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SLUG FORECASTING IN CEREALS

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SLUG FORECASTING

IN CEREALS

by

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ABSTRACT

In a series of field experiments, slug damage to winter wheat seeds was found to be directly related to the biomass of slugs in the soil (determined by soil sampling) and inversely related to the percentage of fine soil aggregates in the seed-bed and to depth of sowing. Sowing at 40-50 mm depth compared to 20-25 mm provided protection equivalent to a broadcast application of molluscicide pellets and in one year resulted in a 9% yield increase. Best protection from slug damage was achieved by drilling at 40-50 mm depth combined with an application of molluscicide pellets broadcast immediately after drilling. A broadcast application of pellets was more effective than pellets drilled with the seeds.

The percentage of winter wheat seeds killed by slugs was monitored, together with various risk factors, at 93 sites throughout the UK. Estimates of slug populations at each site were obtained from traps baited with methiocarb pellets, and it was found that the peak number of slugs trapped during the period from July until just before cultivation was more important than any other risk factor or combination of factors in accounting for differences in seed damage between sites. This factor accounted for 26% of the variability in seed damage. A combined function of the number of slugs trapped at drilling and the percentage of fine soil aggregates in the seed-bed accounted for 21% of the variability in seed damage. Both (i) the peak number of slugs trapped before drilling, and (ii) the combined function of number of slugs trapped at drilling and the percentage of fine soil aggregates in the seed-bed, have potential for identifying fields with a negligible risk of slug damage to wheat seeds. However, further research is needed to improve the accuracy of forecasting slug damage. In particular, other forms of trap should be tested for their potential use in providing more accurate estimates of slug numbers and biomass at drilling, and techniques of assessing seed-bed conditions should be improved.

CONTENTS

1. OBJECTIVES

To develop a practical system of forecasting slug damage in cereals based on estimates of slug numbers, species and population structure, together with other risk factors, especially methods of cultivation and soil conditions at the time of drilling.

2. INTRODUCTION

In surveys conducted in 1986 and 1987, members of the Long Ashton Members' Association (now part of the Arable Research Institute Association) considered that slugs were the most important pest problem in winter wheat, especially in first wheats after oilseed rape, where slugs were the outstanding perceived crop protection problem (Glen, 1989). As a result of concern about possible damage by slugs, 30% and 26% of wheat crops were treated with molluscicides in 1982 and 1988 respectively (Sly, 1986; Davis, Garthwaite & Thomas, 1988). However, ADAS estimates suggest that 90% of molluscicide usage is not justified by the risk of damage to winter wheat.

This highlights the need for a reliable system of forecasting slug damage, which would enable farmers to be more precise in their use of control measures against slugs, thus lowering costs and allowing farmers to concentrate their attention on fields with a high risk of damage, where an integrated approach to slug control is needed, as damage to seeds and seedlings before emergence is not reliably controlled by molluscicide usage alone, despite their widespread use. Furthermore, methiocarb, the most widely used molluscicide in cereals, is known to kill beneficial invertebrates that are important predators of aphids and other pests (Kennedy, 1990). A system of forecasting slug damage, by reducing unnecessary molluscicide usage, would help to conserve predators of insect pests, thus providing potential for further financial savings in insecticide usage.

Since previous studies (Gould, 1961; Stephenson, 1975) show that seed-bed conditions have an important influence on the risk of slug damage, this indicates that a forecasting system should, if possible, take account of soil conditions at the time of drilling as well as the numbers of slugs present in individual fields. In this project we used two complementary approaches to investigate the information needed for a forecasting system, (1) field experiments at IACR Long Ashton Research Station on the effects of seed-bed conditions on slug numbers and damage to winter wheat, and (2) studies of slug numbers and the soil conditions likely to affect the risk of slug damage in a large number of fields in England, Scotland and Northern Ireland. Field experiments also included studies of the efficacy of molluscicide pellets in relation to drilling conditions and pellet placement.

This project complements two other projects on slugs funded by H-GCA (Project no. 0060/1/87, The Role of Soil Water in Regulating the Activity of Terrestrial Slugs (Port & Young, 1991), and Project no. 0019/1/90, Cultural Methods to Reduce Slug Damage to Cereals).

3. MATERIALS AND METHODS

3.1 Field experiments on the effects of seed-bed conditions

Each year from autumn 1987 to autumn 1990, a field experiment with a randomized block design was set up in winter wheat following oilseed rape on clay loam at Long Ashton Research Station.

The 1987 experiment was an investigation of the effects of seed-bed tilth and consolidation (Glen, Milsom & Wiltshire, 1989), with three levels of consolidation imposed on seed-beds with fine, medium or coarse tilth, giving nine different seed-beds, each replicated four times. The 1988 experiment was an investigation of the effects of sowing winter wheat into a coarse seed-bed at two different depths, on three dates, with or without methiocarb pellets broadcast on the soil surface (Glen, Milsom & Wiltshire, 1990), with three replicates of each of the twelve combinations of treatments. The 1989 experiment investigated the effects of sowing winter wheat at two depths, on three dates, into a coarse seed-bed, with six replicates of each of the six combinations of treatments. The 1990 experiment investigated the effect of sowing winter wheat at two depths, without molluscicide or with methiocarb pellets drilled with the seeds or broadcast on the soil surface either immediately after drilling or at emergence. There were four replicates of each of the eight combinations of these treatments.

In all experiments, seed-bed conditions were assessed and slug traps were operated in the same way as described below for fields monitored throughout the UK. In addition, slug numbers in the top 10 cm of soil were estimated by taking one sample of soil, 25 cm x 25 cm x 10 cm deep, per experimental plot at regular intervals after sowing. Slugs were extracted from soil samples by slow flooding as described by Glen, Milsom & Wiltshire (1989, 1990).

3.2 Studies in fields throughout the UK

Each year, fields to be sown with winter wheat were selected with, wherever possible, a history of slug damage. The following risk factors were recorded at each site each year.

3.2.1 Slug numbers.

Slug numbers were recorded in ten bait traps placed in each field when the soil surface was moist, at approximately fortnightly intervals from July until one month after crop emergence. Each trap consisted of an 18 cm diameter inverted plastic flower-pot saucer (terracotta coloured), supported on the soil surface to enable slugs to crawl underneath, covering a small heap (5 ml teaspoonful) of methiocarb pellets in the middle of the area covered by the trap. Traps were left for three days before slug numbers and species were recorded.

3.2.2 Soil conditions.

Soil moisture was determined by weighing, before and after drying, samples of soil collected from the seed-bed as soon as possible after drilling. Moisture was expressed as a percentage of the dry weight of soil. In addition from 1988 onwards, soil moisture was determined in samples of soil collected from each field at the beginning and end of each trapping period.

Aggregate size distribution in the seed-bed was estimated from five samples of soil, each 25 x 25 x 10 cm deep, dug from each field as soon as possible after drilling using a metal frame of the above dimensions inserted into the soil until its top was level with the soil surface. Soil was carefully removed from outside one side of the frame and a spade with a blade 25 cm wide was inserted horizontally underneath. The soil was transferred to a suitable container and left spread out under cover until air-dried, then separated into four aggregate sizes by passing it through sieves of 25, 12 and 6 mm hole size. The soil in each aggregate size class was then weighed.

A sample of soil from each size class was oven-dried and bulk density determined using standard methods. A needle reliefmeter or a swinging beam was used to measure surface roughness as soon as possible after drilling and after crop emergence. Soil temperature at 10 cm and 30 cm depth at the time of drilling and afterwards was obtained from the nearest meteorological site. From 1988 onwards, seed depth was measured at Zadoks Growth Stage 10-12 by carefully removing soil from one side of the drill row and measuring the vertical distance between the seed and the soil surface, or the distance between the seed and the point where the shoot emerged if a shoot was present. This was done 40 times in each field.

pH, organic matter content, soil type and particle size distribution (sand, silt & clay) were determined using standard ADAS advisory techniques.

3.2.3 Damage assessment.

Numbers of seedlings were recorded at Zadoks Growth Stage 11-12 and one month after emergence on ten lengths of 1 m of drill row in each field. The number of plants out of 100 showing signs of leaf grazing by slugs was also noted. If the stand was patchy, or if plant numbers were less than 90% of the numbers of seeds sown, twenty lengths of drill row, each 25 cm long, were dug from the field. These were either hand-sorted in situ or placed in rigid boxes to avoid crushing, then hand-sorted in the laboratory to find seeds and seedlings. Two types of lethal slug damage were recorded, a) characteristically hollowed grain in which slugs had eaten the embryo and sometimes also part of the endosperm, and b) shoots eaten through below ground level, killing the growing point. Sublethal damage to shoots and leaves was also recorded.

4. RESULTS

4.1 Field experiments on the effects of seed-bed conditions

4.1.1 1987 experiment.

In this experiment, the cultivations used to achieve different degrees of tilth and consolidation affected both the size of the slug population and the ability of slugs to reach wheat seeds in the soil. As a result, the percentage of seeds and seedlings killed by slugs ranged from 3 to 33% in different seed-beds.

The percentage of seeds and seedlings killed was directly related to the biomass of slugs in the top 10 cm of soil (Fig. 1a) and was inversely related to depth of sowing (Fig. 1b) and the percentage of fine soil aggregates in the seed-bed (Fig. 1c). These three factors together accounted for 94% of the variance in the percentage of seeds and seedlings killed in different seed-beds (Fig. 1d). Thus, more and larger slugs were capable of causing greater damage, but fine soil and greater depth of sowing made it more difficult for slugs to reach seeds and seedlings below ground and kill them.

There were no significant differences in yield between different seed-beds, despite the large differences in slug damage (Table 1). Detailed results of this experiment are given by Glen, Milsom & Wiltshire (1989).

4.1.2 1988 experiment.

Wheat was drilled at two depths on three dates in autumn 1988 into a coarse seed-bed, with or without methiocarb pellets broadcast on the soil surface immediately after drilling. Drilling date had no significant effect on slug damage, but both drilling depth and methiocarb pellets affected the percentage of seeds and seedlings killed by slugs. As there were no significant differences in slug biomass between plots drilled at different depths, differences in damage were attributable to the effect of drilling depth on the ability of slugs to find the seeds.

