A pilot project to develop farmer-friendly methods for estimating slug infestation incidence in soil: overall report for 4 locations

D. Glen,
Styloma Research & Consulting, Phoebe, The Lippiatt, Cheddar, Somerset, BS27 3QP, England. Email: david.glen@bbsrc.ac.uk

A. El Titi
State Institute for Plant Protection Stuttgart, Landesanstalt für Pflanzenschutz, Reinsburgstrasse 107, 70197 Stuttgart

K. Katzur, W. Büchs, H. Kreye, G. Bartels,
Federal Biological Research Centre for Agriculture and Forestry, Institute for Plant Protection of Field Crops and Grasland, Messeweg 11/12; 38104 Braunschweig

B. Ulber
Institut für Pflanzenpathologie und Pflanzenschutz, Entomologische Abteilung, Universität Göttingen, Grisebachstr. 6, D-37077 Göttingen

Summary

Immature and adult slugs were extracted from soil at nine field sites in four locations (Braunschweig, Göttingen and Stuttgart in Germany, Somerset in England) by flooding soil samples over a 3-day period. 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. Two methods of sampling slug populations in soil were compared at all sites: (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. Soil was sampled to a depth of 10 or 12 cm by both methods. A third simple method, small individual samples, 18 cm x 18 cm diameter, dug with a spade to a depth of 8 cm, was tested at one site. 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. Numbers extracted by Method 2 compared favourably with numbers extracted by a standard method of flooding over 9 days. Slug trapping was done using upturned flower pot saucers or slug mats ('Bayer Schneckentest') baited with slug pellets or chicken layers meal. 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 conditions than trapping. There is some concern that results in July at two sites at Göttingen showed 9 to 14 slugs per slug mat, but only 6 to 12 slugs/m^2 were recorded from large individual soil samples. However, possible reasons for this (method of trapping and dry soil below the surface) are discussed. Method 2 was rather labour-intensive. Despite these reservations, Method 2 provided valuable estimates of the risk of slug damage to oilseed rape at all field sites. Method 3 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 initial 3-day period of flooding. Method 2 is too labour intensive for use by farmers and consultants, but Method 3, with kohlrabi slices to attract slugs to the soil surface, should be suitable for further development to provide farmers and consultants with an accurate estimate 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 give valuable preliminary information on the relationship between slug population density and the severity of slug damage to oilseed rape at establishment.

1. Introduction

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). Likely reasons for this are that several modern agronomic practices are favourable to slug reproduction, growth and survival. Moreover, recent mild wet winters have enabled slugs to extend their period of activity and such winters are likely to occur more frequently in future as a result of climatic change. Since understanding of the population dynamics and the seasonal incidence of slug pests is limited, approaches to develop integrated management systems, infestation-yield loss-relationships and economic damage thresholds are still fragmentary.

Chemical control of slugs is achieved by molluscicides (bait pellets, mainly based on metaldehyde or methiocarb as the active ingredient) which are usually applied prophylactic ally and with varying efficacy (ESTER ET AL., 1996). 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 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. However, there is increasing concern that juvenile slugs which are living below ground and therefore will rarely be captured by refuge traps, may have a major impact on the damage potential of slugs.

The objective of this study was to take the first steps to develop and evaluate a method for monitoring the abundance of slugs within the soil which is simple and easy to use by farmers as well as by pest consultants in slug control programmes. A modification of the standard method of soil flooding, which has been developed by SOUTH (1964) and GLEN ET AL. (1992), was used to test the feasibility of the rapid flooding technique for estimating slug numbers in soil, to compare the results of this technique with standard methods for trapping slugs active on the soil surface and to relate the numbers of slugs caught by these methods to the severity of slug damage in the oilseed rape crop.

In order to evaluate the risk of slug damage to oilseed rape, slug populations should ideally be assessed just before cultivation in preparation for sowing. However, experience shows that any method of estimating slug numbers will only be effective when the upper 10 cm of soil is moist, because slugs move deeper into the soil in dry conditions. For this reason, it may be beneficial to obtain estimates of slug numbers a few weeks earlier than this if the soil is moist. The period just before harvest of the previous crop could be a particularly good time to estimate slug numbers in soil because, provided there has been some rain, the soil is likely to remain moist due to the crop ripening and water uptake by the roots having diminished or stopped. At the same time, the crop canopy shades the soil and protects it from wind, thus reducing the rate of evaporation.

Assessments of this technique were made from late June to October 2002, starting just before the preceding cereal crop was harvested, and continuing through the inter-crop (fallow) period and the establishment phase of winter oilseed rape crops. Slug activity on the soil surface was also estimated during this period, using a standard trapping method. A preliminary evaluation of each technique is made in this report, together with recommendations for further research to develop methods of estimating slug numbers in soil to provide farmers with one or more simple methods for assessing the risk of slug damage to oilseed rape at establishment.

A number of trapping techniques have been developed and used to assess the number of slugs active on the soil surface. Traps currently in use are either baited with slug pellets (e.g. GLEN *ET AL.*, 1993) or non-poisonous bait (e.g. chicken layers mixture) (YOUNG *ET AL.*, 1996). The advantage of using slug pellets as bait is that slugs are likely to be immobilised and remain in the traps, but there is a risk of poisoning non-target species and it is necessary to carry samples of slug pellets when monitoring, which is undesirable. The advantages of non-poisonous baits are that traps can be used safely and good numbers of slugs are attracted to the traps overnight. However, in hot sunny weather the slugs will leave the traps and be unrecorded – examination of traps early in the day is critical under these conditions and it may not be practicable for a farmer or advisor to examine traps early in the morning. Traps of this type will not be developed further within this project, but will be used to provide comparative data on slug populations.

2. Materials and methods

Study locations

The research was done at three locations in Germany (Braunschweig, Göttingen and Stuttgart) and in Somerset, southwest England. At each location, at least two fields were selected which were to be sown with oilseed rape. At each site at least 8 plots each at least 12 m x 12 m, were used for this study. All sampling was done in the central 4 m x 4 m area of each plot. After oilseed rape was drilled, plots were marked out again and divided into subplots at least 6 m x 12 m and slug pellets applied as described below.

Assessing the feasibility and accuracy of a simple, rapid technique for estimating the numbers of slugs in soil

Three methods of soil sampling were compared.

Bulked small soil core samples (Method 1)
From the central area of each of eight plots, one soil sample was taken using a soil corer of 9.5cm (Braunschweig) or 10 cm internal diameter (Göttingen and Somerset), to a depth of 10 cm (Göttingen and Somerset) or 12 cm (Braunschweig). Thus, the total surface area of soil sampled from eight plots was 567 cm^2 (Braunschweig) or 629 cm^2 (Göttingen and Somerset). At Stuttgart, three cores each 5.6 cm diameter x 10 cm deep were taken from each of nine plots and bulked to give one sample of 665 cm^2. Soil samples from all plots were placed together in a watertight opaque plastic

container. Because this method of sampling provided only one bulked sample per field, the above procedure was replicated five times in each field on each sampling occasion, giving a total of five bulked samples per field, so that the mean number of slugs could be compared statistically with that obtained by Method 2.

Large individual soil samples (Method 2)

On the same day as the above samples were taken, one large individual soil sample was collected, using a template from the middle of the same plots sampled using Method 1. Each large individual sample was 25 cm x 25 cm (625 cm^2) x 10 cm deep (Göttingen, Somerset, Stuttgart), or 25 cm diameter (491 cm^2) x 12 cm deep (Braunschweig). The soil was then transferred to an opaque plastic box in such a way that the soil in this sample was disturbed as little as possible.

Small individual soil samples (Method 3)

At Göttingen, in addition to methods 1 & 2, individual samples 18cm x 18cm square x 8cm deep were collected on three occasions at an additional field site by digging, using an ordinary spade. The surface area of one individual soil sample was 324 cm^2; hence two of the small samples (648cm^2) covered approximately the area of one large individual sample (625cm^2). Accordingly, two small individual samples and one large sample were collected from the middle of five of the eight plots on each sampling occasion. (The plastic boxes used for flooding the small samples were not suitable for taking soil samples to a depth of 10cm.) Each sample was transferred into a small plastic box, 20cm x 20cm square x 10cm deep, covered by a close fitting snap-on lid and transported to a cool cellar room for extraction by rapid flooding over 3 days, as described above. In contrast to the standard comparisons between Methods 1 and 2, the extraction process was extended to 9 or 10 days, in order to check the efficiency of the rapid extraction.

Processing of soil samples

All the samples obtained by Method 1 and Method 2, in watertight opaque containers, were covered by opaque lids, to keep the slugs in dark conditions, which encourage slugs to come to and remain at the soil surface. Seals between the lid and box prevented slugs escaping. The containers with the samples were transported from the field and kept out of direct sunshine. Overheating of samples was avoided at all times. Water (2-3 cm deep) was poured into the base of the container and the soil samples were flooded gradually over a period of 3 days by adding 2 cm water to the box each morning and evening. (At Stuttgart, drip irrigation was also used to raise the water level.) Before the water was added, each box was examined carefully and all slugs that had come to the soil surface were identified, kept in containers with moist paper and weighed individually while they were fully hydrated.

