# Further development of farmer-friendly methods for estimating slug infestation incidence in soil and damage risk to oilseed rape

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## Summary

**This project has built on an initial pilot project in 2002 (UFOP Project Nr. 521/024a), to develop a simple technique for estimating the population density of slugs in the soil of fields to be sown with oilseed rape. Soil samples were dug with a spade then placed in a cool place in water-tight and slug-proof containers. Slices of kohlrabi were placed on top of the soil, which was gradually flooded over a period of three days. The technique was tested on at least two field sites in each of five locations ((Braunschweig, Göttingen, Kiel and Stuttgart in Germany, Somerset in England) in 2003, starting before harvest of cereal crops**

**and continuing through the inter-crop (fallow) period and the establishment of winter oilseed rape crops. This simple rapid technique provided high quality data on the populations of slugs from hatchlings to adults in the soil. It is suitable for use by crop consultants and farmers as a rapid and accurate method for estimating slug infestation incidence. It compared favourably with a standard method of soil sampling and flooding and 82-98% of all slugs were extracted after four days. Flooding was compared over 1 day, 2 days and 3 days. 1-day flooding was clearly too rapid to allow all slugs to be recorded. 2-day and 3-day flooding generally gave similar results, but 3-day flooding was more reliable and is preferred, with a further day of observation to collect slugs. Sampling to 20 cm depth was compared to the standard depth of 10 cm and, in all cases except one in oilseed rape stubble, insignificant numbers of slugs were recorded at the greater depth.**

**Slug activity on the soil surface was also estimated during this period, using three different trapping methods: mat traps and enclosed mat traps baited with metaldehyde pellets, and plant-pot saucer traps baited with chicken layers' mash. When traps were left in the field over one night, there was no consistent difference between trap types in the catches of *Deroceras reticulatum* and *Arion* spp., which are the main pest species in cereal - oilseed rape crop rotations. The large mat traps (0.5 x 0.5m) were awkward to use and smaller traps (e.g. 0.25 x 0.25m) are recommended. Traps recorded mainly the larger individuals of each species and did not provide reliable estimates of the numbers of smaller, immature slugs. The use of traps was greatly constrained by dry soil conditions in 2003. Moistening the soil with 5 litres of water per trap did not improve the catch.**

**Because of the exceptionally hot, dry weather experienced in 2003, slug populations collapsed and were low at all sites at the time of oilseed rape establishment. As a result, little slug damage was recorded. Initial recommendations are made for soil sampling and trapping to assess the risk of slug damage to oilseed rape at establishment. However, it will be important to use these methods under a wide range of weather conditions in order to relate slug infestation incidence to subsequent damage levels before widespread adoption.**

# 1. Introduction

This project arose from UFOP Project Nr. 521/024a "Development of farmer-friendly methods for estimating slug numbers in soil" together with discussions with UFOP concerning farmers' need to assess, before sowing oilseed rape crops, the likely risk of slug damage and the use of control measures.

Slugs, especially *Deroceras reticulatum*, are important pests of oilseed rape at establishment in Western Europe (MOENS & GLEN, 2002). Recently, there have been numerous reports of increasing slug problems from various regions of Germany (VOSS ET AL., 1998; STEMAN & LÜTKE ENTRUP, 2001; GLEN, 2002). In order to improve targeted slug control by molluscicides and other control measures as well as to avoid unnecessary pesticide applications, both simple and accurate methods of monitoring slug activity and abundance as well as models for risk assessment are needed. The oilseed rape crop is most vulnerable to slug attack at the time of seedling emergence. If a farmer does not take action until damage is noticed at emergence, it may already be too late to prevent economic damage from these pests. For this reason, it is important for farmers to identify in advance which fields are likely to suffer from severe slug attack, so that appropriate control measures can be taken before seedling emergence.

Refuge traps are commonly used to estimate the activity-density of slugs on the soil surface for the purpose of evaluating the risk of slug damage. However, there is increasing concern that juvenile slugs, which live mostly below ground, will rarely be captured by refuge traps, but may have a major impact on the damage potential of slugs. Moreover, slug traps attract slugs from an unknown distance and, because slugs are very dependent on surface moisture for activity, the soil surface must be moist if slug traps are to provide an estimate of slug activity-density. Experience in UFOP Project Nr. 521/024a in 2002 showed that there were relatively few days during the period between early August and the sowing of oilseed rape crops when the soil surface was sufficiently moist for traps to provide an estimate of slug activity-density. Moistening the soil surface under dry conditions was not effective in increasing the numbers of slugs recorded in traps.

In UFOP Project Nr. 521/024a the first steps were taken towards developing and evaluating a method for monitoring the abundance of slugs within the soil which is quick, simple and easy to use by farmers as well as by pest consultants in slug control programmes. The method was developed from a standard flooding method that has been used at Long Ashton Research Station, England for many years (GLEN *ET AL.*, 1992). Two methods of rapid sampling of slug populations in soil were compared: (1) bulked core samples, each 10 cm in diameter or less; (2) large individual samples, 25 cm x 25 cm square or 25 cm diameter, extracted using a metal template. This was done at a total of nine field sites in four locations (Braunschweig, Göttingen and Stuttgart in Germany, Somerset in England). Soil was sampled to a depth of 10 or 12 cm by both methods then slugs were extracted from soil by flooding the samples over a 3-day period. Method 2 was shown to be more reliable and effective than Method 1. Its efficiency was further improved when slices of kohlrabi were placed on the soil surface to attract slugs to the surface. Numbers extracted by Method 2 over three days compared favourably with numbers extracted by a standard method of flooding over 9 days. Slugs were also sampled by trapping and slug damage to oilseed rape was recorded at the same field sites. Additional tests were done at other field sites. Numbers of slugs recorded in traps were much more dependent on weather and soil surface moisture than the numbers of slugs recorded by rapid soil extraction (Method 2), which provided positive results under a wider range of soil-moisture and weather conditions than trapping and it provided valuable estimates of the risk of slug damage to oilseed rape at all field sites. There was some concern that results in July at two sites at Göttingen showed relatively high numbers of slugs per mat trap, but relatively low numbers by soil extraction Method 2. Moreover, extraction of slugs by Method 2 was rather labour-intensive so it was not itself suitable for use by consultants and farmers. A third, simpler method of digging small individual samples, 18 cm x 18 cm x 8 cm deep, with a spade, was tested at one site. This provided similar numbers of slugs to Method 2 in preliminary tests at one site, although for both techniques a substantial proportion of slugs were recovered after the end of the 3-day period of flooding. Placement of kohlrabi slices on the soil surface improved extraction of slugs from samples taken by Method 2 at two sites. Thus, it is thought that Method 3 with the addition of kohlrabi slices placed on the soil surface during the flooding period, could be a simple and accurate method suitable for use by consultants and possibly farmers as a rapid technique for accurately estimating slug populations in soil in the period from the start of July until the soil is cultivated prior to the establishment of oilseed rape crops. The data from the field sites in UFOP Project Nr. 521/024a also gave valuable preliminary information on the relationship between slug population density and the severity of slug damage to oilseed rape at establishment.

In this project, we tested the simple method of sampling slugs in soil by digging samples with a spade then placing kohlrabi slices on the soil surface during the flooding period (Method 3 + kohlrabi) and we compared it with three methods of trapping slugs, one of which restricted the area from which slugs were attracted to a defined area surrounding each trap.

## 2. Materials and methods

### Study locations

The research was done at four locations in Germany (Braunschweig, Göttingen, Kiel and Stuttgart) and in Somerset, southwest England.

**Simplifying and optimising a rapid technique for sampling and estimating the numbers of slugs in soil developed in UFOP Project Nr. 521/024a**

*Field sites*

At each location, except Kiel, each project partner selected at least two fields, where slugs were known to be present, to be sown with oilseed rape. Within each field, an area of at least 36 m x 48 m (or equivalent area) was marked out, which was not treated with slug pellets. The precise size and shape of the area depended on the study site. Within this area, at least 9 plots were marked out, each plot a minimum of 12 m x 18 m (Fig. 1).

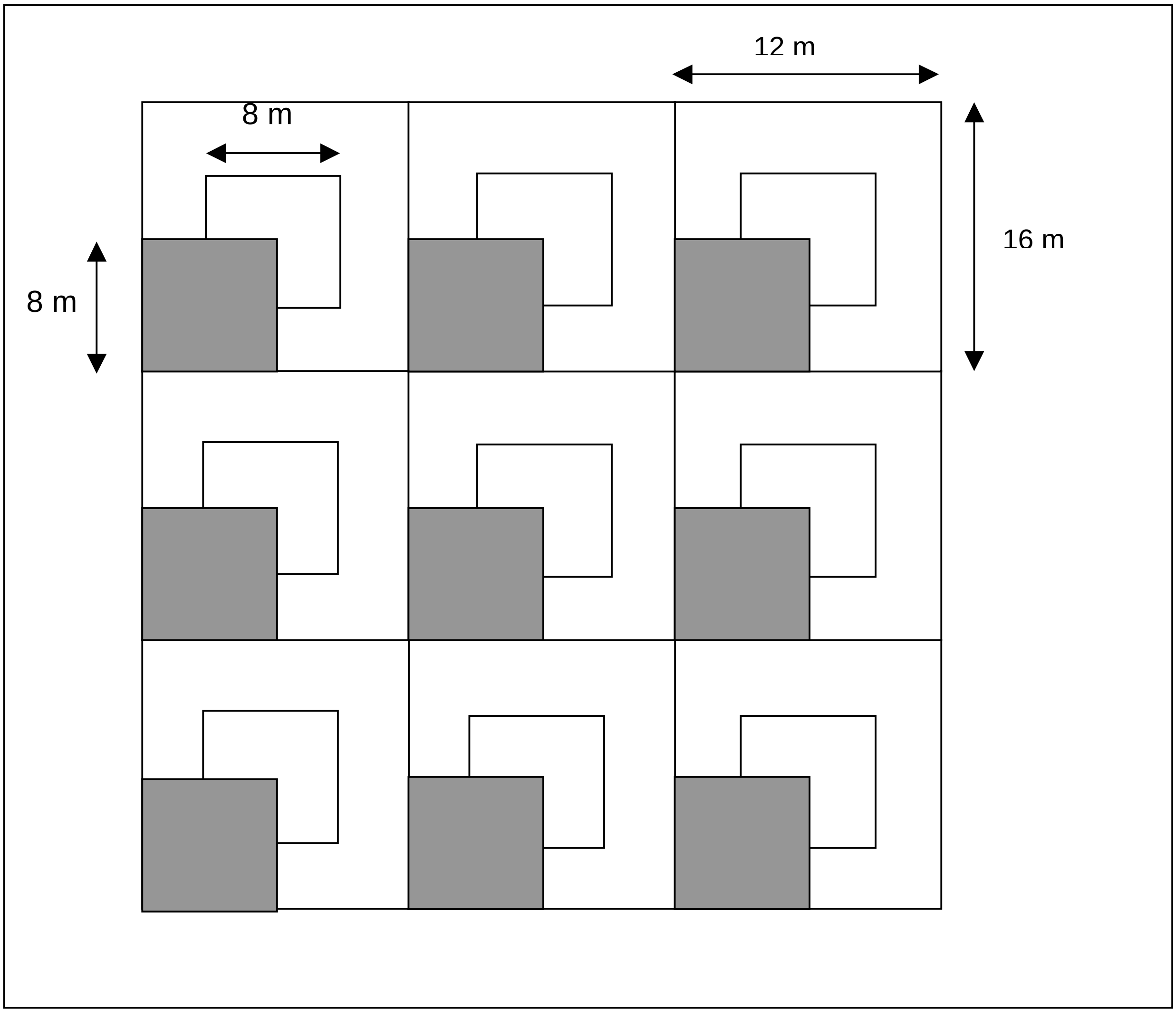



**Fig. 1. Arrangement of plots on trial fields sown with winter oilseed rape in 2003. Trapping was done and soil samples were taken from the inner square of each plot. The grey areas were treated with slug pellets after drilling oilseed rape.**

At Kiel, the research was done in a field going from oilseed rape into winter wheat, where there were five regimes with different combinations of glyphosate herbicide

and cultivations, as summarised in Table 1. The regimes in which slug populations were studied were as follows: -
V1: No glyphosate or cultivation
V3: Glyphosate on 18 August and shallow cultivation on 15 September
V4: Glyphosate on 18 August, shallow cultivation on 18 August and 15 September
V5: Glyphosate on 18 August, shallow cultivation on 18 August, 1 and 15 September.

Because the number of slugs on the selected fields was too small for a thorough evaluation and comparison of all techniques, additional sites were also used. Sampling was done on 7 October in Wendhausen, 10 km to the north-east of Braunschweig in a fallow field which had had a serious slug problem in previous years. Samples were collected on two occasions from a stubble field after harvest of oilseed rape (Wendelsgraben, near Göttingen) during September 2003. For the same reasons, soil sampling and three methods of trapping were compared in a grass/clover field, which had been irrigated throughout the summer, at Cheddar, Somerset on 28-29 October 2003, just after the first substantial rainfall of the autumn.

**Table 1. Five herbicide and cultivation regimes (V1 to V5) with three different dates of shallow tillage (BB1-3) and four dates when slug populations were assessed in an experimental field going from oilseed rape stubble to winter wheat, Kiel, 2003.**

| | T 1<br>15.08 | Glyphosate<br>18.08 | BB 1<br>18.08 | T 2<br>01.09 | BB 2<br>01.09 | T 3<br>15.09 | BB 3<br>15.09 | T 4<br>09.10 |
|---|---|---|---|---|---|---|---|---|
| V1 | X | | | x | | x | | x |
| V2 | | X | | | | | | |
| V3 | X | X | | X | | X | X | X |
| V4 | X | X | X | X | | X | X | X |
| V5 | x | X | x | X | x | X | x | X |
| | T 1-4: time of sampling | | | BB1-3: time of tillage | | V1-5: various intensity of tillage | | |

*Standard sampling procedures*
From the middle 8m x 8m area of each plot, one soil sample was dug with a spade. This sample was 18 cm x 18 cm square at Braunschweig, Göttingen, Kiel and Stuttgart x 10 cm deep. Thus, the total area of soil sampled per plot was equivalent to 324 $cm^2$ (31 samples per $m^2$). In Somerset, slightly larger samples were taken using a spade with a curved blade 19.8 cm wide, which provided soil samples each 435 $cm^2$ (23 samples per $m^2$).

Each of the above samples was placed in a watertight container with a lid in such a way that the samples were kept in the dark. (Darkness encourages slugs to come to and remain at the soil surface). The containers with the samples were also kept out of direct sunshine at all stages of processing and were transported to a cool shaded place for flooding. Overheating of samples was avoided at all times. Slices of kohlrabi approximately 0.5 – 1.0 cm thick were placed on the surface of the soil in each container to cover about 50% of the soil surface, to attract slugs to feed and rest. Water (3 cm deep) was placed in the base of the container and slugs present in the sample were encouraged to come to the surface by flooding the sample from below to drive slugs to the surface.

The soil samples were flooded over a period of 3 days by adding 2 cm water to each container each morning and evening until the water level was about 2 cm below the level of the soil surface. For the final stage of raising the water level to the soil surface, water was added carefully so that the water just reached the surface of the soil sample with only the highest points showing about 1-2mm above the water surface.

Before the water was added on each occasion, each container was examined and all slugs that had come to the soil surface were identified, kept in moist conditions and weighed individually while they were fully hydrated. Each container was examined for at least 3 minutes on each occasion, taking particular care to look for small neonate and juvenile slugs to ensure that none were overlooked. The location where each slug is found were recorded in the following categories: -

- Container lid
- Container sides, above water level
- Container sides, below water level
- On kohlrabi slices
- On soil surface
- Inside cereal stalk or piece of straw
- On soil below water level

After the soil had been fully flooded the samples were left for a further 7 days and examined daily for slugs that came to the surface after the end of the flooding period.

In order to verify whether any slugs remained in soil after completion of the extraction period, the soil samples were washed through a set of graduated sieves on at least two sampling occasions at each location in Germany.

At one field site in southwest England, the numbers of slugs and the size structure of the population extracted by this simple method were compared with the equivalent data for the standard research-method of soil flooding that has been used at Long Ashton Research Station (Glen *et al.*, 1989, 1992), for samples taken from the same plots. Thus, on each sampling occasion, one soil sample 25cm x 25cm x 10cm deep was taken from each plot and processed using the standard method of flooding over nine days.

On each sampling occasion at all field sites, one additional soil sample was taken from each plot at two depths in the soil (0-2 cm and 2-10 cm) to determine soil moisture content. The soil samples were weighed before and after drying (gravimetric method). In addition, daily weather records of maximum, minimum and mean air temperature, and daily rainfall from a nearby weather station were obtained.

Each partner aimed to take a series of samples from each study field, as follows, provided that this could be done when the upper 10-cm layer of soil was moist (if the soil is dry, slugs are not be present in the upper 10-cm layer.):

(i) In the preceding cereal crop before harvest, IF soil conditions were suitable at this time

(ii) In the stubble after harvest and before cultivation

(iii) Prior to, or as soon as possible after, drilling oilseed rape

(iv) At the time from when seedlings were at the cotyledon stage (>50% of seedlings emergence) until the first-true-leaf stage

(v) When oilseed rape had reached the four-true-leaf stage.

*Investigation of the rate of soil flooding*

At one field site in each location, on at least one occasion, two parallel sets of samples were taken in order to compare the numbers and weights of slugs extracted by rapid flooding over 1 day and 2 days with the 3-day flooding period described above. Details of 1-day and 2-day flooding are as follows: -

*1-day flooding:* In the late afternoon/early evening of the day when the samples were taken (Day 0), water was added to the container to half the depth of the soil sample. The following morning (Day 1), water was added to bring the water level to the surface of the soil sample with only the very highest points of soil about 1mm above the water level. The samples were then examined again in the late afternoon or evening of Day 1.

