300 t potatoes were holed in 1966, an average year. This is equivalent to 0·81% of total production. Church, Hampson and Fox (1970) sampled potato crops in stores throughout Great Britain. A total of 3·9% in 1965 and 3·9% in 1966 has slug damage, but only 2·1 and 2·6% respectively had damage making them unacceptable for ware.

Thus estimates of net damage vary between 0·12 and 2·6% of the total potato crop. At 1974 values this would be between £0·14 and £3.17 million, and these figures would be reduced by about 25% if an allowance is made for the value of the damaged crop. However, losses may be slightly less than net damage because slug damage can be confused with cutworm damage, and also because some slug-damaged tubers would normally be rejected because they also have injuries from other causes. Although the average net loss seems small there is much variation in slug damage between different parts of the country, between years, between different potato cultivars and between different fields in the same area. In bad areas, fields with up to 30% or more of slug-damaged tubers are not infrequent, and the great variability in the amount of attack makes it difficult to

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identify crops where chemical protection would be justified. Some of the factors causing variations are discussed below.

Regional variations. It is surprising to find that the incidence of slug damaged tubers is greatest in the ADAS Eastern Region closely followed by the East Midlands and not in the areas of high rainfall nearer the western seaboard. This is probably because of the greater predominance of calcium-rich soils in the east, as calcium is necessary for mollusc metabolism.

TABLE 2

Distribution of slug-damaged potatoes

ADAS province	Percentage of crops in region with slight or moderate damage (adapted from Baker and Waines, 1958)	Percentage of tubers holed (adapted from Hunter, 1969)
East	8·9	1·78
South-east	6·7	0·31
South-west	4·3	0·06
West Midlands	2·9	0·21
East Midlands	8·3	0·87
Yorks and Lancs	2·4	0·09
Northern	5·3	0·01
Wales	5·7	0·04

Slugs prefer heavier soils (Gould, 1962), so they are a particular problem in some of the silt soils of the best potato growing areas round the Wash, where the Terrington Experimental Husbandry Farm is located. When 20 test tubers were planted in early March in 13 fields within a 13 km radius of Terrington, the numbers of tubers holed after one week varied between 1 and 20 (mean 16) and the total number of holes varied between 1 and 114 (mean 49) (ADAS, 1975). The fields were then planted with maincrops of several cultivars, six of the fields receiving no molluscicidal treatment. At harvest the percentage of holed tubers on these six fields varied between nil and 30% though in general those fields in which the test tubers had been least damaged were also those with the least damage to the crop. These preliminary observations illustrate the great variability in the level of damage from field to field and show the need for further detailed investigation.

Annual variation and the effects of weather. Attack of slugs vary greatly from year to year, but there is very little quantitative data about the extent of these variations. In Baker and Waines' surveys, net slug damage varied by a factor of 2·4 in three years, but only by a factor of 1·2 in the two years investigated by Church *et al.*. Some data is available for the NIAB potato trials at Terrington, but since the trial is located on different fields each year the variation between fields is confounded with the differences between years. However, on the assumption that years for which no data is available were years with minimal attack, in a 14 year period there were four years with severe attack, six years with little or no damage and four years with near average damage (Table 3). In discussing slugs attacking cereals, Strickland (1965) concluded that there was an average of one bad, two average and one good year in every four, which is not so dissimilar from the Terrington results. The data for Terrington also shows that in years of severe damage the percentage of damaged tubers was about 2·7 times that in a average year, whereas in years of little damage the percentage of damaged tubers was only 0·08 times that in an average year. It is generally agreed that slug damage to potatoes is worst 'in wet autumns following mild wet summers' (Terrington EHF, 1973), but again there is insufficient data to attempt the correlation of weather with annual variations in damage

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to potatoes; furthermore wet summers increase potato yields besides encouraging slugs (and potato blight). Examination of MAFF data shows that the mean yield of potatoes in Norfolk can vary by about 15% in two successive years; most of this variation is probably the effects of weather on the planting and growth of the crop.

