HGCA

## PROJECT REPORT No. 53

# RESEARCH ON SLUG BEHAVIOUR - TWO PROJECTS

### PART I - THE ROLE OF SOIL WATER IN REGULATING THE ACTIVITY OF TERRESTRIAL SLUGS

### PART II - CULTURAL METHODS TO REDUCE SLUG DAMAGE IN CEREALS

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Part I

# THE ROLE OF SOIL WATER IN REGULATING THE ACTIVITY OF TERRESTRIAL SLUGS

by

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Final report of a forty month project in the Department of Agricultural and Environmental Science, University of Newcastle upon Tyne, NE1 7RU. The work commenced in April 1988 and was funded by a grant of £107,540 from the Home-Grown Cereals Authority (Project No. 0060/2/87).

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ABSTRACT

The influence of soil moisture on slug activity was studied both in the field and in the laboratory. Low moisture levels were shown to restrict slug activity and the presence of a rehydration refuge had no effect on the restriction of movement.

A number of electrical methods of assessing soil moisture content proved satisfactory and weight loss from polyacrylamide gel cylinders was shown to give an accurate indication of evaporation in the field. A visual assessment of soil moisture content was also tested.

Other environmental variables were shown to restrict activity on a microclimate scale, principally temperature, both air and soil, and to a lesser extent humidity and windspeed. A limit model was developed which used this information to predict slug activity. Other models were developed from data collected from two sites, one in Northumberland and a second in North Yorkshire which used meteorological measurements more readily available to growers. The model was validated against information collected from five sites around the U.K. in 1990 and was 73% successful in predicting slug activity at those sites.

OBJECTIVES

The primary objective of this project was to assess the effect of soil surface moisture levels on slug activity. This information along with other environmental parameters was to be used to develop models to predict the level of slug activity in the field.

GENERAL INTRODUCTION

Slug activity is governed by a number of environmental factors as well as by endogenous rhythms. The susceptibility of slugs to stress caused by water loss has led to the development of a number of specialised behaviour patterns in order to allow the slug to forage in potentially hostile conditions, (Prior, 1985). Water can be lost from the slug by evaporation from the body surface, the mantle cavity and through mucus production. Active slugs can loose up to 40% of their body weight within 2 h (Dainton, 1954). The water content of several species of slug was discussed by Lyth, (1982) who found that the water content of slugs varied from 80.2% (wet wt) in *Arion fasciatus* Nilsson to 89.8% in *Arion intermedius* Normand. In standardised conditions slugs were found to regulate their water content to within very narrow limits with no obvious daily fluctuations.

It is apparent that slugs occur within short distances of moist substrates. South (1965) found that *Agriolimax reticulatus* Müller (*Deroceras reticulatum* (Müller)) individuals sheltered under isolated cocksfoot (*Dactylis glomerata* L.) tussocks and that the distribution of *Arion fasciatus* was correlated with soil moisture content. Laboratory and field studies have demonstrated the preference of slugs for areas of high humidity, (Dainton, 1954, Crawford-Sidebotham, 1972, Baker, 1973) and the choice of daytime resting site can be crucial to the survival of the slug. To this end, slugs exhibit homing behaviour as shown by Newell, (1966), South, (1965), Gelperin, (1974) and Cook, (1979). Gelperin (1974) and Cook (1979) both showed that slugs leave their resting site soon after sunset and return shortly before dawn.

Habitat selection and homing can help prevent lethal dehydration, but water loss will occur during foraging, and activity patterns can be considerably affected. Slugs exhibit rehydration behaviour as a result of changes in haemolymph osmolality (Prior, 1984) and can rapidly rehydrate on reaching a damp surface. Dainton, (1954) and Prior (1982, 1984) have shown that this pattern of behaviour is specific and closely regulated by physiological processes within the slug.

Despite the importance of water to slugs many authors have emphasised the role of other climatic factors. Mellanby (1961) found that at 5 °C *Milax* (strictly *Tandonia*) *budapestensis* Hazay and *Arion hortensis* Férrusac were immobilised but that *Deroceras reticulatum* remained active at 0.8 °C. Slug activity has been found to correlate with temperature (Dainton, 1954, Webley, 1964) and humidity (Crawford-Sidebotham, 1972; Baker, 1973). Rollo (1982) carried out studies of the activity of *Limax maximus* L. by monitoring climatic and other variables over single nights and found that the circadian rhythm, light intensity, change in light intensity and the soil surface temperature were the most important factors when regression models were applied to activity data. Hogan (1985) found that activity of *D. reticulatum* in the field was best related to temperature and humidity. Wareing (1987) found that temperature, humidity and rainfall parameters explained 80% of the variance in the mean weight of food eaten by a captive field population of *Deroceras caruanae* Pollonera. Of these studies only Wareing (1987) considered the influence of soil moisture level on activity, a factor which in the light of the evidence outlined above could be expected to be a major limiting factor to slug activity in the field. The initial work on this project considered specifically the relationship between slug activity and soil moisture content (year 1). Once this relationship was quantified the activity of slugs in the field was monitored and related to environmental parameters including soil moisture (years 2-3). Further work was carried out in each year by ADAS. This work broadly followed the pattern of work at Newcastle, providing independent data and increasing the necessarily site-specific fieldwork contributing to the project. ADAS offices used were Newcastle (year 1), Leeds (year 2) and Wolverhampton (year 3) and detailed protocols for each year are included in the Appendix.

## EXPERIMENTAL WORK

### A. MEASUREMENT OF SOIL SURFACE MOISTURE

### INTRODUCTION

A major problem encountered when considering soil moisture measurement is the very nature of the substrate itself. Electrical methods of measurement usually rely on conductivity. Conductivity is a function not only of soil moisture content, but also the concentration of solutes in the soil water. This can be overcome by encasing the electrodes in gypsum as the latter has a comprehensive buffering effect, but it also deteriorates in the soil and is rather heterogeneous, no two encased electrodes having the same resistance. Cranston *et al.* (1987) describe a soil moisture capacitance electrode and the efficiency of this method of measurement was assessed.

Soil moisture content in the field varies considerably within relatively short distances as a result of variables such as shelter and soil conditions. Therefore, if soil moisture is to be included in any prediction of slug activity in practice then it is essential that the moisture content of the soil is measured locally. Local advisors and growers will not have access to complex equipment to measure moisture content, nor in many cases to even a balance and oven required for a gravimetric assessment. In the final year of the project, a scoring system, based on a visual assessment of soil moisture content was developed in conjunction with ADAS at a number of sites around the U.K.

### MATERIALS AND METHODS

1. Electrical measurements.

Potential difference and resistance was measured in six soils from four plots (Plot Nos. 1, 7, 8 and 11) at Palace Leas, Cockle Park, Northumberland, (Grid ref: NZ 201 913) one from Close House walled garden, Northumberland (Grid ref: NZ 128 659) and one from a garden at East Boldon, Tyne and Wear (Grid ref: NZ 367 612). Test soils were first dried in an oven at 90 °C for at least 24 h, sieved and reconstituted to known moisture content using distilled water. Potential difference was measured using a mains powered constant voltage transformer delivering 30 V d.c. with a voltmeter in series connected across two parallel brass cylinders 5 mm in diameter and

19 mm between centres. During measurement the cylinders were inserted into the test soil to a depth of 16 mm. Resistance measurements were taken using a 'Simpson' multimeter by connecting the multimeter over the two brass pins and using the internal batteries as the power source. In practice the two measurements are the inverse of one another (since voltage = (current x resistance)), but $\log_{10}$ resistance is presented here.

After consultation with other workers at Manchester University, studies of the efficiency of capacitance probes were carried out.

2. Polyacrylamide gel

Polyacrylamide gels are widely used in biochemistry for the characterisation of proteins. They have been used in this project as a water holding medium to assess both soil wetness and evaporation rates simultaneously. Gels were made of 20% acrylamide, forming a solid gel and measured 1 cm in diameter and 1 cm in length. At the Close house site (16.08.88 to 15.12.88) five acrylamide gel cylinders were placed in a position adjacent to the area where video recordings were made. Twenty acrylamide gel cylinders were used daily at the Belsay site (ADAS work, year 1). The gels were placed in position late in the day in order that results should represent, as far as possible, the conditions prevailing during the hours of darkness.

3. Visual assessment of soil moisture conditions.

A visual estimate of the soil moisture content was made by ADAS staff at a number of sites around the U.K. (details of sites and full protocol for the ADAS work are in the Appendix). The following criteria were used:

Score

0......no visible moisture apparent anywhere in the top 2.5 cm of fine soil

1......slight dampness apparent anywhere in the top 2.5 cm of compact soil (beneath any clods, and this includes occasions where the soil is virtually dry, but where the top is damp after a light shower)

2......large clods (>8 cm) damp beneath

3......medium clods (>5 cm) damp beneath

4......small clods (>2 cm) damp beneath

5......entire surface appears damp

6......entire surface appears wet (can be smeared when rubbed between the fingers)

In addition a gravimetric assessment of soil moisture content was made at each sampling point by taking a soil core and calculating soil moisture content after drying to constant weight (typically in an oven at 90 °C for 48 h). The only restriction on the size of the sample was that it should be representative and should come from the upper 5 cm of the soil profile.

RESULTS

1. Electrical measurements

There was little variation in the change of resistance with moisture level between the test soils (Figure 1). The pH of the Palace Leas plots has been measured and varies from pH 6.1 in plot 1 to pH 4.3 in plot 11, but this does not appear to have influenced the overall trend observed.

All methods of assessing soil moisture using capacitance probes proved unsuccessful due to the low response of the probe to moisture in relation to the response of the probe in the 'dry' state.

2. Polyacrylamide gel.

In many cases differences in soil moisture could be detected by changes in weight of polyacrylamide gels (Figure 2). The effect of temperature on this relationship seems to be minimal, with the exception of the result at 20 °C. The slope of the regression line for this temperature is very shallow and not significantly different from zero, whereas those for the other temperatures were significant ($p<0.001$).