*2-day flooding:* In the late afternoon/early evening of the day when the samples were taken (Day 0), water was added to the container to 3cm depth. The following morning (Day 1), 3 cm water was added, followed by 3cm in the late afternoon or evening of Day 1 and then sufficient water on the morning of Day 2, to bring the water to the surface of the soil sample with only the very highest points of soil about 1-2 mm above the water level. The samples were then examined again in the late afternoon or evening of Day 2.

After the end of flooding, all samples were left for a period of 10 days in total, as for the standard 3-day flooding process, so that slugs coming to the surface after the end of the flooding period could be recorded.

*Depth of soil sampling*
The fact the slugs may move below the 10 cm depth fixed for soil sampling made it important to investigate if there were any slugs to extract below this level. Accordingly, soil samples were taken to greater depth (20 cm) on at least one sampling occasion at each location. In doing this, it was important when taking samples from the depth of 10-20 cm to be careful to avoid contamination from any surrounding soil falling into the hole. Depending on the soil type, this was very difficult in practice and in some cases it was decided that it was best to take a single sample from 0-20 cm depth and compare this with a sample taken to the standard 10 cm depth from each plot.

**Soil moisture determination and weather records**

On each sampling occasion, at least five additional samples were taken to determine soil moisture content at two depths in the soil (normally 0-2 cm and 2-10 cm). The soil samples were weighed before and after drying (gravimetric method). In addition, daily mean air temperature and daily rainfall data were obtained from a meteorological site at each location.

**Comparison of the rapid soil sampling technique with methods for trapping slugs active on the soil surface**

In UFOP Project Nr. 521/024a, because of short notice before the start of the project, different methods of trapping were used by each partner. In this project it was essential for all partners to use the same methods. Slug mat traps (‘Schneckentest Folie’) as developed by HOMAY & BRIARD (1988) were used at Göttingen and Stuttgart in 2002. These are widely available in Germany, so these traps were used at all field sites in 2003. They are composed of three layers with the top one being metallic silver for maximum light reflection and the bottom one consisting of black perforated plastic. Between these layers an insulating fabric was enclosed to hold moisture within the mat. The mats are *ca.* 50cm x 50cm in size and are placed on the soil surface, with the corners held in place by stones or tent pegs. Metaldehyde pellets (Metarex, 10g/trap) were used as the standard bait in each trap, distributed evenly over the 15x15 cm central ground area underneath each mat, to poison the slugs under the mat and thus reduce the likelihood of them escaping.

Provided that the soil surface was moist at the time when soil samples were taken, one ‘Schneckentest Folie’ mat trap of each of two types (1. Open traps, 2. Enclosed defined area traps) was placed in the middle 8 m x 8 m area of each of the nine plots in each field to evaluate the activity-density of adult slugs. Each trap was at least 2m away from the other trap in the same plot. The traps were examined the following morning. If the soil surface was dry when soil samples were taken, traps were put out on the first opportunity when the soil surface was moist afterwards. However, in the prevailingly dry conditions of July to October 2003, this proved to be difficult. In order to improve the attractiveness of the traps under very dry soil conditions in August and September at Göttingen, the mats and the soil surface underneath the mat traps were moistened with five litres of water per mat.

A sample of up to 20 trapped slugs of each species present was removed from each type of trap and weighed individually.

Immediately after the open traps were examined on the morning after they are put out, the traps were removed and the pellets covered with soil, so that they were no longer available to slugs, in order to prevent them from diminishing the slug population.

*Open mat traps* were simply placed in the field in the usual way.

*Enclosed area mat-traps* were each surrounded by a barrier to prevent slug movement into or out of the traps. Barriers were at least 15 cm high, inserted into the soil to a depth of at least 5 cm to restrict subterranean movement of slugs into or out of the trap area. At Göttingen the barriers were of galvanised sheet metal 15 cm high, which slugs are reluctant to cross. At Braunschweig, 25 cm tall plastic rings with a diameter of 55 cm were placed in the soil 10 cm deep directly after sowing oilseed rape. At Stuttgart and Somerset, plastic lawn-edge 16.5 cm high was used, with the upper part coated in Fluon (Symondson, 1993) to discourage slugs from climbing over the barrier. These traps were examined in the morning after overnight exposure and also after 3 days and 7 days. However, note that although Fluon is an effective coating preventing slug movement when it is fresh, the longer that Fluon-coated barriers are left in the field the less effective they become, because the surface becomes contaminated with soil and plant debris, which allows the slugs to move across the barriers. This could make the results of longer (7-day) exposure unreliable. Fluon-coated barriers were carefully cleaned after each use and given a fresh coat of Fluon before they were used again.

*1 m²-areas* were also used at Braunschweig to collect information on slug activity on the soil surface. Each area was staked out and covered evenly with 40g slug pellets.

*Upturned plant-pot saucers (25 cm diameter) baited with chicken layers' mash (20 ml)* were also used at the sites in Somerset, as this is the method of trapping being used in a related project (Glen *et al.*, 2003). These traps (terracotta-colour) were left overnight and examined the following morning in the same way as the mat traps.

## Severity of slug damage to oilseed rape in relation to the slug population

Slug damage to oilseed rape at establishment was assessed by dividing each of the experimental plots described in Objective (1) into two sub-plots as shown in Figure 1, One sub-plot (at least 6 m x 8 m) of each plot was treated with a broadcast application of slug pellets at drilling, followed by a further application at crop emergence. These plots were then monitored with a view to making further applications of pellets if evidence of slug damage was seen on the treated sub-plots, so that the numbers of plants establishing in the absence of slug damage could be compared with numbers in the sub-plots without slug control treatment.

The number of plants emerged and the percentage leaf area removed by slugs were assessed at about weekly intervals until the plants reached the 4-true-leaf stage. Analysis of variance was used to test whether there was a significant reduction in plant numbers and/or a significant increase in the number and percentage of plants damaged by slugs on untreated subplots compared with treated subplots. Any such significant differences were taken as evidence for slug damage. The percentage reduction in plant numbers and the percentage of plants with slug damage was then compared with measurements of slug numbers made by each method of assessment throughout the period of study, in order to make an assessment of the most reliable method(s) of damage risk assessment.

## 3. Results

Weather data for each location are shown as Figs. 14 to 18 as an Appendix to this report. Weather at all field sites was characterised by long periods of dry weather, with high temperatures in July and August.

**Simplifying and optimising a rapid technique for sampling and estimating the numbers of slugs in soil developed in UFOP Project Nr. 521/024a**

*Recording slug infestation incidence in soil*

The population densities of slugs per $m^2$ recorded by the rapid method of soil sampling on all study fields that were sown with winter oilseed rape in 2003 are summarised in Table 2 (sites in Germany) and Table 3 (sites in south-west England). It should be noted that, for the sites in Germany, 31 slugs/$m^2$ is equivalent to a mean of one slug per sample and, for the sites in England, where the sample size was slightly larger, 23 slugs per $m^2$ is equivalent to one slug per sample.

It was noticeable that slug populations declined markedly at almost all sites in August and September 2003, with the exception of the direct-drilled field at Braunsweig, Sickte. Numbers of slugs were at low levels or below the level of detection for long periods at several sites. However, mean numbers of slugs greater than 20/$m^2$ were recorded from all three sites near Göttingen before harvesting of the previous cereal crop and at one site near Stuttgart before harvest and in the cereal stubble. One site in Somerset (Glebe Field) had substantial numbers of three types of pest slugs (*Deroceras reticulatum, Arion hortensis* agg. and keeled slugs (Milacidae)) in the period before harvest of the previous cereal crop and numbers remained above 20/$m^2$ in this field until oilseed rape was drilled.

## Table 2. Mean numbers of slugs/m$^2$ extracted from soil by rapid soil sampling in all field sites in Germany sown with oilseed rape in 2003.

| Location | Field site | Date or cropping stage | % Soil moisture | | Mean number of slugs per m$^2$ | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 0-2 cm | 2-10 cm | *Deroceras* | *Arion* | Milacidae | All species |
| Braunschweig | Sickte, Field 1 (Direct drilled) | 11 August[2] | | | 0 | 0 | 0 | 0 |
| | | 21 August[4A] | | | 3.1 | 0 | 0 | 3.1 |
| | | 1 Sept.[5] | | | 3.1 | 0 | 0 | 3.1 |
| | | 15 Sept.[6] | | | 3.1 | 9.3 | 0 | 12.4 |
| | Sickte Field 2 (Red. till) | 21 August[4B] | | | 0 | 0 | 0 | 0 |
| | | 1 Sept.[5] | | | 0 | 0 | 0 | 0 |
| | | 15 Sept.[6] | | | 0 | 0 | 0 | 0 |
| | Wülperode (Reduced tillage) | 11 August[2] | | | 0 | 0 | 0 | 0 |
| | | 21 August[4B] | | | 0 | 0 | 0 | 0 |
| | | 1 Sept.[5] | | | 0 | 0 | 0 | 0 |
| | | 15 Sept.[6] | | | 0 | 3.4 | 0 | 3.4 |
| Göttingen | Torland (Reduced tillage) | 29 July[1] | 30.8 | 30.8 | 44.6 | 3.4 | 0 | 48.0 |
| | | 4 August[2] | 10.6 | 12.9 | 24.0 | 0 | 0 | 24.0 |
| | | 1 Sept.[5] | 14.0 | 13.7 | 0 | 0 | 0 | 0 |
| | | 24 Sept.[6] | 16.6 | 13.5 | 0 | 0 | 0 | 0 |
| | | 7 Oct.[7] | 23.3 | 17.6 | 0 | 0 | 0 | 0 |
| | Marienstein (Reduced tillage) | 29 July[1] | 28.1 | 27.8 | 6.9 | 17.1 | 0 | 24.0 |
| | | 12 August[2] | 5.0 | 10.3 | 0 | 0 | 0 | 0 |
| | | 1 Sept.[5] | 13.3 | 14.0 | 0 | 0 | 0 | 0 |
| | | 24 Sept.[6] | 14.4 | 13.3 | 0 | 0 | 0 | 0 |
| | | 7 Oct.[7] | 20.4 | 18.3 | 0 | 0 | 0 | 0 |
| | Uhlenloch (Ploughed) | 29 July[1] | 32 | 28 | 3.4 | 20.6 | 0 | 24.0 |
| | | 1 Sept.[5] | 17 | 11 | 0 | 0 | 0 | 0 |
| | | 24 Sept.[6] | 13 | 14 | 0 | 6.9 | 0 | 6.9 |
| | | 7 Oct.[7] | 19 | 17 | 0 | 13.9 | 0 | 13.9 |
| Stuttgart | Kornberg (Reduced tillage) | 7 July[1] | 14.4 | 13.6 | 130 | 0 | 0 | 130 |
| | | 31 July[2] | 14.2 | 15.8 | 78 | 0 | 0 | 78 |
| | | 20 August[4B] | 8.7 | 11.1 | 0 | 0 | 0 | 0 |
| | | 9 Sept. [5] | 13.7 | 13.3 | 0 | 0 | 0 | 0 |
| | | 8 Oct. | 25.7 | 24.8 | 0 | 0 | 0 | 0 |
| | | 20 Oct. [6] | 18.2 | 19.4 | 0 | 0 | 0 | 0 |
| | | 24 Nov. | 25.7 | 24.5 | 0 | 0 | 0 | 0 |
| | Honigbaum (Reduced tillage) | 7 July[1] | 15.2 | 16.6 | 13 | 0 | 0 | 13 |
| | | 21 July[2] | 8.5 | 11.9 | 0 | 0 | 0 | 0 |
| | | 21 August[4B] | 11.0 | 11.4 | 0 | 0 | 0 | 0 |
| | | 9 Sept. [5] | 12.5 | 13.7 | 0 | 0 | 0 | 0 |
| | | 8 Oct. | 27.3 | 25.7 | 0 | 0 | 0 | 0 |
| | | 20 Oct. [6] | 18.7 | 19.1 | 0 | 0 | 0 | 0 |
| | | 24 Nov. | 25.2 | 24.5 | 0 | 0 | 0 | 0 |
| | Ob-der-Kirche (Reduced tillage) | 7 July[1] | 20.7 | 22.2 | 0 | 0 | 0 | 0 |
| | | 14 July[2] | 11.6 | 12.4 | 0 | 0 | 0 | 0 |
| | | 19 August[4B] | 11.0 | 14.4 | 0 | 0 | 0 | 0 |
| | | 9 Sept. [5] | 18.0 | 20.7 | 0 | 0 | 0 | 0 |
| | | 8 Oct. | 29.1 | 27.0 | 0 | 0 | 0 | 0 |
| | | 20 Oct. [6] | 16.8 | 24.9 | 0 | 0 | 0 | 0 |
| | | 24 Nov. | 28.9 | 28.6 | 0 | 0 | 0 | 0 |

[1]Standing cereals; [2]Cereal stubble, no cultivation; [3]Cereal stubble after shallow cultivation;
[4A]After direct drilling oilseed rape; [4B]After shallow cultivation & drilling oilseed rape;
[5]Oilseed rape at cotyledon stage
[6]Oilseed rape at 4-true-leaf-stage; [7]Oilseed rape at 6-true-leaf-stage.

**Table 3. Mean numbers of slugs/m$^2$ extracted from soil by rapid soil sampling in fields in England sown with oilseed rape in 2003.**

| Location | Field site | Date or cropping stage | % Soil moisture 0-2 cm | % Soil moisture 2-10 cm | Mean number of slugs per m$^2$ *Deroceras* | *Arion* | Milacidae | All species |
|---|---|---|---|---|---|---|---|---|
| Somerset | Glebe Field (Reduced tillage) | 24 June[1] | 22.5 | 22.5 | 20.7 | 43.7 | 9.2 | 73.6 |
| | | 18 July[1] | 23.6 | 22.3 | 13.8 | 32.2 | 4.6 | 50.6 |
| | | 31 July[1] | 24.5 | 24.8 | 29.9 | 147.2 | 18.4 | 195.5 |
| | | 16 August[2] | 17.2 | 22.2 | 9.2 | 39.1 | 9.2 | 57.5 |
| | | 21 August[3] | 16.2 | 21.9 | 4.6 | 16.1 | 0 | 20.7 |
| | | 28 August[4C] | 10.0 | 20.1 | 9.2 | 9.2 | 4.6 | 23.0 |
| | | 5 Sept.[5] | 10.3 | 20.4 | 0 | 6.9 | 2.3 | 9.2 |
| | | 29 Sept.[6] | 11.8 | 18.8 | 0 | 4.6 | 0 | 4.6 |
| | Paddock 123 (Reduced tillage) | 1 August[1] | 24.7 | 25.1 | 0 | 0 | 0 | 0 |
| | | 21 August[2] | 18.2 | 24.2 | 5.1 | 0 | 2.6 | 7.7 |
| | | 29 August[4C] | 25.2 | 25.0 | 0 | 5.1 | 0 | 5.1 |
| | | 30 Sept.[6] | 13.2 | 20.7 | 0 | 0 | 2.6 | 2.6 |

[1]Standing cereals; [2]Cereal stubble, no cultivation; [3]Cereal stubble after shallow cultivation;
[4A]After direct drilling oilseed rape; [4B]After shallow cultivation & drilling oilseed rape;
[4C]After 2nd shallow cultivation & drilling oilseed rape; [5]After emergence of oilseed rape
[6]Oilseed rape at 4-true-leaf-stage; [7]Oilseed rape at 6-true-leaf-stage.

It is likely that dry weather conditions in 2003 contributed to the relatively low levels of slug infestation, especially the marked decline in slug populations following cereal harvest. Soil moisture declined substantially after cereal harvest, especially in the sites in Germany (Table 2). However, this is not the complete explanation. For example, two adjacent study fields in Somerset showed markedly contrasting populations, with low levels in Paddock 123 and high levels in Glebe Field, despite the field with the lower slug populations having higher soil moisture (Table 3).

Glebe Field revealed an important difference between the population structures of the two main pest slug species present. The population of each species was divided into three size classes based on a logarithmic scale: 1-10 mg (neonates or recently hatched slugs), 11-100 mg (juvenile slugs) and >100 mg (adult slugs). (The description for each of these categories is only approximate because different species and different individuals of a species grow at different rates. However, for the purposes of this study, these three weight categories are convenient approximations. *Deroceras reticulatum* was present almost exclusively as adults throughout the period of study in 2003 (Fig. 2b). This contrasted with the population structure of this species in Somerset in 2002 (Fig. 2a), when the population was dominated by neonates and juveniles. Thus, weather conditions in 2003 were probably unsuitable for successful breeding of this species. In particular it is likely that the unusual spell of dry weather in March and April 2003 prevented the normal breeding of this species in spring and the predominantly dry weather from June onwards prevented subsequent breeding and/ or survival of neonates and juveniles. There was some evidence of breeding and egg hatch after the wet weather in late July 2003, but these neonates did not survive well because of the later dry conditions.