Variation between cultivars in resistance to slug attack. Thomas (1947) first reported varietal differences in resistance to attack by slugs. The NIAB trials at Terrington have provided a great deal of information on the relative resistance of potato cultivars (Gould, 1962; Winfield, Wardlow and Smith, 1967; and the Terrington Annual Reviews, 1963–1974), and in Table 4 this data is presented in the form of a 'susceptibility index' for the

TABLE 3

Percentage of damaged tubers of two varieties in the NIAB potato variety trials, Terrington

Year	Majestic	King Edward
1961	12·3	21·5
1962	0·3	1·5
1963	7·1	13
1964	No data	No data
1965	18·8	29·1
1966	4·6	8·0
1967	No data	No data
1968	2·9	2·8
1969	No data	No data
1970	13·2	18·1
1971	12·0	13·9
1972	No data	No data
1973	6	5
1974	2	6
Mean	5·65	8·49

leading varieties grown in 1969 and 1974. The susceptibility index was calculated by taking the mean of the ratios

$$\frac{\text{Percentage damaged tubers in cultivar}}{\text{Percentage damaged tubers in Majestic}}$$

which were calculated for each of the years the cultivar was tested. Majestic was chosen as a standard since it is grown every year in the Terrington NIAB trials and is moderately resistant to slug damage. The susceptibility indices show some variation between years, but the order of ranking is usually very similar. The most resistant cultivar, Stormont Enterprise had a susceptibility index of 0·232, Majestic had a rating of one, and Maris Piper, the most susceptible cultivar had a rating of 4·02, so on average there will be over 20 times as many slug-damaged tubers of Maris Piper compared to Stormont Enterprise.

By multiplying the percentage area of each cultivar grown by the susceptibility index a susceptibility function can be derived showing the relative damage to be expected to the total crop in England and Wales in different years. A small proportion of the crop (12% in 1964 and 6% in 1974) was of minor, unnamed cultivars, but for the purposes of calculation it was assumed that they would have a susceptibility equal to that of Majestic, or the more susceptible King Edward. Thus changes in the cultivars grown, particularly the introduction of the eelworm resistant Maris Piper have increased the likelihood of damage by slugs. From the data in Table 4, between 30 and 60% more slug damaged tubers would be expected in 1974 compared with 1964 if other factors were the same. Of course, these calculations take no account of regional differences in the proportion of different varieties grown or of variations in slug population between years, but in the Terrington area at least, some crops of the susceptible Maris Piper are being grown in

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TABLE 4

Changes in crop susceptibility to slug damage, 1964–1974

	Susceptibility index	1964 % of crop	1964 Susceptibility function	1974 % of crop	1974 Susceptibility function
King Edward	1·82	25·3	46·1	18·1	32·9
Majestic	1	57·0	57·0	3·7	3·7
Maris Piper	4·02	—	—	13·3	53·3
Desiree	1·27	—	—	9·3	11·9
Redskin	2·30	2·2	0·3	0·1	0·2
Pentland Crown	1·63	—	—	23·1	37·7
Pentland Dell	0·75	—	—	10·5	7·8
Pentland Ivory	0·62	—	—	5·6	3·5
Record	1·47	4·3	6·3	9·4	14·6
Other cultivars	—	11·2	—	6·4	—
Total (a)			120·9		170·2
Total (b)			130·0		177·2

(a) Assumes 'other cultivars' have susceptibility of King Edward
(b) Assumes 'other cultivars' have susceptibility of Majestic

fields heavily infested with slugs (ADAS, 1975), although there may be other reasons for this which are considered to outweigh the risk of slug damage.

Molluscicides and methods of application. To control slugs on potatoes metaldehyde (3% pellets at 31·4 kg ha^{-1} or 6% pellets at 15·7 kg ha^{-1}) or methiocarb (4% pellets at 5·6 kg ha^{-1}) are normally used. Rayner (1975) has summarised results of trials between 1968 and 1970 using methiocarb or metaldehyde pellets. There was a considerable variation in the percentage reduction of damaged tubers between years and between sites, but the mean reduction was as follows:

Pre-planting treatment	38%
April/May treatment	44%
July/August treatment	71%
September treatment	64%

Both metaldehyde and methiocarb were used in the earlier two treatments, and were equally effective. The best control was given by July/August treatments, using only methiocarb. There seemed to be no advantage in more than one application of molluscicide.