Results of the polyacrylamide gel studies at Close House indicated that overnight weight losses from the gels were closely correlated with humidity, rainfall, the soil and screen maxima and the soil moisture content (see Table 1).

3. Visual assessment of soil moisture content.

Visual soil assessment scores showed a poor correlation with gravimetric soil moisture content ($r^2=0.14$, Figure 3). The relationship between soil score and numbers of slugs caught at all sites is shown in Figure 4.

DISCUSSION

Electrical methods of moisture assessment would be most appropriate as they may be integrated with a data logger to provide information about the dynamics of moisture variation in the soil. Soil pH seems to have had little effect on the resistance of these soils to electrical current.

Polyacrylamide gel cylinders provided a useful means of assessing water availability on the soil surface without recourse to electrical equipment and they were used in the field studies described below.

Whilst the correlation between the visual assessment and the soil moisture content of the soil was poor (Figure 3), it appears to be a good indicator of slug activity (Figure 4). It was not possible to establish any relationship between soil score and gravimetric moisture content on a site by site basis as there was insufficient data. The poor correlation with soil moisture content may be due in part to the fact that the pooled data came from a number of different sites where soil types varied considerably. The relationship between slug numbers and soil score would indicate that the visual assessment may be a useful aid to predicting slug activity locally.

Table 1. Correlation coefficients of polyacrylamide gel weight loss and environmental parameters.

| Parameter | | $r^2$ |
|---|---|---|
| Soil moisture content | | -0.480 |
| Screen maximum | | 0.370 |
| Screen minimum | | 0.240 |
| Soil maximum | | 0.480 |
| Soil minimum | | 0.269 |
| Rainfall | | -0.314 |
| Windspeed | * | 0.116 |
| Air temperature | * | 0.290 |
| Humidity | * | 0.492 |
| Soil surface temperature | * | 0.313 |
| Subsurface soil temperature | * | 0.322 |
| Deepsoil temperature | * | 0.381 |

(* indicates overnight mean)

Figure 1. Changes in electrical resistance of soils of different moisture content.

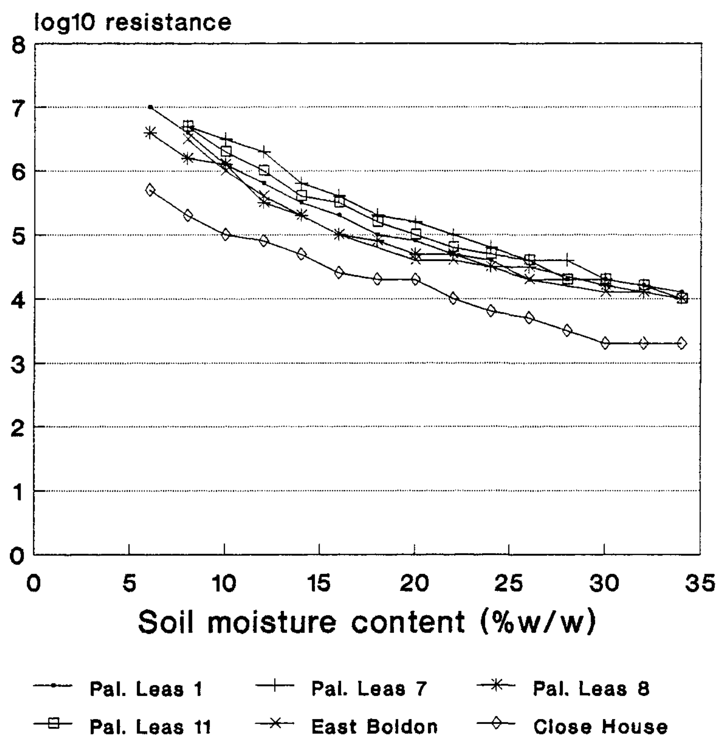


Figure 2. Weight change of polyacrylamide gel on soils of various moisture contents at different temperatures.

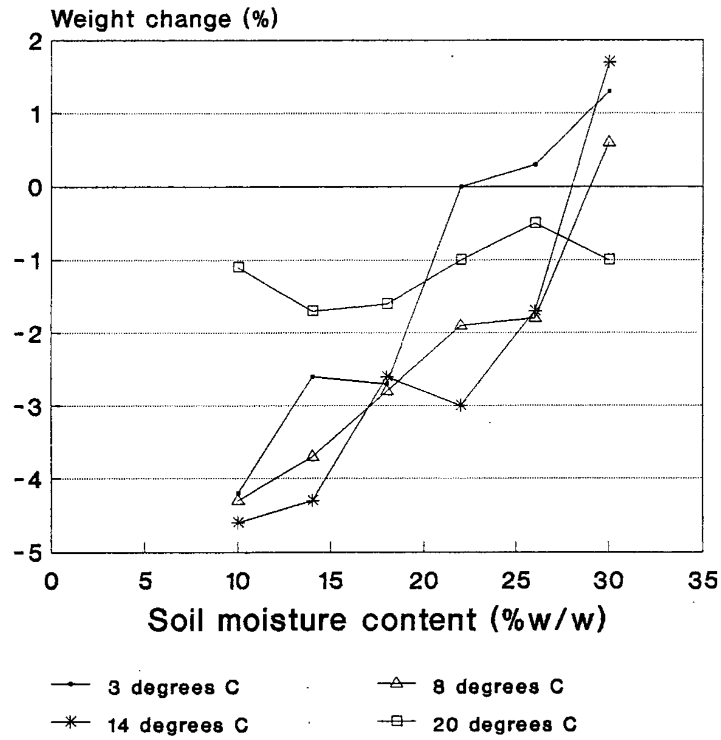
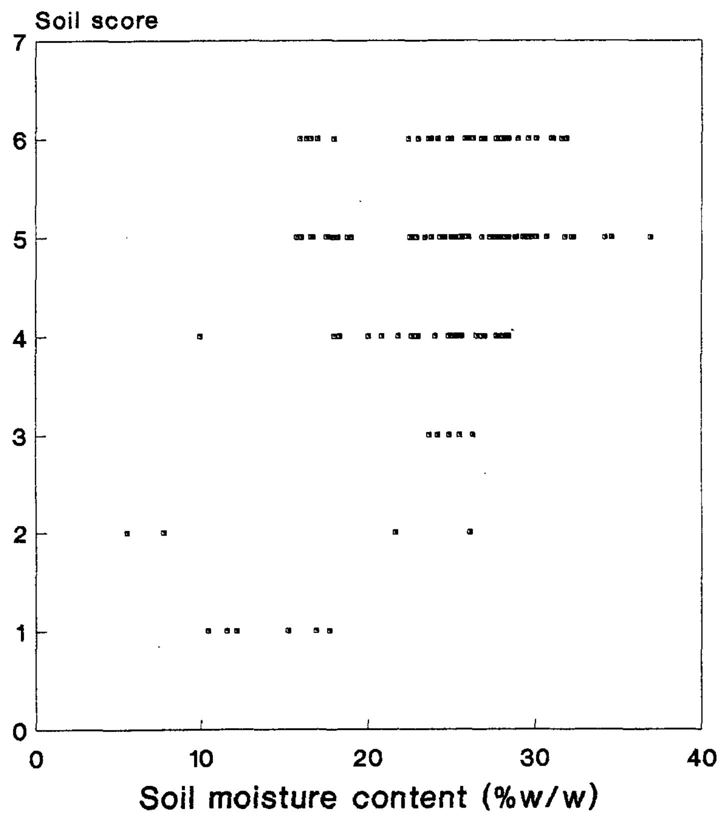
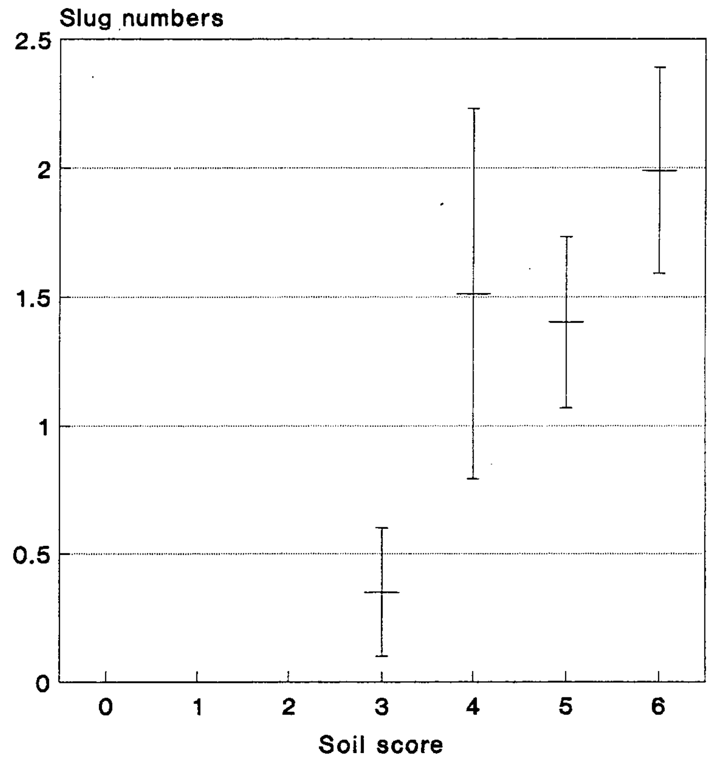


Figure 3. Visual assessment of soil moisture content.



## Figure 4. Relationship between visual soil score and slugs caught in metaldehyde baited traps.




Bars are Standard Error of mean

## B. INFLUENCE OF SOIL SURFACE MOISTURE ON SLUG ACTIVITY

### INTRODUCTION

The primary aim of this part of the project was to investigate the influence of soil moisture on slug activity. No other environmental parameters were considered in conjunction with this factor and the studies were carried out under constant temperature in the laboratory.