Whereas 26% of seeds sown at ca 20 mm were killed by slugs, only 9% of seeds sown at ca 40 mm were killed. The protection provided by this additional 20 mm of sowing depth was comparable with that provided by methiocarb pellets broadcast immediately after drilling (Fig. 2a). The effects of seed depth and pellet application did not interact and were consistent on all drilling dates. Thus, fewest seeds were killed where methiocarb pellets were broadcast on a seed-bed with seeds sown at 40 mm depth; intermediate damage was recorded where seeds were sown at 40 mm depth without pellets, or where pellets were broadcast on seeds sown at 20 mm depth; greatest numbers of seeds and seedlings were killed where seeds were sown at 20 mm depth without pellets (Table 2). Sublethal damage to seedlings, calculated as a percentage of the numbers of seedlings that emerged, was not affected by sowing depth but was reduced ($P<0.001$) where pellets were broadcast immediately after drilling (Fig. 2b). There were no significant differences in yield between treatments, despite the differences in slug damage (Table 2). Further details of this experiment are given by Glen, Milsom & Wiltshire (1990).

4.1.3 1989 experiment.

The seed-beds prepared on all three dates were relatively coarse with, by weight, 33% aggregates <6 mm, 15% 6-12 mm, 19% 12-24 mm and 33% > 25 mm. Differences in damage between sowing dates were not significant (Fig. 3a) despite differences in soil temperature. Over all dates, 9% of wheat seeds sown at ca 50 mm depth were killed by slugs compared to 26% of seeds sown at ca 25 mm ($P<0.001$). There were no significant differences in slug biomass or in seed-bed tilth between plots drilled at different depths.

Crop yield was affected both by drilling depth and drilling date but their effects did not interact (Fig. 3b). The yield from plots drilled at 50 mm (7.37 tonnes/ha) was 9% greater than from plots drilled at 25 mm (6.76 tonnes/ha) ($P<0.01$). The yields from plots drilled in early and late October (7.61 tonnes/ha and 7.12 tonnes/ha respectively) were not significantly different, but plots sown in November yielded 6.46 tonnes/ha, significantly less than plots drilled in early and late October ($P<0.001$ and $P<0.05$ respectively).

4.1.4 1990 experiment.

The seed-bed in this experiment was finer than in the experiments of 1988 and 1989: soil samples taken immediately after drilling winter wheat on 22 October consisted, by weight, of 43% aggregates <6 mm, 17% 6-12 mm, 19% 12-25 mm and 21% >25 mm.

The mean depth of seeds in shallow sown plots was 31 mm, significantly less ($P < 0.001$) than the mean depth of 45 mm in deep sown plots. Plant counts at Growth Stage 11 revealed a mean number of 38 plants m^{-1} of row (315 m^{-2}), with even plant stands on all plots and no significant differences between treatments, indicating that slug damage to seeds and seedlings before emergence was slight. This was confirmed by examining samples dug from the drill rows of untreated plots, where only 4% of seeds sown at both depths had been killed by slugs.

Considerable numbers of seedlings showed grazing damage by slugs when examined on 6 December and 23 January. As the difference between experimental treatments was consistent on both dates, mean figures for both dates are presented in Fig. 4. The percentage of plants with grazing damage (Fig. 4a) was multiplied by the proportion of leaf area consumed on each damaged plant to give an estimate of the overall percentage damage (Fig. 4b), which was substantially (77%) lower on plots where pellets were broadcast immediately after drilling than on other treatments ($P < 0.001$). Where pellets were drilled with the seeds or broadcast at emergence, grazing damage was not significantly different from untreated plots. Sowing depth had no significant effect on grazing damage to seedlings.

Almost all slugs found in soil samples and bait traps belonged to one species, the field slug Deroceras reticulatum. Analysis of slug numbers in traps (Fig. 5a) showed that pellets broadcast immediately after drilling or at crop emergence considerably reduced the numbers trapped whereas pellets drilled with the seeds had no significant effect. (Data from the final date of trapping, 81 days after drilling, are omitted from Fig. 5a as a mean of only 0.03 slugs $trap^{-1}$ was recorded.) Numbers of slugs in traps were not significantly affected by sowing depth.

Differences between treatments in slug numbers recorded in soil samples were less pronounced than for bait traps. However, for the first three dates of sampling, before pellets were applied at emergence, there were significantly fewer slugs ($P < 0.05$) on plots where pellets were broadcast immediately after drilling than on other treatments (Fig. 5b). Numbers of slugs in soil samples were not significantly affected by sowing depth, which did not interact with pellet treatment.

4.2 Studies in fields throughout the UK

Over the four years of the project, slug damage, slug numbers and other risk factors were assessed at 112 sites in England, Scotland and Northern Ireland. Data from sites monitored in 1987, 1988, 1989 and 1990 are summarised in Tables 3, 4, 5 and 6 respectively. The percentage of seeds killed by slugs was estimated at 93 of the 112 sites: a few sites were not drilled with winter wheat in most years, due for example to wet weather in the autumn. Slug damage to seeds was generally slight, 83% of sites having fewer than 5% of seeds hollowed by slugs, but significantly more seeds were killed ($P < 0.01$) in crops following oilseed rape than in crops following cereals (Fig. 6). This corresponded with a higher peak number of slugs ($P = 0.056$) in oilseed rape than in cereals (geometric mean peak numbers 9.1 and 5.2 slugs per trap for oilseed rape and cereals respectively).

The degree of association between the various risk factors and seed hollowing or seedling grazing was investigated by correlation and regression analyses; the best relationships are presented in Table 7. As some aspects of damage and risk were not measured at a number of sites each year, the number of correlations and thus the statistical degrees of freedom (D.F.) are different for most risk factors. It was found that log-log relationships gave the best correlations between slug numbers and damage (Table 7), and the greatest association between any single risk factor and seed damage by slugs was the direct relationship ($P < 0.001$) between the log percentage of seeds killed and the log peak numbers of slugs recorded in traps during the period from July until just before cultivation (Fig. 7a). This relationship accounted for 26% of the variance in the logarithmic percentage of seeds killed by slugs. The previous crop did not significantly affect this relationship. The log number of slugs per trap at the time of drilling was positively correlated ($P < 0.05$) with the log percentage of seeds killed (Table 7, Fig. 7b), but this relationship only accounted for 5% of the variance. The percentage of seeds killed by slugs was negatively correlated with soil temperature (Fig. 7c) and was positively correlated with the surface roughness of the seed-bed (Fig. 7e), but each of these factors accounted for less than 10% of the variance in the percentage of seeds killed. Although seed kill was not significantly correlated with seed depth nor with the percentage of fine soil aggregates in the seed-bed (Table 7), the most severe damage tended to occur at sites where seeds were sown at shallower depths (Fig. 7d), and where there was a low percentage of fine soil aggregates in the seed-bed (Fig. 7f).

Multiple regressions of the percentage of seeds killed on various combinations of risk factors were tested, but most were insignificant or accounted for considerably less variance than the factors shown above. Indeed, no multiple regression explained more variance than was accounted for by the peak number of slugs before cultivation alone. The only multiple regression to approach the degree of association of seed damage with this single factor was a combination of the log number of slugs at drilling together with the log percentage of fine soil aggregates in the seed-bed (Table 7). This accounted for 21% of the variance in the log percentage of seeds killed by slugs. The fit between this function and the percentage of seeds killed is shown in Fig. 8.

The percentage of plants grazed by slugs, assessed at 63 sites, was directly related to the percentage of seeds killed (Table 7, Fig. 9). Thus slug grazing tended to be more severe where slugs had been more active in killing seeds. The log percentage of plants grazed was positively correlated with log slug numbers (Table 7) before drilling (Fig. 10a), at drilling (Fig. 10b) and after drilling (Fig. 10c). Not surprisingly, the best correlation was with slug numbers after drilling; peak numbers after drilling are shown in Fig. 10c, but both mean and peak numbers after drilling gave similar correlations. Other risk factors were not significantly correlated with the percentage of seedlings grazed by slugs.

5. DISCUSSION

5.1 Field experiments

The results of the field experiments show that slug biomass in the soil, sowing depth and the percentage of fine soil aggregates in the seed-bed all have important influences on the percentage of seeds and seedlings killed by slugs. Thus, the potential of the slug population to consume wheat seeds is determined by the biomass of slugs present, but the number of seeds killed by these slugs depends on their ability to move through the soil to reach the seeds, which is affected both by seed depth and by the percentage of fine soil in the seed-bed. For example, at the extremes of seed-bed conditions encountered in the 1987 experiment, the highest biomass of slugs recorded would have killed 49% of seeds in a coarse seed-bed with 31% fine soil aggregates where seeds were sown at a depth of 19 mm, whereas the same biomass of slugs would have killed only 11% of seeds in a seed-bed consisting of 47% fine soil with seeds sown at a depth of 55 mm.

Drilling seeds at 40 - 50 mm depth provided a substantial degree of protection from slug damage in cloddy seed-beds compared to drilling at 20 - 25 mm, irrespective of soil temperature at drilling. The protection afforded by sowing at 40 mm rather than at 20 mm was similar to that provided by a broadcast application of methiocarb pellets immediately after drilling. Moreover, the effects of additional drilling depth and broadcasting pellets were complementary, so that the best protection was provided by broadcasting pellets immediately after deeper drilling. Where seeds were protected from slug damage by seed-bed conditions and sowing depth, pellets drilled with the seeds were ineffective, presumably because they, like the seeds, were hidden from slugs. Pellets broadcast on the soil surface immediately after drilling were, however, effective in killing slugs and provided protection from slug grazing.

Because the field experiments were not designed to investigate the effects of slug damage on yield, it is not possible to draw firm conclusions about the relationship between slug damage and yield of winter wheat from these experiments. However, the results suggest that damage has a rather variable effect on yield: in the experiments sown in 1987 and 1988, up to 33% of seeds were killed by slugs without any significant impact on yield, whereas in the experiment sown in 1989, yield was reduced by 9% on plots where 26% of seeds and seedlings were killed, compared to plots where 9% of seeds were killed. In the 1989 experiment, although difference in yield between plots sown at different depths cannot be attributed to differences in slug damage, it can be concluded that drilling at 50 mm reduced slug damage and gave a 9% yield benefit compared to drilling at 25 mm.

