Assessing the risk of slug damage to oilseed rape and the need for control measures

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Summary

We compared two methods, suitable for use by crop consultants and farmers, for their ability to provide rapid and accurate estimates of the risk of slug damage to winter oilseed rape crops. The first method is a simple technique for estimating the population density of slugs in soil, by rapid flooding of soil samples, developed in 2002 (UFOP Project Nr. 521/024a) and 2003 (UFOP Project Nr. 521/031a). The technique involves digging soil samples with a spade and flooding them over a period of three days with one further day of observation. The second method was the use of traps to record slugs active on the soil surface. These two techniques were tested at a total of 19 field sites (17 distributed throughout Germany, two in southwest England) in 2004. Two times of assessment were compared: (1) before harvesting

cereal crops and (2) during the inter-crop (fallow) period. Slug damage at these sites was measured during the establishment phase of winter oilseed rape. In addition, at eight sites, slug populations were assessed by soil sampling and trapping during oilseed rape establishment.

Relatively low slug densities (<20/m^2) were recorded in soil samples from standing cereals and stubble in Germany, and trap catches were also relatively low at most field sites. This corresponded with low levels of slug damage to oilseed rape at 14 of 16 sites where damage was measured. Of the remaining two fields in Germany with higher damage, one was a direct-drilled field (Sickte) where there was a 23% reduction in plant stand. Direct-drilled oilseed rape is known to be at greatest risk of slug damage because there is no cultivation to reduce slug numbers. However, oilseed rape is only rarely direct-drilling in Germany. The second site with a reduction in plant stand was at Plienzhausen, but here the damage pattern was not typical of slug damage and may have been due to some other cause. Severe slug damage was recorded at one site in England where a slug density of 90/m^2 was recorded in cereal stubble in late August. There was evidence of strong breeding activity by slugs in late summer at this site in south west England, as well as in a field with oilseed rape stubble in northern Germany: the proportions of small (1-10mg), medium (10-100mg) and large (>100mg) slugs were remarkably similar in late August in south west England and northern Germany.

The method of rapid flooding of soil samples was more labour-intensive than slug trapping. However, when results were collated over for the three-year period 2002-2004, rapid flooding of soil samples taken from cereal stubble was found to give the best prediction of the risk of slug damage to oilseed rape. Soil sampling in sanding cereal crops was less reliable, as was slug trapping in both standing cereals and stubble. However, slug trapping in standing cereals may have some potential for risk assessment. These conclusions are very preliminary because only two sites (both in England) had substantial slug damage after cultivation and more data on severe slug damage are needed from cultivated sites, especially in Germany.

A third method of assessing slug populations by pulling up cereal roots shortly before or after harvest was also be tested and found to be unsuitable.

Slug populations in oilseed rape stubble and a following crop of winter wheat were investigated in northern Germany in 2004, together with slug damage to wheat. Shallow cultivation, particularly with two or three passes appeared to be more successful than metaldehyde pellets in reducing slug damage. The use of fertiliser (Kalkstickstoff) was also investigated. The results suggest that this treatment might have reduced slug numbers and damage, but further results are needed.

1. Introduction

In 2002 (UFOP Project Nr. 521/024a) and 2003 (UFOP Project Nr. 521/031a) we made considerable progress in developing and testing methods of assessing slug infestation incidence in fields to be sown with winter oilseed rape. Based on this research, two methods were selected: -

1. Rapid soil sampling and flooding to assess slug population density in soil
2. Refuge trapping to assess slug activity-density

In 2004, these two methods were tested in parallel for validation of risk assessment, as it is thought that the two methods are complementary, as described below.

Soil samples are dug with a spade to a depth of 10 cm, placed individually in water-tight containers and flooded over a period of 3 days, with a further one day period of observation after the end of flooding. Soil samples must be dug when the upper 10 cm of soil is moist, but it is not necessary for the soil surface to be moist. Soil sampling takes more time than trapping but only one visit to the field site is required per sample and sampling can be done under a wider range of soil moisture conditions than trapping.

Refuge traps are put out when the soil surface is moist, baited with slug pellets, and examined the following morning before the traps are exposed to direct sun. The requirement for moist soil surface considerably restricted the number of days on which trapping could be done in both 2002 and 2003.

Because of the predominantly dry nature of the weather in 2002 and 2003, slug damage was slight at most study sites and it was not possible to draw final conclusions about the use of these two methods to assess slug damage risk to oilseed rape. Monitoring of slug populations and damage at a larger number of sites is needed in order to validate the assessment of damage risk to oilseed rape based on the techniques that we have developed.