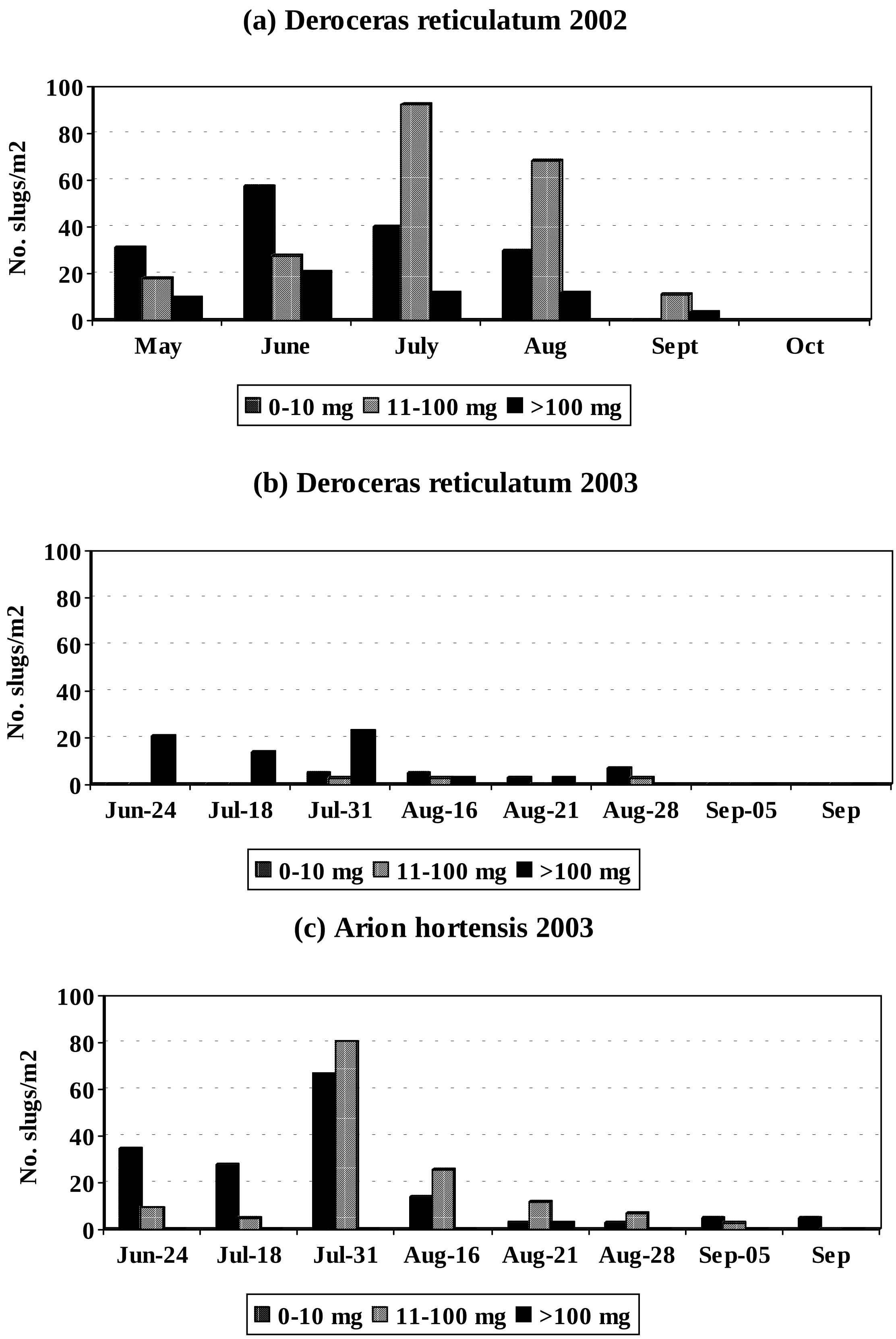



**Fig. 2. Population densities of three size classes of slugs in study fields in Somerset in 2002 and 2003.**

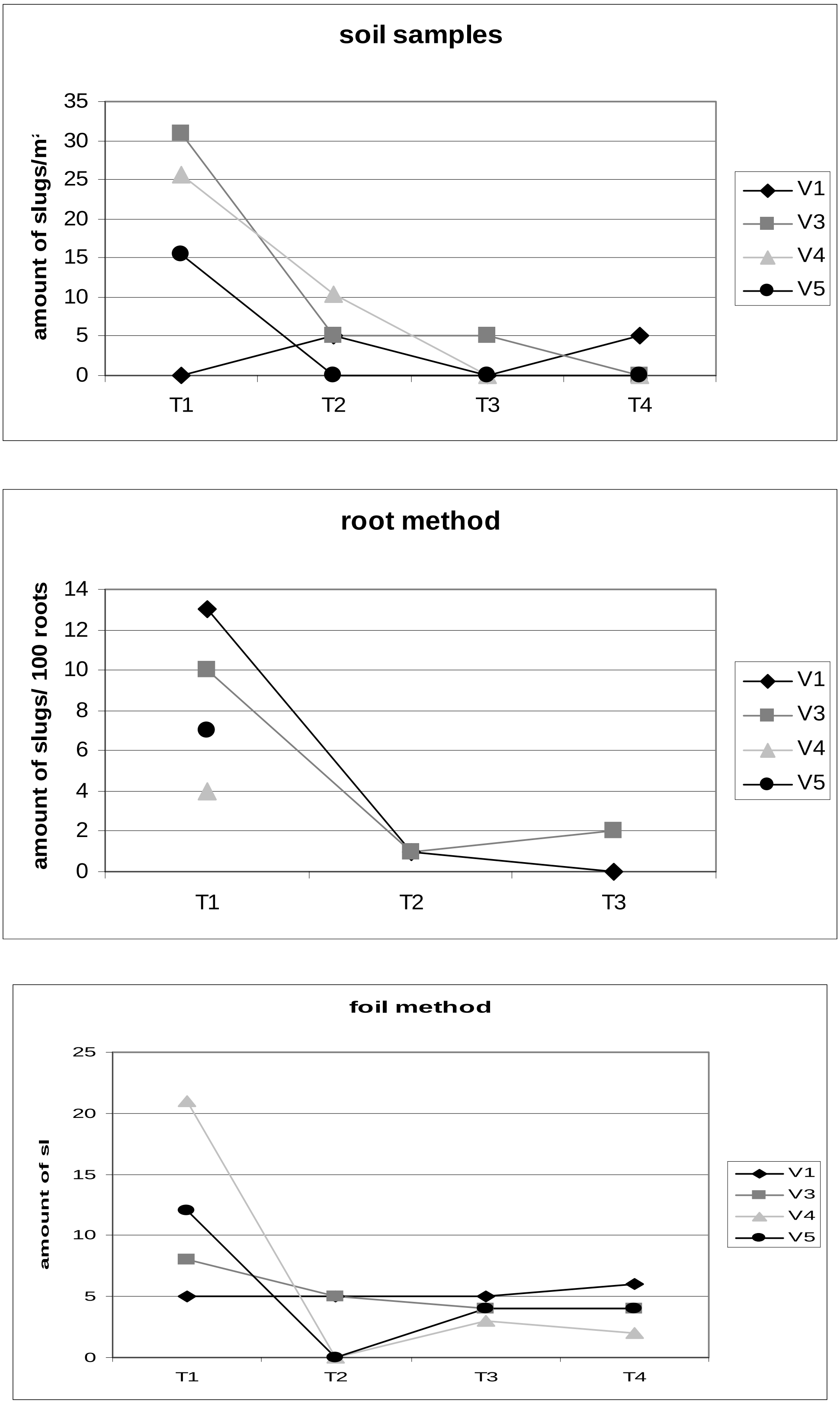



**Fig. 3. Numbers of slugs recorded in oilseed rape stubble, Kiel, on four different cultivation regimes (V1, V3, V4 and V5) on four sampling dates in 2003 (15.08, 1.09, 15.09 and 9.10), by soil sampling by pulling up roots of oilseed rape plants after harvest and by mat traps (foil method).**

In contrast to the picture for *D. reticulatum*, the population of *A. hortensis* at Glebe Field was dominated by neonates and juveniles (Fig. 2c) and it appeared that this species had a successful breeding season in spring 2003, perhaps as a result of the generally wet weather in May and early June.

In the experimental field with different tillage regimes in the Kiel region (Fig. 3), slug numbers in soil samples were greatest on the first sampling date (15 August), before any cultivations had been done, then numbers declined to low levels on all tillage regimes, even where no cultivations were done. Slug numbers were also recorded on this field site on a sample of 100 roots of oilseed rape per plot, which were pulled by hand (Fig. 3). The number of slugs per 100 roots on the first date of sampling was about half the number per $m^2$ recorded by soil sampling on the same date. Because of the rather low numbers of slugs, especially in soil samples from the uncultivated treatment (V1) at this site, it is not possible to draw conclusions about the effects of cultivation. The moisture content of the soil at this site was very low, especially on the first three sampling dates, from mid August to mid September (Fig. 4). Thus, the dryness of the soil probably accounted for the decline in slug numbers.

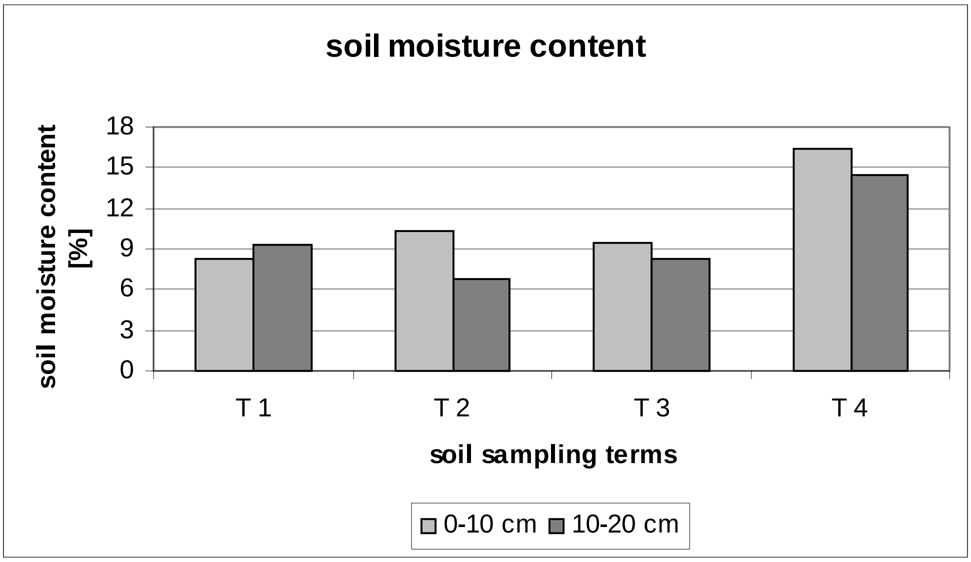



**Fig. 4. Soil moisture content of the field site near Kiel, on four sampling dates (15.08, 1.09, 15.09 and 9.10.03).**

*Ease of use of the rapid method of soil sampling*

The rapid method of soil sampling used for monitoring slug populations in 2003 was considerably less effort than the methods used in 2002; it was quicker and easier to dig the soil samples and to transport them. The process of examining the samples was made considerably easier by the use of kohlrabi slices placed on top of the soil. Many slugs were recorded on the kohlrabi slices or resting on the soil or stubble directly below the slices (Table 4). This was especially true for *A. hortensis* and for milacid slugs. A lower percentage of *D. reticulatum* were found resting on or beneath kohlrabi slices but most of the remaining individuals of this species were easily seen because they rested on the lids or the walls of the container.

**Table 4. Numbers and percentages of slugs recorded in different locations during the process of rapid flooding of soil, 2003.**

| Place found | *Deroceras reticulatum* | | *Arion hortensis* | | Milacidae | |
|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % |
| Container lid | 45 | 33 | 7 | 4 | 0 | 0 |
| Container sides, above water level | 14 | 10 | 0 | 0 | 1 | 3 |
| Container sides, below water level | 0 | 0 | 2 | 1 | 0 | 0 |
| Kohlrabi slices | 46 | 34 | 146 | 78 | 28 | 82 |
| Soil surface | 29 | 21 | 24 | 13 | 3 | 9 |
| Cereal stalks | 1 | 1 | 7 | 4 | 1 | 3 |
| Soil below water | 1 | 1 | 0 | 0 | 1 | 3 |
| Total recorded | 136 | 100 | 186 | 100 | 34 | 100 |

Relatively few slugs were recorded after the end of the flooding period. The results for Glebe Field in Somerset, where the largest numbers of slugs were recorded, are shown in Table 5. Notably, 88% of all slugs were recorded by day 3 and 98% were recorded by day 4 of the extraction. This suggests that it is sufficient to examine the samples during the 3-day period of flooding and for one day afterwards.

**Table 5. Numbers and percentages of slugs extracted from soil over a period of 10 days with 3-day flooding, Glebe Field, 2003.**

| | Period of extraction (days) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| No. | 49 | 66 | 56 | 19 | 3 | 1 | 0 | 0 | 0 | 0 |
| % | 25.3 | 34.0 | 28.8 | 9.8 | 1.6 | 0.5 | 0 | 0 | 0 | 0 |
| Cum. % | 25.3 | 59.3 | 88.1 | 97.9 | 99.5 | 100 | | | | |

*Investigation of the rate of soil flooding*

At the study sites near Braunschweig and Stuttgart, too few slugs were extracted from soil samples to make any meaningful comparisons of rates of flooding or depth of sampling. At Braunschweig, a total of seven slugs were found, all in soil samples which had been flooded for three days.

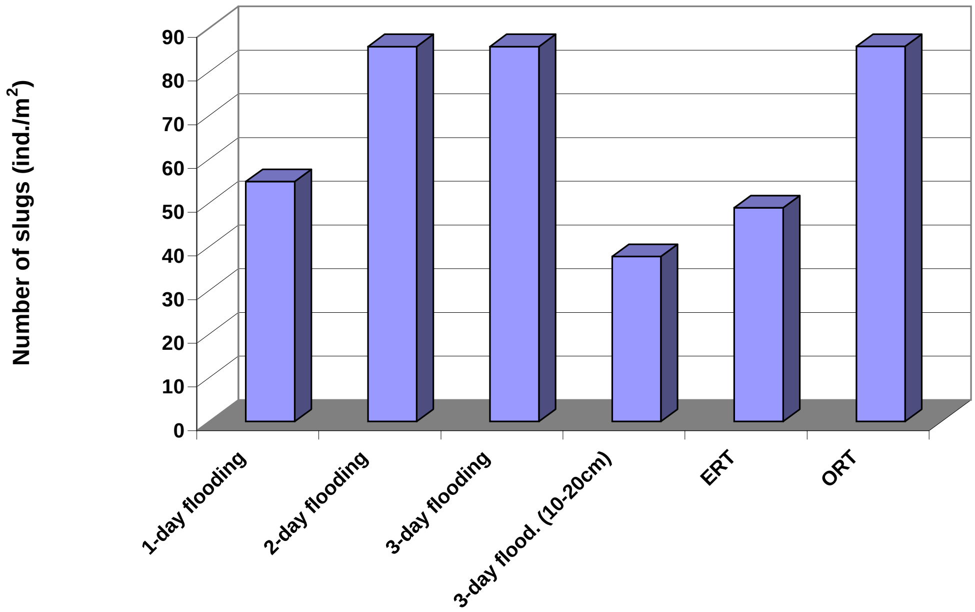
At Göttingen, the optimal rate of flooding of the soil samples was studied by taking three parallel sets of nine soil samples from a stubble field after harvest of oilseed rape on 15 September and 29 September 2003 (Wendelsgraben). This field yielded significantly higher numbers of slugs than the newly established oilseed rape fields (Figure 5). On each date, 100% and 94%, respectively, of slugs collected by flooding soil samples were identified as *Arion* sp. Very few slugs (0 - 6%) were found to be *D. reticulatum* and *Boettgerilla pallens*.

On both sampling occasions, the number of slugs extracted by rapid flooding over 1 day, as compared with the number extracted by flooding over 3 days, was clearly reduced. The 2-day flooding of soil samples resulted in a reduced number of slugs extracted only on 29 September. On 15 September, peak numbers of slugs were extracted by the 1-day, 2-days and 3-days flooding on Day 1, Day 2 and Day 3, respectively (Fig. 6). Only few slugs were found on Day 4 and Day 5 in the samples subjected to 3-day flooding and 90% had been extracted by Day 4. In contrast, on 29 September, for 1-day and 2-day flooding, the peak numbers of slugs were extracted on Day 2. The 3-day flooding yielded peak numbers of slugs on Day 3. Some specimens were detected on Day 4, 5 and 7 (Fig. 6) particularly after 3-days flooding (82% extracted by Day 4). Similarly, very few slugs were found at daily inspections up to Day 10 when the flooding had been completed after 1 or 2 days.

The mean weight of slugs extracted by 1-day, 2-day and 3-day-flooding at Göttingen on 15 September and 29 September ranged between 19mg and 65mg, and no significant difference was found between these treatments (Fig. 7). The mean weight of slugs collected on each single day of extraction by 1-day flooding, 2-day-flooding and 3-day-flooding and the proportion of each of three weight classes did not show clear differences (Fig. 8). However, while the small neonate slugs (<10mg) were predominant on 15 September, most of the individuals extracted on 29 September were of medium body weights (10-100mg). There was no clear indication that the juvenile slugs emerged from the samples later than the adult slugs (>100mg/ind.).

At Kiel, totals of 5, 4 and 6 slugs were recorded by 1-day, 2-day and 3-day flooding, respectively. The majority of slugs were recorded on day 1 of the extraction period, irrespective of the length of the flooding (Table 6). Single slugs were recorded from then on. For 3-day flooding, 5of a total of 6 slugs (83%) were recorded by day 4.