5.2 Studies in fields throughout the UK

The study of risk factors affecting slug damage at 112 sites throughout the UK supported the widely held belief (Port & Port, 1986; Glen, 1989) that winter wheat following oilseed rape is at greater risk of slug damage than wheat following cereals. Nevertheless, even after oilseed rape, 5% or fewer seeds were killed by slugs at 64% of sites, and 10% or fewer seeds were killed at 80% of sites. The finding that the percentage of seeds killed was better correlated with the peak number of slugs in traps during the period from July until just before cultivation than with any other individual factor confirms the conclusion of Spaull (1990), from studies in south east Scotland, that severe damage appeared to be more closely related to slug numbers recorded in traps in the summer months than numbers at drilling. However, even this relationship accounted for only 26% of the variance in seed kill (Table 7). Since this relationship was not improved by inclusion of the previous crop as a factor in the regression analysis, this suggests that the greater risk of damage to wheat seeds following oilseed rape than cereals was probably due to the larger number of slugs found in oilseed rape than in cereals. There was a poor correlation between seed kill and slug number in traps at drilling (Table 7) and, moreover, some instances of severe damage to seeds occurred where no or very few slugs were recorded in traps at drilling (Fig. 7b). Thus slug numbers trapped at drilling did not, on their own, provide a reliable basis for damage forecasting. As soil moisture is important for slug surface activity (Young & Port, 1991), it is likely that the low moisture contents in seed-beds at many sites (Tables 3-6) restricted slug surface activity and thus trap catches at these sites, and this may have contributed to the poor correlation between trap catch and seed damage. However, inclusion of soil moisture in the relationship between seed damage and trap catch at drilling did not improve the degree of fit. Nevertheless, the relationship between seed kill and slug numbers trapped at drilling was considerably improved by taking into account the percentage of fine soil aggregates in the seed-bed (Fig. 8), which is known from the field experiments described above to affect the ability of slugs to reach wheat seeds.

This function of slug numbers at drilling and the percentage of fine soil aggregates in the seed-bed is based on estimates of two of the three elements that were found to explain 94% of the variation in seed damage in the 1987 field experiment (slug biomass in the soil, the percentage of fine soil aggregates and seed depth (Fig. 1)). Inclusion of seed depth did not significantly improve the description of seed damage at different sites, and the two factors above accounted for only 21% of the variance in seed damage at these sites. Possible reasons for this rather poor relationship compared to the field experiment are: (1) slug numbers in traps at drilling probably gave a poor indication of slug biomass in the soil; (2) estimates of seed-bed tilth obtained from the percentage of fine soil aggregates were probably inaccurate, due to consolidation and high moisture content in the seed-beds of some sites, which would have resulted in fine soil aggregates sticking together and being recorded as larger aggregates; (3) differences in soil type between sites may have been important. These sources of error may also perhaps explain why seed depth had no significant effect on seed damage at different sites.

Saucer traps baited with methiocarb pellets, as used in this project to provide estimates of slug numbers and activity at sites throughout the UK, have been shown by Young (1990) to be more effective than tile traps for recording Deroceras reticulatum and to be equally effective for other species. Nevertheless saucer traps did not appear to provide accurate estimates of the numbers and biomass of slugs in the seed-bed at the time of drilling winter wheat, possibly because low soil moisture may have restricted slug surface activity at many sites and because seed-bed preparation may have disrupted normal slug activity patterns. Other forms of trap such as metallic-backed padded blankets (Hommay & Briard, 1988) or defined area traps (Ferguson, Barratt & Jones, 1989) may be more effective for estimating numbers of slugs in seed-beds, as slugs may be more likely to be drawn to the soil surface under such traps than under saucers. Clements & Murray (1991) compared catches of slugs in defined area traps, blanket traps and saucer traps in cereals and concluded that as defined area traps catch slugs from a known area, they give a more reliable estimate of the slug population than other traps. However, they would not be convenient for use by farmers and advisors, and Clements & Murray (1991) did not specifically study numbers of slugs in seed-beds. Thus, further studies are required on the relationship between numbers and biomass of slugs in wheat seed-beds and catches of slugs in different types of trap.

The negative relationship between seed kill and soil temperature fits with the belief (Port & Port, 1986) that seeds sown into colder soil are at greater risk from slug damage, but conflicts with the results of the field experiments where soil temperature at the time of drilling had little effect on slug damage to seeds, when seed-bed conditions were similar.

The relationships shown in Table 7 and Figs 7 and 8 between seed kill by slugs and various risk factors would clearly have to be used with caution as a means of forecasting the risk of slug damage. In all cases a considerable number of the observed values for slug damage lie well above the regression line, showing that the average relationship would have considerably underestimated the risk of slug damage at many sites. In order to forecast slug damage from the relationships in Fig. 7 and Fig. 8, it would be necessary to use the upper limits so as to be reasonably sure that slug damage to seeds would not be greater than predicted. This upper limit is shown as a dashed line in Fig. 7a and Fig. 8. Taking 10% damage by slugs as a safe level that would be unlikely to affect yield or even to cause concern to the farmer, the log of 10 + 1 = 1.04, and in Fig. 7a it can be seen that the upper limit for this level of damage was reached when the log (peak number of slugs + 1) per trap was 0.69, i.e. 4 slugs per trap. This is remarkably similar to the threshold level of four slugs per trap on prepared seed-beds or after drilling winter wheat, recommended in past years by ADAS, suggesting that treatment may be justified where more than four slugs per trap are recorded. However, it must be emphasised that the safe level of four slugs per trap in the present study was for traps operating before the soil had been disturbed for drilling and when the soil surface was moist and thus suitable for slug activity; in a related H-GCA project, visual assessment of soil moisture content has been found to give a good indication of periods when conditions are suitable for slug activity (Port & Young, 1991). Disadvantages of this method of assessing risk are: (1) traps can only give a reliable indication of slug numbers if soil conditions are moist and thus favourable for slug activity, (2) in this study traps were operated from July onwards (however it may not be necessary to trap for lengthy periods in order to assess the risk of slug damage). Although soil temperature can also affect slug surface activity (Port & Young, 1991), this is unlikely to have much effect on trap catch in the period from July to September.

A threshold of four slugs per trap during the period before cultivation would have correctly predicted that molluscicide treatment was not needed at 43% of sites. Alternatively, using the upper limit for the relationship between seed kill and a function of slug number in traps at drilling together with the percentage of fine soil aggregates in the seed-bed (Fig. 8), this would have correctly predicted that treatment was not needed at 34% of sites. Thus slug numbers in the previous crop would have been a better way of reducing unnecessary use of molluscicides than the function based on numbers at drilling and the percentage of fine soil in the seed-bed. However, by using the latter function it is possible to make a risk assessment at drilling, without any previous slug trapping, and, since this function takes account of seed-bed conditions at drilling, there is undoubtedly considerable potential for improvement in the accuracy of forecasting (see Conclusions).

The positive correlation between the percentage of seeds killed by slugs and the incidence of slug grazing on seedlings (Fig. 9) suggests that where there is a high risk of seeds being killed by slugs, the risk of grazing damage is also high. Thus the ability of a broadcast application of molluscicide pellets immediately after sowing to protect both seeds and seedlings could be valuable. Although there were good relationships between the number of plants grazed and the number of slugs trapped (Fig. 10), the need for a forecast of slug grazing is much less than for seed kill: grazing is easily visible and timely treatment can be based on this.

6. CONCLUSIONS

This project has clearly established that the percentage of wheat seeds killed by slugs is influenced by slug biomass, seed-bed tilth and seed depth, and has demonstrated that sites with a negligible risk of slug damage can be identified from (1) slug numbers trapped in the period from July until just before cultivation, or (2) slug numbers trapped at drilling together with an estimate of the percentage of soil aggregates <6 mm in the seed-bed. However, further studies are needed in order to improve damage forecasts. In particular, the bait traps used in the current project did not appear to provide an accurate estimate of slug numbers and biomass in the seed-bed at time of drilling: other forms of trap such as metallic-backed padded blankets and defined area traps should also be tested. In addition, the technique of assessing seed-bed conditions should be improved to provide greater accuracy with less effort than the technique used in the present study: passing a known volume of soil through a 6 mm sieve at the time of drilling or a photographic method, based on surface soil appearance, may be more suitable.

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Table 1. Percentage of seeds and seedlings killed by slugs and yield of winter wheat in field experiment with different degrees of seed-bed tilth and consolidation, sown in autumn 1987. Consolidation on fine and medium tilths was achieved by cultivation before drilling; cloddy seed-beds were consolidated by rolling immediately after drilling.

Seed-bed conditions		Seeds and seedlings killed by slugs by GS 12 (%)	Yield (t/ha)
Tilth	Consolidation		
Fine	Loose	2.5	9.28
	Medium	8.3	9.39
	Consolidated	32.5	9.31
Medium	Loose	5.7	9.55
	Medium	16.2	9.77
	Consolidated	30.8	9.37
Cloddy	Loose	14.7	9.17
	Medium	15.4	9.03
	Consolidated	20.7	8.98
LSD ($P < 0.05$)		16.7	0.83
Coefficient of variation (%)		-	6.1

Table 2. Percentage of seeds and seedlings killed by slugs, percentage of plants with sublethal damage by slugs and yield of winter wheat in field experiment with two different sowing depths, with or without methiocarb pellets broadcast immediately after drilling, sown on three dates in autumn 1988.

Sowing depth and pellet treatment		Seeds and seedlings killed		Seedlings with sublethal damage		Yield (t/ha)
Depth	Pellets	%	Angle	%	Angle	
Shallow (ca 20 mm)	No pellets	33.4	32.0	96.9	85.6	8.17
	With pellets	17.8	20.1	80.8	71.8	7.90
Deep (ca 40 mm)	No pellets	11.8	16.0	94.6	83.8	8.09
	With pellets	6.8	10.0	75.1	64.2	8.05
LSD ($P<0.05$)			9.5		8.6	0.74

Table 3. Summary of information on slug damage, slug numbers and other risk factors collected from fields throughout the UK in 1987, sown to winter wheat unless otherwise stated.