In addition to the comparison of sampling techniques, three parallel sets of five samples of 25cm x 25cm x 10cm deep each were taken on three sampling dates at Braunschweig and Göttingen in order to study the effect of attractants placed on top of the sample, on the numbers and weights of slugs extracted. This was done to encourage slugs to remain and feed on the soil surface, thereby facilitating their collection. The following treatments were compared (5 replicates of each per date):

- No attractant
- Irrigation matting impregnated with diluted rapeseed oil (70 ml oil + 70 ml water per irrigation mat)
- Slices of kohlrabi 0.3-0.5 cm thick (Braunschweig) or green leaves of lettuce (Göttingen)

Comparison of rapid soil extraction Method 2 with standard soil extraction method
At Long Ashton Research Station, Somerset, the numbers of slugs and the size structure of the population extracted by Method 2 were compared with the equivalent data for the standard research-method of soil flooding used at Long Ashton (e.g. (GLEN *ET AL.*, 1989, 1992; SYMONDSON *ET AL.*, 1996, 2002; BOHAN *ET AL.*, 2000), for samples taken from ten plots at one site (Field 75). Following discussions at the UFOP Office in Berlin on 21 June 2002, the first set of 10 soil samples for rapid extraction were dug on 24 June. These were compared with standard samples that had been taken from the same plots on 19 June. Further sets of samples were taken for comparison of Method 2 with the standard method of extraction, on 10 July (in standing wheat) and 12 August (in wheat stubble after harvest). For the standard method, the samples were dug using the same technique as Method 2, but each sample was transferred to a special plastic tub with holes drilled at the base of the walls. These holes allow water to enter the tubs, and they are covered in mesh to prevent slugs escaping. The tubs were transferred to large troughs in a glasshouse, where 2 cm of water was introduced to the base of each trough together with a drip-feed from a glasshouse irrigation system. The drip-feed of water gradually raised the water in the troughs so that the soil samples were steadily flooded over a period of about 9 days. Slugs were collected from the samples daily from Mondays to Fridays and the drip rate was adjusted over the weekend so that the total increase in water level was equivalent to the normal overnight rate.

Frequency of sampling
A series of samples were taken from each study field. As far as was possible, this was done when the upper 10-cm layer of soil was moist and the slugs in the soil were present in the upper soil layers: -

(i) In the preceding cereal crop, before harvest
(ii) In the stubble after harvest and before cultivation
(iii) On the day after drilling oilseed rape
(iv) At the time when seedlings are at the cotyledon stage to first true leaf emergence)
(v) When oilseed rape has reached the four-true-leaf stage.

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 (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. Weather data for each location are shown as Figs. 5, 6, 7 and 8 in an Appendix.

Comparison of technique for estimating slugs in soil with trapping slugs active on the soil surface

At the same time as the above soil samples were taken, a refuge trap was placed in the middle of each of the plots in each field to evaluate the activity-density of adult slugs. A sample of up to 20 trapped slugs of each species present was removed and weighed individually. Traps were of two types.

1. Up-turned plastic flower-pot saucers (terracotta-colour, 25-cm diameter) baited with metaldehyde pellets (Braunschweig) or 20 ml of chicken layers meal, placed in a small heap centrally under the traps (Somerset, Stuttgart). One refuge trap per plot was placed in the field in the afternoon or evening (before sunset**)**. The traps were left in the field overnight and examined the next morning. In Somerset, the soil surface moisture condition was noted as moist, drying, drying+ or dry when traps were put in place and examined.

2. Slug mats (‘BAYER Schneckentest’) as developed by HOMAY & BRIARD (1988) were used at Göttingen and Stuttgart. These 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 is enclosed to hold moisture within the mat. The mats were 50cm x 50cm in size and were placed on the soil surface. At Göttingen, metaldehyde pellets (Metarex, 10g/trap) were distributed on the ground underneath the mats, to poison the slugs under the mat and thus prevent them from escaping. In order to improve the attractiveness of the traps under very dry soil conditions in August and September, the mats and the soil surface underneath the mats were wetted with 2 l of water. At Stuttgart, 3 g methiocarb pellets were placed in the centre of each trap and some traps were quartered to give four small traps each 25 cm x 25 cm. In replicated trials, these traps, baited either with slug pellets or chicken layers meal, were compared with upturned flower pot saucers (25 cm diameter) with the same baits.

Effects of the time of examination on trap catch

It is widely reported that lack of trapping success may be due to rising temperature under the trap-cover due to radiation. Slugs are reported to leave such refuge for cooler and protected places. This may lead to misinterpretation of trap results. Two experimental series were conducted at Stuttgart using upturned flower pots with chicken layers meal as a bait. In the first experiment 9 traps (one per experimental plot) were set up in the evening of 23 September 2002. The examination of the trap started early next morning and continued through the following day. The slugs under the trap were counted but not removed. In the second series, on 1, 2 and 10 October, the slugs were removed in the morning and afternoon.

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 at each field site into two sub-plots. Thus, each subplot was at least 6 m x 12 m and all subsequent assessments were done in the central 2 m x 4 m area of each subplot. One sub-plot of each plot was treated with a broadcast application of metaldehyde pellets at drilling, followed by a further application after crop emergence. The numbers of plants emerged and the percentage leaf area removed by slugs were assessed at regular intervals until the plants reached the 4-true-leaf stage. On each occasion, plants were recorded in four areas each 0.5 m x 0.5 m (0.25 m^2) in the central area of each plot.

3. Results

Assessing the feasibility and accuracy of a simple, rapid technique for estimating the numbers of slugs in soil

Comparison of rapid extraction of Method 1 (bulked soil cores) and Method 2 (large individual samples)

The mean numbers of slugs obtained by Methods 1 & 2 at the four locations are summarised in Table 1. At Stuttgart, only 1 slug was extracted from a total of 25 samples of each type taken on five dates. At Göttingen, few slugs were extracted by both techniques. Because of this it is not possible to draw conclusions from both these locations. However, at field site Sikte, Braunschweig, more than twice as many slugs per unit area were collected by large individual samples (Method 2) compared to bulked core samples (Method 1). (Numbers were lower but comparable for both methods at the other Braunschweig site.) In Somerset, sufficient slugs were recorded to permit statistical comparison of the two methods. This showed that there was a significant interaction between method of extraction and month (P = 0.003), with mean numbers/m^2 extracted by large individual samples (Method 2) in July being about twice as great as numbers extracted by Method 1 (bulked core samples). However, there was no significant difference between the two methods in August.

At Stuttgart, soil sampling by Method 1 using a standard soil auger 5.6 cm in diameter was considered to be easy, but it was not possible to use this method at one site (Darschberg) because of soil hardness and stones. At Göttingen, sampling by Method 1 could be done by one person, but the technique used for Method 2 required two people. At Braunschweig, both soil sampling methods were considered to be very time-consuming. For flooding the samples (4 times) and searching for slugs (4 times) during the 48 hours of examination at least 1 hour/ sample was needed in both methods. Besides the sampling itself and the transport was rather difficult and combined with a heavy duty because of the weight of the large metal cylinder and the containers filled with the soil samples. The sampling was most difficult on the first date (short time before harvest of winter wheat) because of the height of the plants. In addition the plants were damaged. Furthermore the soil was compressed when the soil cores were taken out of the small metal cylinders. Thus slugs within the soil core may have been affected. Time was needed for the levelling of the soil samples in the containers, because the soil cores had to be broken up. In contrast the big soil cores fell in pieces when taken out of the metal cylinders. In Somerset, both methods required only one person but Method 1 was more time-consuming and required considerably more effort than Method 2. Depending on the layout of the site, crop and soil conditions etc, Method 1 required a total of 15-25 minutes per sample, whereas Method 2 required only 6 -10 minutes per sample for sample collection.

Table 1. Mean numbers of slugs/m^2 extracted from soil by bulked core samples (Method 1) compared with single large samples (Method 2).

Location	Field site	Date	Mean number of slugs per m^2	
			Method 1 (bulked cores)	Method 2 (large samples)
Braunschweig	Grassel	31 July-2 Sept.	3.1	3.2
		11-30 Sept.	0.0	0.0
	Sickte	5 Aug. – 8 Oct.	8.5	19.7
Göttingen	Torland	July – Sept.	6.4	6.4
	Intext	Aug. – Sept.	3.2	1.6
Somerset	Field 75	July	60.8	98.6
		August	60.8	56.0
	Holbrook	July	31.8	83.2
		August	191.0	185.6
	Cowley’s	July	-	-
		August	98.6	62.4
Stuttgart	Honigbaum	17 July -28 Sep	0	0
	Darschberg		-	0

Comparison of attractant materials

Slugs found during levelling and conditioning of the soil in the containers were not considered for the comparison of attractant materials. At Braunschweig, the most slugs were detected by using kohlrabi as attractant material. Numbers at Sickte were sufficient for statistical analysis, after transformation to log (n + 1). Significantly more slugs were found in samples with kohlrabi as an attractant compared to samples without any attractant (Fig. 1). Samples with rapeseed oil were intermediate and not significantly different from either extreme. At Grassel, a total of five slugs were found on soil samples with kohlrabi. No slugs were found on other treatments. At Göttingen, the numbers of slugs collected from the three treatments were too low to draw firm conclusions. However the largest number of slugs (7) was recorded with lettuce leaves, compared to 4 with rapeseed oil and 3 with no attractant.