**15 September**




**29 September**

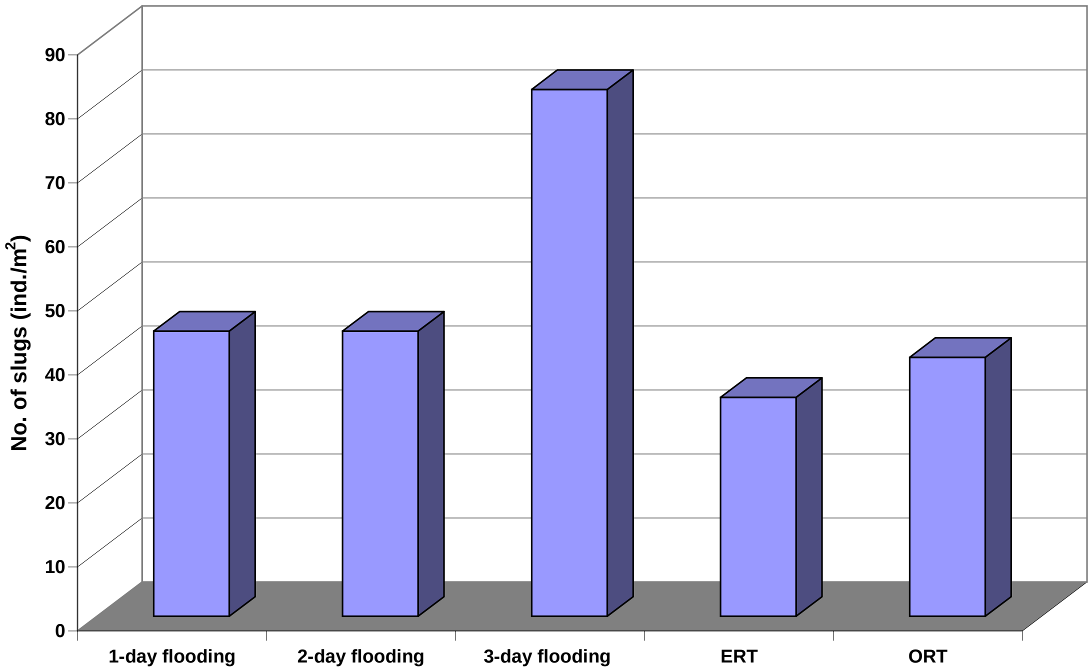
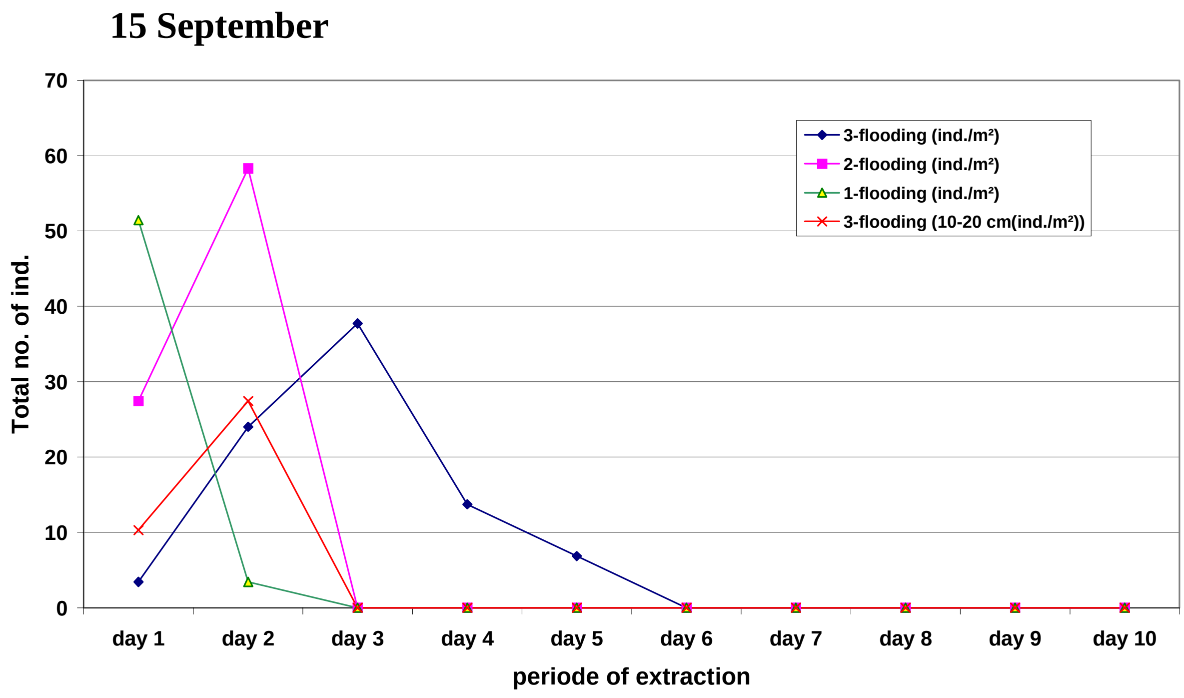



**Fig. 5. Number of slugs extracted from soil samples by 1-day, 2-days- and 3-days flooding and number of slugs collected by enclosed refuge traps (ERT) and open refuge traps (ORT), 15 and 29 September, oilseed rape stubble, Wendelsgraben, 2003.**



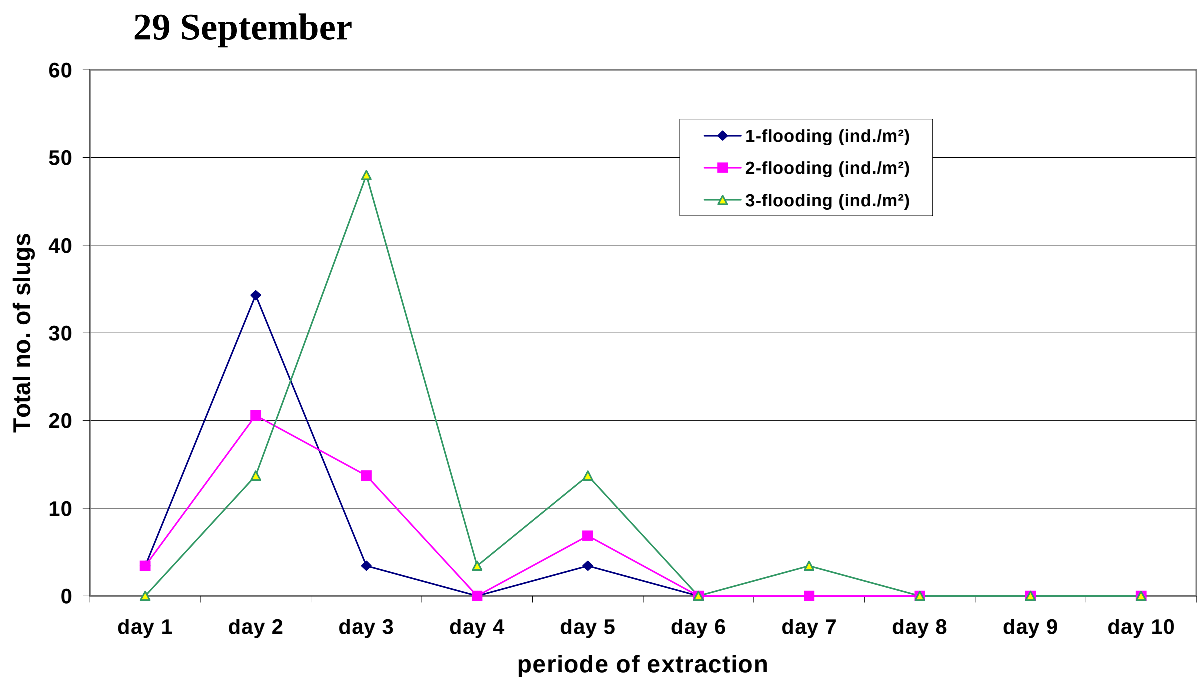




**Fig. 6. Number of slugs extracted from soil samples by 1-day, 2-day and 3-day flooding over a period of 10 days 15 & 29 September, oilseed rape stubble, Wendelsgraben, 2003.**

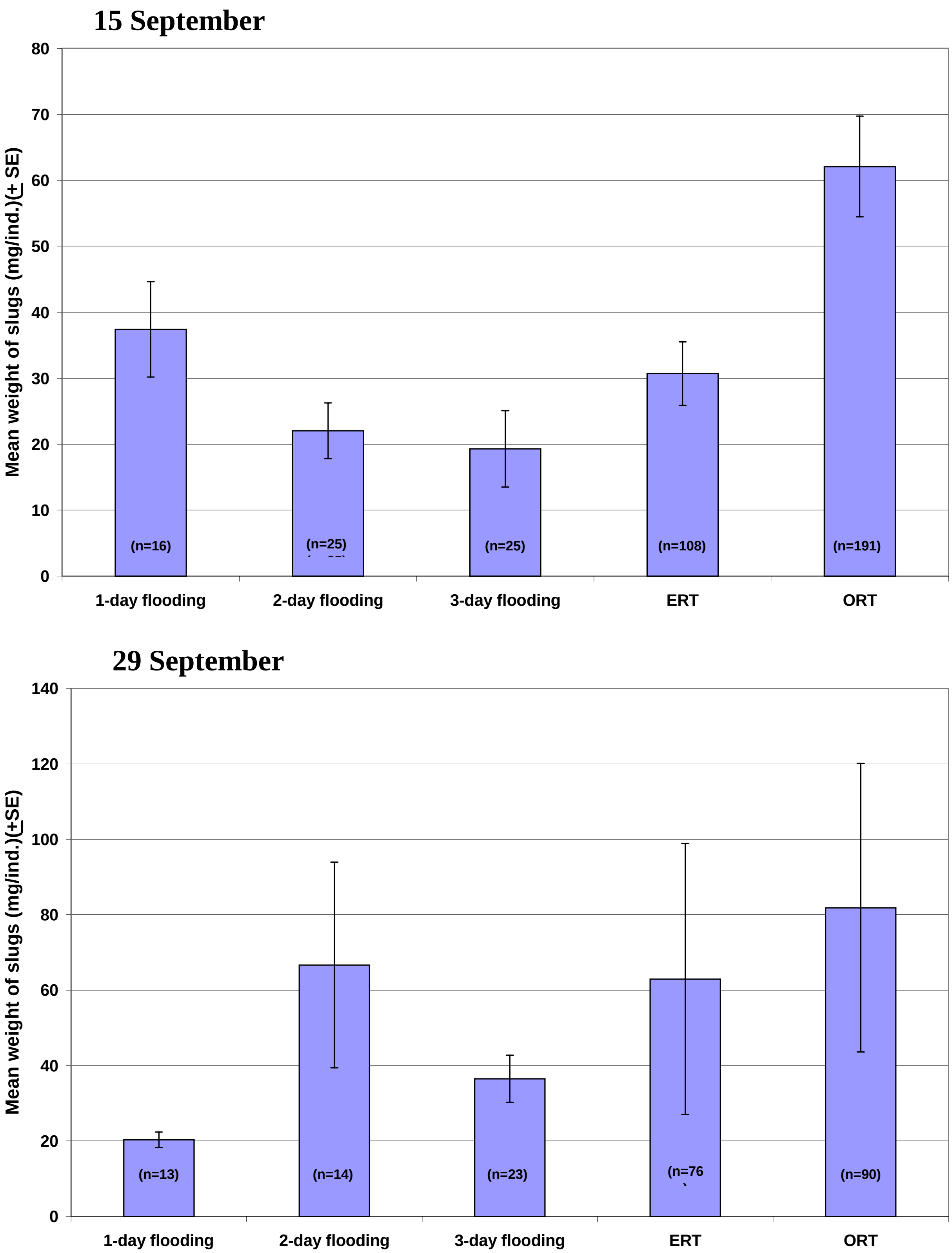
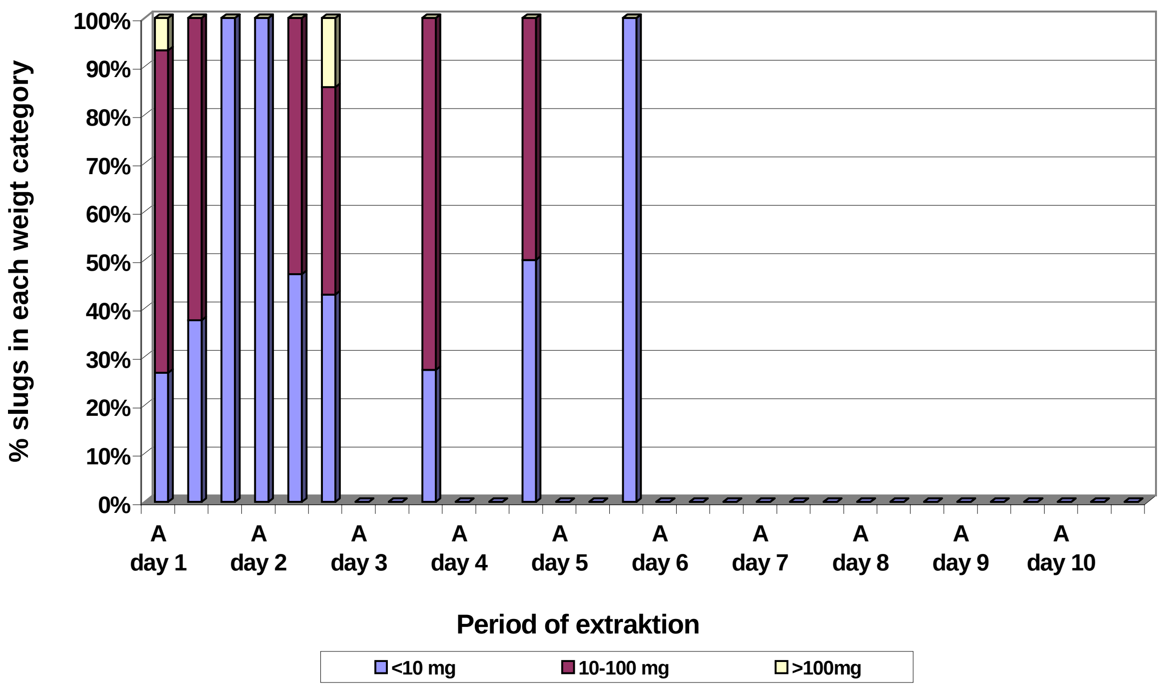



**Fig. 7. Mean weight of slugs extracted from soil samples by 1-day, 2-day- and 3-day flooding and weight of slugs collected by enclosed refuge traps (ERT) and open refuge traps (ORT). 15 & 29 September oilseed rape stubble, Wendelsgraben, 2003.**

**15 September**




**29 September**

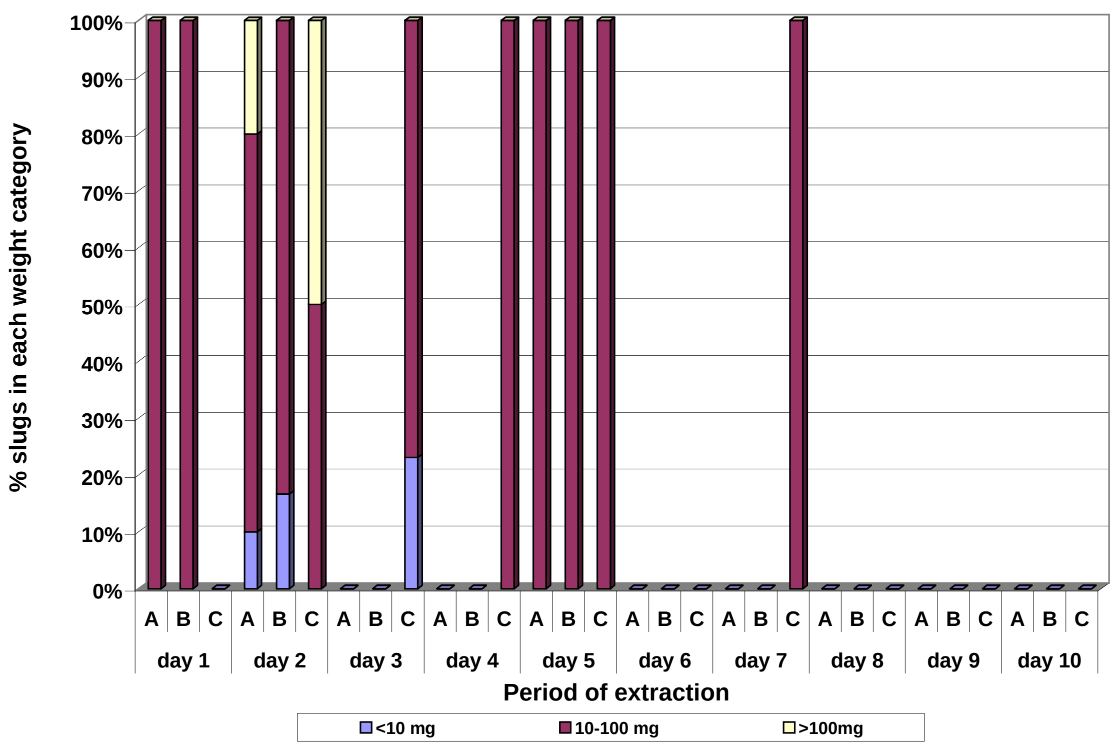



**Fig. 8.** **Proportion of slugs in three weight categories extracted from soil samples by (A) 1-day, (B) 2-day- and (C) 3-day flooding over a period of 10 days. 15 & 29 September oilseed rape stubble, Wendelsgraben 2003.**

**Table 6. Number of slugs extracted from soil samples by 1-day, 2-day and 3-day flooding over 10 days, oilseed rape stubble, Kiel.**

| | Period of extraction (days) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 day | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 day | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 3 day | 4 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |

At the site in Somerset with good numbers of slugs (Glebe Field), different rates of flooding of samples dug to 10 cm depth on 16 August were compared and these samples were compared with samples dug to 20 cm depth (Fig. 9). Three types of slugs were recorded: *D. reticulatum, A. hortensis* and Milacidae. There was clear evidence that one-day flooding was too rapid for effective extraction of slugs, especially for *A. hortensis*. Two-day flooding gave similar results to three-day flooding of samples dug to 10 cm depth.