### MATERIALS AND METHODS

Laboratory experiments were carried out using low light, time-lapse video recording to analyse the relative importance of the soil wetness in regulating activity. All experiments were carried out at 11 °C.

Night time illumination was provided by two 25 watt tungsten filament bulbs behind Kodak 'Wratten' gelatin filters (87C) which allow light from only the 'near' infra-red (wavelength >750 nm) to fall on the field of view of the camera. The lights were positioned approximately 75 cm from the observation arena. Two markers were placed in the arena at a distance of 30 cm from each other to provide an accurate indication of scale for analysis of the recording. Recordings were made using a Panasonic video camera and a Panasonic 8050 time-lapse video recorder, recording at 1/80 normal tape speed. Final playback was thus at 80 times normal speed and a night period of 10 hours can be replayed in a period of 7.5 minutes. Slug activity, in terms of both distance moved and time spent on the surface, was assessed from digitised tracks analysed by computer.

The arenas used were plastic boxes (60 x 40 x 15 cm) filled with soil, and incorporating an electric fence to prevent escape of slugs.

1. Batches of soil (10 kg) were dried and reconstituted to 10, 16, 24 and 30% soil moisture as required. The overnight activity of 5 starved and acclimatised *Deroceras reticulatum* per treatment was recorded using time-lapse video. Initially recording of four arenas was attempted. This was later found to introduce inaccuracies into the experiment as the reflection from the drier soils was severe enough to make it impossible to see any slug movement. Thus the drier soil treatments were carried out

separately to those of the 24 and 30% treatments and this allowed better resolution of slug activity. The number of replicates was greater in the drier treatments to ensure the accuracy of the experiment.

2. A study was carried out to assess the importance of soil surface wetness in regulating slug activity. Four arenas were set up simultaneously, two contained soil at field capacity, two contained soil dried for 3 days at 35 °C. One arena of each type were altered in that soil from the surface of each was transferred to the other, imitating field situations of damp soil exposed to dry atmospheric conditions and dry soil exposed to a shower of rain. Six adult *Deroceras reticulatum* were placed in a covered 5 cm deep well in the centre of the arena. Activity was monitored over 4 night periods of 9.5 h.

3. Six adult *Deroceras reticulatum* were placed in arenas containing soil of 16% moisture content. Half of the arenas also contained 2.5 x 5.0 cm glass tubes buried to their rim in soil and filled with water. The tubes contained a small piece of tissue paper, to block the open end of the tube and prevent slugs drowning, yet still providing a source of water for rehydration. Indication of the level of slug activity was recorded in terms of the time spent by slugs moving on the surface of the soil.

RESULTS

1. Effect of variation in soil moisture level.

The results in Table 2 indicated that soil moisture levels below 24% significantly inhibit slug activity in the laboratory.

2. Effect of variation in soil surface moisture.

The results in Table 3 indicate that the soil surface moisture was a critical factor in regulating slug activity. Slugs in arena 2, with subsoil at field capacity and a dry surface layer, showed significantly lower activity levels than slugs in arena 3 where the soil surface was at field capacity. There was, however a reduction in activity of slugs in arena 3 compared to arena 1 where only wet soil was present.

3. Influence of water refuges.

The presence of water refuges had no significant effect on the time spent on the surface by *D. reticulatum* (Table 4). Slugs were observed to crawl on and off the water refuges and frequently used them as daytime resting places.

## DISCUSSION

Soil moisture levels below 24% inhibit slug activity in the laboratory. Levels below this occur regularly on the soil surface in the field and it is therefore reasonable to assume that moisture level could limit activity in the field. In the work covered later in this report, the moisture content of soil cores taken from the upper 2.5 cm of the soil profile was consistently lower than that of the next 7.5 cm ($p<0.001$). Since *Deroceras reticulatum* is known to forage on the soil surface, it is not surprising that the most important area of the soil profile in terms of soil moisture content is the soil surface (since slugs that were presumably fully hydrated were less active in arena 2 with dry topsoil than in arenas 1 and 3 with wet topsoil).

Slugs under hydration stress have been shown to actively seek out water sources in order to rehydrate (Prior, 1984). In this study slugs were observed to seek out wet refuges, but the availability of these refuges had no effect on the level of activity of the slugs. The models presented in this and previous reports indicate that slug activity on bare ground may be limited by soil moisture content. Prior (1984, 1985, 1989) showed that *Limax maximus* exhibits a specific behavioural response to dehydration mediated by an increase in haemolymph osmolality. Dehydrated slugs move onto damp areas to rehydrate, and whilst the slugs in this study did indeed follow this pattern of behaviour, this did not have the effect of increasing their ability to forage on soil shown earlier to be too dry for normal activity. The result of this laboratory study would appear to indicate that slugs would not become active in a crop when soil moisture levels are below threshold levels even though the crop plants themselves would act as a potential water source.

Table 2. Activity of *D. reticulatum* on soils of different moisture content. Means within a column followed by the same letter are not significantly different at p=0.05.

| Soil Moisture content (% w/w) | Mean distance moved per night by all slugs (cm) | SE | Mean time spent on surface (h) | SE | n |
|---|---|---|---|---|---|
| 10 | 260.1 a | 41.0 | 10.96 a | 1.67 | 10 |
| 16 | 278.4 a | 64.8 | 10.91 ab | 1.33 | 12 |
| 24 | 583.2 a | 80.9 | 15.01 ab | 3.84 | 5 |
| 30 | 828.0 b | 132.8 | 18.99 b | 2.90 | 5 |

Table 3. The activity of *D. reticulatum* on soils of different surface moisture content. Means followed by the same letter are not significantly different at p=0.05.

| Arena type | Time on surface (h) | SE | n |
|---|---|---|---|
| 1 wet | 33.65 a | 5.16 | 4 |
| 2 wet, dry top soil | 1.48 c | 0.34 | 4 |
| 3 dry, wet top soil | 14.82 b | 2.42 | 4 |
| 4 dry | 0.55 c | 0.55 | 4 |

Table 4. The activity of *D. reticulatum* on soil with 16% moisture content with and without an additional water source.

| Water availability | Mean time spent on surface (h) | n |
|---|---|---|
| No water | 8.05 | 11 |
| water available | 10.84 | 11 |

Paired t-test, p=0.116 ns

## C. ASSESSMENT OF THE RELATIVE EFFICIENCY OF BRAN-BAITED SLUG TRAPS

### INTRODUCTION

Field work associated with the control of pest slug populations often uses trapping methods as a means of obtaining an indication of species composition, a relative assessment of slug activity or indirectly assessing population size.

A number of trap types have been used, the commonest being some form of shelter placed on the soil surface which may or may not cover bait. Boards (30.5 cm square) placed over cleared areas of soil were used by Judge (1972) to assess slug activity and by Judge and Kuhr (1972) to assess the relative efficacy of molluscicides. Glen and Wiltshire (1986) used inverted plastic plant pot saucers (18cm diameter) covering molluscicide bait in their work on the assessment of populations from bait trap catches, and Byers and Bierlein (1984) used roof shingles (30.5 cm square) placed over areas of alfalfa to assess residual populations of slugs following molluscicide applications.

Until recently trapping was an unreliable way of estimating the size and composition of slug populations, as the proportion of the population sampled was unknown. New techniques using defined area traps ((DATs) Ferguson, Barratt and Jones, 1989) allow this assessment to be carried out without resorting to more laborious and destructive methods such as soil washing (Pinder, 1974) or soil flooding (South, 1964). Defined area traps are not in fact traps *sensu strictu* as they do not 'catch' slugs, they simply enclose a population, which is sampled (removed) as slugs move to the surface. Refuge traps such as those described in this study are only 'traps' if they are baited with molluscicide, i.e., slugs can enter, but not leave. Recent studies (Howling and Port, 1989, Wareing and Bailey, 1989) have shown that slugs may move some distance after consuming molluscicide baits and care must be taken in interpreting data collected in this way. Baiting with bran reduces their status to that of a refuge, as slugs can both enter and leave; however in keeping with common usage the term 'trap' will in this report refer also to refuge 'traps'.

Glen and Wiltshire (1986) showed that traps consisting of inverted plant pot saucers baited with molluscicide provided a reasonable estimate of the number of large slugs in the top 10 cm of soil, but also that the traps gave no indication of the number of small slugs present. Plant pot saucers and similar forms of trap have been widely used to forecast slug damage in crops (Oakley, 1984) and under these circumstances they are assumed to provide a reasonably accurate short-term assessment of the level of slug activity at the soil surface. In developing a forecast of slug activity traps were used to monitor slugs at many sites. Given their importance in the project this particular study was done to assess the accuracy of the trapping results.

## MATERIALS AND METHODS

Three independent trials were carried out in 1988 and 1989, each using the same experimental plan. Twenty 16.5cm diameter inverted plastic plant pot saucers and twenty 15cm ceramic tiles were used. They were arranged alternately at 2m intervals in a 5 x 8 matrix and baited with wheat bran. All traps were laid on the surface of the soil, the uneven nature of the soil surface providing sufficient spaces for slug movement. The traps were emptied daily and the slugs caught were identified to species and returned to the plot. Bait was replaced as it became depleted or showed signs of becoming mouldy.

In 1988 (30.9 to 15.12) and 1989 (24.8 to 7.12) trapping was carried out at a garden site at Close House, Northumberland (Grid ref: NZ 128 659). On both occasions the plot was fallow, but in 1988 the plot had previously grown potatoes, whilst in 1989 the trapping followed a mixed brassica crop. In 1989 (same period) a further replicate was carried out on a field site approximately 1 km from the previous site (Grid ref: NZ 132 657). The field site had been fallow for a number of months but was cleared of weeds prior to the start of trapping.