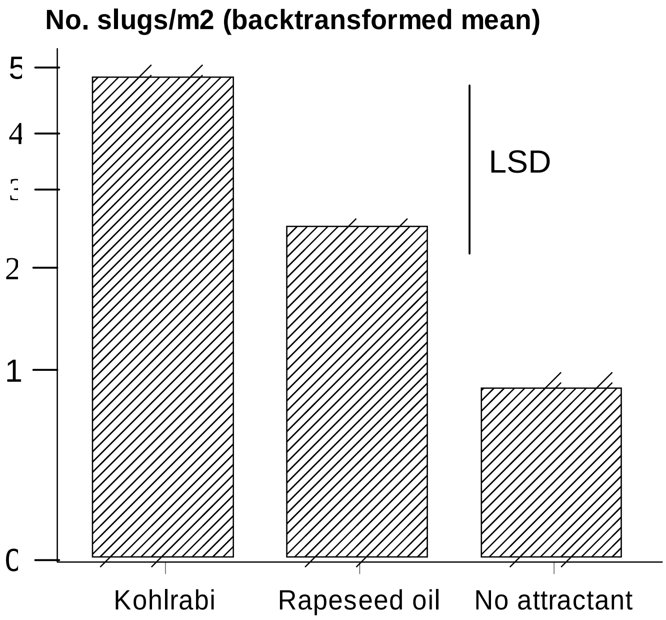

Fig. 1. Mean no. slugs/m^2 (back-transformed) detected by flooding soil samples from the field site Sickte with two different attractants or no attractant placed on the soil surface during flooding. (LSD = least significant difference, *P* = 0.05.)

Comparison of large soil samples (25 cm x 25 cm) (Method 2) and small individual samples (18 cm x 18 cm) (Method 3)

In these tests at Göttingen, similar numbers of slugs were found in large and small soil samples. This was particularly evident in samples from 13 September and 30 September (Fig. 2), which were sampled from a stubble field after harvest of oilseed rape. This field yielded significantly more slugs than the newly established oilseed rape fields. More than 90% of collected slugs were identified to be *D. reticulatum*. Few slugs were found to be *Arion* spp.

Although the addition of water to the samples was completed after 3 days, considerable numbers of slugs were found at daily inspections up to the 10th day of observation (Fig. 3 shows this for the samples collected on 30 September). Between day 4 and day 10, 47% and 28% of the total numbers of slugs were collected from large and small samples, respectively, in the samples of 13 September, and 16% and 20%, respectively, in the samples of 30 September.

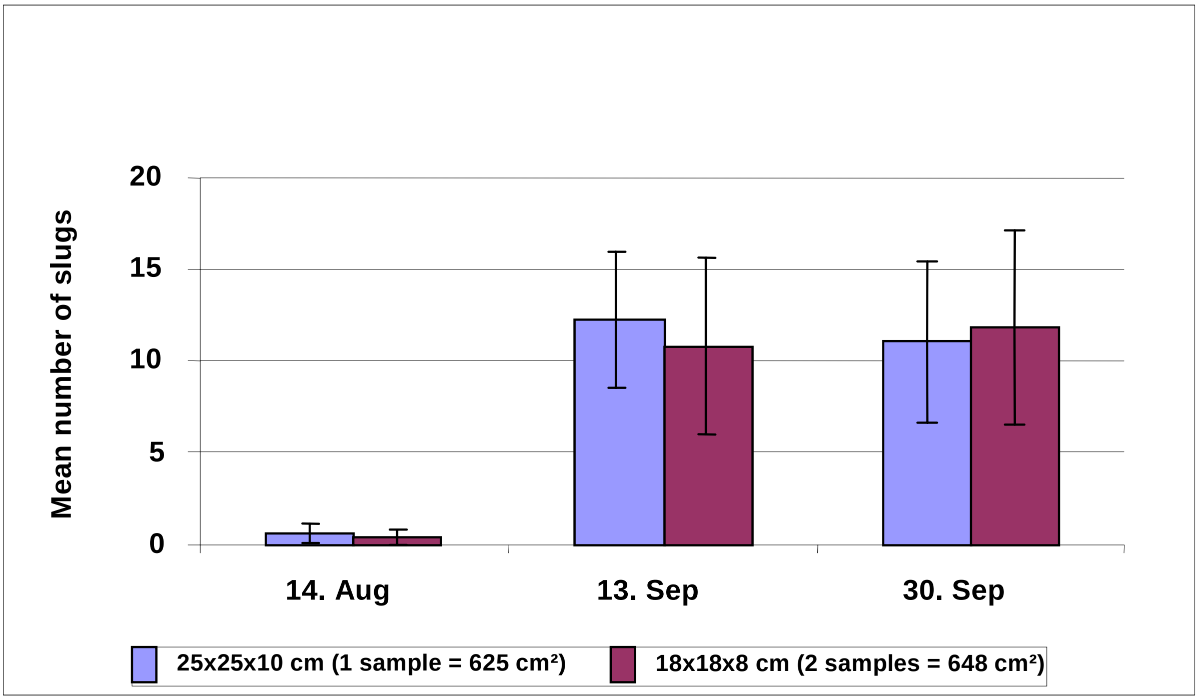

Fig. 2. Number of slugs extracted from large and small soil samples by flooding over 10 days, Göttingen. Means (± SD) per one large sample or two small samples.

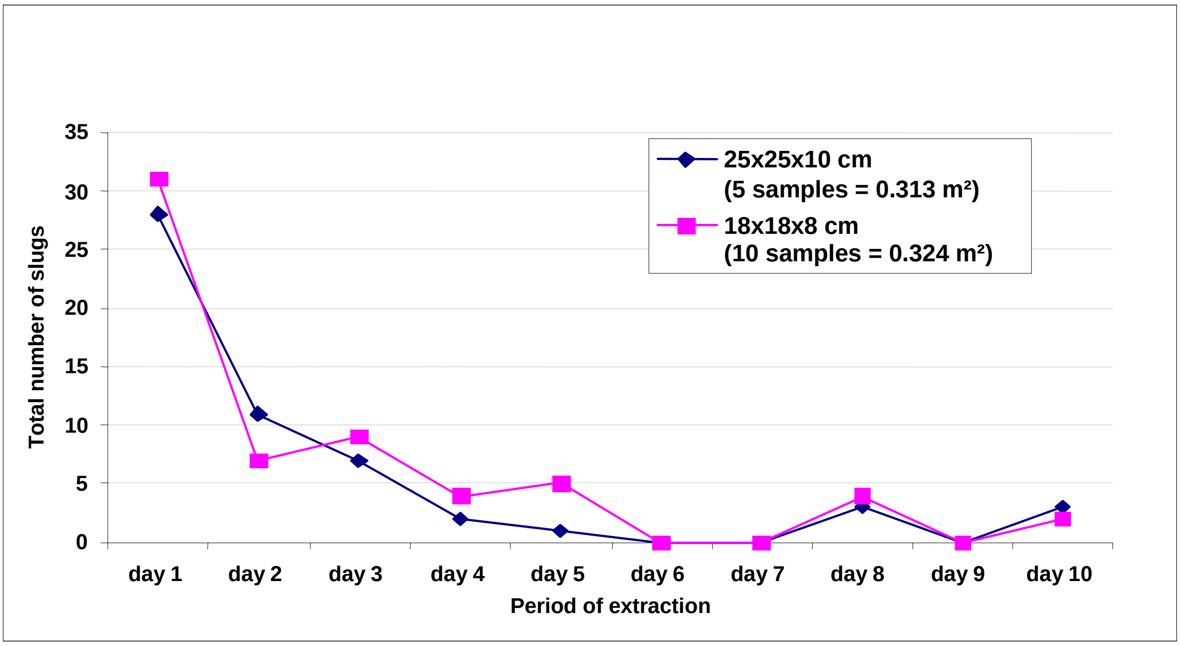

Fig. 3. Number of slugs extracted from soil samples collected on 30 September and flooded over a period of 10 days, Göttingen.

The mean weight of slugs extracted from large and small samples of 13 September was 48 mg and 69 mg, respectively, and 128 mg and 140 mg, respectively, in the samples of 30 September. The mean weight of slugs collected on individual days of extraction from large and small soil samples did not show striking differences. However, particularly in the small samples (18cm x 18cm) the mean weight gradually decreased during the first 4 to 5 days, and then increased again towards the end of extraction. The proportion of neonate slugs (< 10mg) tended to increase on day 4 – 6 (13 September) and on day 3 – 5 (30 September), indicating that these had hatched from the eggs in the course of the extraction process. On both sampling occasions, the proportion of juvenile slugs (10 – 100 mg) found from day 4 until the end of extraction appeared to be the same as the proportion of juveniles sampled on day 1 to day 3; there was no clear indication that the juvenile slugs emerged from the samples later than the adult slugs (> 100mg).