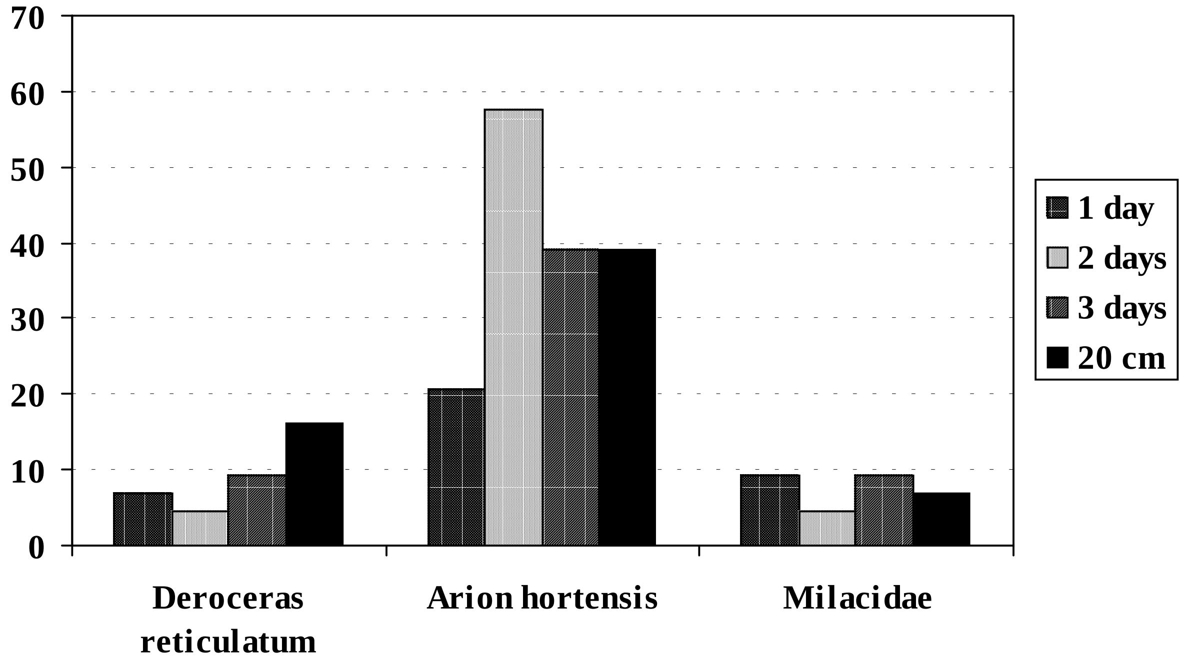



**Fig. 9. Mean numbers of three types of pest slug extracted from soil samples taken from cereal stubble, Glebe Field, Somerset on 16 August. Soil samples were dug to 10 cm depth and flooded for one day, two days or three days, or samples were dug to 20 cm depth and flooded for three days.**

*Investigation of the depth of soil sampling*

The seven slugs collected from study sites at Braunschweig all came from soil samples from a depth of 0-10 cm. At Göttingen, The effect of the depth of soil sampling was investigated on one sampling occasion at each site. On 4 August at Torland, seven slugs were extracted from nine soil samples from the depth of 0 – 10cm, but none from nine samples from the 10-20 cm depth. On 12 August at Marienstein, two slugs were found in 9 samples only from the depth of 10 – 20 cm. This might have resulted from the soil water content, which was slightly higher at Torland than at Marienstein (Table 2). At Uhlenloch, no slugs were found in samples taken from both the depth of 0 – 10 cm and 10 – 20 cm. At Wendelsgraben, on 15 September, the number of slugs in samples of 0 – 10cm was twice as high as the number in samples of 10 – 20cm depth (Fig. 5).

In cereal stubble at Glebe Field, Somerset, on 16 August, one sample was dug to a total depth of 20 cm from each of the 10 study plots and placed in a plastic container which was sufficiently large to permit the sample to be placed in two 10-cm depth layers side-by-side. These samples were taken at the same time as the series of three 10-cm depth samples that were dug from each plot to investigate different rates of flooding. The 20-cm depth samples were then flooded over three days in the same way as for 10 cm depth samples. The numbers of slugs of each species extracted (Fig. 9) were similar to those extracted from the samples dug to a depth of 10 cm and flooded for 2 or 3 days.

*Comparison of rapid method of sampling with standard method*

On 6 dates at Glebe Field in Somerset, the rapid method of sampling (with samples flooded over a three-day period), was compared with the standard method of soil sampling and flooding that was developed and used at Long Ashton Research Station (Fig. 10). For samples dug on 24 June and 31 July, more slugs were extracted from samples taken and processed using the rapid method than for samples taken and processed using the standard method. The difference was especially noticeable for *A. hortensis* in samples dug on 31 July. For samples taken on subsequent dates, there were no significant differences between the two methods. It seems likely that the poor performance of the standard method on the first two dates was because the samples were flooded in a glasshouse during periods of exceptionally hot weather (Fig. 18) during which the samples had heated to temperatures that were lethal to slugs, especially *A. hortensis*.

*Soil washing of samples after the end of flooding*

After the 10-day flooding and monitoring period at Stuttgart, 54 soil samples, taken during the stubble period before soil cultivation, were washed on a set of six sieve meshes, starting with a mesh size of 10x10 mm and ending with 1 mm². The results showed no single slug but a total of 4 slug eggs. The outcome supports the hypothesis that adult and juvenile slugs, being affected by the drought and high temperature, were already dead or at greater depth in soil, out of reach when the soil samples were taken. The few eggs left in the soil samples are likely to refer to be the remains of previous slug activity and oviposition.

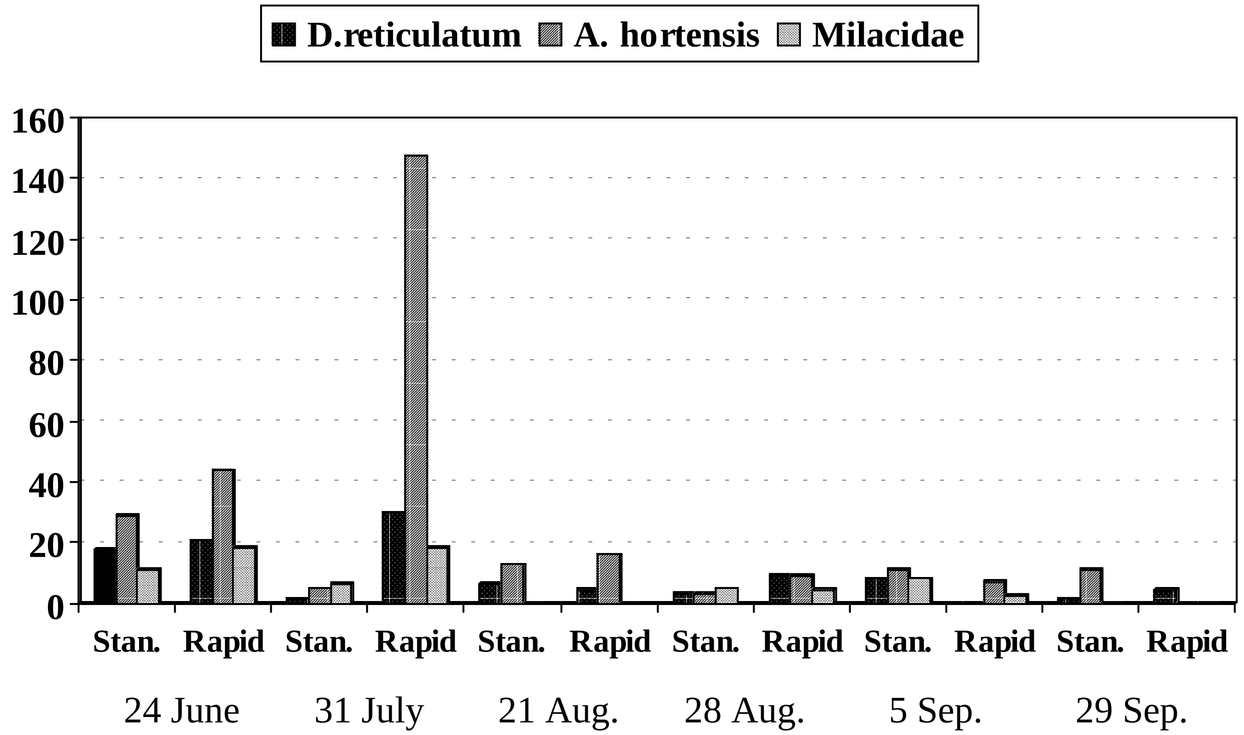



**Fig. 10. Numbers of three types of pest slug (*Deroceras reticulatum*, *Arion hortensis* and Milacidae) extracted by the standard (Stan.) method of soil sampling and flooding, compared with the rapid method of soil sampling and flooding developed in this project. This comparison was made on six dates from June to September 2003, Glebe Field, Somerset.**

**Comparison of the rapid soil sampling technique with methods for trapping slugs active on the soil surface**

*Braunschweig*

Three different types of traps were placed on the trial fields for estimating slug infestation incidence. Whilst mat traps enclosed by barriers only recorded slugs which came from the soil directly underneath the traps, slugs from outside the area were found underneath the mat traps and on the 1m² areas strewn with slug pellets. During the study period, 136 slugs of the genus *Deroceras* were recorded in the direct drilling plots in Sickte and 3 slugs of the genus *Arion*. The numbers of slugs recorded in the mat traps and the 1m² areas were similar, with an average of 4.7 and 4.8 *Deroceras*/m² respectively and 0.1 *Arion*/m² each (Tables 7 and 8). Slug infestation incidence in the soil recorded using mat traps surrounded by barriers was 0.4 *Deroceras*/m². No *Arion* spp. were recorded in Sickte using this kind of trap.

In the reduced tillage plots, seven slugs of the genus *Deroceras* were recorded, all underneath the mat trap, corresponding to an activity density of 0.6 slugs / m² (Table 5). The 13 slugs recorded in Wülperode all belonged to the genus *Arion*. Slightly more than half of the slugs were recorded with mat traps (Table 8). The types of traps were equally as effective for both genera (Tables 7 and 8).

*Comparing the average weight of the slugs recorded.* In the study period from the beginning of July to the end of October 2003 at Sickte, smaller slugs of both genera were caught on average in mat traps with barriers and soil samples than in 1m²-areas and open mat traps (Table 9). Whilst only slugs up to a weight of 600mg were found in enclosed mat traps and soil samples, slugs from all weight classes were found underneath the open mat traps and on 1m²-areas (from <100mg to >1000mg). This applied to both genera.

**Table 7. Average number of individuals of the genus *Deroceras*/m², recorded using the different types of traps, Sickte, July to October 2003.**

| Trial field | Enclosed mat trap | Mat trap | 1m² area |
|---|---|---|---|
| Direct drilling, Sickte | 0.4 | 4.7 | 4.8 |
| Reduced tillage, Sickte | 0 | 0,6 | 0 |
| Wülperode | 0 | 0 | 0 |

**Table 8. Average number of individuals of the genus *Arion*/m², recorded using the different types of traps, Sickte, July to October 2003.**

| Trial field | Enclosed mat trap | Mat trap | 1m² area |
|---|---|---|---|
| Direct drilling, Sickte | 0 | 0.1 | 0.1 |
| Mulching, Sickte | 0 | 0 | 0 |
| Wülperode | 0.5 | 1.3 | 0.7 |

The slugs recorded in the reduced tillage plots underneath the mat traps in Sickte of the genus *Deroceras* all weighed over 300 mg and on average 546mg, about 100mg more than those recorded in direct drilling area using the same trap method.

In Wülperode, only slugs of the genus *Arion* were recorded up to a weight of 400mg. The single slug recorded in the soil samples weighed 208 mg. Seven slugs recorded in open mat traps weighed an average of 61 mg, three slugs in the enclosed mat traps weighed on average 143 mg and one slug in the 1 $m^2$ area weighed 74 mg.

**Table 9. Number of slugs in the individual weight classes and average weights in the different types of traps from August to September 2003, direct drilling area, Sickte.**

| **Direct drilling, Sickte** | **1m² area** | | **Mat trap** | | **Enclosed mat trap** | | **Soil sample** | |
|---|---|---|---|---|---|---|---|---|
| | *Deroceras* | *Arion* | *Deroceras* | *Arion* | *Deroceras* | *Arion* | *Deroceras* | *Arion* |
| 1-10 mg | | | | | | | | |
| 10.1-32 mg | | | | | | | | 1 |
| 32.1-100 mg | 1 | | 2 | | | | | |
| 101-200 mg | 18 | 2 | 7 | | 1 | | | |
| 201-300 mg | 15 | | 9 | | 4 | | 1 | |
| 301-400 mg | 17 | | 14 | | | | 1 | |
| 401-500 mg | 20 | | 16 | | | | | 1 |
| 501-600 mg | 11 | | 12 | | | | 1 | 1 |
| 601-700 mg | 9 | | 5 | | | | | |
| 701-800 mg | 0 | | 4 | | | | | |
| 801-900 mg | 2 | | 2 | 1 | | | | |
| 901-1000 mg | 1 | | 1 | | | | | |
| > 1000 mg | | 1 | | | | | | |
| *Average weight (mg)* | *389* | *1496* | *433* | *826* | *244* | -- | *364* | *319* |

*Population development of* Deroceras *spp., Sickte*. The weights of all slugs of the genus *Deroceras*, found on the direct drilling area in Sickte underneath the open mat traps and in 1m²-areas, were categorised in size groups on a weekly basis (Fig. 11). This process showed clearly that the frequency of small (young) slugs decreased and the frequency of larger (older) slugs increased from week to week. Despite the low number of individuals, this tendency could also be observed in slugs taken from soil samples and mat traps surrounded by barriers.

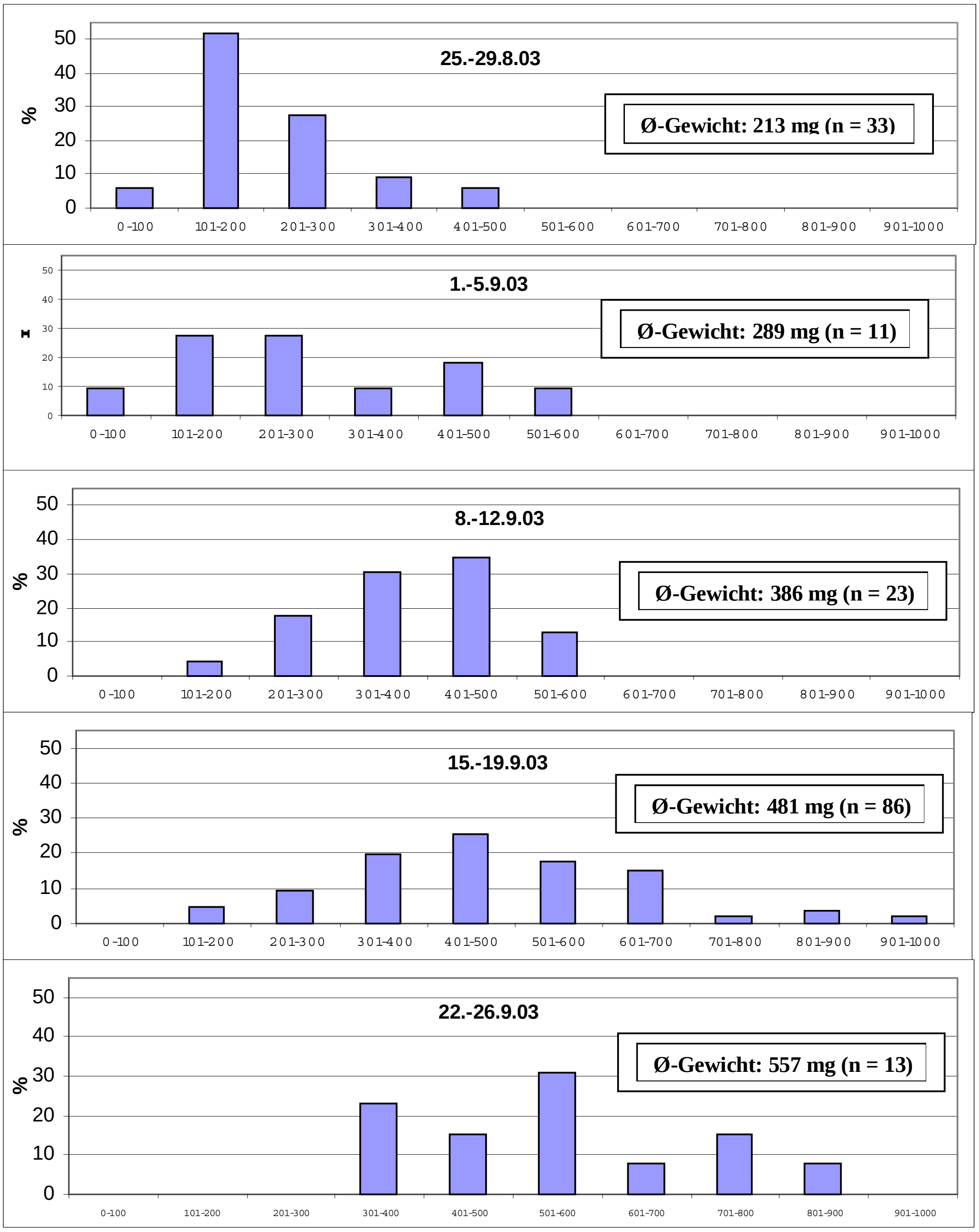



**Fig. 11. Percentage of *Deroceras spp*. in the respective size groups, recorded with direct drilling from 25.8.-26.9.03 by means of mat traps and in 1m²-areas in Sickte.**

*Comparison of methods*. In order to compare the methods, only slugs recorded in traps 1 day after the equivalent soil samples were taken into consideration. On nearly all assessment days a higher slug infestation incidence was found in soil using soil samples than by using enclosed emergence traps (Table 10). This applied to both genera. On sampling day V in the direct drilling area in Sickte, about three times as many *Arion* compared to *Deroceras* were recorded in soil samples. In contrast, all other methods used on this day did not record any *Arion spp*. During the determination of activity density on the soil surface, on most assessment days more slugs were recorded under mat traps than in the areas of 1m². Altogether, the number of slugs recorded on all three trial sites increased towards the end of the trial period.