Site	Slug damage		Slug numbers/trap				Date of sowing	Soil temp 10cm C	Seed-bed conditions				Slug pell. use this year	Previous slug problems	Previous crop
	% seed holl.	% plants grazed	Max. pre-sowing	at sowing	Mean post sowing	Max. post sowing			Seed dpth (mm)	Surf. rough-ness	% fine soil agg.	% moisture			
E 1	0	*	7.2	2.9	2.3	6.8	7.10	14.5	*	55s	53	*	*	yes	w.wheat
E 2	0	*	1.7	0.5	1.8	4.8	5.10	14.6	*	51s	22	*	*	yes	o.s.r.
E 3	0	*	10.3	0.1	1.1	3.2	9.10	10.4	*	42s	25	*	*	yes	grass
E 4	3	*	30.1	4.5	1.4	2.2	27.90	10.3	*	*	*	*	*	yes	o.s.r.
E 5	3	*	1.3	0.1	0.3	0.5	28.09	10.2	*	*	*	*	*	yes	w.wheat
E 6	3	*	15.5	3.8	5.0	11.6	29.09	10.1	*	*	*	*	*	yes	d.wheat
E 7	0	*	28.7	4.8	11.9	18.3	1.10	9.9	*	29s	40	*	*	yes	o.s.r.
E 8	*	*	5.3	(not drilled due to wet autumn)						*	*	*	*	yes	*
E 9	*	*	35.9	(not drilled due to wet autumn)						*	*	*	*	yes	*
E 10	*	*	12.9	(not drilled due to wet autumn)						*	*	*	*	yes	*
E 11	*	*	6.5	(not drilled due to wet autumn)						*	*	*	*	yes	*
E 12	*	*	9.5	(not drilled due to wet autumn)						*	*	*	*	yes	*
E 13	*	*	0.8	(not drilled due to wet autumn)						*	*	*	*	yes	*
S 1	*	*	14.0	0.0	0.0	0.0	4.11	7.2	*	40n	34	18	no	yes	w.wheat
S 2	12.3	*	47.0	0.6	3.4	7.0	12.10	5.6	*	40n	9	21	yes	yes	o.s.r.
S 3	*	*	19.0	4.7	3.6	6.0	4.10	8.0	*	40n	22	22	yes	yes	w.wheat
S 4	*	*	9.0	0.2	6.7	13.0	3.10	9.4	*	40n	25	19	yes	yes	o.s.r.
S 5	24.6	*	118.0	0.1	1.0	1.0	7.10	8.4	*	40n	13	19	yes	yes	w.wheat
S 6	*	*	53.0	0.8	1.9	3.0	12.10	5.6	*	*	*	*	yes	yes	w.wheat
N 1	5.9	25	2.7	0.4	6.0	7.8	28.09	8.2	*	33s	76	*	no	no	o.s.r.
N 2	3.0	17	7.8	1.6	0.6	1.5	5.11	8.6	*	44s	76	*	no	no	w.wheat
N 3	6.0	18	17.7	4.8	6.0	13.4	16.10	7.7	*	32s	74	*	no	no	w.wheat

E = England/Wales, S = Scotland, N = Northern Ireland
* = no data

s = swinging beam
n = needle reliefmeter
o.s.r. = oilseed rape

Table 4. Summary of information on slug damage, slug numbers and other risk factors collected from fields throughout the UK in 1988, sown to winter wheat unless otherwise stated.

Site		Slug damage		Slug numbers/trap				Date of sow-ing	Soil temp 10cm C	Seed-bed conditions				Slug pell. use this year	Prev-ious slug prob-lems	Prev-ious crop
		% seed holl.	% plants grazed	Max. pre-sow-ing	at sow-ing	Mean post sow-ing	Max. post sow-ing			Seed dpth (mm)	Surf. rough -ness	% fine soil agg.	% mois-ture			
E	1	10.4	7.4	24.3	0.2	0.8	3.6	14.11	5.0	34	45s	13	23	*	yes	o.s.r.
E	2	0	1.2	24.3	5.0	0.5	2.2	14.10	9.3	33	44s	25	32	*	yes	o.s.r.
E	3	0	6.2	2.0	0.3	0.6	0.9	4.10	11.0	15	40s	17	21	*	yes	w.wheat
E	4	0.6	0.0	0.7	0.3	0.1	0.5	26.09	14.4	32	57n	31	*	*	yes	w.wheat
E	5	1.0	0.6	46.8	0.1	0.1	0.2	29.09	14.6	18	56n	23	*	*	yes	w.wheat
E	6	12.1	14.6	19.1	13.8	0.7	1.2	22.09	10.1	30	52n	35	*	*	yes	o.s.r.
E	7	0	46.4	12.3	*	3.9	4.3	9.10	8.2	36	39n	29	18	*	*	o.s.r.
E	8	0	37.7	36.1	*	0.3	0.6	1.11	5.5	18	47n	8	17	*	*	w.wheat
E	9	18.2	65.8	*	*	8.3	8.9	6.11	4.8	24	42n	9	*	*	*	o.s.r.
E	10	9.0	78.0	26.6	*	6.3	14.9	3.10	11.0	33	61n	24	*	yes	yes	w.wheat
E	11	5.0	46.0	9.1	*	5.1	11.5	3.10	11.0	33	51n	52	*	yes	yes	w.wheat
E	12	16.0	68.0	19.4	*	7.2	19.2	3.10	11.0	34	66n	20	*	no	yes	s.barley
S	1	0.0	*	119.4	0.0	0.0	0.0	28.09	8.9	15	34n	9	20	no	yes	w.wheat
S	2	30.0	*	37.5	0.1	0.3	0.9	15.10	4.5	19	37n	12	16	yes	yes	o.s.r.
S	3	2.0	*	30.6	12.0	3.2	12.0	29.09	6.9	26	*	13	22	yes	yes	o.s.r.
S	4	*	*	8.1	0.1	0.1	0.1	19.11	3.2	*	*	*	18	yes	yes	o.s.r.
S	5	*	*	15.1	0.6	0.4	1.0	6.10	7.6	*	*	*	19	yes	yes	o.s.r.
S	6	*	*	8.1	1.6	0.6	1.6	30.09	4.3	*	*	*	15	no	yes	o.s.r.
S	7	*	*	10.7	*	*	*	*	*	*	*	*	21	no	yes	w.wheat
S	8	*	*	26.6	0.0	3.4	11.4	3.09	11.0	*	*	*	14	yes	yes	w.barley
N	1	2.8	40.0	4.8	1.0	5.5	12.0	19.10	12.2	19	3n	39	26	no	no	grass
N	2	0.0	21.0	14.3	1.3	5.1	9.8	1.10	7.9	30	7n	63	23	no	no	w.wheat
N	3	0.0	8.1	5.9	0.0	1.4	3.5	1.10	7.9	35	23n	48	25	no	no	oats
N	4	0.0	4.0	1.7	0.0	0.3	0.6	4.11	2.3	23	15n	37	30	no	no	s.barley
N	5	0.0	1.0	1.1	0.0	0.1	0.3	4.11	2.3	45	7n	38	26	no	no	grass

E = England/Wales, S = Scotland, N = Northern Ireland
* = no data

s = swinging beam
n = needle reliefmeter
o.s.r. = oilseed rape

Table 5. Summary of information on slug damage, slug numbers and other risk factors collected from fields throughout the UK in 1989, sown to winter wheat unless otherwise stated.

Site		Slug damage		Slug numbers/trap				Date of sowing	Soil temp 10cm C	Seed-bed conditions				Slug pell. use this year	Previous slug problems	Previous crop
		% seed holl.	% plants grazed	Max. pre-sowing	at sowing	Mean post sowing	Max. post sowing			Seed dpth (mm)	Surf. roughness	% fine soil agg.	% moisture			
E	1	0.0	5.0	0.2	*	0.0	0.1	30.09	13.8	33	40s	13	23	*	yes	w.wheat
E	2	0	2.0	0.4	*	0.0	0.2	27.09	13.5	33	44s	22	25	*	yes	w.wheat
E	3	0	2.0	0.6	*	0.6	0.8	27.09	13.2	30	44s	17	21	*	yes	w.wheat
E	4	0	0	0.2	0.0	0.01	0.2	28.09	11.4	35	34n	30	11	*	yes	peas
E	5	0	0	2.0	0.0	0.2	0.4	30.09	11.4	33	19n	48	11	*	yes	w.wheat
E	6	0	0	0.1	0.2	0.0	0.0	30.09	11.4	31	44n	27	8	*	yes	o.s.r.
E	7	0	35.0	5.6	*	1.5	2.3	30.09	13.6	33	47n	22	41	*	*	w.barley
E	8	0	3.0	0.1	*	0.7	0.9	28.09	13.6	33	44n	16	17	*	*	w.wheat
E	9	0	5.0	0.1	*	0.3	0.9	28.09	13.6	33	44n	21	17	*	*	w.barley
S	1	0.0	*	*	0.0	0.2	0.7	11.10	10.9	21	38n	20	12	no	yes	w.wheat
S	2	0.0	*	3.8	0.1	0.1	0.1	18.09	12.5	30	38n	*	15	yes	yes	w.wheat
S	3	*	*	10.5	*	*	*	*	*	*	*	*	*	no	yes	w.wheat
S	4	*	*	3.1	*	*	*	*	*	*	*	*	*	no	yes	w.wheat
S	5	0.0	*	1.1	0.0	0.1	0.1	29.09	9.4	28	37n	*	13	no	yes	w.wheat
S	6	*	*	0.1	0.0	0.3	1.5	28.08	10.4	(oilseed rape)			11	no	yes	w.wheat
S	7	*	*	1.0	*	*	*	*	*	*	*	*	*	no	yes	w.wheat
S	8	2.0	*	14.9	0.0	1.5	4.4	13.10	7.9	47	38n	13	14	yes	yes	o.s.r.
S	9	0.0	*	2.8	0.0	0.3	1.6	3.10	9.8	32	37n	*	14	yes	yes	o.s.r.
S	10	0.0	*	3.9	0.7	2.2	4.4	26.10	6.4	33	37n	*	14	yes	yes	o.s.r.
S	11	0.0	*	2.0	0.5	0.5	1.0	28.09	9.9	25	37n	*	15	no	yes	s.barley
N	1	0.0	8.0	0.3	0.0	0.6	1.7	5.10	11.4	29	7n	74	18	no	no	o.s.r.
N	2	0.0	0.0	6.0	0.2	1.6	3.5	4.10	11.9	40	10n	68	15	no	no	o.s.r.
N	3	0.0	*	57.4	0.3	2.6	4.2	6.10	11.9	56	18n	44	22	yes	yes	o.s.r.
N	4	0.0	35.0	1.9	0.5	2.9	9.4	5.10	13.4	36	10n	58	18	no	no	s.barley
N	5	0.0	39.0	*	1.1	1.5	1.9	12.10	7.3	28	12n	51	25	no	no	s.barley
N	6	0.0	15.2	2.4	5.7	6.3	8.8	21.10	7.3	26	10n	51	19	no	yes	o.s.r.
N	7	0.0	42.0	3.3	1.5	4.7	7.6	17.10	11.4	28	5n	46	17	no	no	o.s.r.
N	8	1.3	9.1	20.4	1.7	1.0	1.9	16.11	13.3	27	13n	43	31	no	no	o.s.r.
N	9	0.0	1.8	1.1	0.3	0.3	0.4	16.11	7.7	26	23n	42	30	no	no	w.wheat

E = England/Wales, S = Scotland, N = Northern Ireland
* = no data

s = swinging beam
n = needle reliefmeter
o.s.r. = oilseed rape

Table 6. Summary of information on slug damage, slug numbers and other risk factors collected from fields throughout the UK in 1990, sown to winter wheat unless otherwise stated.