Comparison of slug numbers obtained by rapid extraction of large individual samples (Method 2) with standard soil flooding technique

All slugs extracted from soil samples from Field 75, Long Ashton Research Station, Somerset, were weighed individually and classified into three weight categories: -

1. Neonate slugs (1-10 mg)
2. Juvenile slugs (11- 100 mg)
3. Adult slugs (>100 mg)

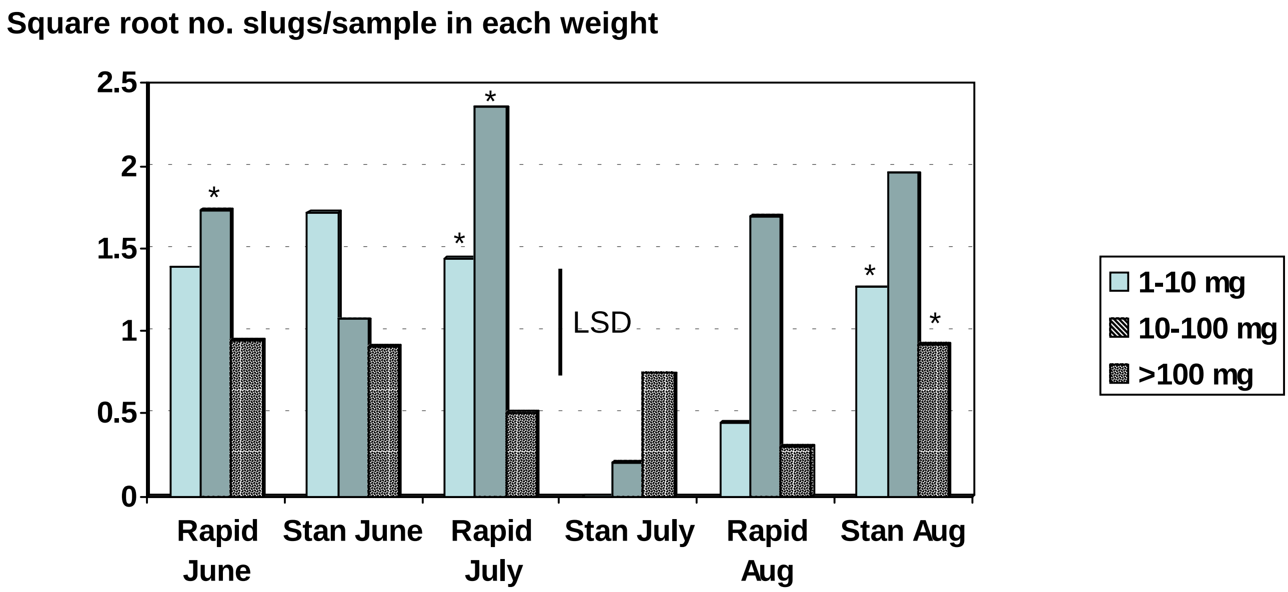

Fig. 4. Numbers of slugs, in three weight categories, extracted by two methods (rapid Method 2 and standard) in June, July and August from Field 75, Somerset. (LSD = least significant difference, *P* = 0.05). A star (*) above a column indicates that the number of that weight category extracted by that method is significantly greater than the number extracted by the other method on that date.

Note that the name given to each of these categories is not definitive and is used here simply for convenience. The numbers in each category obtained by Method 2 and standard extraction from each plot on three dates were transformed to square roots (Fig. 4) and compared by analysis of variance. The slugs extracted from the field site used for this study were almost all *D. reticulatum*, with a few *Arion intermedius*. There was a highly significant interaction ($P < 0.001$) between method of extraction, slug weight category and date of sampling. In June, numbers were similar in the neonate and adult categories for both methods, but more juvenile slugs were extracted by the rapid method than the standard method. In July, considerably more neonate and juvenile slugs were extracted by the rapid method compared with the standard technique. Numbers of adult slugs were similar for both methods. The explanation for the poor performance of the standard method in July was that a period of very hot sunny weather followed after sampling on 10 July and the temperature inside the glasshouse where soil samples were being flooded increased to levels that were lethal to the slugs. In August, significantly fewer neonate and adult slugs were extracted by the rapid method compared with the standard method, whilst numbers of juveniles were similar for both methods.

Comparison of the value of rapid soil extraction technique with trapping slugs active on the soil surface

At Stuttgart, where only one *D. reticulatum* was extracted from a total of 50 soil samples on five occasions between July and September, the mean catch per upturned flowerpot saucer trap baited with chicken layers meal, on four occasions during the period from 17 July to 11 September, was 2.0 and 1.1 slugs per trap, at Honigbaum and Darschberg, respectively. Most of these slugs were *Arion lusitanicus* juveniles and adults. Very few *D. reticulatum* (0.03 and 0.07 per trap at the two sites, respectively) were recorded, all adults.

At Göttingen, the numbers of slugs captured by refuge traps in the trial fields Torland and Intex were relatively high in July and decreased sharply in August and September (Table 2), probably because the top soil had become very dry in August, as shown by the % moisture in the 0-2 cm layer of soil. The majority of the slugs found in the traps were *D. reticulatum*. On 26 August and 6 September, no slugs were found in refuge traps at Intex, even when these were moistened with water and the trapping period was extended to 6 days. However, the high incidence of slugs captured by refuge traps on the soil surface at both sites on 16 and 30 July contrasted with low numbers of slugs found within the corresponding soil samples (only bulked samples were taken on 16 July, with mean numbers of 3.2 and 6.4 slugs/m^2 at Torland and Intex, respectively). One possible reason for this is that the soil was relatively dry on these dates, even in the layer from 2 – 10 cm (Table 2), so slugs had probably moved deeper into the soil. The mean body weights of slugs trapped under refuge traps and of slugs collected from soil samples on 16 July and 30 July were on the same order (Table 2). For example, on 30 July 47% and 55% of all slugs captured under refuge traps from Torland and Intex, respectively, weighed less than 100mg/individual.

Within the corresponding soil samples, 53% of all slugs collected on 30 September weighed less than 100mg/individual.

Table 2. Numbers and mean weights (mg±SD) of slugs (mainly *D. reticulatum*) extracted from soil by Method 2 at Göttingen, compared with numbers of slugs and mean weight of slugs in Bayer mat traps baited with metaldehyde pellets. Soil moisture (%) at two depths is also shown.

Site	Date	Crop	Slugs/m^2 in soil samples (rapid extraction, Method 2)		Slugs in traps		% Soil moisture	
			Total no.	Mean wt (mg) (no. indivs.)	No. slugs/ trap	Mean wt. in traps (mg) (no. indivs.)	0-2 cm	2-10 cm
Tor-land	16 July	Wheat	-	-	14.5	156 ± 20 (116)	16.5	14.0
	30 July	Stubble	12.8	104 ± 110 (4)	9.5	142 ± 98 (76)	18.6	15.3
	26 Aug.	OS Rape	3.2	2 (1)	0.4	193 ± 140 (3)	12.4	17.6
	6 Sep.	OS Rape	6.4	16 ± 18 (2)	0	-	7.8	15.0
	24 Sep.	OS Rape	3.2	304 (1)	1.4	260 ± 141 (11)	18.6	20.9
Intex	16 July	Wheat	-	-	11.4	183 ± 29 (91)	13.7	13.7
	30 July	Stubble	6.4	87 ± 117 (2)	9.0	199 ± 124 (72)	15.0	14.7
	26 Aug.	OS Rape	0	-	0	-	9.6	17.8
	6 Sep.	OS Rape	0	-	0	-	2.6	16.5
	24 Sep.	OS Rape	0	-	0.3	1519 ± 1713 (2)	17.6	17.3

At Braunschweig, all slugs except one found at the Grassel site belonged to the family Arionidae, whilst at Sickte 162 belonged to the family Agriolimacidae and 39 were Arionidae. Compared to saucer traps, Arionidae from soil samples showed a considerably lower average weight at both sites (Table 3), because adults of the large species (*Arion ater* agg.) were only present in saucer traps. For *Deroceras* spp. There was less difference between the average weight of slugs recovered in soil samples and that of slugs found in saucer traps.

Table 3. Numbers and mean weights of slugs (mainly *D.* reticulatum) extracted from soil by Method 2 at Braunschweig compared with numbers of slugs and mean weight of slugs in saucer traps baited with metaldehyde pellets. % soil moisture at two depths is also shown.

Site	Date	Crop	Slugs/m^2 in soil samples (rapid extraction, Method 2)		No. slugs/ trap	Mean wt. in traps (mg)	% Soil moisture	
			Total no.	Mean wt (mg)			0-2 cm	2-10 cm
Grassel	31 July	Wheat	4.1	197 (*Deroceras)*	1.6		-	-
	19 Aug.	Stubble	2.7		1.9		12.3	21.1
	2 Sep.	OS Rape	2.7		0		14.1	20.1
	11 Sep.	OS Rape	0	37 (Arionidae)	0	4735 (Arionidae)	15.3	24.5
	30 Sep.	OS Rape	0		0		21.0	23.8
Sickte	5 Aug.	Wheat	12.3	215 (*Deroceras)*	1.5	303 (*Deroceras)*	-	-
	21 Aug.	Stubble	13.6		1.4		25.2	17.4
	4 Sep.	OS Rape	39.7		0.5		25.4	17.7
	25 Sep.	OS Rape	2.7	695 (Arionidae)	4.6	5393 (Arionidae)	20.4	17.7
	8 Oct.	OS rape	30.1		4.8		24.2	18.2

In Somerset, 89% of all slugs extracted from Field 75 by Method 2 from June to August weighed less than 100 mg. In contrast, almost all slugs recorded in saucer traps weighed more than 100 mg, with mean weights from 234 mg to 512 mg (Table 4). For this reason, Table 4 shows both the total number of slugs/m^2 extracted from soil and the number/ m^2 weighing more than 100 mg, in comparison to the numbers recorded in saucer traps baited with chicken layers meal.