In addition, further information is needed on the best sampling times for risk assessment. Although the fallow period between harvesting cereals and drilling oilseed rape is in theory the best time to assess slug numbers, this period is very short, it is a busy time for farmers and slugs can be difficult to detect because the soil tends to be dry and slugs hide in the deeper soil slayers. For this reason it may be better to assess slug infestations in standing cereal crops before harvest.

The spade-sized soil samples taken in 2003 are thought to be about the right size for ease of sampling and for detecting potentially damaging slug populations. It will be necessary to finalise the number of samples that need to be taken to assess slug numbers in a field, but for the purposes of validation in this project, we dug 9 samples per field, as in 2003.

In addition to the authors of this report, experienced consultants were included in the project consortium in 2004, to permit slug infestation incidence and slug damage to be studied at more field sites covering all the main regions of Germany. Within each region, a minimum of two field sites were investigated so as to provide information on variability between individual fields as well as between regions. The level of investigation by existing partners was more intensive than that conducted by the new consultant partners.

Extra investigations were conducted, to test whether it is possible to detect the presence of slug eggs & juveniles just before or after cereal harvest by pulling up cereal roots. This method was used successfully by Hanse Agro in 2003 to detect slugs on roots of oilseed rape plants after harvest, but it was not known whether this technique would be effective for detecting slugs on cereal roots before drilling oilseed rape. In addition, the success of soil washing for eggs was tested and different methods of trapping for slugs were compared.

2. Materials and methods

Field sites

The locations of study sites in Germany are shown in Fig. 1 (northern and mid Germany) and Fig. 2 (southern Germany). Each project partner, except Hanse Agro, selected at least two fields, where slugs are known to be present, to be sown with winter oilseed rape in 2004. Within each field, an area of at least 36m x 36m (or equivalent area) was selected, which was not treated with slug pellets. The area for sampling was chosen based on knowledge of previous slug infestation. The precise size and shape of the area depended on the study site and the distance between tramlines, which were used for access to the cereal crop preceding oilseed rape. This area was divided into 9 plots, each plot a minimum of 12 m x 12 m. It was only necessary to mark out these plots precisely in the period after oilseed rape was sown. Up until then, the necessary sampling was done by pacing out the distance between samples along tramlines.

Figure 1. The five study locations (ringed) in northern and mid Germany in 2004, with 2-3 study fields at each location.

Figure 2. The study fields in southern Germany

(A) Baden-Württemberg:

1) **Waldshut**
2) **Plienzhausen**
3) **Übrighausen**
4) **Berolzheim**
5) **Hohenstadt**
6) **Eubigheim**

B) Bayern:

7) **Oberthulba**
8) **Burghausen**

C) Additional studies:

M1) Merklingsen/NRW

At Kiel, the research was done in a field going from oilseed rape into winter wheat, where there were different regimes of cultivations, fertiliser and slug control treatments, as summarised in Fig. 3 and Table 1.