Site	Slug damage		Slug numbers/trap				Date of sowing	Soil temp 10cm C	Seed-bed conditions				Slug pell. use this year	Previous slug problems	Previous crop
	% seed holl.	% plants grazed	Max. pre-sowing	at sowing	Mean post sowing	Max. post sowing			Seed dpth (mm)	Surf. rough -ness	% fine soil agg.	% moisture			
E 1	3.7	1.4	0.0	0.0	0.5	1.0	4.10	9.8	25	36s	23	10	no	yes	grass
E 2	0.8	0.2	0.0	0.0	0.2	0.6	10.10	12.5	31	34s	31	12	no	yes	s.beans
E 3	0.0	0.9	0.0	0.0	1.0	2.8	10.10	12.5	32	32s	28	*	no	yes	w.wheat
E 4	0.0	0.0	0.1	0.0	0.0	0.0	12.10	11.5	48	36s	52	*	no	yes	o.s.r.
E 5	0.0	0.0	0.0	0.0	0.04	0.2	4.10	11.9	30	25s	38	18	no	yes	O.s.r.
E 6	0	9.3	*	*	0.4	1.6	27.10	9.7	38	38s	9	30	yes	yes	w.wheat
E 7	0	31.9	*	*	0.8	2.9	27.10	9.7	29	49s	11	31	yes	yes	w.wheat
E 8	0	11.6	*	*	1.9	6.6	31.10	10.0	26	48s	15	28	yes	yes	w.wheat
E 9	0	0.0	0.0	0.0	0.2	0.8	14.10	12.4	*	40s	25	10	no	yes	potatoes
E 10	0	0.0	0.0	*	0.1	0.5	16.10	12.1	37	31s	16	17	no	yes	peas
E 11	0.0	100.0	*	*	3.2	5.9	18.10	12.2	52	51s	5	18	no	yes	o.s.r.
E 12	1.2	3.7	*	0.0	1.3	3.3	28.09	12.4	32	36s	26	25	no	yes	w.wheat
E 13	0.0	0.4	*	0.0	0.04	0.1	8.10	11.6	32	31s	61	26	no	yes	o.s.r.
E 14	0.6	1.4	*	0.0	0.5	1.3	19.10	11.6	31	35s	41	22	no	yes	w.wheat
S 1	4.8	*	7.6	0.4	0.2	0.4	26.09	7.6	30	37n	*	24	yes	yes	s.barley
S 2	4.5	*	3.0	2.8	1.3	5.4	4.10	8.2	45	38n	*	23	yes	yes	o.s.r.
S 3	13.7	*	13.4	0.0	4.2	9.2	3.10	11.1	40	38n	*	24	no	yes	o.s.r.
S 4	8.0	*	28.9	0.0	7.0	28.9	23.10	7.2	20	37n	*	23	yes	yes	o.s.r.
S 5	17.3	*	*	4.8	4.3	15.9	28.09	10.5	20	38n	*	23	yes	yes	o.s.r.
S 6	4.8	*	1.1	0.0	0.4	0.6	17.09	10.2	40	37n	*	22	no	yes	w.wheat
S 7	5.4	*	21.1	0.0	0.0	0.0	26.10	9.0	15	37n	*	31	yes	yes	o.s.r.
S 8	3.7	*	6.6	0.0	6.5	1.6	31.10	5.4	10	38n	*	21	no	yes	beans
S 9	4.9	*	3.4	0.4	1.8	5.6	14.09	10.6	35	38n	*	22	no	yes	o.s.r.
S 10	9.2	*	7.5	0.1	1.6	4.0	25.09	7.5	20	37n	*	25	no	yes	o.s.r.
N 1	3.8	44.9	25.6	*	8.4	13.9	28.09	12.9	32	13n	63	28	no	no	o.s.r.
N 2	9.5	97.3	36.7	31.3	23.9	36.1	22.10	10.5	36	23n	54	21	no	no	o.s.r.
N 3	6.3	59.8	14.4	*	19.8	27.9	28.09	12.9	33	9n	54	27	no	no	o.s.r.
N 4	0.3	13.2	3.5	0.7	0.6	0.8	5.10	13.2	29	14n	51	24	no	no	w.wheat
N 5	0.0	7.5	0.7	0.0	0.5	0.8	21.09	8.8	32	15n	56	20	no	no	w.wheat
N 6	1.9	17.6	26.2	0.0	1.6	5.1	28.09	12.9	30	4n	54	22	no	no	w.wheat
N 7	0.0	0.0	*	0.0	0.1	0.2	27.09	9.5	22	14n	38	27	no	no	w.oats
N 8	0.0	0.0	*	0.0	0.0	0.0	27.09	9.5	22	7n	37	34	no	no	s.barley
N 9	0.0	0.0	*	0.0	0.0	0.0	27.09	9.5	26	7n	35	28	no	no	s.barley
N 10	1.7	55.8	3.3	3.1	9.5	22.4	6.10	13.5	41	13n	43	20	no	no	s.barley
N 11	2.8	52.4	5.9	3.9	5.6	11.8	6.10	13.5	40	6n	51	20	no	no	s.barley
N 12	0.9	24.1	1.1	1.3	2.2	3.3	1.10	11.0	40	12n	62	17	no	no	s.barley

E = England/Wales, S = Scotland, N = Northern Ireland
* = no data

s = swinging beam
n = needle reliefmeter
o.s.r. = oilseed rape

Table 7. Relationships between slug damage, slug numbers before, at and after drilling, and conditions at drilling at field sites monitored throughout the UK.

Type of damage	Relationship between damage and risk factors	Correlation coefficient	D.F.	% variance accounted for
% seeds killed by slugs	1. $\log K = 0.043 + 0.398 \log N_{pre}$	0.520	77	26.1***
	2. $\log K = 0.276 + 0.329 \log N_d$	0.254	72	5.1*
	3. $K = 9.82 - 0.666\ T$	-0.326	91	9.7***
	4. $K = 5.89 - 0.102\ D$	-0.163	78	N.S.
	5. $K = 0.17 + 0.0893\ R$	0.241	87	4.7*
	6. $K = 0.519 - 0.160\ F$	-0.101	73	N.S.
	7. $\log K = 1.086 + 0.345 \log N_d - 0.795 \log T$	-	72	9.8**
	8. $\log K = 0.369 \log N_d + 0.435 \log R - 0.348$	-	68	11.8**
	9. $\log K = 1.197 + 0.436 \log N_d - 0.661 \log F$	-	54	20.3***
% plants grazed by slugs	10. $G = 13.10 + 3.336\ K$	0.523	61	26.1***
	11. $\log G = 0.439 + 0.727 \log N_{pre}$	0.608	49	35.6***
	12. $\log G = 0.487 + 1.141 \log N_d$	0.621	42	37.1***
	13. $\log G = 0.232 + 1.252 \log N_{post}$	0.807	61	64.5***

*$P<0.05$, **$P<0.01$, ***$P<0.001$

K = % seeds killed by slugs
G = % plants grazed by slugs
N_{pre} = Peak number of slugs/trap before drilling
N_d = Number of slugs/trap at drilling
N_{post} = Peak number of slugs/trap after drilling
T = Soil temperature (°C) at 10 cm depth
R = surface roughness
F = Fine soil aggregates (<6 mm) as % of weight of soil in seed-bed
D = Seed depth (mm)