Conditions were not always ideal for slug trapping when soil samples were taken. In Field 75, the soil surface was moist when traps were put out in June, but recorded as drying when the traps were examined the following morning. In July, soil surface conditions were moist and suitable for trapping, but in August, in stubble, soil conditions were recorded as drying+, and in September, after oilseed rape was drilled, soil conditions were dry when traps were put out and examined. As expected, these dry or drying conditions reduced the number recorded in traps, relative to the number of slugs >100 mg recorded in soil. In July, when the soil surface was moist and ideal for trapping, the number of slugs/trap was about the same as the number of slugs >100 mg/m^2 in the soil. In drying conditions (June) the trap number was 36% of that in soil; in drying+ conditions (August), trap number was 10% of the number in soil; and in dry conditions, no slugs were recorded in traps when 3/ m^2 in the weight category >100 mg were recorded in soil.

Table 4. Numbers of slugs (mainly *D. reticulatum*) extracted from soil by Method 2 in Somerset, compared with numbers of slugs and mean weight of *D. reticulatum* in saucer traps baited with chicken layers meal. Soil surface moisture appearance is given for the time of trap examination, together with soil moisture content (% of wet weight of soil) at two depths on the date of soil sampling.

Site	Date	Crop	Slugs/m^2 in soil samples (rapid extraction, Method 2)		No. slugs/ trap	Mean wt. in traps (mg)	Soil surface moisture	% Soil moisture	
			Total no.	No >100 mg				0-2 cm	2-10 cm
Field 75	24 June	Wheat	107.2	20.8	7.6	472	Drying	25.2	24.8
	10 July	Wheat	144.0	11.2	12.4	512	Moist	27.1	26.5
	12 Aug.	Stubble	70.4	4.8	0.5	234	Drying+	24.8	25.6
	31 Aug.	OS Rape	14.4	4.8	0	-	Dry	18.21	21.3
	10 Sep.	OS Rape	6.4	1.6	-	-	Dry	11.8	21.8
	4 Oct.	OS Rape	8.0	0	1.4	263	Moist	20.1	22.4
Hol-brook	12 July	Oats	86.4	57.6	28.9	393	Moist	21.0	20.5
	19 Aug.	Stubble	198.0	32.0	3.9	225	Drying+	14.6	17.5
	5 Sep.	OS Rape	2.0	0.0	-	-	Dry	10.4	15.4
	19 Sep.	OS Rape	28.0	0.0	-	-	Dry	10.7	16.2
	7 Oct.	OS rape	20.0	6.0	-	-	Dry	13.4	15.9
Cow-ley's	9 Aug.	Barley stubble	62.0	18.0	7.5	225	Moist	33.2	30.8
	12 Sep.	OS rape	6.4	0.0	-	-	Dry	15.3	27.8
	11 Oct.	OS rape	12.8	6.4	-	-	Dry	15.2	23.9
	18 Oct.	OS rape	12.8	0.0	-	-	Moist	33.0	35.6

In Holbrook Field (Table 4) in July, the trap catch in moist conditions was 50% of the number of slugs >100 mg/m^2. In August, when the soil surface was drying, trap catch was only 12% of the total number of slugs >100 mg/ m^2. Trapping and soil sampling were done in Cowley's Field, in August, after harvest (Table 4), when trap catch, in moist soil surface conditions, was 42% of the number of large slugs/m^2.

Comparison of trap types and baits

At Stuttgart, mini-Bayer refuge traps (each 25 cm x 25 cm) baited with methiocarb pellets or chicken layers meal were compared with upturned flower pot saucers with the same baits (3 replicates per treatment), in a slug-infested field. Mini-Bayer traps baited with slug pellets recorded 2.3 *D. reticulatum* per trap compared with 0.3 for the same traps baited with chicken layers meal, and 0.3 and 0 for saucer traps baited with slug pellets and chicken layers meal respectively. In contrast, the only *Arion lusitanicus* caught were in mini-Bayer traps baited with chicken layers meal (2.7 per trap).

This experiment was followed by a laboratory study at Stuttgart of the attractiveness of different baits (chicken layers meal, meal of dried oilseed rape leaves, slug pellet placebo without active ingredient, and fish meal). The results of three trials showed that the first three baits were all attractive to slugs over a period of 2.5 h. Fish meal appeared to be less attractive than the other baits.

Effects of time of trap examination

This experiment was fist done on 24 September at Stuttgart. Trap catch declined steadily from a peak of just over 3 slugs per trap at 7.15 h, to just under 1 per tap at 11.15 h, then declined more slowly to 0.5 slugs per trap at 18.15h. The experiment was then repeated on three further occasions, with the traps being examined at 8.30 h and 14.00 h, with trapped slugs being removed and weighed on each occasion. The results (Table 5) showed consistently more slugs at 8.30 than at 14.00 h. However, the strong variability of trap catch from day-to-day is also evident in Table 5, emphasising the need to take account of factors influencing slug activity on the soil surface and the likelihood of slugs resting in traps.

Table 5. Total numbers and mean weight of slugs recorded in nine traps on three dates at Berolzheim, Stuttgart.

Sampling date	Time of examination			
	08.30 h		14.00 h	
	No. slugs/ 9 traps	Slug mean wt (mg)	No. slugs/ 9 traps	Slug mean wt (mg)
1 October	9	520	3	950
2 October	34	618	6	575
9 October	1	632	0	-

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

Plant numbers and slug damage on untreated plots compared to plots treated with slug pellets

Slug damage (Table 6) 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. The results for each of the locations are described in the order of increasing severity of slug damage recorded.

At Stuttgart, crop emergence and establishment were affected by the diamondback moth (*Plutella xylostella*) which was found in exceptional numbers in late summer 2002. Because the symptoms of feeding by caterpillars of this moth are similar to slug damage, it was not possible to record the percentage of plants with slug damage. The number of plants establishing at Honigbaum without slug treatment (33.6/m^2) was significantly greater than on plots treated with metaldehyde pellets (21.1/m^2). At Darschberg there was no significant difference in plant numbers between treated and untreated plots (28.6 and 29.6/m^2, respectively). Thus there was no evidence of slug damage at either site.

At Göttingen, there was no significant loss of oilseed rape plants on untreated plots compared to plots treated with metaldehyde pellets. No characteristic symptoms of slug damage were found in any of the four damage assessments.

At Cowley's Field in Somerset, 9.6% of plants were damaged by slugs on untreated plots, significantly ($P < 0.05$) more than on treated plots (2%). About 100 plants established per m^2 and slugs did not decrease plant establishment. In Field 75, about 40 plants established per m^2 on the subplots treated with slug pellets. Numbers on untreated subplots were slightly but not significantly lower than this, indicating that slugs did not significantly affect plant establishment. On untreated plots, 48% of plants were damaged by slugs at the 4-true-leaf stage, significantly more ($P = 0.01$) than the 17% damaged on treated plots. On this site there was also a considerable amount of flea beetle damage, together with caterpillar and pigeon damage. Whilst in most cases this could be distinguished from slug damage, it is possible that some may have been wrongly recorded as slug damage. Perhaps this accounted for the relatively high slug damage recorded on treated plots. In Holbrook Field, 69 plants established per m^2 on the subplots treated with slug pellets. Numbers on untreated subplots (37/m^2) were significantly ($P < 0.001$) lower than this, indicating that slugs reduced the numbers of plants establishing by 46%. The percentage of plants damaged by slugs was also influenced by pellet treatment ($P < 0.001$). On untreated plots, slug damage reached 81% of plants when plants had reached the 4-true-leaf stage compared to only 10% on treated plots.

At Grassel site, Braunschweig, similar numbers of plants established on treated and untreated subplots (19 and 16/m^2, respectively). The damaged leaf area increased to 68% and 66% on treated and untreated subplots, respectively. Because treated and untreated areas showed similar levels of damage, it is concluded that it is unlikely that this damage was caused by slugs. At Sickte, no plants survived on the untreated areas, whereas 23 plants/m^2 established on the treated areas. Thus slug feeding resulted in total crop loss at this site.

Slug damage in relation to populations recorded by soil sampling and trapping

Slug numbers in soil/ m^2 and numbers/trap, from July to October 2002, are summarised in Table 6 for each of nine field sites at four locations, together with the effects of slugs on the numbers of oilseed rape seedlings and the percentage of seedlings damaged by slugs at each site. Numbers of slugs/m^2 in soil were estimated by rapid flooding of large individual soil samples (Method 2). These measurements in July (just before harvest) and especially in August (in cereal stubble) appeared to provide the most useful predictor of the severity of slug damage at the nine sites, when the likely effects of method of cultivation and number of passes is taken into account. Slug traps sometimes also provided a useful measure at this time on some sites. However, on several occasions, traps underestimated slug populations, because soil surface conditions were dry or drying. This was particularly the case in August and September, when the soil surface was often too dry to be suitable for trapping.

On five sites (two at Stuttgart, two at Göttingen and Grassel at Braunschweig) where low numbers of slugs (0-12.8/m^2) were recorded by rapid flooding of large individual soil samples in August, no significant slug damage was recorded. Numbers in soil were relatively low (13.6/m^2) at Sikte, Braunschweig, in August, where slug damage subsequently resulted in total failure of oilseed rape establishment. However, this site was established by direct drilling, which would have allowed slugs to survive. Trap catches at this site were low, at 1.5 and 1.4/trap in July and August, respectively. Thus, trapping did not provide a reliable assessment of damage risk at this site.