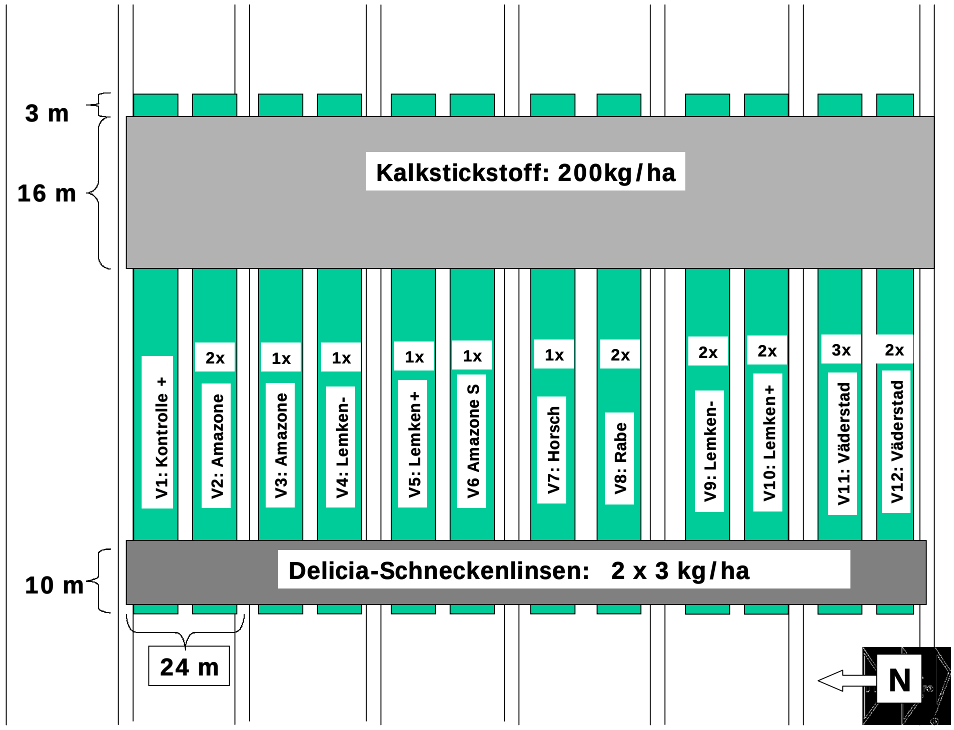


Figure 3. Cultivation regimes without or with shallow tillage on 1 to 3 dates, and without or with fertiliser (Kalkstickstoff) or slug control (Delicia Schneckenlinsen) in a field going from oilseed rape stubble to winter wheat, Löhndorf, Kiel, 2004.

Table 1. Dates of shallow tillage (BB1-3) in a field going from oilseed rape stubble to winter wheat, Löhndorf, Kiel, 2004.

	BB 1 23.08	BB 2 07.09	BB 3 17.09
No cultivations			
1 Cultivation	X		
2 Cultivations	X	X	
3 Cultivations	X	X	X

Standard sampling methods

Times for estimating slug populations
All partners took soil samples and trapped for slugs in each study field, on two occasions as follows, when the upper 10-cm layer of soil was moist, if possible:
1. in the preceding cereal crop before harvest
2. in the stubble after harvest and before cultivation

In addition, the authors of this report took at least one additional sample:
3. When oilseed rape seedlings were at the cotyledon stage to the two-true-leaf stage.

Standard soil-sampling for slugs
From the middle 8m x 8m area of each plot, one soil sample was dug with a spade. This sample area was as determined by the width of the spade used, 18cm x 18cm square (in Germany) or 19.8cm x 19.8cm (with a curved blade, in south west England). Thus, the total area of soil sampled per plot was equivalent to 324cm^2 (31 samples/m^2) or 435 cm^2 (23 samples per m^2), respectively. The samples were taken to a depth of 10cm.

Each of the above samples was placed in a watertight container covered with a slug-proof lid. During processing the samples were kept in the dark because darkness encourages slugs to come to and remain at the soil surface. The containers with the samples were kept out of direct sunshine at all stages of processing and were transported to a cool 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 box 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, the 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 recorded and removed. 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. Special attention was paid to looking inside cut cereal stems and pieces of straw etc lying on the soil surface, where small slugs are known to shelter. The location where each slug was found was 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 has been fully flooded the samples were left for a further day and then a final examination was made for slugs. Slugs collected from soil samples were kept in moist conditions, identified to genus and, if possible, to species.

All partners also classified the size of each slug as small, medium or large. This classification was based on life-sized drawings of slugs in each category. The five partners who were involved in the project in 2003 classified the slugs into the three size categories as above, and then weighed each slug as a check on the accuracy of the method of size classification.

Small:	1 - 10mg
Medium:	11 – 100mg
Large:	>100mg

The six new consultant partners in the project used these life-sized drawings to classify slugs into the three weight categories, but did not weigh the slugs.

Sampling for soil moisture
On each sampling occasion, 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).

Weather records
Daily records of maximum, minimum and mean air temperature, and daily rainfall were obtained from a nearby weather station.

Slug trapping
At the same time as the soil samples were taken, one refuge trap as described below was placed in the middle 8m x 8m area of each of the nine plots in each field to evaluate the activity-density of adult slugs.

Mat traps (‘Schneckentest Folie’) as developed by HOMMAY & BRIARD (1988) were used. These traps 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 are supplied in a size of 50cm x 50cm. However, in research in 2002 and 2003, this large size has been found to be unnecessary and to present practical difficulties because nine large traps are difficult to carry, especially when wet, and it is not possible to deploy the traps in standing cereal crops without destroying an area of the crop. For these reasons, in some cases each trap was cut into four squares, to give smaller traps each 0.25 cm x 0.25 cm.

The bait used in each trap was metaldehyde pellets (Metarex, 7-10g/trap) distributed evenly over the 15x15 cm central ground area underneath each mat, to poison the slugs under the mat and thus reduce the chances of them escaping.

The traps were placed in the field when the soil surface was moist and examined the following morning. If possible, traps were put out or examined on the same day that soil samples were taken from the field site, provided that the soil surface was visibly moist at this time. 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.