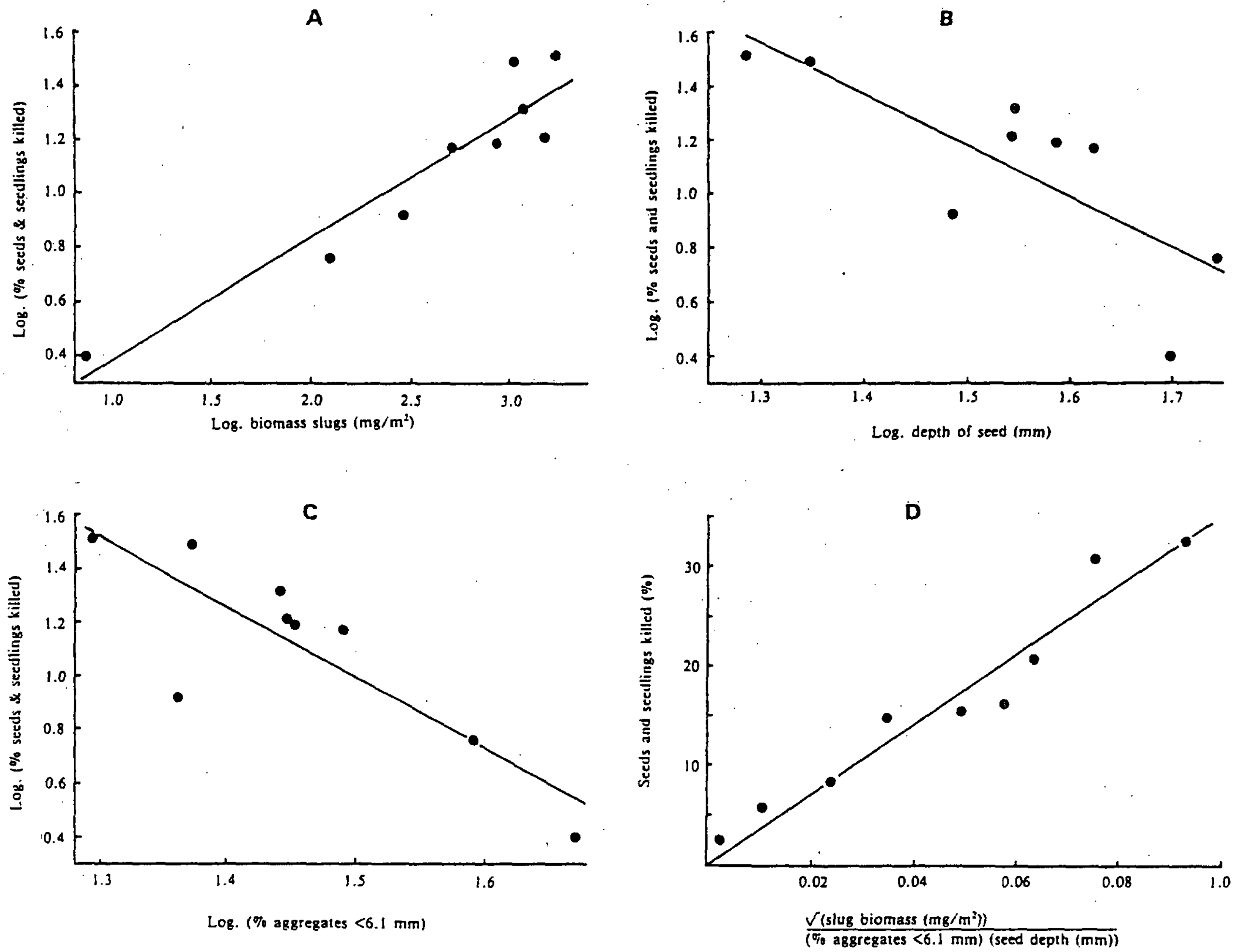

Figure 1. Percentage of winter wheat seeds and seedlings killed by slugs in 1987 field experiment in relation to (a) slug biomass in the upper 10 cm of soil, (b) seed depth, (c) percentage of fine soil aggregates (<6 mm) in the upper 10 cm of soil, and (d) a function of all three factors combined.

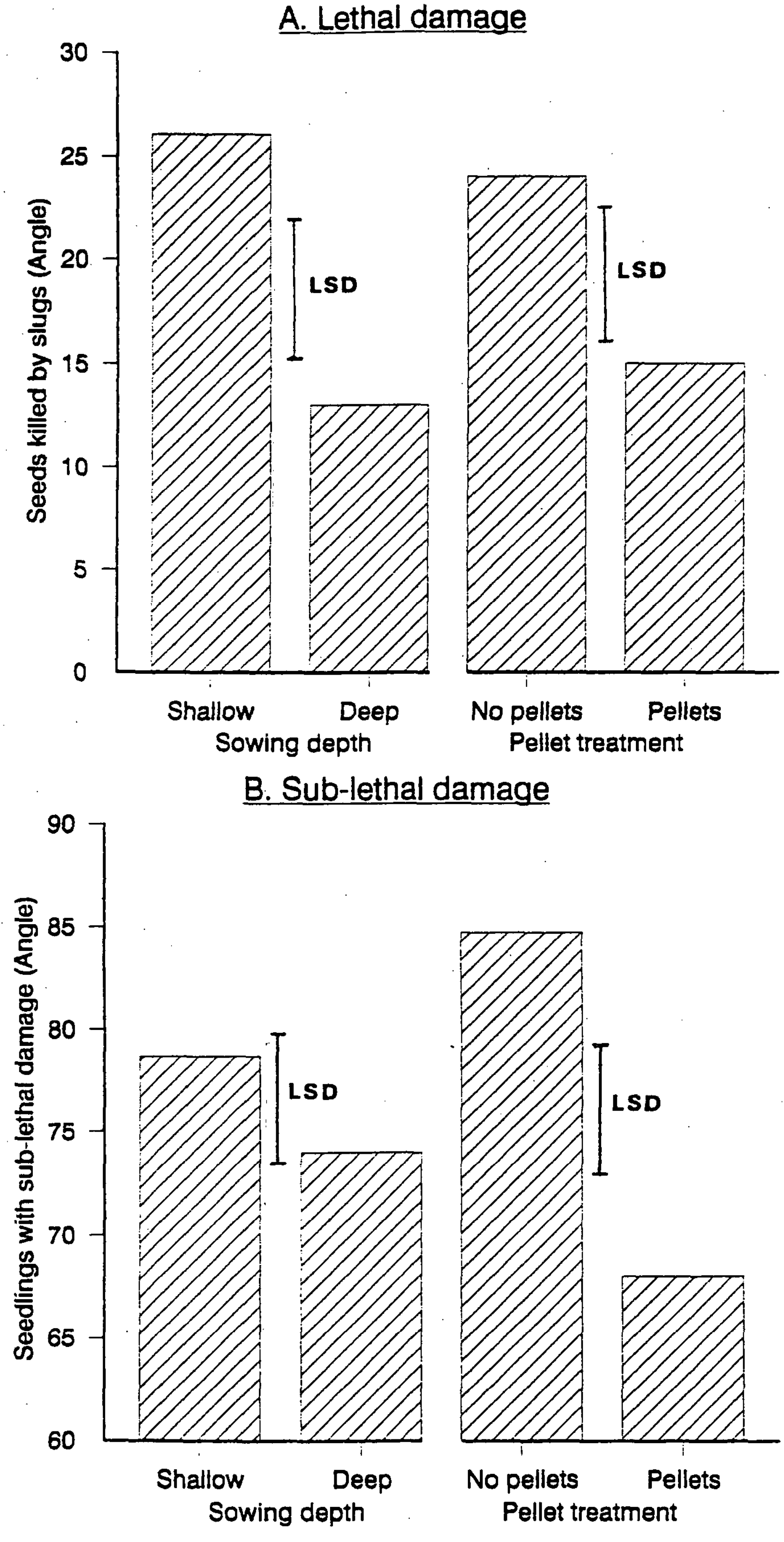

Figure 2. Overall effects of seed depth and of methiocarb pellets in 1988 experiment on (a) percentage of winter wheat seeds and seedlings killed by slugs and (b) seedlings with sublethal damage as percentage of seedlings emerged (percentages transformed to angles for statistical analyses). LSD bars show the least significant differences between treatments.

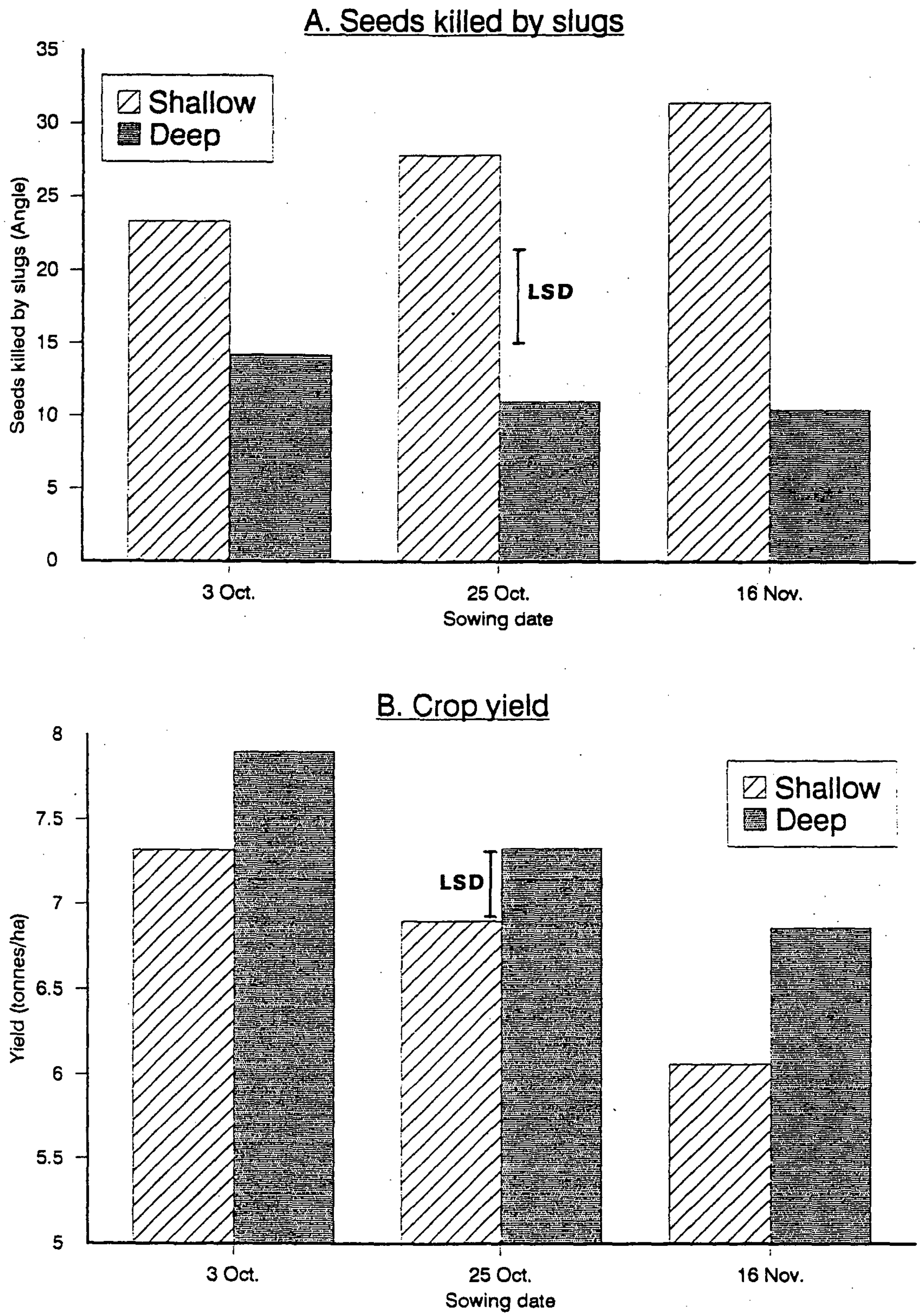

Figure 3. Effects of seed depth and date of drilling in 1989 experiment on (a) percentage (transformed to angle) of seeds and seedlings killed by slugs and (b) yield of winter wheat. LSD bars show the least significant differences between sowing depths.