In the three sites in Somerset, 10% of plants were damaged by slugs in Cowley's Field, where slug population density in August (62/ m^2) was higher than on any of the German locations, but similar to that on Field 75, Somerset (70/m^2), where slug damage to oilseed rape was substantially higher at 48%. A possible explanation for this apparent anomaly is that Cowley's Field was shallow cultivated twice, whereas Field 75 (and also Holbrook Field) was cultivated once only at drilling. It is likely that this additional cultivation killed slugs and helped to reduce the damage risk. However, it is necessary to be cautious with this interpretation, as the slug numbers recorded after drilling oilseed rape were similar on both sites. Despite the slug damage, there was no evidence that slugs reduced plant numbers significantly on Cowley's Field and Field 75. On Holbrook Field, Somerset, plant establishment was reduced by 46%, with 81% of the surviving plants damaged. This severe damage was consistent with the high numbers (190/m^2) of slugs recorded in the soil of cereal stubble in August. This field also had the highest trap catches of slugs in the standing cereal crop in July, although not in August, when soil surface conditions were too dry. Numbers and biomass of slugs recorded after emergence on this site were higher than on the other two sites, except for the first assessment, on the day after drilling, when only 2 slugs/m^2 were recorded. When soil samples were taken from the field on that date, the soil was very loose and the samples did not retain their shape and structure in the usual way after they were transferred to plastic boxes. It seems possible that this disintegration of the soil samples, just one day after the slugs had also been disturbed by cultivation, may have resulted in many slugs being trapped within the samples and unable to escape.

Table 6. Slug population density in soil, estimated using Method 2 (large individual soil samples) and the numbers of slugs per trap, from July to the time when oilseed rape reached the 4-true-leaf stage, on nine field sites at four locations in 2002. Method of cultivation and slug damage to oilseed rape at each site are also shown.

Location	Site & method of cultivn.	Data	Standing cereals	Cereal stubble	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
Stuttgart	Honig-baum (Reduced tillage)	No./m^2 soil	0	0	0	0	0	0	0
		No./trap	4.3	0.9	0.2	0	-		
	Darsch-berg (Reduced tillage)	No./m^2 Soil	0	0	0	0	0	0	0
		No./trap	2.8	1.6	0.2	0	-		
Göttingen	Torland (Reduced tillage)	No./m^2 Soil	-	12.8	3.2	6.4	3.2	0	0
		No./trap	14.5	9.5	0.4	0	1.4		
	Intex (Stubble cultivn. & plough)	No./m^2 Soil	-	6.4	0	0	0	0	0
		No./trap	11.4	9.0	0	0	0.3		
Braunsch-weig	Grassel (Reduced tillage)	No./m^2 Soil	4.1	2.7	2.7	0	0	0	0
		No./trap	1.6	1.9	0	0	0		
	Sickte (Zero tillage))	No./m^2 Soil	12.3	13.6	39.7	2.7	30.1	100	-
		No./trap	1.5	1.4	0.5	4.6	4.8		
Somerset	Cowley's (2 x Reduced tillage)	No./m^2 Soil	-	62.0	6.4		12.4	0	9.6
		No./trap	-	7.5	-	-	-		
	Field 75 (Reduced tillage)	Nos/m^2 Soil	144.0	70.4	14.4	6.4	8.0	0	48.4
		No/trap	12.4	0.5	0	-	1.4		
	Holbrook (Reduced tillage)	Nos/m^2 Soil	86.4	198.0	2.0	28.0	20.0	46	81
		No/trap	28.9	3.9	-	-	-		

4. Discussion

At three of the nine study sites in this project, slug numbers recorded by rapid extraction Method 2 (single large soil samples) were about twice as great as those recorded by Method 1 (bulked core samples) on at least one occasion. At the other sites numbers were low for both methods, too low to draw firm conclusions. The reduced efficiency of Method 1 may have resulted from slugs being killed in the soil samples due to shearing forces when the core samples were twisted to extract them. Indeed, slugs were observed to be killed on several occasions at Sikte field site, Braunschweig. Rapid extraction of large individual soil samples (Method 2) was shown to give results for slug populations that were broadly comparable to those obtained by a standard method of slow flooding of soil samples at Long Ashton Research Station. There were some differences between methods on individual dates for different size categories of slugs, but neither method was consistently better or worse than the other. Notably, in July, results for Method 2 were substantially better than for the standard method, as a result of slugs being killed by exceptionally hot conditions in the glasshouse used for the standard extraction.

In Somerset, the technique used for taking large individual soil samples (Method 2) required considerably less effort and was quicker and more convenient than bulked core samples (Method 1). Because of the consistent efficiency and relative ease of using Method 2, it was strongly preferred over Method 1 and, for this reason, Method 2 alone was used in Somerset to assess slug populations throughout oilseed rape establishment. Other project partners reported that the technique of Method 2 was labour intensive and heavy work. However, the soil sampling technique can be made considerably easier, as shown by the success of digging individual samples using a spade at Göttingen. This finding is highly encouraging because it indicates that the process of taking soil samples in the field can be made simpler and faster without loss of efficacy for estimating slug populations.

One area of concern is the finding at Göttingen that substantial numbers of slugs (16 – 40% of the total) continued to be collected on the soil surface when samples were monitored for a further seven days after the end of the three-day flooding period. This phenomenon needs to be investigated further. It may be due to the difficulty of detecting small and well-camouflaged juvenile slugs on the soil surface. Not only are such slugs difficult to see, but they often hide inside the cereal stalks in stubble during the important intercrop period. The experience of taking small samples (18 cm x 18 cm x 8 cm deep) with a spade and putting them into boxes just larger than the sample itself was that it was easier and less time-consuming to find the slugs in these samples than from large samples (25 cm x 25 cm x 10 cm deep) which had broken into pieces in large containers (39 cm x 32 cm x 22 cm). Also, many slugs were found crawling inside the lid of the small boxes, where they could be easily found.

Results from tests of different attractants strongly indicate that the detection of slugs on the soil surface is greatly improved by placing food materials on the surface of soil, especially kohlrabi. Thus, the use of kohlrabi (and possibly other materials) as an attractant needs to be further investigated, particularly to see whether it can increase the percentage of slugs recovered from soil during the three-day flooding period. With such an attractant, it may even be possible to reduce the flooding period to 1 or 2 days, thus providing a more rapid figure for slug population estimate. This also warrants further investigation.

Rapid extraction Method 2 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 most cases adequate soil moisture below the surface throughout the period of study especially in the 2–10 cm soil layer (Tables 2, 3 & 4). The main cause for concern is that in two sites at Göttingen, substantial numbers of slugs were recorded in Bayer traps in July/early August (14.5 and 11.5 slugs per trap in July and 11.4 and 9.5 slugs per trap in August, at Torland and Intex, respectively). In July at both sites soil data are available only for bulked core samples (Method 1: 3.2 and 6.4 slugs/m^2), whilst in August, there were 12.8 and 6.4 slugs/m^2 in large individual samples from these two sites, respectively (Method 2). The low slug numbers in soil in July may be explained by slugs being killed in the process of taking bulked core samples, as was also apparently happening at other locations. It is also important to note that the mean size of slugs in soil samples and traps at this site were rather similar. The reason for this could be that the mat traps used at both sites are known to be better for recording the presence of small juvenile slugs (HOMMAY & BRIARD, 1988) than the saucer traps used at other sites. Thus the trapping method could have also contributed to the apparently anomalous result at Göttingen in July and August. It is also notable that the soil was rather dry at the time of field sampling on these sites in July and August, so slugs may have moved deep into soil, below the level of sampling.

The methods of rapid extraction used in this project were not intended to be directly suitable for use by farmers and consultants. The intention was to make initial small modifications to a well proven research method to see if it would still provide useful data. Now that this has been shown, it should be possible to make further modifications based on the findings described here to develop a technique that would be suitable for more general use. Inevitably, however, the question remains whether any such method is more likely to be used than the trapping methods in current use.

Because of lack of time before the start of this project, it was not possible to standardise the method of trapping used and, as a result, all partners used different techniques of trapping. Thus, it is necessary to be cautious in comparing the results of different partners. It has already been mentioned that the weights of *D. reticulatum* in traps at Göttingen were similar to those found in soil samples. In contrast, the weights of this species found in soil samples from Somerset were considerably less than the weights of slugs in traps. This could reflect differences in the size structure of the populations of this important slug pest between the two locations or it could be a simple consequence of the difference in trapping technique. For future studies it will be important to standardise on, say, two or three trapping techniques, one of which should be a form of defined area trapping, which delimits the area from which slugs are able to come to the trap. However, the design of the defined area traps and the technique for examination need to be more convenient and practical than those described originally by FERGUSSON *ET AL*. (1989).

Trapping provided variable results, probably depending largely on soil surface moisture conditions together with weather conditions on the day of examination. For example, there was an almost four-fold increase in slug numbers recorded catch in traps examined at 08.30 h on two successive days at Stuttgart (Table 5). The usefulness of trapping as a tool for assessing damage risk was greatly restricted by dry soil surface conditions from about mid August when the soil surface was normally too dry for trapping to be a suitable method for estimating slug numbers. For this reason, traps generally underestimated slug populations in stubbles after harvest before sowing oilseed rape. Traps did provide useful results when it was possible to use them when the soil surface was moist. However, because they are much more dependent than rapid soil extraction on recent weather conditions, it may not be possible to provide predictive information for slug-damage risk assessment by using this method alone. At Göttingen, an attempt was made to overcome this problem by wetting the soil surface under each trap with 2 l water. However, on two dates when this was done, no slugs were found in the traps, even when these were moistened with water and the trapping period was extended to 6 days. The species recorded in traps presented a rather biased picture because large active species such as *A. ater* and *A. lusitanicus* were over-represented in traps, whilst smaller *Arion* species were under-represented.