Costs of control. Methiocarb is more expensive than metaldehyde (1976 costs for materials but not application are £11.54 ha^{-1} for methiocarb and £5.54 ha^{-1} for metaldehyde).

Rayner gives a table of 1974 costs which has been adapted as follows:

TABLE 5

Costs per hectare of molluscicidal treatments

	By hand or seed fiddle	Aircraft	Tractor-mounted distributor
Methiocarb pellets at 5 lb acre^{-1} (5·6 kg ha^{-1})	£7.41	£7.41	£7.41
Variable costs of application	Nil	£4.94	£0.49
Estimated wheeling losses	Nil	Nil	£13.59
Total	£7.41	£12.35	£21.49

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Assuming a crop yield of 30 t ha^{-1}, valued at £22.35 t^{-1} and a 50% reduction is damaged tubers as a result of treatment, he calculated the value of the increased saleable ware resulting from treatment, and this has been adapted as follow:

Percentage of crop damaged in the absence of treatment	3	5	8	10	15
Value per hectare of increase in saleable ware resulting from treatment	£9.79	£16.30	£26.09	£32.61	£48.92

and he suggested that treatment by tractor is therefore only worth while where damage would reach about 8%. This is a very rough economic threshold, since labour costs were not included, and both the costs of application and the value of the crop have increased in the last 18 months. Potatoes are a crop for which the demand is inelastic but yields vary from year to year, and there is great variation in the prices received by producers, making it extremely difficult to define economic thresholds. At the current exceptionally high prices of £100–200 t^{-1}, treatment might be justified by damage levels of 5·0%, including costs of application by tractor and wheeling damage.

Need for treatment. Routine treatments with molluscicides are likely to be uneconomic except where susceptible varieties are grown in districts where large slug populations are frequent, such as Terrington. In the years between 1961 and 1974, the mean percentage of damaged tubers in variety trials at Terrington was 5·7 for Majestic and 8·4 for King Edward. If the economic threshold is taken as 8% damaged tubers, routine treatment would have been justified for the susceptible King Edward, but not for the more resistant Majestic. Hunter's method for investigating slug numbers before the main crop is planted has already been described (page 173) but it cannot yet be quantitatively related to the risks of damage to the crop.

Proportion of crops treated. Assuming that the relationship between costs of control and the values of the crop is likely to return to approximately 1974 ratios, on what proportion of the crop are control measures justified? The mean percentage loss of tubers in a year of average damage in the Eastern Region was 1·78% (Hunter, 1969b). Data from the NIAB trials at Terrington suggest that in a bad year the percentage of damaged tubers is about 2·7 times the average. As a rough estimate the percentage of damaged tubers in the Eastern Region in a bad year is probably $1{\cdot}78 \times 2{\cdot}7 = 4{\cdot}8\%$, which is still below the economic threshold. The survey of 13 fields near Terrington (ADAS, 1975) suggested that three of the 13 fields had more than 1·5 times the average damage, and the mean of these was 1·75 times the average, so in a bad year about a quarter of the fields in the Eastern Region would repay treatment. Assuming one bad year in every four, this suggests an average of at least 6% of the potato area in Eastern Counties would repay treatment, i.e. about 3000 ha. This calculation makes no additional allowance for the small proportion of fields damaged in average or good years, nor for damage in other regions. In 1974, only 252 ha of the maincrop potatoes in England and Wales were actually treated with molluscicides (Sly, unpub.) which is less than a third of that estimated by Hunter for 1966, of which 95% was in the Eastern Region. Hunter considered 1966 as a year of average damage, whereas 1974 was a wet year favouring slugs, so probably only a minority of crops where treatment was justified actually received molluscicide.