**Table 10. Average infestation incidence of slugs (*Deroceras* spp. and *Arion* spp.) in soil (per m²), recorded by means of soil samples and enclosed mat traps and the activity density (per m²) established by mat traps and in areas of 1m² on different sampling days, Sickte and Wülperode, 2003.**

| | Sampling days | **II** | | **III** | | **IV** | | **V** | |
|---|---|---|---|---|---|---|---|---|---|
| **Site** | Soil samples/ type of trap | *Deroceras* | *Arion* | *Deroceras* | *Arion* | *Deroceras* | *Arion* | *Deroceras* | *Arion* |
| **Sickte, direct drilling** | Soil samples | 0 | 0 | 3.9 | 0 | 3.9 | 0 | 3.9 | 11.6 |
| | Enclosed mat traps | - | - | 0 | 0 | 0 | 0 | 0.7 | 0 |
| | Mat traps | - | - | 2.7 | 0 | 4.7 | 0.7 | 14 | 0 |
| | 1m²-areas | - | - | 3.5 | 0.7 | 0.7 | 0 | 6.7 | 0 |
| **Sickte, Reduced tillage** | Soil samples | - | - | 0 | 0 | 0 | 0 | 0 | 0 |
| | Enclosed mat traps | - | - | 0 | 0 | 0 | 0 | 0 | 0 |
| | Mat traps | - | - | 0 | 0 | 0 | 0 | 4.0 | 0 |
| | 1m²-areas | - | - | - | - | 0 | 0 | 0 | 0 |
| **Wül-perode** | Soil samples | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.4 |
| | Enclosed mat traps | - | - | - | - | 0 | 0.7 | 0 | 0.7 |
| | Mat traps | - | - | - | - | 0 | 1.3 | 0 | 0 |
| | 1m²-areas | - | - | - | - | 0 | 0.7 | 0 | 0 |

*Göttingen*

At Göttingen, The number captured in open mat traps and enclosed mat traps, as in soil samples, was relatively high in July and decreased sharply in August and September (Table 11), probably because the top soil had become very dry in August (Table 2). Moistening the soil with 5 litres of water per trap did not increase trap catch. Generally, the total number of slugs per $m^2$ extracted on all sampling occasions by flooding of soil samples tended to be higher than the total number per $m^2$ captured by refuge traps. The number of slugs found under the open mat traps on most sampling dates proved to be greater than the number found in the enclosed mat traps (Table 11).

While *D. reticulatum* was the predominant species in the soil samples and trap catches from Torland, *Arion* spp. (probably mainly *Arion distinctus*) represented ca 70% of all slugs sampled from Marienstein and ca 97% of all slugs sampled from Uhlenloch (Table 12). The species composition sampled by different techniques did not show any clear difference.

## Table 11. Number of slugs collected by flooding of soil samples and by refuge trapping, Göttingen

*TORLAND*

| Sampling date | Soil samples (No. of ind./m²) | Enclosed mat traps (No. of ind./m²) | Mat traps (No. of ind./m²) |
|---|---|---|---|
| **29 July** | **48.0 (3)** | **2.7 (4)** | **12.0 (9)** |
| **4 August** | **24.0 (3)**<br>**0*** | **1.3 (2)** | **2.2 (2)** |
| **1 September** | **0** | **0** | **1.3 (1)** |
| **24 September** | **0** | **0. 4 (1)** | **0** |
| **7 October** | **0** | **0** | **0.4 (1)** |

* Depth of sampling 10-20 cm; ( ) = total number of samples or traps yielding slugs

*MARIENSTEIN*

| Sampling date | Soil samples (No. of ind./m²) | Enclosed mat traps (No. of ind./m²) | Mat traps (No. of ind./m²) |
|---|---|---|---|
| **29 July** | **24.0 (3)** | **2.7 (5)** | **4.0 (5)** |
| **12 August** | **0**<br>**6.9* (1)** | **0** | **0** |
| **1 September** | **0** | **0** | **0.4 (1)** |
| **24 September** | **0** | **0** | **1.3 (3)** |
| **7 October** | **0** | **0.9 (2)** | **1.3 (3)** |

* Depth of sampling 10-20 cm; ( ) = total number of samples or traps yielding slugs

*UHLENLOCH*

| Sampling date | Soil samples (No. of ind./m²) | Enclosed mat traps (No. of ind./m²) | Mat traps (No. of ind./m²) |
|---|---|---|---|
| **29 July** | **24.0 (3)** | **0.4 (1)** | **0.4 (1)** |
| **1 September** | **0**<br>**0*** | **0** | **0** |
| **24 September** | **6.9 (2)** | **0.9 (2)** | **0.9 (1)** |
| **7 October** | **13.9 (3)** | **2.4 (5)** | **3.6 (5)** |

* Depth of sampling 10-20 cm; ( ) = total number of samples or traps yielding slugs

## Table 12. Slug species and number of individuals collected from each set of nine samples by flooding of soil samples and by refuge trapping, Göttingen, 2003.

*TORLAND*

| Sampling date | Soil samples | Enclosed refuge traps | Refuge traps |
|---|---|---|---|
| **29 July** | 13 *D. reticulatum*<br>1 *Arion* ssp. | 6 *D. reticulatum* | 21 *D. reticulatum*<br>9 *Arion* ssp. |
| **4 August** | 7 *D. reticulatum* | 3 *D. reticulatum* | 5 *D. reticulatum* |
| **1 September** | 0 | 0 | 3 *D. reticulatum* |
| **24 September** | 0 | 1 *D. reticulatum* | 0 |
| **7 October** | 0 | 0 | 1 *D. reticulatum* |

Total no. of slugs collected from all samples: *D. reticulatum:* 62 ind.; *Arion* ssp.: 10 ind.

*MARIENSTEIN*

| Sampling date | Soil samples | Enclosed refuge traps | Refuge traps |
|---|---|---|---|
| **29 July** | 2 *D. reticulatum*<br>5 *Arion* ssp. | 4 *D. reticulatum*<br>2 *Arion* ssp. | 3 *D. reticulatum*<br>11 *Arion* ssp. |
| **12 August** | 2 *Arion* ssp. | 0 | 0 |
| **1 September** | 0 | 0 | 1 *D. reticulatum* |
| **24 September** | 0 | 0 | 3 *Arion* ssp. |
| **7 October** | 0 | 2 *Arion* ssp. | 2 *D. reticulatum*<br>1 *Arion* ssp. |

Total no. of slugs collected from all samples: *D. reticulatum:* 12 ind.; *Arion* ssp.: 26 ind.

*UHLENLOCH*

| Sampling date | Soil samples | Enclosed refuge traps | Refuge traps |
|---|---|---|---|
| **29 July** | 1 *D. reticulatum*<br>6 *Arion* ssp. | 1 *Arion* ssp. | 1 *Arion* ssp. |
| **1 September** | 0 | 0 | 0 |
| **24 September** | 2 *Arion* ssp. | 2 *Arion* ssp. | 2 *Arion* ssp. |
| **7 October** | 3 *Arion* ssp. | 6 *Arion* ssp. | 9 *Arion* ssp. |

Total no. of slugs collected from all samples: *D. reticulatum:* 1 ind.; *Arion* ssp.: 31 ind.

*WENDELSGRABEN*

| Sampling date | Enclosed refuge traps | Refuge traps | Total<br>% (n) |
|---|---|---|---|
| 15 September | 97 *Arion* spp.<br>1 *D. reticulatum*<br>10 *B. pallens* | 154 *Arion* spp<br>10 *D. reticulatum*<br>28 *B. pallens* | 84% (251)<br>3% (11)<br>13% (38) |
| 29 September | 72 *Arion* spp.<br>3 *D. reticulatum*<br>2 *B. pallens* | 75 *Arion* spp.<br>7 *D. reticulatum*<br>9 *B. pallens* | 88% (147)<br>6% (10)<br>6% (11) |

## Table 13. Mean weight of slugs collected by flooding of soil samples and refuge trapping, Göttingen, 2003.

*TORLAND*

| Sampling date | Soil samples (mg/ind.) | Enclosed refuge traps (mg/ind.) | Refuge traps (mg/ind.) |
|---|---|---|---|
| 29 July | 359.6 (14) | 126,1 (6) | 780,1 (45) |
| 4 August | 53.8 (7) | 157,6 (3) | 69,3 (5) |
| 1 September | 0 | 57,9 (2) | 72,3 (6) |
| 24 September | 0 | 272,0 (1) | 0 |
| 7 October | 0 | 0 | 438,6 (1) |

( ) = total no. of slugs

*MARIENSTEIN*

| Sampling date | Soil samples (mg/ind.) | Enclosed refuge traps (mg/ind.) | Refuge traps (mg/ind.) |
|---|---|---|---|
| 29 July | 51.1 (7) | 96.9 (12) | 1340.3 (14) |
| 12 August<br>(10-20 cm) | 0<br>1.6 (2) | 0 | 0 |
| 1 September | 0 | 0 | 50.5 (1) |
| 24 September | 0 | 0 | |
| 7 October | 0 | 129.0 (2) | 305.5 (8) |

( ) = total no. of slugs

*UHLENLOCH*

| Sampling date | Soil samples (mg/ind.) | Enclosed refuge traps (mg/ind.) | Refuge traps (mg/ind.) |
|---|---|---|---|
| 29 July | 12.6 (7) | 51.8 (2) | 75.0 (1) |
| 1 September | 0 | 0 | 0 |
| 24 September | 36.4 (2) | 15.2 (3) | 24.8 (3) |
| 7 October | 17.0 (4) | 27.8 (18) | 62.0 (30) |

( ) = total no. of slugs

The body weight of slugs collected from rapid soil flooding ranged from 1 mg to 5691 mg, with very small juveniles being found at Uhlenloch and at Marienstein on 12 August. The mean weight of slugs captured by open refuge traps and enclosed refuge traps was higher. However, there was no consistent difference between the number and weight of slugs extracted from samples of both locations by the two techniques (Table 13).

*Exposure time required for refuge trapping*. In order to investigate the exposure time required for refuge trapping, the slugs captured by open mat traps and enclosed mat traps at all three study sites at Göttingen were collected in the morning after the first overnight exposure and for a second time after 3 days of exposure (Table 14). The number trapped after overnight exposure on most occasions was identical to or even higher than the number trapped after three days. If no slugs had been captured after the first night the same results was usually obtained after three days. There was only one exception, on 1 September at Torland, when 2 slugs were found in 9 enclosed refuge traps only on Day 3.

*Stuttgart*

Mat traps, both open and enclosed, were set up only if soil was visibly wet or after a rain event. These conditions suitable for trapping were rare. Three occasions were utilised despite being sub-optimal and not fitting the minimum requirements specified in the project protocols. Except for a single slug trapped on the first occasion, both types of mat traps did not reveal any further slugs. The total precipitation on the specified occasions was extremely low and most of the resulting moisture was lost by evaporation. The Soil remained therefore rather too dry to encourage slug activity.

*Kiel*

Mat traps showed a similar pattern in slug numbers to soil sampling and the method of pulling up plant roots (Fig. 3), with largest numbers on the first date of sampling and smaller numbers later.

*Somerset*

Trapping was done at the same time as soil sampling on six occasions in Glebe Field from June to August 2003 (Table 15). On all these dates, plastic plant-pot saucers baited with chicken layers' mash were used as the traps. The picture of the slug population provided by trapping was very different to that revealed by soil sampling. The most common slugs in the traps at Glebe Field were large individuals of *D. reticulatum* all over 100 mg and averaging about 300 – 400 mg. In contrast, *A. hortensis* were present in low numbers traps but in large numbers in soil. Thus, traps failed to show that there were large numbers of *A. hortensis* present in the soil. The few individuals of *A. hortensis* recorded in the traps were on average smaller than *D.* reticulatum, but *A. hortensis* of the size range found in traps were rather uncommon in soil samples. Slugs of the family Milacidae were found in low numbers in both traps and soil.

## Table 14. Number of slugs captured by enclosed refuge traps and open refuge traps on the 1st and 3rd day of exposure, Göttingen.

*TORLAND*

| Sampling date | Enclosed mat traps No. of ind./$m^2$ captured after | | Open mat traps No. of ind./$m^2$ captured after | |
|---|---|---|---|---|
| | 1 day | 3 days | 1 day | 3 days |
| **29 July** | **2.7** | **0** | **12.0** | **8.0** |
| **4 August** | **1.3** | **0** | **2.2** | **0** |
| **1 September** | **0** | **0.9** | **1.3** | **1.3** |
| **24 September** | **0.4** | **0** | **0** | **0** |
| **7 October** | **0** | **0** | **0.4** | **0** |

*MARIENSTEIN*

| Sampling date | Enclosed mat traps No. of ind./$m^2$ captured after | | Open mat traps No. of ind./$m^2$ captured after | |
|---|---|---|---|---|
| | 1 day | 3 days | 1 day | 3 days |
| **29 July** | **2.7** | **2.7** | **4.0** | **2.2** |
| **12 August** | **0** | **0** | **0** | **0** |
| **1 September** | **0** | **0** | **0,4** | **0** |
| **24 September** | **0** | **0** | **1.3** | **0** |
| **7 October** | **0.9** | **0** | **1.3** | **2.2** |

*UHLENLOCH*

| Sampling date | Enclosed refuge traps No. of ind./$m^2$ captured after | | Open refuge traps No. of ind./$m^2$ captured after | |
|---|---|---|---|---|
| | 1 day | 3 days | 1 day | 3 days |
| **29 July** | **0.4** | **0.4** | **0.4** | **0** |
| **1 September** | **0** | **0** | **0** | **0** |
| **24 September** | **0.9** | **0.4** | **0.9** | **0.4** |
| **7 October** | **2.4** | **1.8** | **3.6** | **9.8** |

**Table 15. Densities of different size classes of three types of pest slug recorded in soil samples and saucer traps, Glebe Field, Somerset, June to August (winter wheat going to oilseed rape) and from a grass/clover sward on 29 October, Cheddar, Somerset**

| Date When traps examined | *Deroceras reticulatum* | | | | | | |
|---|---|---|---|---|---|---|---|
| | Soil samples: No./$m^2$ | | | | Saucer traps | | |
| | 1-10 mg | 11-100 mg | >100 mg | Total | No. per Trap | % >100 mg | Mean wt (mg) |
| 24 Jun | 0 | 0 | 20.7 | 20.7 | 5.1 | 100 | 406 |
| 18 Jul. | 0 | 0 | 13.8 | 13.8 | 12.6 | 100 | 303 |
| 1 Aug. | 4.6 | 2.3 | 23.0 | 29.9 | 30.8 | 100 | 293 |
| 2 Aug | 4.6 | 2.3 | 23.0 | 29.9 | 17.6 | - | - |
| 30 Aug. | 6.9 | 2.3 | 0 | 9.2 | 0 | - | - |
| 29 Oct | 0 | 20.4 | 86.9 | 107.3 | 6.4 | 100 | 367 |

| Date When traps examined | *Arion hortensis* | | | | | | |
|---|---|---|---|---|---|---|---|
| | Soil samples: No./$m^2$ | | | | Saucer traps | | |
| | 1-10 mg | 11-100 mg | >100 mg | Total | No. per Trap | % >100 mg | Mean wt (mg) |
| 24 Jun | 34.5 | 9.2 | 0 | 43.7 | 0.4 | 100 | 289 |
| 18 Jul. | 27.6 | 4.6 | 0 | 32.2 | 0.2 | 67 | 113 |
| 1 Aug. | 66.7 | 80.5 | 0 | 147.2 | 1.6 | 27 | 82 |
| 2 Aug | 66.7 | 80.5 | 0 | 147.2 | 0.3 | - | - |
| 30 Aug. | 2.3 | 6.9 | 0 | 9.2 | 0 | - | - |
| 29 Oct | 2.6 | 89.4 | 110 | 202.0 | 3.2 | 85 | 185 |

| Date When traps examined | Milacidae (keeled slugs) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Soil samples: No./$m^2$ | | | | Saucer traps | | |
| | 1-10 mg | 11-100 mg | >100 mg | Total | No. per Trap | % >100 mg | Mean wt (mg) |
| 24 Jun | 2.3 | 6.9 | 9.2 | 18.4 | 1.3 | 80 | 524 |
| 18 Jul. | 0 | 0 | 4.6 | 4.6 | 0.1 | 100 | 463 |
| 1 Aug. | 0 | 18.4 | 0 | 18.4 | 1.9 | 94 | 495 |
| 2 Aug | 0 | 18.4 | 0 | 18.4 | 0.4 | - | - |
| 30 Aug. | 0 | 4.6 | 0 | 4.6 | 0 | - | - |
| 29 Oct | 2.6 | 0 | 10.2 | 12.8 | 1.0 | 88 | 527 |

Despite the fact that traps were put out only when the soil surface was moist and suitable for slug activity, there was considerable variability in the relationship between the number of slugs per trap and the number of slugs >100 mg in soil samples on different dates (Table 15). It was particularly notable that when traps were put out and examined on two successive days (1 and 2 August) at Glebe Field, there was a 43% drop in the activity of *D. reticulatum* and proportionately greater reductions in the activity of other slug species on the second day.

Open Mat traps baited with metaldehyde pellets were compared with saucer traps baited with chicken layers' mash in the standing winter wheat crop in Glebe Field on 19 July (Table 16). Enclosed mat traps surrounded with barriers were not included in this comparison on this date because of the difficulty of inserting the barriers around the traps within a standing wheat crop. Both types of traps were examined the following morning then removed. Significantly more ($P$ <0.05) *D. reticulatum* were recorded in saucer traps than in mat traps and the mean weight of *D. reticulatum* in saucer traps was significantly greater ($P$ < 0.01) than in the mat traps. Small numbers per trap of *Arion hortensis* and Milacidae were recorded in both types of trap, insufficient for statistical analysis of numbers and weights.