When allowance is made for the probable effects of the different methods of cultivation and numbers of passes before establishing oilseed rape, on the slug population densities at the different field sites, then it becomes clear that the densities of slugs recorded after harvest in the soil at the nine study sites by rapid extraction Method 2 were consistent with the different levels of slug damage to oilseed rape recorded at establishment. Importantly, at all the sites where few slugs were found in soil, there was no subsequent damage to oilseed rape.

5. Conclusions, unanswered questions and further developments

This project has demonstrated the feasibility of using a rapid method of extracting juvenile as well as adult slugs from soil by taking large individual soil samples and flooding them over a 3-day period (Method 2)). This method is not suitable in its present form for use by farmers or consultants to assess the risk of slug damage to oilseed rape. However, results indicate that it should be suitable for further development as a technique to provide farmers and consultants with a true picture of the slug population in soil in the period leading up to establishment of oilseed rape crops. In particular, it should be possible to use a simple method of digging samples with a spade, then transferring them to a plastic box, where an attractant such as kohlrabi slices is placed on top of the soil to increase the rate at which slugs can be recorded at the soil surface This should be combined with development of the method to optimise ease of use and speed of extraction of slugs from soil.

It will be important to test the reliability of such a method of soil sampling under a wide range of weather, soil and agronomic conditions. Therefore, further studies of this rapid method of extracting slugs should be done at several field sites and locations. At the same time, trapping methods for estimating slug numbers should be further studied, including defined area trapping. Special attention should be paid to soil moisture conditions during these studies, with visual records of soil surface moisture and measurements of % soil moisture at depths of 0-2 cm and 2-10 cm. It may also be worthwhile to use soil moisture probes together with data loggers to provide continuous records of soil moisture at selected field sites. It may be appropriate to use the population estimates obtained in these ways as inputs to population models, such as those currently being developed at Long Ashton Research Station, to provide flexible and powerful tools for assessing the risk of slug damage to oilseed rape.

The data from the three field sites in this study provide valuable preliminary information on the relationship between slug population density and the severity of slug damage to oilseed rape at establishment. However, it is important to bear in mind that the weather in both Germany and England at the time of establishment of oilseed rape was exceptionally dry and warm, and therefore relatively unsuitable for slug activity. It seems possible that the same densities of slugs could have inflicted considerably more damage to oilseed rape seedlings under cooler wetter conditions, which are more suitable for slug activity and in which seedlings may have grown more slowly. This emphasises the need for further investigations under a wide range of weather, soil and agronomic conditions.

6. References

BOHAN, D.A., D.M. GLEN, C.W.W. WILTSHIRE, L. HUGHES, 2000: Parametric intensity and the spatial arrangement of the terrestrial mollusc herbivores *Deroceras reticulatum* and *Arion intermedius. Journal of Animal Ecology* **69**, 1031-1046.

ESTER, A., A. DARWINKEL, H.W.G FLOOT, J.H. NIJENSTEIN, 1996: Control of field slug (*Deroceras reticulatum*) in winter wheat using seeds treated with pesticides. In: *Slug & Snail Pests in Agriculture*. British Crop Protection Council Symposium Proceedings No. **66**, 165-172.

FERGUSON, C.M., B.I.P. BARRATT, P.A. JONES, 1989: A new technique for estimating density of the field slug (*Deroceras reticulatum* (Müller)). In: *Slugs and Snails in World Agriculture*. British Crop Protection Council Monograph No. **41**, 331-336.

GLEN, D.M., 2002: Biologie und Kontrolle von Schnecken im Raps. RAPS **20**, 72-76.
GLEN, D.M., N.F. MILSOM, C.W.W. WILTSHIRE, 1989: Effects of seedbed conditions on slug numbers and damage to winter wheat in a clay soil. *Annals of Applied Biology* **115**, 177-190.
GLEN, D.M., A.M. SPAULL, D.J. MOWAT, D.B. GREEN, A.W. JACKSON, 1993: Crop monitoring to assess the risk of slug damage to winter wheat in the United Kingdom. *Annals of Applied Biology* **122**, 161-172.
GLEN, D.M., C.W. WILTSHIRE, N.F. MILSOM, 1992: Some aspects of forecasting slug damage in arable crops. *Journal of Medical and Applied Malacology* **4**, 147-152.
HOMMAY, G., P. BRIARD, 1988: Apport du piegage dans le suivi des peoplements de limaces en grande culture. *Haliotis* **18**, 55-74.
MOENS, R., D.M. GLEN, D.M., 2002: Agriolimacidae, Arionidae and Milacidae as pests in west European oilseed rape. In: Barker, G.M. (Ed.) *Molluscs as Crop Pests*, CABI Publishing, Wallingford, UK, pp. 425-439.
SOUTH, A., 1964: Estimation of slug populations. *Annals of Applied Biology* **53**, 251-258.
STEMAN, G., N. LÜTKE ENTRUP, 2001: Ackerschnecken bereits vor dem Rapsanbau bekämpfen? RAPS **19**, 24-27.
SYMONDSON, W.O.C., D.M. GLEN, C.W. WILTSHIRE, C.J. LANGDON, J.E. LIDDELL, 1996: The effects of cultivation techniques and methods of straw disposal on predation by *Pterostichus melanarius* (Coleoptera: Carabidae) upon slugs (Gastropoda: Pulmonata). *Journal of Applied Ecology* **33**, 741-753.
SYMONDSON, W.O.C., D.M. GLEN, A.R. IVES, C.J. LANGDON, C.W. WILTSHIRE, 2002: Dynamics of the relationship between a generalist predator and slugs over five years. *Ecology* **83**, 137-147.
VOSS, M. C., B. ULBER, H.H. HOPPE, 1998: Impact of reduced and zero tillage on activity and abundance of slugs in winter oilseed rape. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz*. **105**, 632-640.
YOUNG, A. G., G.R. PORT, A.D. CRAIG, D.A. JAMES, T. GREEN, 1996: The use of refuge traps in assessing risk of slug damage: a comparison of trap material and bait. In: *Slug & snail pests in agriculture*. British Crop Protection Council, Farnham, UK, pp. 133-140.
YOUNG, A.G., G.R. PORT, 1989: The effect of microclimate on slug activity in the field. In: *Slugs and Snails in World Agriculture*. British Crop Protection Council Monograph No. **41**, 263-269.

7. Appendix of weather records

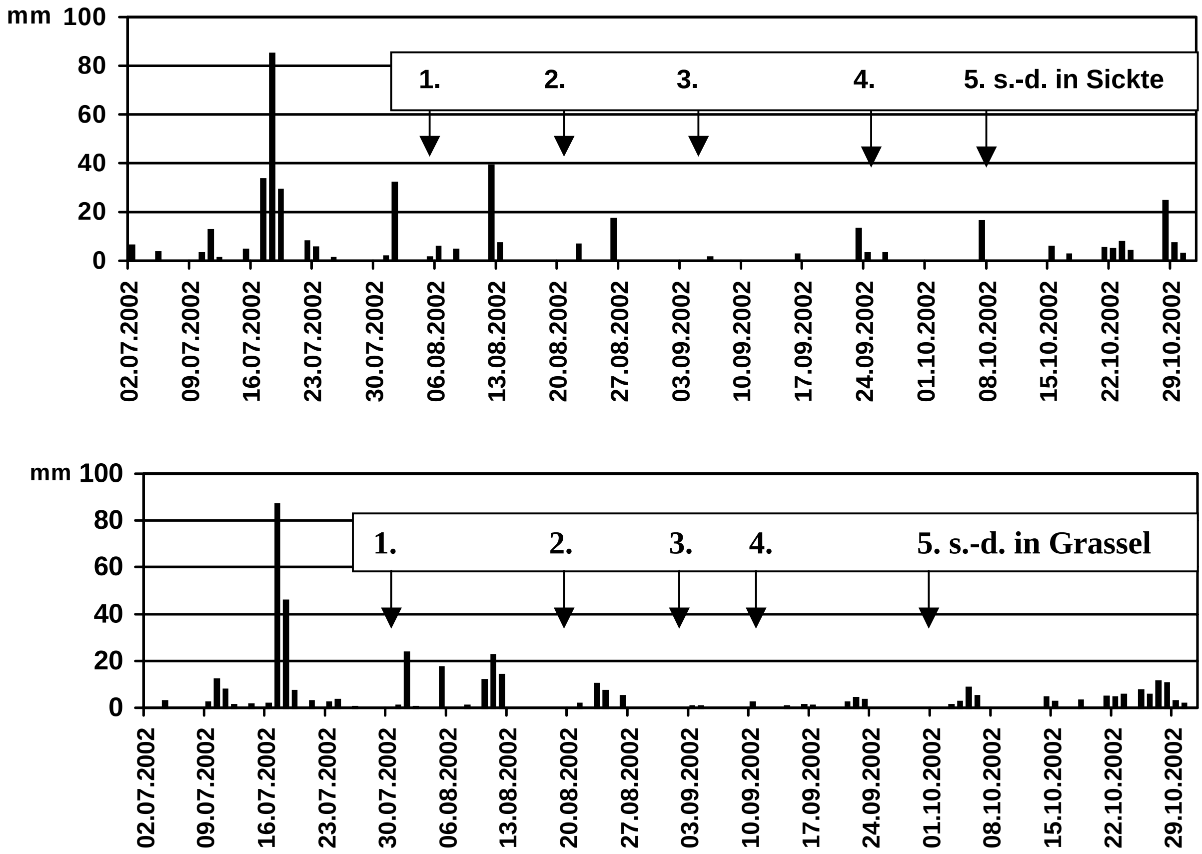

Fig. 5: Quantity of precipitation and sampling-dates (s.-d.) at the field sites Sickte and Grassel, July – October 2002.