At the garden site a second assessment of slug activity on the soil surface was made using time-lapse video photography. Recording was carried out continuously, but daytime activity rarely occurred. Night-time illumination was similar to that used in the indoor studies in Section B. The lights were positioned approximately 75 cm from the observed area of bare soil which measured approximately 60 x 40 cm. Slugs were free to move into and out of the field of view of the camera and as before, two markers were placed on the observed area at a distance of 30 cm from each other to provide an accurate indication of scale for analysis of the recording.

Recording was carried out using a Panasonic video camera and a Panasonic 8050 time-lapse video recorder, recording at 1/80 normal tape speed. Slug activity was assessed from digitised tracks analysed by computer. Recording started when a slug entered the field of view and continued until it either burrowed below the soil surface or left the field of view. Track lengths were summed for each night to give an index of activity.

Data were analysed using SPSSx. Paired t-tests were carried out on individual species scores and pooled totals. All data were transformed to $\log_{10}$ prior to analysis.

RESULTS

Trap catches and paired t-test results are given in Tables 5, 6 and 7. Correlations between trap catches and the video assessment of activity at the garden plot site are given in Tables 5 and 6.

In 1988 significantly more slugs were caught under saucer traps than under tile traps. This was due to greater numbers of *Deroceras reticulatum* and *Milax budapestensis*, there being no such effect in the case of *Arion distinctus* Férrusac.

In 1989 at the garden site there were again significantly more slugs trapped under saucers, but a slight difference in the species composition of the catch. *M. budapestensis* were present in much greater numbers than in 1988 and showed no trap preference. *D. reticulatum* and *A. distinctus* trap catches were similar to those of 1988. During the trapping period, a number of 'other' slugs were recorded and it is worth noting that *Deroceras caruanae* also showed a significant preference for saucer traps.

In 1989 at the field site, there was no overall preference shown by the slug population for trap type. The species composition of the site differed considerably from the garden site, there being a predominance of *Arion* species and no *M. budapestensis* present. However *D. reticulatum* again showed a preference for saucer traps and this preference was also shown by *Arion subfuscus* (Drapernaud).

In all cases the correlations between the trap catches and the video assessment of activity was low, but were significant when slugs occurred in traps in large numbers.

DISCUSSION

It is clear from this study that the two commonest forms of bran-baited trap do not in fact sample the active population in the same way. *Deroceras* species seem to prefer saucer traps in each experiment, and the other species, with the exception of *Arion subfuscus* on the field site, show no such preference. The preference for saucer traps shown by *Milax budapestensis* in 1988 at the garden site is probably an anomaly, this preference not being shown in 1989 when the slugs were caught in much larger numbers. The reason for the preference shown by *Deroceras* sp. for saucer traps is unclear, there being no detectable difference between the air temperature (unpublished data) beneath the traps. It is unlikely that the relative humidity will be anything other than very high under either trap and air movements will be only very slight.

Glen and Wiltshire (1986) showed that saucer traps caught a significantly lower proportion of small slugs than mature slugs. Whilst measurement of size was not carried out in this study it was obvious that both trap types caught very few juvenile slugs.

In all cases the correlation between the numbers of slugs caught in traps and the distance moved by slugs as recorded by the video was low. The video recording was only carried out over a small area of ground, and whilst the technique provides an absolute measurement of activity over the field of view, this may not be representative of the whole plot. It is not possible to distinguish between slug species when reviewing video-tape recordings of slug activity and no species specific comparison of surface activity with trap catches can be made. Therefore correlations between trap catches and video studies could not be expected to be high, especially with those species that are present in low numbers, or are comparatively inactive. Nevertheless, significant correlations with video recordings of activity were obtained with all but the saucer traps in 1989.

Broadly speaking, *Deroceras reticulatum* is the major pest species in the U.K. and it would seem that saucer traps, since they sample more of the population, would be better than tile traps for forecasting damage in crops. There are instances where this species forms a smaller proportion of the population but the saucer traps are as effective as tiles for other species.

Table 5. Slug trap catches; Close House garden plot 1988 (number of nights = 71)

| Species | Trap type | Mean catch. $trap^{-1}$ $day^{-1}$ | Paired t-test t | p | Video correlation r | p |
|---|---|---|---|---|---|---|
| *Deroceras reticulatum* | saucer | 0.244 | 5.40 | 0.00 * | | |
| | tile | 0.097 | | | | |
| *Arion distinctus* | saucer | 0.062 | 0.08 | 0.94 | | |
| | tile | 0.060 | | | | |
| *Milax budapestensis* | saucer | 0.036 | 4.61 | 0.00 * | | |
| | tile | 0.0006 | | | | |
| Total | saucer | 0.342 | 5.47 | 0.00 * | 0.19 | 0.06 |
| | tile | 0.157 | | | 0.42 | 0.00 * |

* $p<0.05$

Table 6. Slug trap catches; Close House garden plot 1989 (number of nights = 100)

| Species | Trap type | Mean catch. $trap^{-1}$ $day^{-1}$ | Paired t-test t | p | Video correlation r | p |
|---|---|---|---|---|---|---|
| *Deroceras reticulatum* | saucer | 0.145 | 5.29 | 0.00 * | | |
| | tile | 0.058 | | | | |
| *Arion distinctus* | saucer | 0.018 | 0.001 | 0.99 | | |
| | tile | 0.015 | | | | |
| *Milax budapestensis* | saucer | 0.149 | 1.34 | 0.18 | | |
| | tile | 0.145 | | | | |
| Other species | saucer | 0.017 | 4.16 | 0.00 * | | |
| | tile | 0.045 | | | | |
| Total | saucer | 0.328 | 2.74 | 0.01 * | 0.33 | 0.00 * |
| | tile | 0.222 | 0.42 | 0.00 * | | |

('Other species' scores were; saucer - 25 *Deroceras caruanae* (Pollonera), 1 *Arion sylvaticus* Lohmander and 6 *Arion circumscriptus* Johnston. Tile - 1 *Deroceras caruanae* and 8 *Arion circumscriptus*.) * $p<0.05$

Table 7. Slug trap catches; Field plot, 1989
(number of nights = 100)

| Species | Trap type | Mean catch. $trap^{-1}$. $day^{-1}$ | t | p |
|---|---|---|---|---|
| *Deroceras reticulatum* | saucer | 0.218 | 3.22 | 0.00 * |
| | tile | 0.122 | | |
| *Arion distinctus* | saucer | 0.142 | 1.61 | 0.11 |
| | tile | 0.149 | | |
| *Arion circumscriptus* | saucer | 0.023 | 0.72 | 0.47 |
| | tile | 0.022 | | |
| *Arion subfuscus* | saucer | 0.069 | 2.59 | 0.01 * |
| | tile | 0.049 | | |
| *Arion fasciatus* | saucer | 0.112 | 1.36 | 0.18 |
| | tile | 0.109 | | |
| Total | saucer | 0.564 | 1.32 | 0.19 |
| | tile | 0.449 | | |

*$p<0.05$

## D. DEVELOPMENT OF MODELS TO PREDICT SLUG ACTIVITY

### INTRODUCTION

The use of molluscicides to control slugs in temperate crops has increased in recent years (Port and Port, 1986), yet the control achieved, primarily with pelleted bait, has often been inadequate as a result of poor treatment timing and pellet avoidance by slugs (Kelly and Martin, 1989). The study of slug behaviour, especially the regulation of activity and foraging behaviour, may facilitate improved control with pelleted baits (Howling and Port, 1989).

Rollo (1982), Ford (1986) and Wareing (1987) noted that slug activity may be regulated simultaneously by a number of environmental variables and that any single variable could become a limiting factor to activity. This section describes the initial development of a model to predict activity based on microclimate recording which was adapted into one based on standard meteorological measurements. Fieldwork was done over three years at Close House in Northumberland and at a variety of other sites by ADAS.

### MATERIALS AND METHODS

Collection of environmental data.

<u>Close House - microclimate measurements</u>

For the recording period up to and including spring 1990, environmental data was recorded using a data logger ('Windlogger', Hexatec Systems Ltd., Hexham, Northumberland) recording data during the hours of darkness and the output was analysed to provide mean values for each variable during the preceding night (a 'night' being the period between dusk and dawn, the duration of which consequently varied with season). Temperature changes were recorded in air 15cm above the soil surface, at the soil surface and at 1 and 10cm below the soil surface. Humidity was measured at 2cm above the soil surface using a Lee and Dickens humidity probe. Windspeed was measured, also at 2cm above soil level, using a cup anemometer (Vector Instruments).

For the remainder of the project, a Grant Squirrel data logger was used to record temperatures at this site. No record of windspeed or relative humidity was made, but wet and dry thermistor readings were recorded, from which relative humidity and vapour pressure can be derived.

Close House - meteorological measurements

Standard meteorological measurements, namely soil maximum, soil minimum, screen maximum and screen minimum temperatures and rainfall, were recorded ('screen' means measurements were taken from a Stevenson screen 1.5m above ground level). These data were collected at around 0900 h GMT and thus refer to the 24 h up to and including each 'night' period.

Soil moisture content at Close House was monitored daily by taking a soil core of approximately 300g and drying to constant weight in an oven at 90 °C. Initially, the soil core was taken to a maximum depth of 5 cm to ensure the moisture content recorded represented the level of moisture available to the slug whilst foraging on the surface. Later, the soil moisture content for the upper 2.5 cm was measured along with that of the next 7.5 cm.

Recording of slug activity.

At the Close House garden site activity levels of terrestrial slug species were recorded using low light time-lapse video photography, the details of which are described in section C. Track lengths were summed for each night to give an index of activity.

Video records of slug activity were made between 12.5.88 and 15.12.88 (149 nights), 5.1.89 and 19.4.89 (63 nights), 1.6.89 and 7.12.89 (138 nights) and 27.6.90 and 30.6.91. (306 nights). The soil type at this site was a sandy clay loam.

ADAS fieldwork.