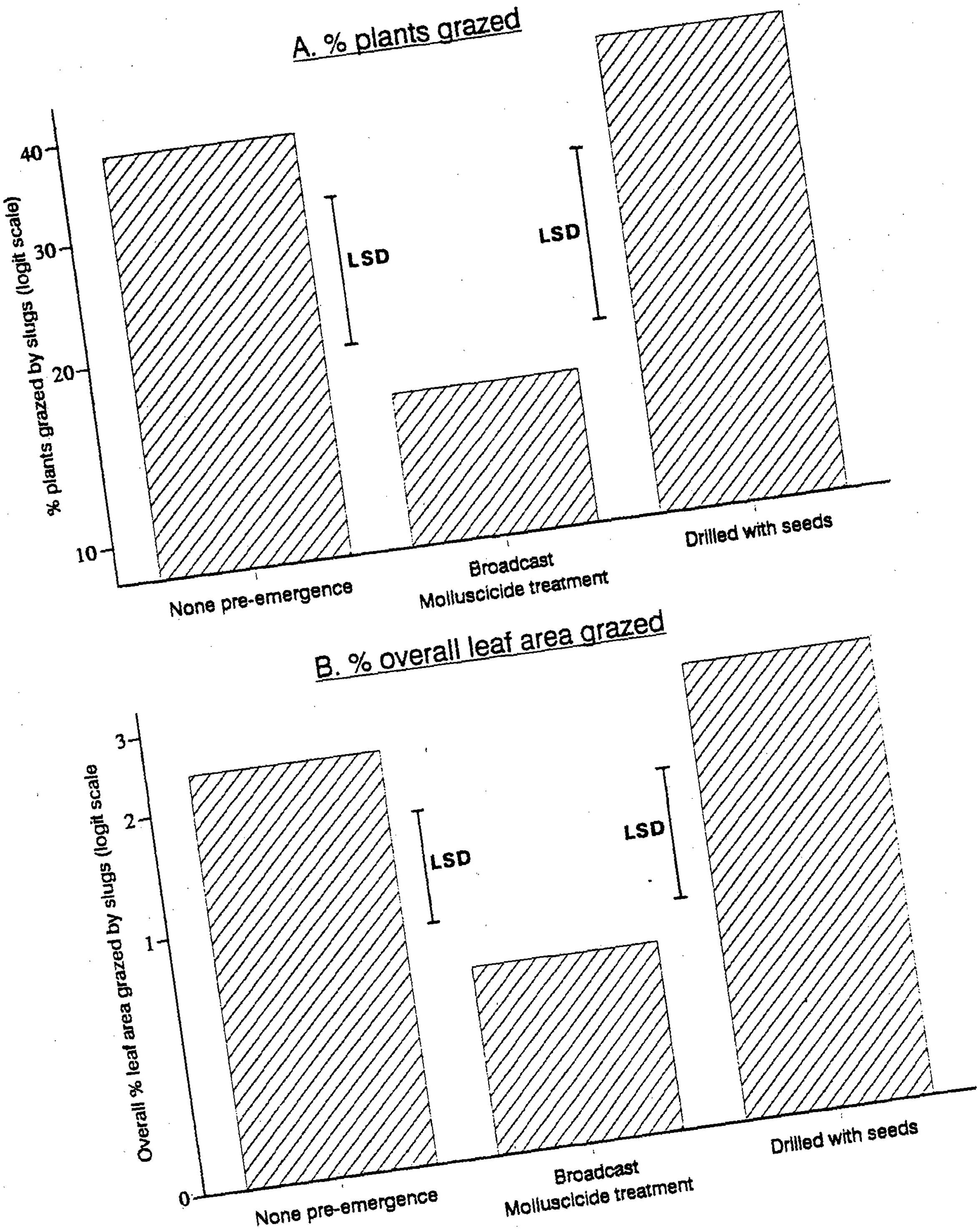

Figure 4. Effects of different molluscicide placements and timings in 1990 field experiment on (a) percentage of winter wheat seedlings grazed by slugs, and (b) overall percentage leaf area grazed (percentages transformed to logits for statistical analysis). Left LSD bar shows the least significant difference between untreated plots and those treated with molluscicide; right LSD bar shows least significant difference between broadcast molluscicide and molluscicide drilled with seeds.

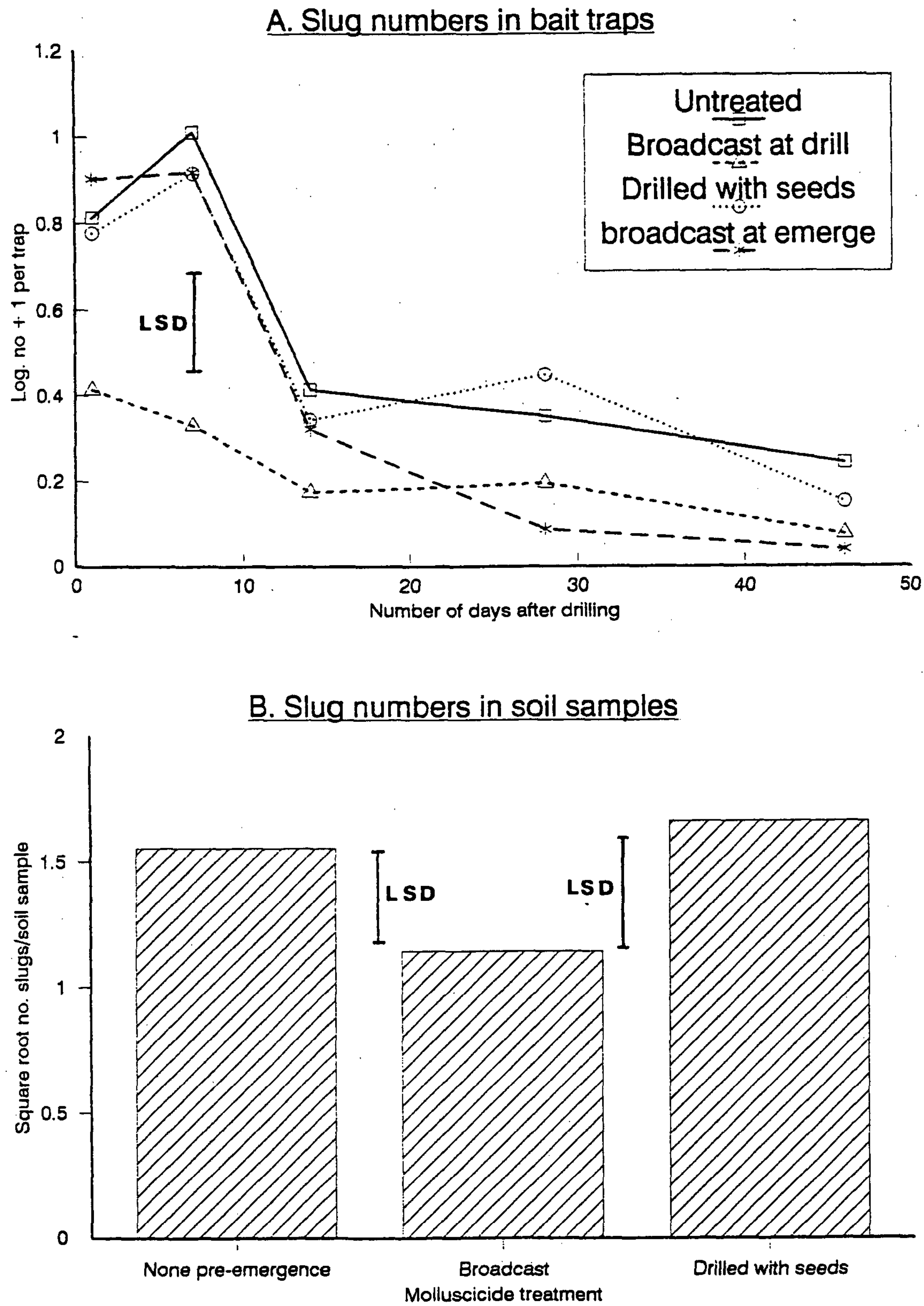

Figure 5. Effects of differences in molluscicide placement and timing on numbers of slugs in 1990 field experiment; (a) numbers recorded in bait traps at intervals up to 46 days after drilling and (b) mean numbers in soil samples during the first fifteen days after drilling. LSD bars show the least significant differences between treatments.

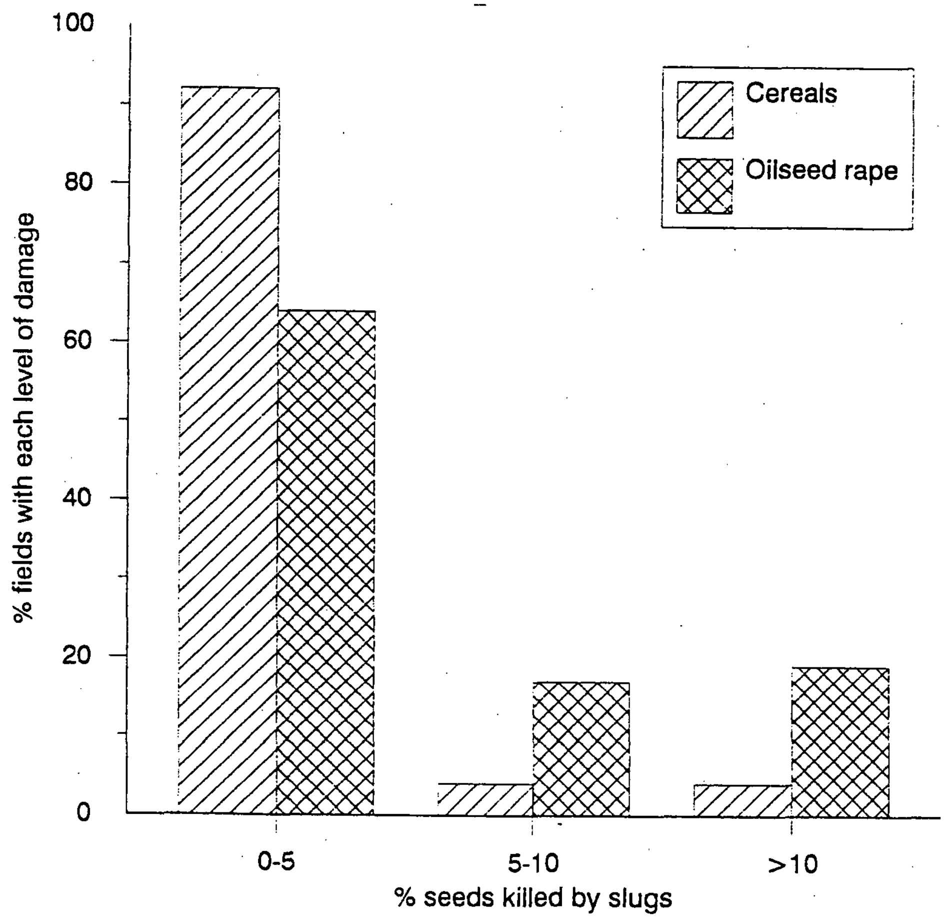

Figure 6. The effect of the previous crop (cereals or oilseed rape) in fields monitored throughout the UK on the percentage of winter wheat seeds killed by slugs.