## Table 16. Comparison of slug catch in two types of trap left overnight before examination, Glebe Field, 19 July.

| Trap type | *Deroceras reticulatum* | | *Arion hortensis* | | Milacidae | |
|---|---|---|---|---|---|---|
| | No./trap | Mean wt (mg) | No./trap | Mean wt (mg) | No./trap | Mean wt (mg) |
| Saucer traps | 12.6 | 303 (n=20) | 0.2 | 114 (n=3) | 0.1 | 463 (n=2) |
| Mat traps | 8.6 | 216 (n=16) | 0.3 | 138 (n=1) | 0.4 | 270 (n=3) |
| Least significant difference | 3.2 | 56 | - | - | - | - |

Open mat traps baited with metaldehyde pellets were compared with mat traps surrounded by barriers and with saucer traps baited with chicken layers' mash in recently drilled oilseed rape in Glebe Field and Paddock 123 on 29 and 30 August respectively. However, too few slugs were found for a meaningful comparison of trap types.

It was not possible to put out traps on other occasions in these study fields because the predominantly dry weather considerably restricted opportunities for trapping. Because of this, an additional comparison of trapping methods and soil sampling was made on 28-29 October, after the first substantial autumn rains, in a field in Cheddar, Somerset with a grass/clover sward which had been irrigated during summer. After one night, more individuals of *D. reticulatum* were recorded in the open mat traps than in either the saucer traps or the enclosed mat traps, but this difference was not statistically significant (Fig. 12). Numbers of *A. hortensis* agg. were similar in all three trap types, but more than twice as many Milacidae (*Tandonia budapestensis, Tandonia sowerbvi* and *Boettgerilla pallens*) were recorded in the open mat traps than in the saucer traps (Fig. 12) and this difference was statistically significant ($P < 0.05$). It is not possible to say whether this difference in trap catch of keeled slugs was due to the nature of the trap cover or to the difference in baits: saucer traps were baited with chicken layers' mash, whereas the mat traps were baited with metaldehyde pellets.

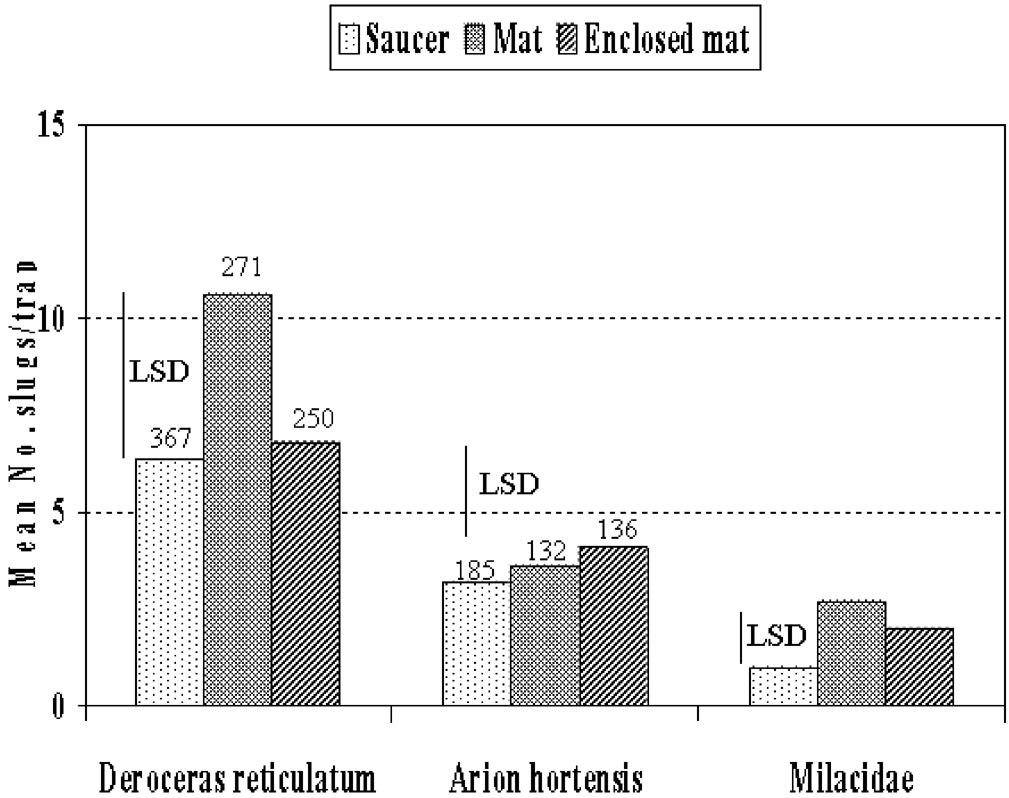



**Fig. 12. Comparison of slug catch in three different types of traps after one night, 29 October 2003, grass/clover sward, Cheddar. (LSD = Least significant difference, *P* = 0.05). Figures above columns are mean weights.**

The mean weights of *D. reticulatum* and *A. hortensis* in each type of trap are also shown in Fig. 12. The mean weights of both species in saucer traps were significantly greater ($P < 0.05$) than in the open and enclosed mat traps. However, these differences in weights between trap types need to be treated with caution because of the differences in bait: slugs in saucer traps would have increased in weight by consuming the chicken layers' mash used as bait, whereas slugs recorded in the mat traps could have lost weight due to the water loss which results from metaldehyde poisoning.

Enclosed mat traps were left for seven days. The total numbers/m$^2$ of *D. reticulatum* and *A. hortensis* recorded over this period were similar to the number/ m$^2$ of individuals >100mg of the same species recorded in soil samples extracted by rapid flooding (Fig. 13), indicating that the enclosed traps provided an accurate estimate of the density of slugs of these species >100 mg present in soil. However, for slugs of the family Milacidae, the density recorded in enclosed mat traps was considerably greater than the density of Milacidae >100 mg in soil samples (Fig. 13). This may indicate that soil sampling to 10 cm depth underestimated the density of large individuals of milacids in soil, perhaps because they were resting at greater depth in the soil during the day when the samples were taken.

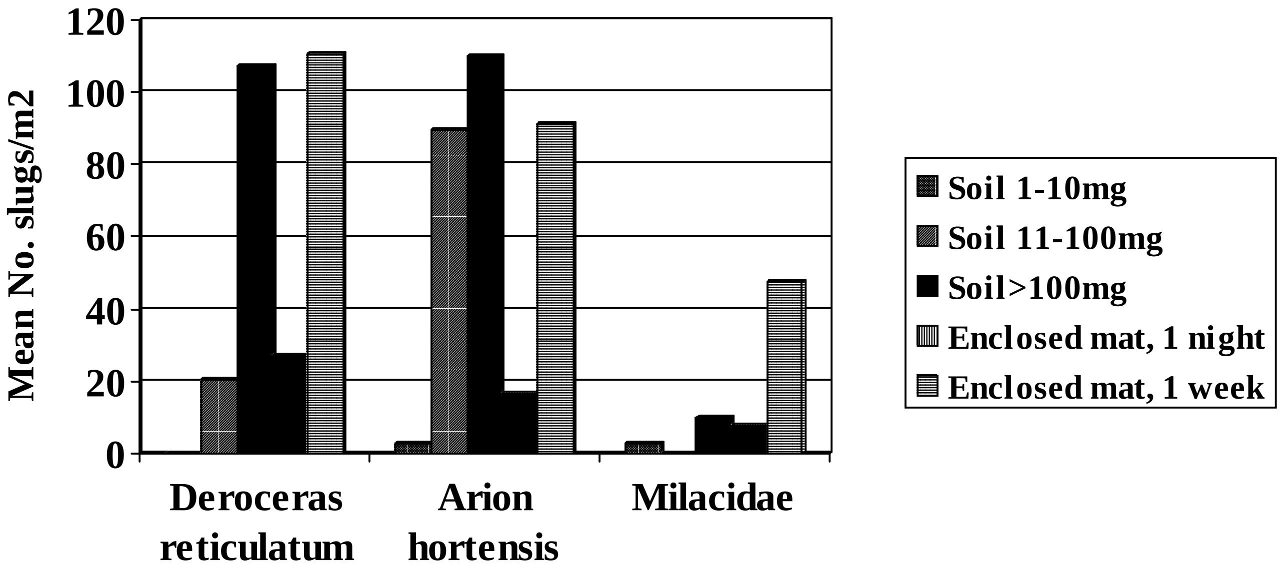



**Fig. 13. Comparison of slug numbers/m$^2$ in three size classes in soil samples and the numbers/m$^2$ in enclosed mat traps after one night and one week, October-November 2003, grass/clover sward, Cheddar.**

### Severity of slug damage to oilseed rape in relation to the slug population

*Plant numbers and slug damage*

Slug damage (Table 17) was measured as (1) the % reduction in the mean number of oilseed rape seedlings/m$^2$ on untreated plots compared with plot areas treated with metaldehyde pellets, and (2) the percentage of seedlings with slug damage on untreated plots compared with plot areas treated with metaldehyde pellets at the same site.

There was no evidence of a significant difference in numbers of plants establishing on metaldehyde-treated compared with untreated plots on any of the 11 study sites. Nor was there evidence of any significant difference in the percentage of seedlings with slug damage between treated and untreated plots on 8 of the 11 study sites. On the remaining three sites, slug damage on the direct-drilled area at Sickte, Braunschweig, reached 19% on untreated plots compared to none on treated plots at the cotyledon stage. By the 4-true-leaf stage, damage had risen to 34% on untreated plots compared to 23% on treated plots. This sharp increase in damage on both treated and untreated plots suggests that other pests, e.g. caterpillars, may have been responsible for much of this damage. Similarly, on the reduced tillage area at Sickte, by the 4-true-leaf stage, damage had reached 12% on untreated plots compared to 22% on treated plots. In this case it was evident that this damage was due to game animals (deer etc) and not slugs.

On Paddock 123, Somerset, damage increased from 2.5% to 5.5% on the untreated plots by 30 September (4-true-leaf stage). On both dates, damage on the treated plots was not significantly less than these values, but there had been a significant increase in damage ($P < 0.05$) on the untreated plots by 30 September, compared to no significant increase on the treated plots, suggesting that there was a little slug damage at this site. At the third site with damage, Glebe Field, there was significantly more damage on the untreated plots (4.6%) than on the treated plots at the 2-true-leaf stage on 12 September. By the 4-true-leaf stage on 29 September, damage had increased on both treated and untreated plots to a mean of 7.4%, but the difference between treated and untreated areas was no longer significant, again suggesting that other pests may have been responsible for most of the damage by the later date.

## 4. Discussion

The rapid method of soil sampling developed and tested in this project in 2003 proved to be quick, simple and highly effective. The results confirm results from 2002 that the detection of slugs on the soil surface during the flooding process is greatly improved by placing kohlrabi slices on the surface of soil. With a 3-day period of flooding, followed by seven further days of observation, 82-98% of all the slugs recovered from soil samples were recorded during the initial 4-day period (three days of flooding followed by one further examination one day later). The numbers recovered in this way compared favourably with a standard method of slower flooding, over nine days, and there was no evidence of slugs remaining in the soil samples at the end of the 10-day period of observation. The comparison with the standard method of flooding revealed the key importance of keeping soil samples cool throughout the period for processing samples, as hot weather in June and July clearly resulted in reduced numbers being extracted from the standard soil samples, which were processed in a glasshouse.

**Table 17. Slug damage to oilseed rape on 11 fields in 2003, together with slug infestation, estimated using the rapid sampling method and the numbers of slugs per trap.**

| Location | Site & method of cultivn | Slug data | Standing cereals | Cereal ctubble | Oilseed rape establishment (Sept.-Oct.) | | | Slug damage | |
|---|---|---|---|---|---|---|---|---|---|
| | | | July-early Aug. | Late July-Aug. | Drill | Emer-gence | 4-true-leaf | % decrease plant no. | % Plants damaged by slugs |
| Braunsch-weig | Sikte Field 1 (Direct drilled) | No./m² Soil | - | 0 | 3.1 | 3.1 | 12.4 | 0 | 19 |
| | | No./trap | 4.8 (mean for all dates) | | | | | | |
| | Sikte Field 2 (Reduced tillage) | No./m² Soil | - | 0 | 0 | 0 | 0 | 0 | 0 |
| | | No./trap | 0.6 (mean for all dates) | | | | | | |
| | Wülperde (Reduced tillage) | No./m² Soil | - | 0 | 0 | 0 | 3.4 | 0 | 0 |
| | | No./trap | 1.3 (mean for all dates) | | | | | | |
| Göttingen | Torland (Reduced tillage) | No./m² Soil | 48.0 | 24.0 | 0 | 0 | 0 | 0 | 0 |
| | | No./trap | 3.0 | 0.6 | 0.3 | 0 | 0.1 | | |
| | Marienstein (Reduced tillage) | No./m² Soil | 24.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | No./trap | 1.0 | 0 | 0.1 | 0.3 | 0.3 | | |
| | Uhlenloch (Ploughed) | No./m² Soil | 24.0 | - | 0 | 6.9 | 13.9 | 0 | 0 |
| | | No./trap | 0.1 | - | 0 | 0.2 | 0.9 | | |
| Stuttgart | Kornberg (Reduced tillage) | No./m² Soil | 78 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | No./trap | - | 0 | - | - | - | | |
| | Honigbaum (Reduced tillage) | No./m² Soil | 13 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | No./trap | - | 0 | - | - | - | | |
| | Ob-der-Kirche (Reduced tillage) | No./m² Soil | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | No./trap | - | 0 | - | - | - | | |
| Somerset | Glebe Field (2 x Reduced tillage) | No./m² Soil | 195.5 | 57.7 | 23.0 | 9.2 | 4.6 | 0 | 4.6 |
| | | No./trap | 33.1 | - | 0 | - | 0.3 | | |
| | Paddock 123 (2 x Reduced tillage) | No./m² Soil | 0 | 7.7 | 5.1 | - | 2.6 | 0 | 2.5 |
| | | No./trap | 3.2 | - | 0 | - | - | | |

Comparisons of 1-, 2- and 3-day periods of flooding showed that 1-day flooding is definitely too short to permit extraction of the full number of slugs from soil. Two-day flooding performed well in most cases, but there was evidence that this period was too brief in one case, so it is recommended that a three-day flooding period is used.

The weather conditions in summer and early autumn 2003 were exceptionally dry and hot. This combination provided poor conditions for the activity and reproduction of *Deroceras reticulatum*, which is highly dependent on soil moisture. This was equally true in Germany and England, with clear evidence of a lack of successful breeding buy this species. At Braunschweig *D. reticulatum* appeared to be able to survive as adults on the direct-drilling area at Sickte (or possibly it was able to move into this area from a neighbouring area). The surviving adults grew larger as the autumn progressed, but with no evidence of hatch of juvenile slugs by the end of the period of study in late September.

In contrast to *D. reticulatum*, small juveniles of *Arion* spp., especially *A. hortensis*, were found at several sites in 2003 and it therefore appeared that this species had been able to breed in spring 2003. This was especially the case at one field site where small immature *A. hortensis* were found in considerable numbers in soil samples. In contrast, refuge trapping at this site failed to detect significant numbers of *A. hortensis*. Thus, trapping failed to detect a significant threat from *A. hortensis*, indicating strongly that, on its own, trapping is not a suitable method for assessing the risk of slug damage to oilseed rape.

As in 2002, the rapid method of soil sampling provided useful estimates of slug numbers in soil even when soil surface conditions were recorded as dry or drying. This was because, despite the dry surface, there was in at least some cases adequate soil moisture below the surface throughout the period of study especially in the 2–10 cm soil layer (Tables 2 & 3). Slug numbers recorded in soil samples declined markedly in all cultivated field sites during August and September. It is likely that this was due to the combined effects of dry weather and cultivation. This suggestion is supported by the observation that the only site where slug numbers increased during September was the direct-drilled area at Sickte.

Comparisons of sampling to 10 and 20 cm depth showed, in all but one case, no evidence of substantial numbers of slugs in the lower 10-20 cm layer. The exception was in oilseed rape stubble at Wendelsgraben in mid September, where the density of slugs in the 10-20 cm layer was about half that in the upper, 0-10 cm layer. This may have been a consequence of the dead roots of oilseed rape plants providing channels to enable slugs to move deeper into the soil than they would normally do in cereal crops or cereal stubbles before drilling oilseed rape.

Because one standard method of rapid soil sampling and two standard methods of slug trapping were used at all sites, it is possible to compare results between partners, in a way that could not be done for trapping in 2002. For the purpose of practical risk assessment, there appeared to be no advantage in using enclosed traps, surrounded by barriers, which could only record slugs from the defined area of the trap. These traps were time-consuming to set up in the field, especially in stony soils where it was difficult to insert the barriers into the soil. (Such traps do, however, have advantages for research purposes, as shown, for example, by the results in Fig. 13).

The large mat traps, each 0.5 m x 0.5 m, used as the standard method of trapping in this study, appeared to have no consistent advantage over smaller traps when the traps were left out overnight for monitoring *D. reticulatum* and *Arion* spp. Only for keeled slugs (Milacidae) was there evidence of any advantage in using the larger mat traps baited with metaldehyde pellets. However, it is not possible to say whether this difference was due to the trap or the bait.

Smaller traps of dimensions 0.25m x 0.25 m square or 0.25 m in diameter have considerable advantages in ease of use over the larger mat traps: they are easier to transport to and from the field, especially when the traps have been exposed to rain overnight and the heavy dripping wet traps are removed in the morning. One further important advantage of the smaller traps is the ability to place them in standing cereals before harvest without having to cut down a patch of the crop.

As in 2002, trapping provided variable results, probably depending largely on soil surface moisture conditions together with weather conditions on the day of examination. The usefulness of trapping as a tool for assessing damage risk was again greatly restricted by dry soil surface conditions. At Göttingen, as in 2002, an attempt was made to overcome this problem by wetting the soil surface under each trap. In 2003 the amount of water used was increased from 2 litres to 5 litres. Despite this, no improvement in trap catch was recorded.