Year 1

In the first year of the project additional fieldwork was conducted by Mr D. Nichols and Mr N. French of ADAS, Newcastle, at two sites, for a total of 61 nights between 2.11.88 and 15.2.89. Monitoring was carried out initially at a site near Throckley, Northumberland (Grid ref: NZ 155 688) but few slugs were found at this site and recording was transferred to a site 2 km south of Belsay, Northumberland (Grid ref: NZ 131 759).

Monitoring was similar to that at Close House, microclimate was monitored with a 'Hexatec' data logger, slug activity was monitored with bran-baited refuge traps.

Year 2

Monitoring of slug activity and collection of meteorological data was done at two sites at the Ministry of Agriculture Experimental Husbandry Farm at High Mowthorpe, near Malton in north Yorkshire by Mr. D. Green and Mr B. Emmett of ADAS, Leeds.

Site 1 'Crow Wood' field was sown with winter wheat following a crop of winter beans. The soil type at this site is non-calcareous with flints. Site 2 'Kirby Field', was sown with winter wheat following winter rape. The soil type at this site is a silty clay loam. Slug activity was recorded each night at sites 1 and 2 for four day sampling periods between 17.11.89 and 10.1.90 and between 5.4.90 and 10.7.90 (a total of 77 nights).

The methods of recording slug activity were similar to the trapping method used at Close House and were identical at each site. Traps comprised twenty, 15 cm ceramic tiles and twenty, 15 cm inverted plant pot saucers placed alternately at 2 m intervals in a 5 x 8 matrix. The traps were baited with bran and emptied daily, slugs being recorded to species and returned to the plot. Bait was replaced when it became depleted or if it showed signs of deterioration. Variation in the trap catches between saucer and tile traps is reported below. Saucer traps provide a more reliable indication of slug activity and the results from these traps only will be considered here.

Meteorological data was recorded at a weather station approximately 1 km from the experimental sites.

Year 3

Monitoring of slug activity, recording of soil moisture content (visual and gravimetric) and damage to test plants was coordinated by Mr. D. Green of ADAS, Wolverhampton. Fourteen sites were used as follows:

| Site | | ADAS office conducting trials |
|---|---|---|
| 1 Drayton, | Warwicks. | Midlands and West, Wolverhampton |
| 2 Drayton, | Warwicks. | |
| 3 Drayton, | Warwicks. | |
| 4 Windsor, | Berks. | South Eastern, Reading |
| 5 Windsor, | Berks. | |
| 6 Bleadon, | Avon | South Western, Bristol |
| 7 Bleadon, | Avon | |
| 8 Bleadon, | Avon | |
| 9 Tadcaster, | West Yorks. | Northern, Leeds |
| 10 Tadcaster, | West Yorks. | |
| 11 Harewood, | North Yorks. | |
| 12 Caersws, | Powys | Wales, Aberystwyth |
| 13 Welshpool, | Powys | |
| 14 Welshpool, | Powys | |

The protocol for this work is included in the Appendix, it comprised an activity measurement using metaldehyde-baited saucer traps (metaldehyde bait was used as traps could be emptied only twice a week), a damage assessment using cabbage seedlings, a visual and gravimetric assessment of soil moisture content and the collection of local meteorological records.

Analysis of data and model development.

The relationship between each meteorological variable and slug activity was examined to identify upper and lower activity-thresholds for each variable. The variables were then reviewed as a group so that nights when all were within their assigned thresholds were identified by the model - on these nights slug activity was expected to be high. The nights for expected high activity were then compared with nights when high levels of activity were observed (slug activity was deemed to be 'high' when it exceeded the mean for the sampling period). The variables selected and their associated thresholds were then adjusted to maximise the similarity between the nights when activity was observed and those predicted retrospectively by the model. Initially, assessment of the resulting models was made by eye, 'predicted' nights being overlayed on a record of slug activity (Figure 5). Later it became necessary to make more standardised judgements as the models became more accurate. A formula was used to quantify the similarity between the expected and observed numbers of nights of high activity. The formula accounts for correct prediction of both activity and inactivity: $C_S = 2C/(P + O)$, where, $C_S$ = Coefficient of similarity between observed and expected 'high activity' nights, C = Number of nights in which prediction was correct, P = Number of nights in which activity was predicted and O = Number of nights in which activity was observed. $C_S$ has a maximum value of 1 (for a perfect fit) and a minimum of 0.

## RESULTS

### Year 1

A model (Table 8) was constructed from the microclimate data and video records of slug activity collected at Close House, and the the model was tested on activity records taken from the bran-baited slug traps at Close House. The results of the predictions of the model are illustrated in Figure 5. Assuming a threshold of activity of 10 slugs (0.25 slugs/trap) the model correctly predicted 17 of the 20 nights of high activity (85%). It wrongly predicted 5 nights on which activity did not reach this level. A chi-square test of the model indicates no significant difference between the predicted 'active' nights and the actual 'active' nights at the $p<0.05$ level indicating that the model correctly, within statistical limits, predicts activity in the field. However the choice of 0.25 slugs/ trap as a level of activity is a purely arbitrary one. The model accurately predicts activity down to a threshold of 0.125 slugs/trap; below this level the model predicts too few 'active' nights.

It was intended that data collected at Belsay (ADAS year 1) could be used to further assess the validity of the model as constructed from the Close House field data. This was not possible, however, owing to data loss from the logger, particularly of windspeed and humidity variables. It was possible, however, to formulate another model incorporating the remaining data and the results from the much larger polyacrylamide gel data set (Table 9). The model correctly 'predicts' 89% of nights when slug activity was 'high' in terms of the saucer trap catches at Belsay. It was not possible to assign upper limits to the two temperature variables as temperatures during the period of recording at Belsay did not reach the levels recorded at Close House during the much longer recording period there.

A preliminary model based on meteorological data has also been constructed in the same way as the model above for microclimatic measurements (Table 10). The model correctly predicted 91% of the nights when 'high' activity occurs.

Year 2

Application of the microclimate model (Table 8) to data from year 2 at Close House was unimpressive, it being only 46% correct in it's prediction. A more extensive adaption of the model involving manipulation of all thresholds raised the predictive power of the model to 71% (Table 11). Temperature limits were altered only slightly, as was the windspeed variable. A significant adjustment was made to the soil moisture parameter.

However, the preliminary model based on meteorological data (Table 10) was 77% accurate when applied to 1989 data.

The two sites at High Mowthorpe (ADAS year 2) were within 1 km of each other and the slug catch at the two sites showed a strong correlation ($r^2 = 0.59$, $p < 0.001$) despite the small catch at the Kirby Field site. The data collected at High Mowthorpe did not include measurements of soil moisture and a direct comparison with the model from Close House cannot be made. Inclusion of rainfall data or some aspect of rainfall (e.g. cumulative rainfall over the previous 3 days) in the model did not improve the goodness of fit of the model. Slug activity at High Mowthorpe showed a distinct increase when soil temperature rose above 10 °C (Figure 6), this trend being apparent with all species at these sites. The screen maximum thresholds from the model for Close House (Table 10) could equally be applied to the data from High Mowthorpe, the $C_S$ value being 0.700. However, a more successful model employing only soil temperature (Table 12) at High Mowthorpe successfully predicted 25 of 26 nights where slug activity exceeded the mean for the recording period ($C_S = 0.74$). Whilst soil moisture content was not available for High Mowthorpe and could therefore not be included in the model in Table 12, removal of this parameter from the model for Close House reduced the $C_S$ value to 0.587.

Year 3

The extensive data collected by ADAS in the final year of the project provided a basis for rigorous, independent validation of the models developed above. As expected, slug activity varied between sites and as a result only those sites with substantial slug activity (1,7,11,12,14) were used in model testing. The output from the models was compared with the mean slug activity at each site. The meteorological model developed for Close House in years 1 and 2 of the project (Table 10) was again the most successful model (Cs=0.73) in predicting slug activity at these sites.

DISCUSSION

Whilst all five variables in our first microclimate model could limit activity, humidity and windspeed did so only infrequently, the majority of activity regulation being caused by low temperature or soil moisture content. Beyer and Saari (1978) found that *Arion subfuscus* was similarly limited by temperature and moisture and Crawford-Sidebotham (1972) found that the activity of all slugs, irrespective of species, was related to temperature and vapour pressure deficit. Consequently it is not surprising that standard meteorological measurements of temperature and soil moisture content were strongly associated with slug activity at Close House.

The meteorological readings taken in this study represent the 24 h prior to their collection. Since the period they represent includes day-time readings, it is not surprising that the temperature thresholds included in the model in Table 10 are higher than those in the microclimate model of Table 8 which used only overnight means.

The strong correlation between slug catch at the High Mowthorpe sites implies that while site specific factors such as soil type and cultural conditions influence overall population size, exogenous factors such as weather regulate activity.

One temperature parameter alone was sufficient to predict slug activity at High Mowthorpe. Hogan (1985) found temperature to be the key factor regulating slug activity in a grass/clover sward. The cover provided by the developing winter wheat crop at High Mowthorpe appeared to reduce the effect of soil moisture content on activity, an essential part of the model developed at Close House where there was no vegetation cover. Whilst it appears that the crop is providing shelter for foraging slugs it is difficult to be certain that this is the sole reason for the difference in the models formulated at each site. The sampling periods at the two locations (Close House and High Mowthorpe) were markedly different, much of that at High Mowthorpe being late spring to mid-summer 1990, whilst monitoring at Close House was done in autumn

1989. Ford (1986) has shown that activity of *Limax pseudoflavus* (Evans) was limited by temperature and wind in winter whilst evaporative stress and daylength was limiting in summer and therefore season may well influence the parameters governing slug activity at these sites.