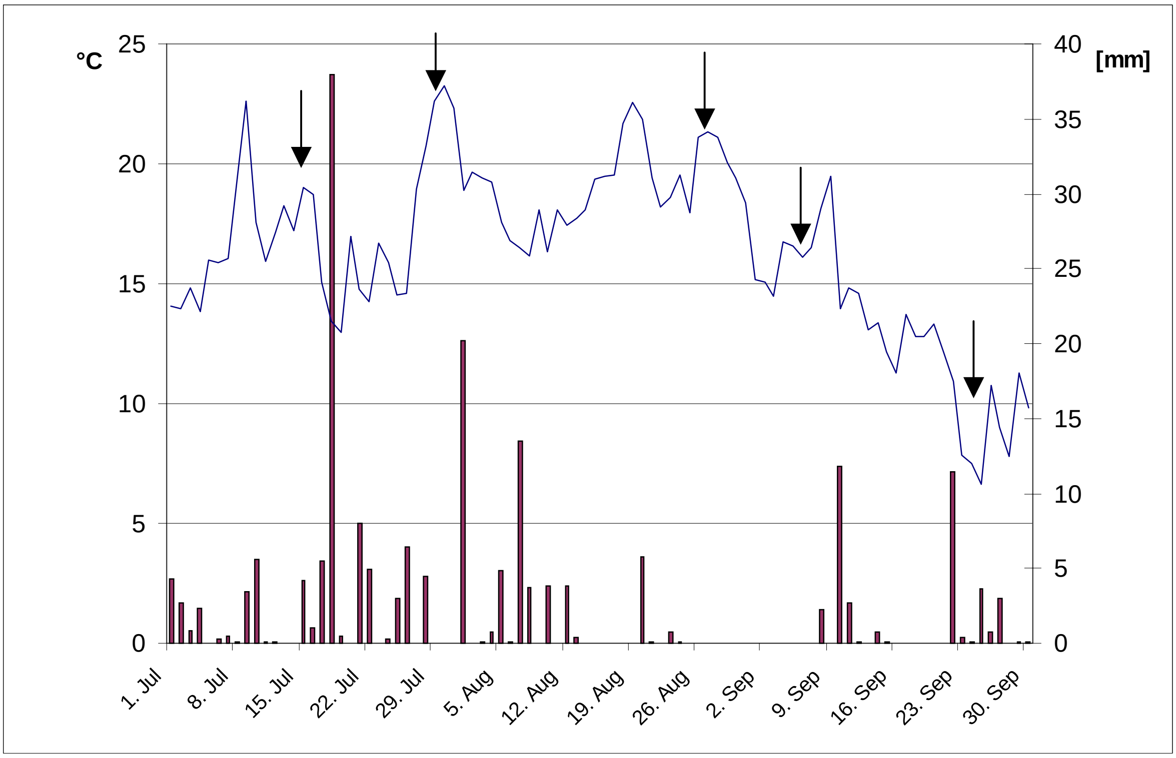

Fig. 6. **Daily temperature and precipitation at experimental sites, Göttingen, in July – September 2002. Arrows indicate dates of sampling large individual samples vs bulked core samples.**

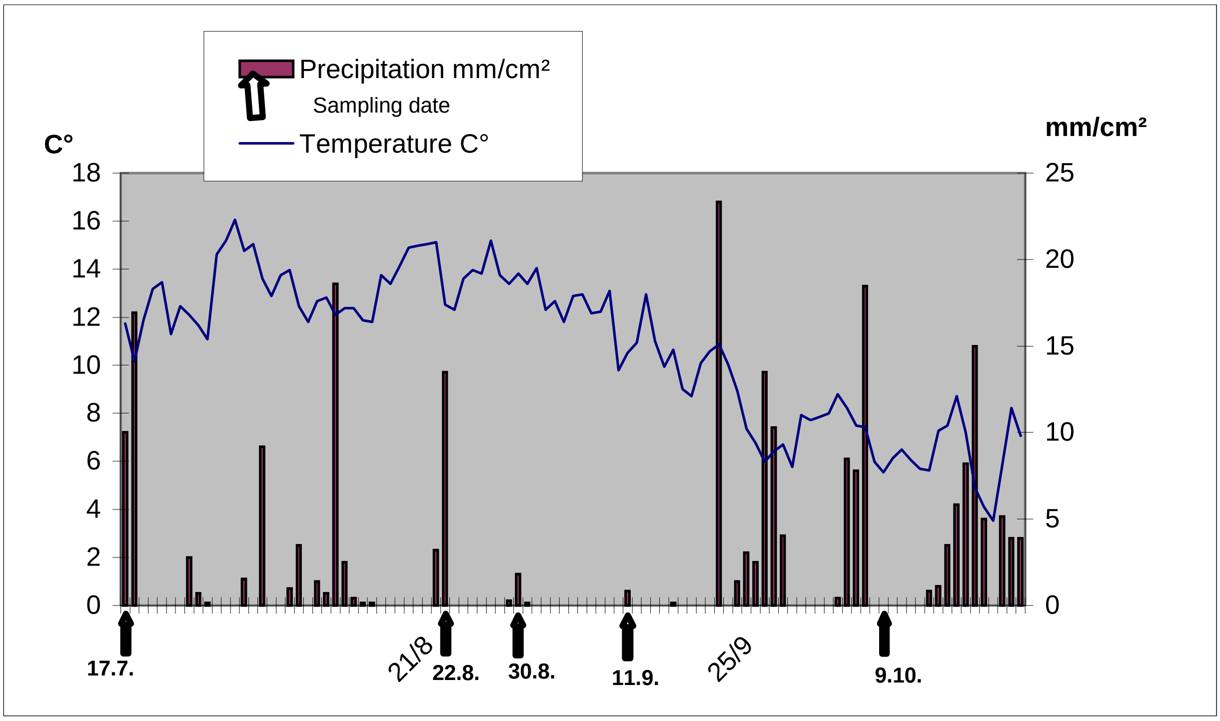

Fig. 7. **Distribution of rainfall and changes of average temperature at the Berolzheim site, Stuttgart, over the period 17th July till 22nd October 2002, based on standard daily measurements.**

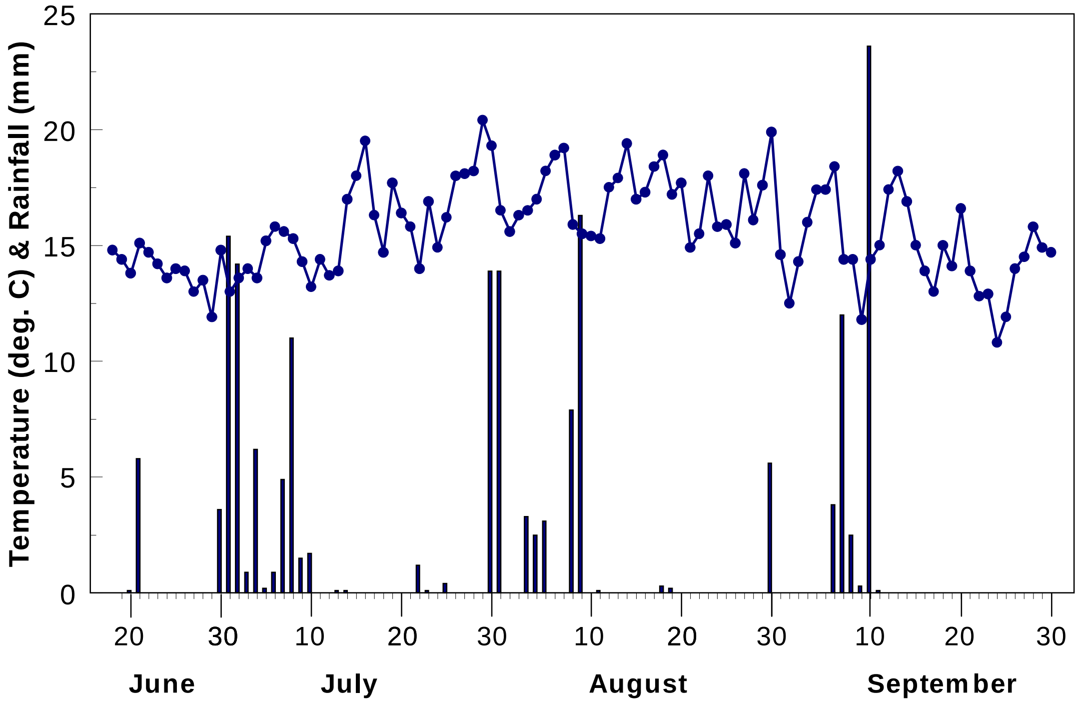

Fig. 8. **Daily mean air temperature (^{o}C) (shown as points connected by lines) and daily rainfall (mm) (vertical bars) recorded at the meteorological site at Long Ashton Research Station, Somerset, southwest England, from mid June to the end of September 2002.**