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Slugs and cereals

Nature of damage. Wheat sown in autumn is the cereal crop most often damaged by slugs. Serious attacks on spring-sown crops are rare, probably because the soil is drier. Germinating seeds or very young seedlings are most easily injured and most of the damage is done soon after sowing, but slugs will also graze older seedlings and even bore into the base of shoots. *Agriolimax reticulatus* is the most common slug attacking cereals, but *Arion hortensis* also causes damage and other species are occasionally implicated. Crops sometimes fail completely, but more often damage is uneven, and only the patches of badly thinned crops are re-drilled.

Estimates of losses. These are based on the areas re-drilled, but this may exaggerate damage, as wheat plants can compensate for very drastic thinning of young crops. It is likely that much re-drilling is unnecessary, the growers being misled by the poor appearance of an attacked crop. There is no reported work on the subsequent yield of plots attacked by slugs but not re-drilled and since there is no data on the size of slug populations (as distinct from the number of slugs caught in traps) conventional pest intensity/yield relationship curves (damage functions) cannot yet be constructed.

In Strickland's (1965) review of pest losses, slugs ranked amongst the three most important pests of wheat, the others being wheat bulb fly and wireworms. The annual loss from slug damage was estimated at 16 600 ha out of a total area of 743 000 ha, i.e. 2·23% but he considered that in bad years grain-hollowing may occur on 40 500 ha of heavy-land wheat (over 5% of total area). Much of this loss was partly recoverable by re-drilling, but as already mentioned, there is no information on subsequent yield loss.

Hunter (1969b) surveyed the opinion of ADAS district advisers. He concluded that about 9800 ha out of 879 000 needed either re-drilling or treatment with molluscicide in 1966/67, i.e. 1·11%, which is only half Strickland's estimate. With both these estimates it should be remembered that the losses refer to winter wheat, but the total wheat acreage is for the combined winter and spring sown crops. MAFF figures on crop area do not distinguish between the two planting seasons, and although the majority of wheat is winter sown the percentage of the winter crop damaged would be greater than that of the total wheat crop.

Because there are not enough data to transform estimates of acres damaged into the amount of yield loss it is difficult to express losses in monetary terms. Nevertheless, ADAS advisers in Hunter's survey provided monetary estimates for the total losses which included the cost of molluscicide application, the cost of re-drilling and the cost of loss of yield consequent on sowing spring instead of winter wheat. The total came to £191 700 for a crop valued at £86·2 million, i.e. 0·22%, so losses were only a fifth of the potential yield of areas that were re-drilled or treated with molluscicide. Both the yield and value of the wheat crop have increased; using 1974 figures a loss of 0·22% would be valued at £0·6 million.

Regional variations and the effect of previous cropping. Hunter subdivided his data by ADAS regions, and in Table 6 his results have been used to calculate the percentage of the crop treated or re-drilled in the various ADAS regions, and the monetary loss per hectare.

Crops on the Eastern side of England were considered more susceptible to damage and loss, but the differences between regions are not nearly as marked as with slug damage to potatoes. With both crops attacks are most frequent on heavy soils (Brown, 1955), but unlike attacks on potatoes previous cropping has a great influence on slugs attacking cereals as most damage is done early in the life of the crop. Previous crops which provide good surface cover increase the number of slugs. Gould (1961) surveyed 92 fields in East

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TABLE 6

Slug damage to wheat

Region	Area grown (ha)	Percentage of crop treated or re-drilled	Loss in £'s per ha
East	308 700	1·97	0·23
South-east	140 800	1·23	0·23
South-west	79 600	0·83	0·20
West Midlands	86 800	1·35	0·16
East Midlands	175 400	1·84	0·25
Yorks and Lancs	56 900	1·63	0·18
Northern	21 700	0·11	0·05
Wales	8 700	0·14	0·01

Anglia chosen from farms where at least one other field was known to have had slug damage. No damage was seen after a full fallow, or after sugar beet, and damage was very light after potatoes (5% loss of stand on two fields out of 16 visited). The data for other previous crops are summarised below.