Local weather centres are capable of providing growers and advisors with predictions of screen maximum and soil temperatures which would allow models such as these to be used to forecast periods of increased slug activity. Consequently model development has been concentrated on these variables, rather than the more accurate (in terms of the slug population) microclimate measurements. Clearly it should be possible to derive very accurate models to describe, retrospectively, slug activity if several variables are used for one site in one season. The effectiveness of a single model for prediction at all sites and in all seasons is more problematical; models which can only predict slug activity in a single season, or at a single site would be of little practical use. However the model developed in years 2 an 3 at Close House (Table 10) was found to give the most accurate predictions of slug activity at a number of sites throughout the U.K. in the final year of the ADAS work. The on-site assessment of soil moisture content presents a potential problem in the development of a forecasting scheme, but the visual assessment work has indicated that an on-site assessment of soil moisture would be possible. This model has therefore considerable potential in the development of a forecasting scheme for slug activity in the U.K.

Concluding remarks.

This project has progressed from models predicting activity from microclimate data to predictions based on meteorological readings and has addressed some of the potential problems in initiating a forecasting system.

The next step in this development would be to assess the utility of these findings in predicting slug activity and providing advice to farmers. Such work would require support for a project to collect further field data and produce the forecast and recommendations. Information from such a system might be disseminated by HGCA, ADAS or other organisations. In the first phase a pilot scheme operating at regional level would be necessary, developing into a national scheme in due course.

Table 8. Limiting values of environmental variables which regulate slug activity in the field, derived from observations at Close House. On nights when all variables lie within these limits slug activity will be 'high'

| Variable | Lower limit | Upper limit |
|---|---|---|
| Windspeed ($m.s^{-1}$) | - | 0.30 |
| Air temperature (°C) | 1.4 | 16.5 |
| Soil surface temperature (°C) | 5.1 | 15.1 |
| Humidity (r.h. %) | 81.5 | - |
| Soil moisture content (% w/w) | 26.2 | - |

Table 9. Limiting values of environmental variables which regulate slug activity in the field, derived from observations at Belsay. On nights when all variables are above these limits slug activity will be 'high'

| Variable | Lower limit |
|---|---|
| Air temperature (°C) | 3.0 |
| Soil surface temperature (°C) | 1.0 |
| Mean gel weight loss (%) | 15.0 |

Table 10. Limiting values of environmental variables which regulate slug activity in the field, derived from observations at Close House incorporating locally collected meteorological data. On nights when all variables lie within these limits slug activity will be 'high'

| Variable | Lower limit | Upper limit |
|---|---|---|
| Screen maximum temperature (°C) | 9.0 | 20.0 |
| Soil maximum temperature (°C) | 7.0 | 35.0 |
| Soil moisture content (% w/w) | 26.2 | - |

Table 11. Limiting values of environmental variables which regulate slug activity in the field, based on microclimatic recordings made in 1989. On nights when all variables lie within these limits slug activity will be 'high'

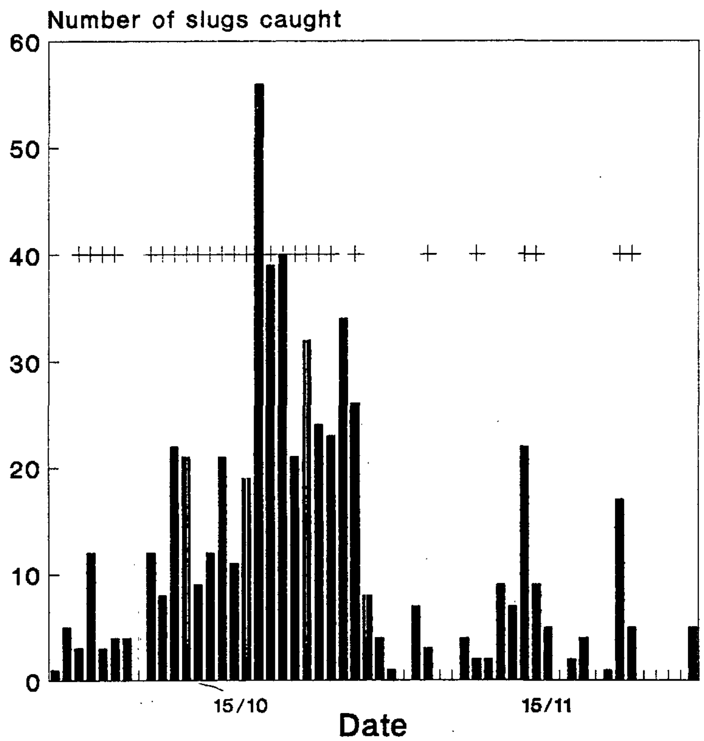
| Variable | Lower limit | Upper limit |
|---|---|---|
| Windspeed ($m.s^{-1}$) | - | 0.35 |
| Air temperature (°C) | 1.4 | 17.0 |
| Soil surface temperature (°C) | 4.0 | 15.1 |
| Humidity (r.h.) | - | - |
| Soil moisture content (% w/w) | 20.0 | - |

Table 12. Limiting value of a meteorological variable for a model to associate slug activity in the field with locally collected meteorological data at High Mowthorpe (sites B and C).

| Variable | Lower threshold |
|---|---|
| Soil temperature (°C, 0900 GMT) | 10.0 |

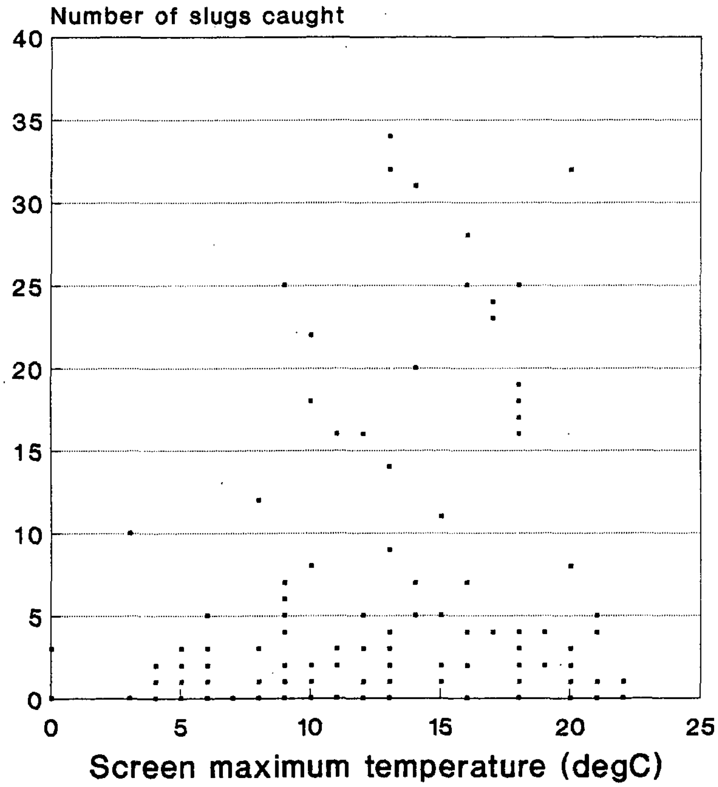
$C_S$ = 0.740

Figure 5. Comparison of data from micro-climate model with slug trap catches at Close House, autumn 1988.




(crosses indicate those days when activity was predicted by the model)

Figure 6. Saucer trap catches at High Mowthorpe EHF (sites B and C) in relation to screen maximum temperature.



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APPENDIX

ADAS Fieldwork Protocol-Year 2

Twenty 6" tile and twenty 6" plant pot saucer traps were arranged alternately in a 5 x 8 grid, with 2m spacing. Traps were laid on the ground and baited with approximately two tablespoons of wheat bran and emptied after a single night. Slugs caught should be identified to species and catches for each trap type were kept separate. If possible, slugs were returned to the plot. Bait was renewed when necessary.

In addition two defined area traps (DATs) were placed within the trapping areas. They were also emptied each night (where possible) and the slugs caught identified to species and returned to the plot. At the end of each 7-day period, the soil enclosed within the trap was dug up and soil flooding was carried out to expel any remaining slugs. The DAT trap was then re-sited within the plot.

The number of nights per week when trapping was carried out was determined by the person concerned, but the trap catches always represented only the activity from the previous night, i.e. traps were emptied after a break in monitoring (weekend) and results taken the following morning.

Meteorological data should be provided for each night over which the traps were set and for all days for the duration of the experiment, whether trap catches were monitored or not, to allow any cumulative effect to be assessed.

ADAS Fieldwork Protocol-Year 3

Monitoring was carried out twice weekly and took approximately 10 min per site. The work was comprised of four parts, on sites of known (high) slug activity, where winter wheat was sown:

1. Slug Numbers.

Ten saucer traps were set at each site. The saucers were approximately 15 cm diameter and were baited with metaldehyde bait. They were placed upside down over the bait on bare soil at least 5 m from any field boundary and 2 m from each other. The number of slugs at each trap and in the surrounding 1 $m^2$ was counted at each visit and recorded to species. The bait was used for no longer than one week, and in some cases was replaced at every visit.

2. Damage Assessment

Cabbage seeds, cv Best of All, were sown in shallow pots to provide 10 seedlings at each of 5 assessment points on the site. The seeds were sown with the pot filled to the brim with compost in sufficient time to allow the seeds to germinate and the first two leaves to fully expanded before they were required. This took approximately 7 days at 15 °C When seedlings were required the weakest were pulled out leaving 10 strong seedlings in each of 5 pots. The seedlings were then taken to the site and the pots sunk to their rim in soil. Assessment of the damage to seedlings was carried out at the end of the sampling period according to the following criteria for each group of 10 seedlings;

Score

0.....no damage

1.....slight damage (less than 50% of leaf removed) to 1-2 plants

2.....slight damage to 3-5 plants

3.....slight damage to 6+ plants

4.....severe damage (more than 50 % of leaf removed) to 1 plant, slight on most others

5.....severe damage to 2-5 plants, slight on most others

6.....severe damage on 6+ plants

3. Soil moisture assessment

See page 6.

4. Weather recordings.

Weather records were obtained either from local stations or from the nearest Meteorological Office were obtained

The record for each visit therefore included ten saucer trap results, 5 damage assessments, one gravimetric soil moisture content, one visual assessment of soil moisture and the local daily meteorological data.