Slugs were identified to genus and, if possible, to species and were classified into the three size categories described for soil samples.

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

Assessing the severity of slug damage to oilseed rape in relation to slug populations

Slug damage to oilseed rape at establishment was assessed by dividing each of the nine experimental plots into two sub-plots. One sub-plot (at least 6 m x 12 m) of each plot was treated with a broadcast application of metaldehyde slug pellets (Metarex) at drilling. All 18 subplots (9 treated and 9 untreated) were then monitored on three occasions:-

1. At the cotyledon stage
2. At 2-true-leaves
3. At 4-true-leaves

Further applications of pellets were made on the treated plots at the cotyledon stage if evidence of slug damage was seen, 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.

In each subplot on each occasion, four quadrats (each 0.25m x 0.25m) were placed at random, but in line with the crop rows, within the central area (2m x 8m) of each subplot. In each quadrat, the number of plants was recorded, together with the number of plants with signs of slug damage. Analysis of variance was used to test whether there is 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 of slug damage. The percentage reduction in plant numbers and the percentage of plants with slug damage were 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 timing(s) and method(s) of damage risk assessment.

Cereal root samples

On one occasion at one site at least, either just before or just after cereal harvest, provided that the soil was moist, each partner uprooted 10 cereal plants from each plot (a total of 90 plants per field) and examined these for the presence of active slugs and slug eggs. Slugs were classified into three size categories as described above for soil samples.

Additional studies

Comparison of defined area traps (DATs) and metre square areas
At Braunschweig, defined area traps (DATs) were installed in four of the eight plots in both trial fields in Sickte on 1 September 2004. For that purpose, a plastic ring 25 cm high and 55 cm in diameter (0.25 m²) was inserted 10 cm deep into the soil. The soil surface inside the ring was strewn with 10g Metarex slug pellets and the ring covered with black, light-impervious fabric. These traps were regularly checked. Mouldy bait was removed and replaced by fresh pellets. Slugs were collected, determined, weighed and classified by weight.

Areas of one square metre were set up in the right corner at the front of all test plots in all three trial fields after sowing, and were treated with 40 g Metarex. These one-square-metre areas were regularly checked and slugs collected, determined, weighed and classified by weight.

Comparison of different refuge traps and duration of trapping period
At Göttingen, the number of slugs foraging on the soil surface was recorded by using two different types of refuge traps, standard mat traps, as described above, and saucer traps. Metaldehyde pellets (Metarex, 7 g/trap) were distributed evenly over the 15 cm x 15 cm central area on the ground underneath each mat as bait. One refuge trap was placed in the middle of each of the nine plots on the days of soil sampling. Upturned flowerpot saucer traps (27 cm Ø) were set up in parallel in the middle of each plot, about 3 m away from the mat traps. The plastic saucer traps were also baited underneath with metaldehyde pellets (Metarex, 7 g pellets/trap).

On each sampling occasion, the slugs captured under each refuge trap were collected twice, on the morning following the first night (Day 1) and on the morning following the second night of exposure (Day 2). The number, body weight and species identity of slugs was determined. Subsequently, the traps and the bait pellets were removed from the soil surface of the plots.

3. Results

Weather

Weather data for each main location are shown as Figs. 17 to 22 as an appendix to this report. There was more rain in the period of study from July to October 2004 than in the equivalent period in 2003.

Slug infestation incidence in soil and traps

The population densities of slugs per m^2, recorded by the rapid method of soil sampling, on all study fields sown with winter oilseed rape in 2004, are summarised in Table 2a to 2f. It should be noted that, for the sites in Germany (Tables 2a, b, c, d, e and g), 31 slugs/m^2 is equivalent to a mean of one slug per sample and, for the sites in England (Table 2f), where the sample size was slightly larger, 23 slugs per m^2 is equivalent to one slug per sample.

Slug populations in soil were low at all sites sown with oilseed rape in Germany in 2004 (Table 2a, b, c, d, e). The highest density recorded was 19.3 slugs/m^2 in the direct-drilled field at Sickte, in cereal stubble on 2 August (Table 2a). The numbers of slugs recorded in traps were also rather low at most sites in Germany, with less than one slug per trap on most sampling dates. Notable exceptions to this were at Torland, Göttingen, in standing cereals in July and in cereal stubble in mid August (Table 2b), where slug numbers reached 8-10 per trap. It was notable that the soil was dry, below 20% moisture content, on most dates in July and August in Germany.

At Braunschweig, ten slugs of the genus *Arion* were found, all of them in the Wülperode trial field. 120 slugs were of the genus *Deroceras*, found in the Sickte trial fields only, with the greatest numbers recorded on the direct drilled field.