TABLE 7

Slug damage to wheat in relation to previous cropping

	Previous crop				
	Dry harvesting peas	Clover and grass leys	Beans	Cereals	Brassicas for seed
No. of fields	23	23	3	5	15
No. of fields with slug damage	22	14	3	5	11
Range of estimated percentage loss of stand on damaged fields	20–90	5–70	5–35	15–70	5–90
Mean	30	20	Not given	53	Not given

The slug problem has been aggravated in recent years by a great increase in the area sown to oilseed rape, and also by an increased area subjected to minimal cultivation techniques, especially direct-drilling. Any residues of surface trash in newly sown cereals provide cover for slugs, and such residues are common with direct-drilled crops, whilst the slits in which seeds are sown in sod-seeding provide shelter and enable slugs to feed on exposed seed.

The area of brassica seed crops (including oilseed rape) has increased from 5127 ha in 1971 to 38 970 ha in 1975. The dense cover of brassica seed crops and the debris after harvest provides ideal conditions for slugs. Such crops are usually followed by cereals, commonly winter wheat. In autumn 1974 there were 38 000 ha of direct-drilled winter wheat, an estimated 5·6% of all winter wheat sown (Allen, 1975). Edwards (unpub.) has compared slug populations on direct-drilled and conventionally sown wheat plots on six different sites in Britain. Direct-drilled plots had a mean of 6·4 times as many as ploughed ones, and in an earlier trial there were 23 times as many slugs in a direct drilled plot. If it is assumed that losses are proportional to slug numbers, and also that there are 6·4 times as many slugs in direct-drilled plots, the amount of direct drilling in 1974 would be expected to increase slug damage by 36%. The increased acreage of brassica crops is similar to that of direct-drilled winter wheat, so both these changes together may well have increased slug losses by about half as much again since the mid-sixties, or by about £0·3 million at today's prices.

Control of slugs on wheat. As with potatoes, baits of metaldehyde or methiocarb are a

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recommended method of control. They can be used either just before or just after planting and although the evidence is contradictory, treatments applied just before sowing are probably the most effective in preventing grain hollowing. Sprays of copper sulphate or metaldehyde can also be used.

Results of slug control experiments are usually assessed by trapping slugs, and sometimes also by plant counts. Grain yields from such experiments have not been published by British workers. Gould and Webley (1972) commented that in 1972 a yield increase of at least 0·25 t ha^{-1} would be needed to pay the costs of molluscicides and this is still approximately true. Provided damage occurs at an early stage of growth, wheat crops have very considerable powers of compensation for large losses in stand (Bardner, 1968). Jessop (1969) simulated slug damage by the December removal of wheat seedlings sown in late September–early October. Removal of 20% of the plants decreased yields by an average of 6%, of 65%, 19%, and when 82% of plants were removed yield decreased by 66%. For wheat yields of about 5 t ha^{-1}, a potential 20% loss of stand would be needed to recover the costs of a molluscicide (ignoring labour and tractor costs), but on present data it is impossible to define the size of a slug population that would cause that loss.

Slugs and other crops. Besides cereals and potatoes, slugs also damage many other crops, such as clover, re-seeded ryegrass, root crops, especially in the seedling stage, and many kinds of fruit and vegetables. There are few quantitative data about these losses, though Hunter (1969a) believed that total losses in suger beet, newly sown grass leys, carrots, brassicas, flowers and bulbs probably exceeded the value of damage to wheat and potatoes. Slugs can also transmit some plant pathogens (Runham & Hunter, 1970), but there is little data on the importance of this aspect of damage.

Some data on the acreage of sugar beet requiring re-sowing have been provided by Dunning and Davis (1975). In 1973, there were 7 ha, in 1974, nil and in 1975, 34 ha. In 1975 the total sugar beet area was 197 603 ha, so in this year 0·0172% of the total acreage would have been affected. Assuming the loss was equal to about half the gross return of £590 per ha, the total loss in 1975 would have been about £10 000. However, slugs may become more important as the greater use of precision drilling continues to decrease seeding rates. Precision drilling (planting to a stand) was done on 65% of the sugar beet area in 1975, compared with 30% in 1970 (Dunning & Davis, 1975).