HGCA PROJECT REPORT No. 53

# Part II

# CULTURAL METHODS TO REDUCE SLUG DAMAGE IN CEREALS

by

A. M. SPAULL

Final report of a fifteen month project at the Scottish Agricultural College - Edinburgh, West Mains Road, Edinburgh, EH9 3JG. The work commenced in April 1990 and was funded by a grant of £11,472 from the Home-Grown Cereals Authority (Project No. 0019/1/89).

**Research collaborator**
D. H. K. DAVIES
Scottish Agricultural College - Edinburgh

**CONTENTS**

**ABSTRACT**

Three different times of ploughing were tested at a site in South East Scotland where winter wheat followed oilseed rape in rotation. Areas were ploughed: soon after OSR harvest, in early, and in late September. A further area, ploughed in late September, was also treated with herbicide. Plots within the cultivated areas were left untreated or molluscicide was applied before or after drilling. Grain hollowing of winter wheat was significantly less where molluscicide was applied after drilling but was not affected by the timing of ploughing. Plant counts were larger where molluscicide was applied than where it was not and were also greater in the area ploughed soon after OSR harvest than in all other areas. Populations of volunteer oilseed rape plants were assessed; although there was some trend to larger numbers of volunteer rape after early ploughing, the differences were not significant in this trial. The trial needs to be repeated in further seasons and tested at other sites.

Differences in susceptibility to slug attack of ten winter wheat cultivars were tested under laboratory conditions. Damage to untreated seeds by the field slug <u>Deroceras reticulatum</u> was measured after 1, 2 and 5 days. In general, cv.Avalon showed the greatest damage and Slejpner also tended to be heavily grazed. Only cv.Parade showed any tendency not to be eaten by slugs. Differences in seed damage may depend, in part at least, on release of sugars and other solutes.

These results need to be substantiated with a wider range of recommended cultivars and under less artificial conditions. The possibility that observed behaviour reflects both attractants and deterrents within wheat seeds requires further study.

## 1. OBJECTIVES

This project had two objectives:
1) to investigate the effect of cultural practices on slug numbers and potential problems from oilseed rape volunteers;
2) to assess varietal differences in winter wheat seed susceptibility to slug damage.

## 2. INTRODUCTION

Slugs are the pests causing greatest concern to wheat growers in the UK, especially in crops following oilseed rape, where slugs are the major crop protection problem (Glen, 1989). Various studies have shown that seed-bed conditions have an important influence on the risk of slug damage (Gould, 1961; Stephenson, 1975; Glen, Milsom & Wiltshire, 1989, 1990). The percentage of seeds and seedlings killed by slugs was directly related to slug biomass in the soil and was inversely related to the depth of sowing (Glen, Milsom & Wiltshire, 1990). An additional 20 mm sowing depth provided as much protection from slug damage as a broadcast application of methiocarb pellets. Similarly, it is known that preparing a good seedbed will tend to prevent slug damage, especially during the most vulnerable stages of early development. However, achieving this in practice often obliges ploughing shortly after harvesting the preceding crop. Where oilseed rape precedes winter wheat, ploughing can be at least 6 weeks (and frequently longer) before drilling. Such early drilling is likely to run counter to advice for preventing serious problems from oilseed rape volunteers. Three times of ploughing were tested in autumn 1990 at a site where oilseed rape volunteers and slugs have caused problems in the past.

It is recognised that potato cultivars differ in their susceptibility to slug attack and this characteristic is tested in new maincrop cultivars. Atkin (1979) found that cultivars with a low total-protein content were preferred, but starch, glycoalkaloid and phenolic acid content have all been implicated (Storey, 1985). Some preferences have been found between species of wheat, where those with a high total-nitrogen content in the seed were attacked more by slugs (Port & Port, 1986). Nothing is known about differences amongst commercial cultivars of winter wheat, which was tested using Deroceras reticulatum under laboratory conditions.

This project complements two other projects on slugs funded by H-GCA: Project no. 0010/3/87, Slug Forecasting in Cereals (Glen & Wiltshire, 1992) and 0060/2/87, The Role of Soil Water in Regulating the Activity of Terrestrial Slugs (Port & Young, 1992).

## 3. MATERIALS AND METHODS

### 3.1 Field experiment

The site had a silty clay loam soil and the previous crop was oilseed rape, harvested at the end of July 1990. The trial consisted of four adjoining areas, each of which was a plough timing treatment. Replicate plots, split for molluscicide treatments, were sited within these areas. Three timings of ploughing were tested:
shortly after harvest, 2.8.90;
3.9.90 (mid-way between harvest and drilling); and
27.9.90 (immediately before drilling);
additionally a similar area was ploughed 27.9.90 to which paraquat had been applied 36h previously at the recommended dose. Four replicate plots 18 x 12 m were distributed across each ploughed area and split to give three 6 x 12 m sub-plots- one subplot was left untreated, the other two were treated with methiocarb pellets (5.5 kg

product/ha) either before ploughing 27.9.90 or after drilling 28.9.90. It was intended that the pre-ploughing treatment be applied several days before cultivation, but conditions changed rapidly during the day, allowing earlier cultivation than requested.

Grain hollowing was assessed from four, 30 cm lengths of drill row in each subplot at GS11-12 (30.10.90). Plant counts were assessed from four, 1 m lengths of drill row in each subplot at GS12 (7.11.90). Populations of volunteer oilseed rape plants were observed throughout the winter and a detailed assessment made from five replicated counts from 0.25 $m^2$ quadrats in each subplot (24.1.91).

3.2 Laboratory experiments

Untreated seed of ten cultivars of winter wheat were used: cvs. Apollo, Avalon, Boxer, Galahad, Longbow, Mercia, Motto, Norman, Parade and Slejpner. Tests were conducted at 18-21°C in the laboratory: four seeds of each cultivar were arranged on well-moistened filter paper in the base of a 9 cm petri dish such that the seeds were equidistant from each other and the edge of the dish. A single adult field slug, *Deroceras reticulatum* was placed in the centre and the dish sealed with parafilm. Ten replicates were used for each cultivar and grain hollowing was scored as the percentage lost from individual seeds in the dish.

Total water-soluble sugar content of seeds of some of the ten cultivars and exuded water-soluble sugars were measured. Electrical conductivity (an indirect measure of electrolytes) was also assessed at temperatures of 5, 10 and 20 °C. Each was assessed by standard methods, described in Spaull & Eldon, 1990.

## 4. RESULTS

### 4.1 Field experiment

Seed was drilled at a depth of 2.5-3 cm. Grain hollowing was significantly affected by molluscicide application but not by plough timings or paraquat use (see Table 1). Plots where methiocarb was applied on the day of drilling had significantly less hollowed grain than other treatments. Plant counts of winter wheat were greater from both molluscicide treatments than untreated subplots, and were also larger in the area ploughed in early August than in other plough treatments (see Table 2). Populations of oilseed rape volunteers were small at any one time; when assessed in January most plants were at cotyledon to 2 underdeveloped leaves stages. There were no significant differences between treatments but larger numbers of volunteer rape plants apparently occurred where ploughing had been early; fewer tended to occur in the area treated with paraquat (Table 3). However, plant numbers were too small and variation too large and analysis was weakened. By mid March most volunteer plants had disappeared following some 6 weeks of cold weather, with periods of lying snow.

### 4.2 Laboratory experiments

Differences in slug damage were already apparent when measured after 1 day. Cv. Parade had been grazed significantly less than the cvs Galahad, Avalon, Slejpner and Norman (Fig. 1a). After 5 days, cv. Parade had been the least attacked (10% hollowed) and cv. Avalon the most (44% hollowed); while the two extremes were significantly different there was considerable overlap among the remaining cultivars tested (Fig. 1c).

Electrical conductivity measurements made after 24 h differed significantly between cultivars; those from Motto and Avalon were greater than from Slejpner, which had significantly higher conductivity than the remaining cultivars tested (Table 4). After 3 days, electrical conductivity from cv. Parade remained significantly smaller than the other cultivars and Avalon, Motto and Longbow continued to give amongst the highest measurements (Table 4).

The total water-soluble sugar content was estimated from seven cultivars. Cv. Parade had a significantly smaller water-soluble sugar content than all the other cultivars tested; the cvs Galahad, Avalon and Mercia had the largest sugar content (Table 5). Electrical conductivity and leaching of water soluble sugars were affected by temperature (Table 6), both were usually greater at 20 °C than at 5 °C and less from cv. Parade than cv. Avalon.

## 5. DISCUSSION

Ploughing soon after the preceding oilseed rape crop was harvested reduced slug damage to the following winter wheat crop but might have increased the numbers of volunteer rape plants slightly. It is recognised that direct-drilled wheat is particularly vulnerable to slug injury (Glen, Wiltshire & Milsom, 1988) and that cultivations tend to reduce this risk (Port & Port, 1986).

Experimental evidence of the effect of soil conditions in the field suggest that the percentage of fine soil aggregates in the seed bed and depth of sowing are important factors contributing to slug damage; damage is greater where there is a low percentage of fine soil aggregates and seed are sown at shallower depths. This suggests that the early plough timing helped to create a seed bed with a proportion of fine soil aggregates in excess of about 35%, that was usually associated with insignificant slug damage (Glen & Wiltshire, 1992). Drilling depth was in the middle of the range these authors tested. Some increase in volunteer rape problems might be predicted from early drilling, leading to a flush of germination; in this trial the increase was not significant and the trial needs to be repeated in other seasons and at a range of sites.

Applying methiocarb on the day of drilling gave better control of slug attack than when applied before drilling or not at all. However, it should be noted that the application before drilling should have occurred some days earlier and that the pellets applied would have been ploughed into the soil only some 24 h after application. Rogers-Lewis (1977) found that treatments applied near the time of drilling were all effective, whereas applications made 7 weeks before drilling gave no effective control. Port & Port (1986) also considered that treatments at or about the time of drilling are most effective in years when weather follows the normal pattern.