## 5. Conclusions and further developments

The method of rapid soil sampling for slugs developed and used in this project involves simply digging soil samples with a spade and flooding them over a 3-day period, with a further one day period after the end of flooding for collecting slugs. It provides a full picture of all the active stages in the slug life-cycle (that is, all stages except eggs). This method is suitable in its present form for use by farmers and consultants to provide a true picture of the slug population in soil in the period leading up to establishment of oilseed rape crops.

The data from the field sites in this study, together with the earlier pilot project in 2002, provide valuable preliminary information on the relationship between slug population density and the severity of slug damage to oilseed rape at establishment. However, in 2003 slug populations were low and the weather was dry and unsuitable for slug activity on all study sites at the time of drilling oilseed rape and during the critical period of early establishment when the seedlings are most vulnerable to slug damage. For these reasons, it is not possible to specify threshold slug numbers in soil samples or traps indicating different levels of risk of slug damage to oilseed rape. It is likely that the amount of damage will depend on both slug numbers and their behaviour at oilseed rape establishment, as determined by soil and weather conditions. This emphasises the need for further investigations under a wide range of weather, soil and agronomic conditions.

It is also not possible at this stage to identify soil sampling or slug trapping as the single best method of monitoring, as soil sampling and trapping both possess advantages and disadvantages, which are summarised below.

*Soil sampling - advantages*

- provides excellent data on slug populations, even in hot weather,
- detects slugs (including small juveniles) under a wide range of soil & weather conditions,
- Only one visit to field site is required per assessment
- 3 day period of flooding is sufficient for good results
- 10-cm depth of soil samples gives good results

*Soil sampling - disadvantages*

- Takes more time than trapping
- A relatively small area of soil sampled (ca. 30 samples/$m^2$), so this does not detect low densities of large adults

*Trapping - advantages*

- Relatively quick & easy, if small traps, *ca.* 0.25 m square or diameter, are used
- Can detect relatively low densities of adult slugs

*Trapping - disadvantages*

- Soil surface MUST be moist
- Poor at detecting juvenile slugs
- Two visits required per sample

Because both methods possess both advantages and disadvantages, it is recommended that both soil sampling and trapping are used in further investigations.

It is not possible to specify whether the best time of monitoring for risk assessment is before cereal harvest or during the fallow period after harvest. If conditions are suitable for soil sampling and trapping, then the fallow period is possibly the best time for monitoring. However, monitoring in cereals before harvest may be the better option in some circumstances. Many farmers now grow winter wheat rather than winter barley immediately before oilseed rape in the crop rotation. The later harvest of wheat gives the farmer less time to assess the risk of slug damage in the brief fallow period before oilseed rape is drilled. This is a busy time for farmers and experience in 2002 and 2003 shows that rapid drying of the soil can result in unsuitable soil conditions for slug sampling, with slugs moving deep into the soil where they cannot be detected. Assessment of slug numbers before cereal harvest would also alert farmers to the need for cultural control measures, such as two passes of shallow tillage, which appeared to be effective at study sites in 2002 and 2003.

It will be important to test the reliability of soil sampling and trapping for assessing the risk of slug damage to oilseed rape under a wide range of weather, soil and agronomic conditions. Therefore, these techniques should be validated for the purpose of risk assessment at several field sites and locations. The process of validation should include crop consultants to give a practical perspective on the technology as well as to provide wider geographical cover of the regions of Germany.

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# 7. Appendix of weather records

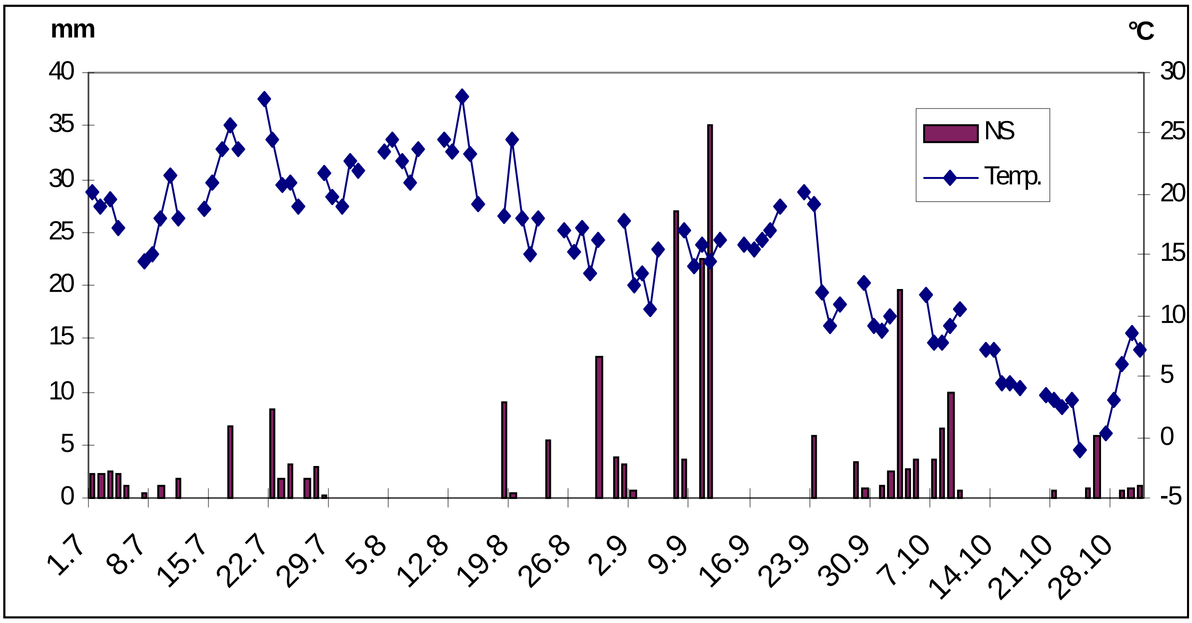


**Fig. 14. Average daily temperatures and rainfall from July to October 2003 in Sickte, Braunschweig.**

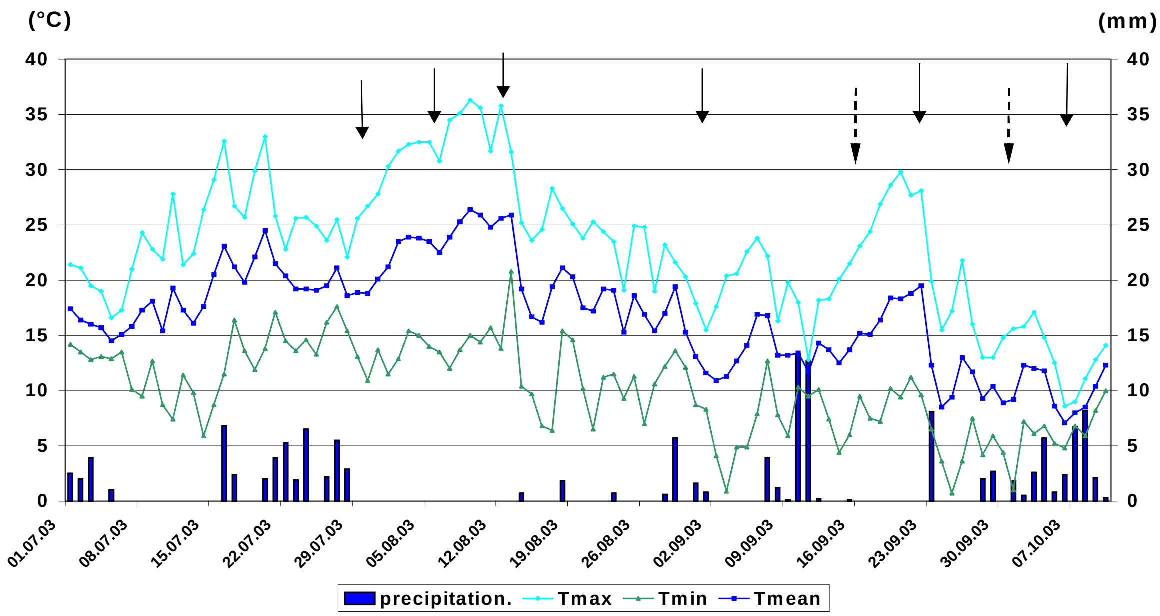


**Fig. 15. Daily maximum, minimum and average temperature and precipitation at Göttingen, July – September 2003. Arrows indicate dates of sampling.**

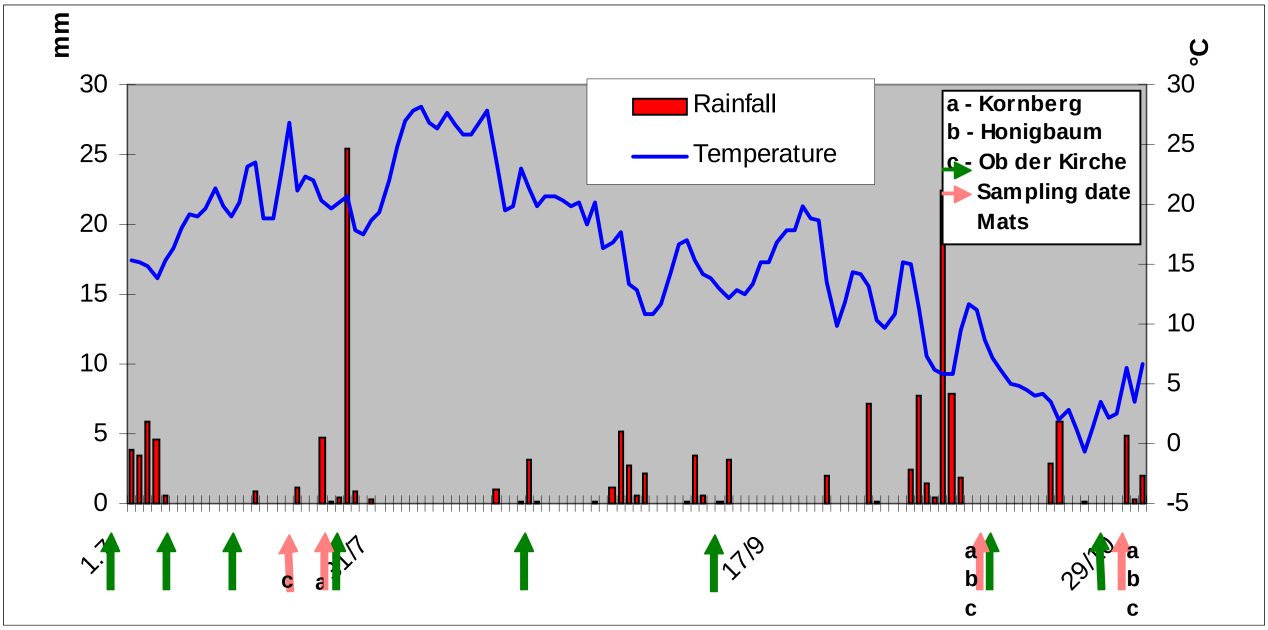


**Fig. 16. Average daily temperature and precipitation at Berolzheim, Stuttgart, 17th July to 22nd October 2003.**

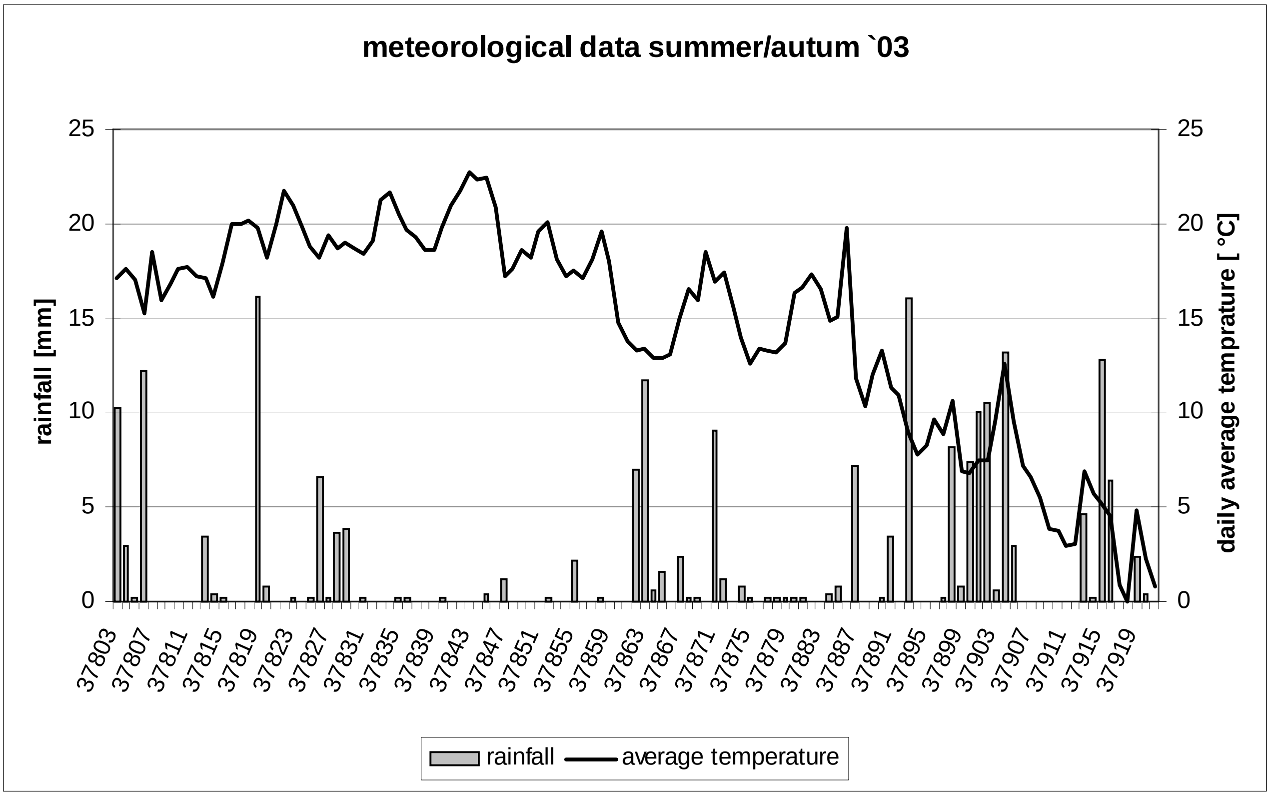


**Fig. 17. Average daily temperature and precipitation, Kiel, July to October 2003.**

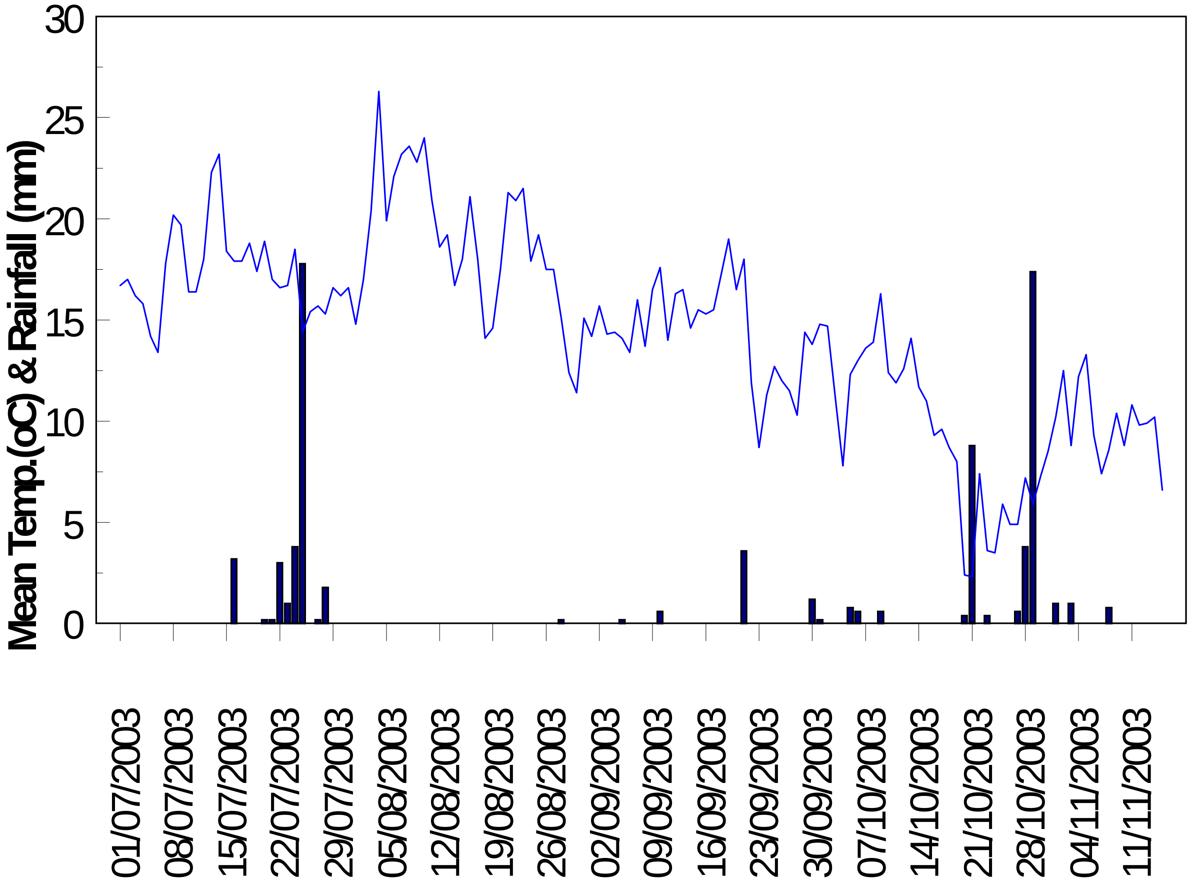


**Fig. 18. Average daily temperature and precipitation, Yeovilton, Somerset, July to November 2003.**