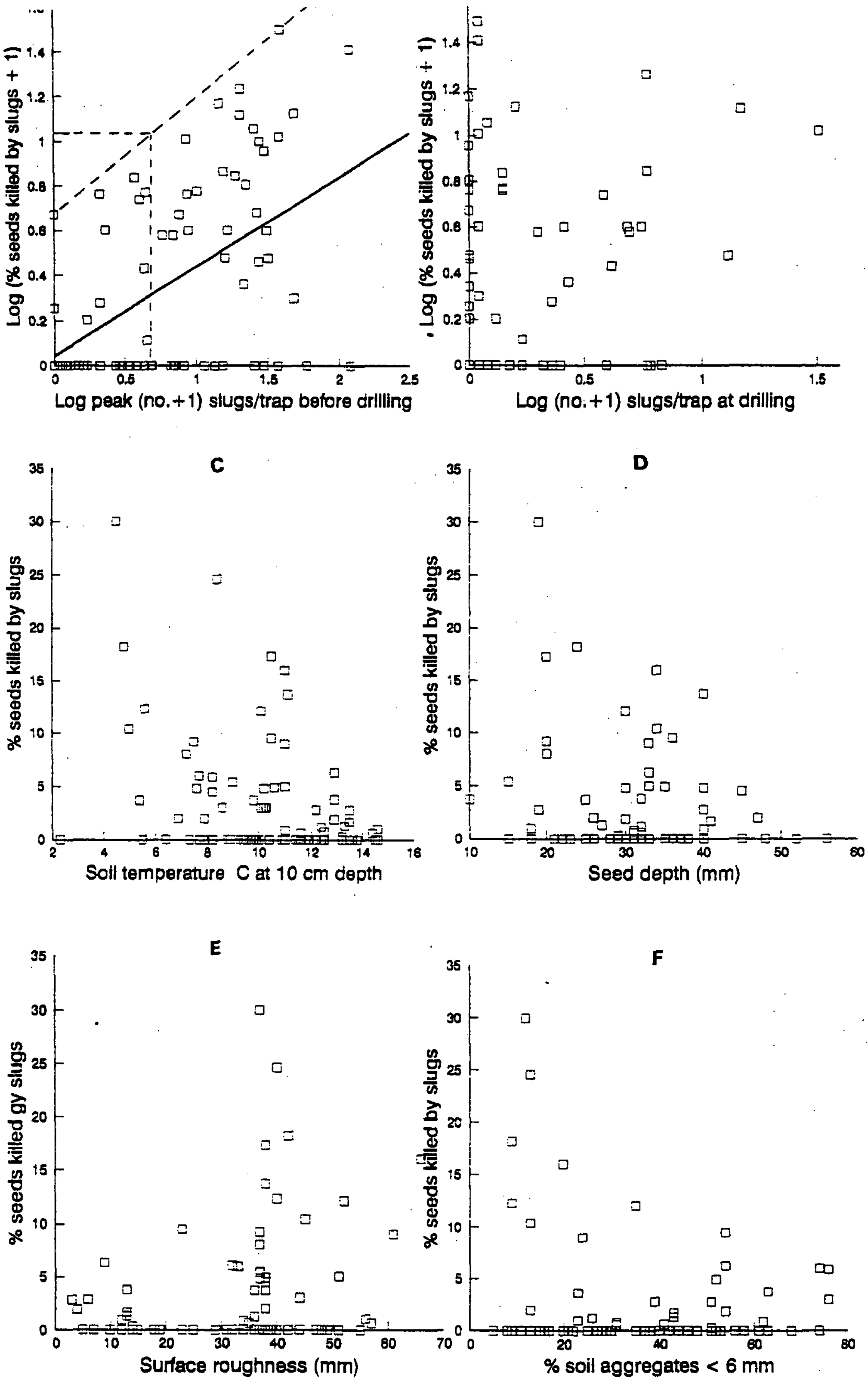

Figure 7. Relationships between the percentage of winter wheat seeds killed by slugs in fields throughout the UK and various risk factors, (a) the peak number of slugs/trap during the period from July until just before drilling, (b) the number of slugs/trap at drilling, (c) soil temperature at 10 cm depth at the time of drilling, (d) seed depth, (e) surface roughness of the seed-bed, and (f) the percentage of soil aggregates <6 mm in the upper 10 cm of seed-bed. In (a), the fitted regression is shown by the solid line, and the upper limit of the relationship is shown by the sloping dashed line which was used to determine in which fields the trap catch could be used to indicate a negligible risk of slug damage.

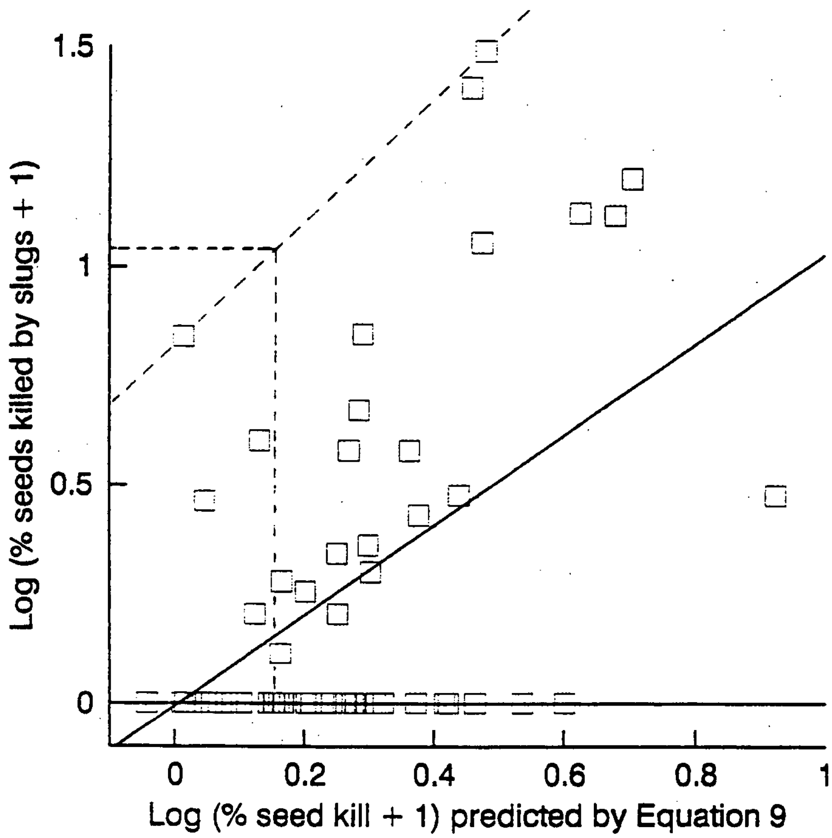

Figure 8. The percentage of winter wheat seeds killed by slugs in fields throughout the UK in relation to the percentage predicted by a function describing the number of slugs/trap at drilling and the percentage of soil aggregates <6 mm in the upper 10 cm of seed-bed (Equation 9, Table 7). The solid line represents a perfect fit between observed and predicted values. For many sites the observed values lie above the predicted levels, and the sloping dashed line showing the upper limit of the observed values was used to determine a level below which there was a negligible risk of slug damage.

Figure 9. Relationship between the percentage of winter wheat seedlings grazed by slugs and the percentage of seeds killed by slugs at field sites throughout the UK.

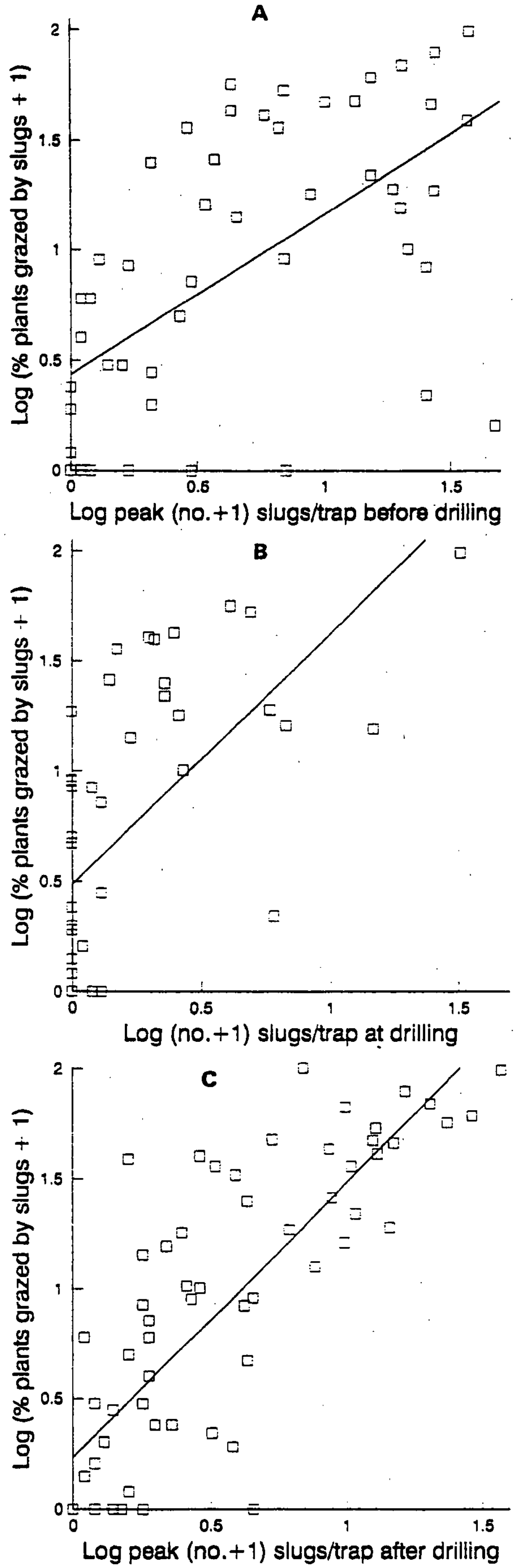

Figure 10. The percentage of winter wheat seedlings grazed by slugs at field sites throughout the UK in relation to numbers of slugs recorded in traps; (a) peak number of slugs/trap during the period from July until just before drilling, (b) number of slugs/trap at drilling, and (c) peak number of slugs/trap after drilling.