In five days, a mean of 44% of each seed of the most susceptible cultivar (Avalon) was hollowed in the laboratory study, compared with 10% hollowing of the least susceptible cultivar (Parade). Other cultivars were not significantly different from either extreme. Port & Port (1986) reported that differences occurred between the level of attack from Deroceras reticulatum suffered by a range of wheat species and concluded that the preference arose from larger total nitrogen content in the seeds.

The basis for cultivar preference is unclear although it is recognised that slugs are generally attracted to sugars (Henderson & Parker, 1986). Thus, a cultivar that exuded sugary solutes during the earlier stages of germination might be predicted to be more attractive to slugs. Electrical conductivity was used as an indirect assessment of all electrolyte leakage and was greatest after three days at room temperature from cvs Avalon, Motto and Longbow and least from cv. Parade. Electrolyte leaching was affected by temperature, being slowest at 5 C and greatest at 20 °C. Cv. Parade always had the smallest and cv. Avalon the largest conductivity, indicating more rapid leakage of electrolytes. The total water-soluble sugar content also broadly reflected the distinction between cvs Avalon and Parade in feeding tests.

In the feeding tests (conducted at room temperature), cv. Avalon had been attacked significantly more than cv. Parade. Other cultivars had total sugar contents similar to cv. Avalon yet were less severely grazed by slugs in feeding tests; however, only cv. Avalon had both a large total water-soluble sugar content and a more rapid rate of solute leaching. These results indicate that cultivars of winter wheat may differ enough in the amount of at least one attractant for some protection to be afforded to those cultivars that leach relatively smaller amounts, but further testing is required.

## 6. CONCLUSIONS

This project has clearly identified that differences in susceptibility to the field slug, Deroceras reticulatum occur between cultivars of winter wheat and that these differences may be related to differences in the total sugar content of the seeds and the extent to which solutes leach during the early stages of germination. However, further studies are needed to confirm the relationship between sugar content and susceptibility in a wider range of recommended cultivars and to repeat the feeding studies under less artificial conditions. The results from the field trial indicated that, as suspected, the best timing of cultivation to achieve good slug control was likely to increase problems from oilseed rape volunteer plants. More data from a wider range of sites is needed to establish this with any confidence; these cultural methods of slug control would be of immediate benefit to farmers.

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**TABLE 1**

Proportion of winter wheat grain hollowed at a site with different times of ploughing and molluscicide application

(% seed hollowed)

| | | | | |
|---|---|---|---|---|
| **Plough timing :** | **early Aug** | **early Sept** | **late Sept** | **late Sept + paraquat** |
| | 11.6 | 12.3 | 15.6 | 14.9 |
| | | nsd | | |

| | | | |
|---|---|---|---|
| **Methiocarb :** | **untreated** | **pre-drilling** | **post-drilling** |
| | 16.6 | 12.9 | 11.3 * |

SED = 2.04 (t=24)

* significantly different from untreated as indicated

**TABLE 2**

Numbers of winter wheat plants counted at a site with different times of ploughing and molluscicide application (mean nos/ m row)

| Plough timing: | early Aug | | early Sept | late Sept | late Sept + paraquat | mean | |
|---|---|---|---|---|---|---|---|
| **Methiocarb** | | | | | | | |
| **untreated** | 24.3 | | 18.9 | 13.8 | 15.3 | 18.1 | |
| **pre-drill** | 28.4 | | 17.8 | 18.9 | 19.7 | 21.2 | * |
| **post-drill** | 30.8 | | 21.3 | 19.8 | 22.3 | 23.5 | *** |
| **mean** | 27.8 | *** | 19.3 | 17.5 | 19.1 | | |

SED (plough) : 0.91 (t=9) interaction : nsd
SED (mollusc.) : 1.27 (t=24)
* significantly different as indicated

**TABLE 3**

Population of Oilseed rape volunteers in January 1991 at a site with different times of ploughing and molluscicide application (nos/m$^2$)

| **Plough timing:** | **early Aug** | **early Sept** | **late Sept** | **late Sept + paraquat** | **mean** |
|---|---|---|---|---|---|
| **Molluscicide** | | | | | |
| **untreated** | 1.8 | 4.2 | 1.4 | 1.6 | 2.3 |
| **pre-drill** | 1.6 | 2.1 | 1.2 | 0.6 | 1.4 |
| **post-drill** | 1.0 | 2.8 | 1.4 | 0.8 | 1.5 |
| **mean** | 1.5 | 3.0 | 1.3 | 1.0 | |
| SED | 0.6 | 0.9 | 0.6 | 0.6 | |

**TABLE 4**

Electrical conductivity (uS) of leachate from seed of winter wheat cultivars. (expressed per g seed)

| Cultivar | Day 1 | Day 2 | Day 3 |
|---|---|---|---|
| Apollo | 9.3 | 15.1 | 20.5 |
| Avalon | 14.3 | 18.3 | 21.6 |
| Galahad | 6.9 | 14.8 | 20.4 |
| Longbow | 7.4 | 19.7 | 25.8 |
| Mercia | 8.4 | 13.1 | 18.7 |
| Motto | 14.0 | 19.6 | 23.7 |
| Parade | 7.8 | 10.9 | 12.6 |
| Slejpner | 11.6 | 14.5 | 17.2 |
| | | | |
| SE | 0.70 | 1.16 | 1.51 |

**TABLE 5**

Total water soluble sugar content of seed of seven cultivars of winter wheat (glucose equivalents)

| **Cultivar** | **$g/l \times 10^{-2}$** |
|---|---|
| Apollo | 3.9 a |
| Avalon | 5.9 b |
| Galahad | 5.9 b |
| Longbow | 4.6 a |
| Mercia | 6.9 b |
| Parade | 0.3 |
| Slejpner | 2.3 |

a,b figures not signifcantly different according to Duncan's Multiple Range test.

**TABLE 6**

Effect of three temperatures on electrical conductivity and leaching of water soluble sugars from seed of winter wheat cultivars (glucose equivalents).

**a) Day 1**

| **Cultivar** | **Conductivity uS** | | | | **Sugars mg/l** | | |
|---|---|---|---|---|---|---|---|
| **Temp °C** | **5** | **10** | **20** | | **5** | **10** | **20** |
| Avalon | 10.21 | 10.70 | 10.80 | | 0.17 | 0.12 | 0.38 |
| Longbow | 8.01 | 8.58 | 11.05 | | 0.38 | 0.38 | 0.83 |
| Parade | 7.05 | 6.07 | 7.60 | | 0.19 | 0.24 | 0.56 |
| Slejpner | 7.84 | 8.18 | 9.06 | | 0.07 | 0.14 | 0.40 |
| SED = 0.412 | | | | 0.055 | | | |
| **Mean** | 8.28 | 8.38 | 9.63 | | 0.20 | 0.22 | 0.54 |

**b) Day 2**

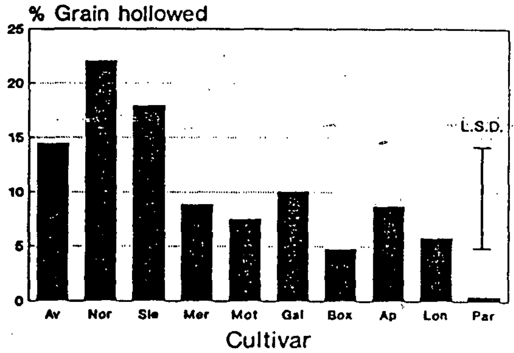
| **Cultivar** | **Conductivity uS** | | | | **Sugars mg/l** | | |
|---|---|---|---|---|---|---|---|
| **Temp °C** | **5** | **10** | **20** | | **5** | **10** | **20** |
| Avalon | 10.55 | 17.75 | 18.81 | | 1.19 | 1.69 | 1.80 |
| Longbow | 8.07 | 12.04 | 18.36 | | 2.04 | 3.38 | 1.36 |
| Parade | 7.11 | 10.57 | 10.69 | | 0.67 | 1.25 | 0.46 |
| Slejpner | 8.60 | 12.16 | 13.98 | | 0.90 | 1.89 | 1.73 |
| SED = 0.954 | | | | 0.224 | | | |
| **Mean** | .58 | 13.13 | 15.46 | | 1.20 | 2.05 | 1.34 |

**c) Day 3**

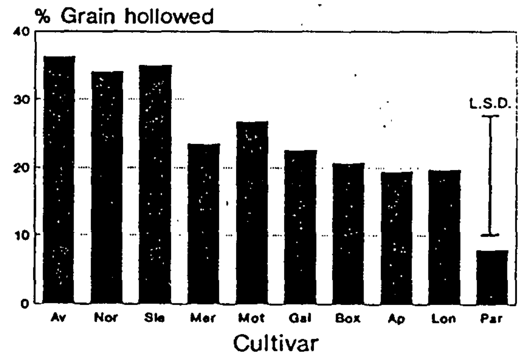
| **Cultivar** | **Conductivity uS** | | | | **Sugars mg/l** | |
|---|---|---|---|---|---|---|
| **Temp °C** | **5** | **10** | **20** | | **5** | **10** |
| Avalon | 1.32 | 17.17 | 20.75 | | 1.93 | 3.08 |
| Longbow | 9.29 | 13.72 | 21.88 | | 3.17 | 4.43 |
| Parade | 7.16 | 10.81 | 12.57 | | 1.46 | 2.27 |
| Slejpner | 8.69 | 12.43 | 17.12 | | 1.71 | 2.39 |
| SED = 0.744 | | | | 0.223 | | |
| **Mean** | 9.12 | 13.53 | 18.08 | | 2.07 | 3.04 |

# FIGURE 1. Percentage grain hollowed by *Deroceras reticulatum*

a) Day 1




b) Day 2




c) Day 5