Apart from the injuries they inflict on plants, the presence of slugs in crops that are dehydrated or frozen immediately after harvest can contaminate the produce and lead to prosecution of the suppliers. Bundy (1968) suggested that a level of 1200 slugs or caterpillars per hectare would result in one slug or caterpillar in every 1000 packets if 99% of the pests were removed during processing. Even if only one in ten customers complained this would be considered a seriously high level, and for this reason measures which give only 65–70% control in such situations have serious shortcomings.

Peas are often harvested at night when the humidity is high and slugs are likely to be active on the foliage. Wharton and Ensor (1969), suggested that 4% methiocarb pellets applied at 11 kg ha^{-1} will give an immediate 90% reduction in slug activity; this treatment is best applied when peas are flowering. They also commented that slugs were not a serious problem with peas grown on the extensive area of light land in Norfolk, but that this might not be true of the medium to heavy land of North Lincolnshire.

Hunter (1969a, b) quotes an unattributed source that 'the cost of slug damage to brussels sprouts in Huntingdonshire and Bedfordshire alone exceeds that to wheat throughout England and Wales'. In 1972, which is the last year for which figures are available, the value of the brussels sprout crop in these two counties at average yields and prices would have been about £3 million, and losses to the wheat crop for that year, based on Hunter's data, would have been worth about £0.35 million, so if the statement is

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correct losses would have been about 10% of the value of the crop, which seems a very high figure.

Conclusions

The effects of slugs on crop yields are like those of many other pests in Britain. Losses are a small proportion of the national value of most crops but are still substantial in monetary terms, amounting to a total of £1.6–3·6 million for wheat and potatoes. Losses to individual growers are often unexpected and sometimes large. Fields with 30% or more of potato tubers damaged by slugs are not uncommon in districts where severe slug attacks are frequent. Constant changes in agricultural practice are a necessary response to economic pressures, but during the last ten years a side effect of changes in potato cultivars and in methods of cereal growing has been to increase the risk of slug damage to these crops, possibly by about 50%.

Routine chemical control is not usually justified, but methods of predicting the attacks of slugs and methods of controlling the damage they cause are not as advanced as are similar techniques for other agricultural pests, such as aphids. Though this unsatisfactory state of affairs is partly due to the difficulty of working with slugs it is also due to the lack of coordination in slug research.

Possible improvements can be considered under two headings, short term and long term. Short-term possibilities include improvements in the formulation of existing slug toxicants, particularly their resistance to weathering and their persistence in wet conditions. The effectiveness of slug pellets containing stomach poisons would be increased if an attractant and/or substances which increase their palatability are included in the formulation. Better bait pellet formulations are needed, especially for use with potato crops. There is also a requirement for an effective seed treatment for wheat and sugar beet. The possibilities should be investigated of developing an early warning system for attacks on potatoes grown around the Wash.

In the long term, several lines should be pursued. It is especially important to develop a practicable method of measuring slug populations that is not dependent on slug activity, as are present baiting methods. An improved method of assessing populations would be of great value for predicting likely attacks, for pest assessment, and for evaluating the results of field experiments on control of slugs. It is also a prerequisite for investigations of the population dynamics of slugs. Very little is known about the quantitative effects of such density-dependent factors as predators, parasites, diseases or competition between slugs, and even less about the interrelationship of these factors with density-independent factors such as weather and soil conditions. Experience with other pests show that some understanding of their population dynamics, even if incomplete, can lead to new methods and strategies for pest control and the avoidance of damage to crops.

A study of the relationship between chemical structure and the toxicity of existing slug poisons could lead to the development of new and more effective compounds with greater toxicity, persistence or selectivity. New methods of control could also result from investigations of slug mucus and ways to decrease its effectiveness in protecting slugs from desiccation and from contact poisons.

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