One site in south west England (Eight Acres, Table 2f) had substantial numbers of slugs (mainly *Deroceras reticulatum,* but also some *Arion* spp.). There were moderate numbers (30/m^2) in the soil of standing cereals on 15 July, falling to 9/m^2 on 3 August and rising to a peak of 90/m^2 on 21 August. Interestingly, slug numbers in traps peaked at 40/trap at this site on 3 August, at about 10 times the level on 15 July. On 3 August, the soil was noticeably dryer at 2-10 cm depth (21.2% moisture) than at 0-2 cm (23.8% moisture). Because of the relatively dry soil at 2-10cm it is possible that slugs were resting in the soil below the depth of sampling. In contrast, the activity of larger slugs was relatively high on that date because of the moist soil surface following rain. As in previous years, slug numbers in soil fell substantially (by 85-92%) following cultivation (two passes with a disc cultivator and roller). The second site in south west England showed low but increasing populations in July-early September, but this site had to be abandoned after drilling because of accidental overall treatment with slug pellets.

Table 2a. Mean numbers of slugs in soil and traps in all field sites in Braunschweig sown with oilseed rape in 2004.

Field site	Date & cropping stage	% Soil moisture		Mean number of slugs in soil samples, per m^2				Mean number of slugs per trap			
		0-2 cm	2-10 cm	*Deroceras*	*Arion*	Milacid	All species	*Deroceras*	*Arion*	Milacid	All species
Sickte, Field 1 (Direct drilled)	2 August[2]	13.1	13.1	19.3	0	0	19.3	0.5	0	0	0.5
	23 August[4]	13.3	13.3	0	0	0	0	1.5	0.3	0	1.8
	31 Aug.[5]	18.2	18.2	0	0	0	0	0.6	0	0	0.6
Sickte Field 2 (Reduced tillage)	2 August[2]	13.1	13.1	0	0	0	0	0.6	0	0	0.6
	23 August[4]	13.3	13.3	0	0	0	0	0	0	0	0
	31 Aug.[5]	18.2	18.2	0	0	0	0	0	0	0	0
Wülperode (Reduced tillage)	2 August[2]	17.2	17.2	0	3.9	0	3.9	0	0.1	0	0.1
	23 August[4]	16.0	16.0	0	0	0	0	0	0	0	0
	31 Aug.[5]	21.3	21.3	0	0	0	0	0	0.2	0	0.2

[1]Standing cereals; [2]Cereal stubble, no cultivation;
[4]After drilling oilseed rape; [5]Oilseed rape at cotyledon stage

Table 2b. Mean numbers of slugs in soil and traps in field sites, Göttingen, sown with oilseed rape in 2004.

Field site	Date & cropping stage	% Soil moisture		Mean number of slugs in soil samples, per m^2				Mean number of slugs per trap			
		0-2 cm	2-10 cm	*Deroceras*	*Arion*	Milacid	All species	*Deroceras*	*Arion*	Milacid	All species
Torland (Reduced tillage)	20 July[1]	20.6	16.7	6.9	6.9	0	13.7	8.7	1.2	0	9.8
	17 August[2]	22.2	17.8	10.3	0	0	10.3	6.0	1.8	0	7.8
	6 Sept.[5]	13.8	18.0	10.3	0	0	10.3	0.1	0	0	0.1
Am Tannenberg (ploughed)	14 July[1]	18.4	17.3	0	0	0	0	0	0.6	0	0.6
	20 July[1]	18.4	18.0	0	13.7	0	13.7	0.2	1.4	0	1.7
	27 July[2]	19.6	18.3	0	13.7	0	10.3	0.2	0	0	0.2
	1 Sept.[5]	18.1	19.8	0	0	0	0	-	-	-	-

[1]Standing cereals; [2]Cereal stubble, no cultivation;
[4]After drilling oilseed rape; [5]Oilseed rape at cotyledon stage

Table 2c. Mean numbers of slugs in soil and traps in field sites of Aurich and Gelnhausen (Göttingen Consultants), sown with oilseed rape in 2004.

Field site	Date & cropping stage	% Soil moisture		Mean number of slugs in soil samples, per m^2				Mean number of slugs per trap			
		0-2 cm	2-10 cm	*Deroceras*	*Arion*	Milacid	All species	*Deroceras*	*Arion*	Milacid	All species
Aurich, Loquard (Ploughed)	4 August[1]						3.4				-
	12 August[2]						0				-
	6 Sept[5]						-				0
Aurich, Pewsum (Plough)	4 August[1]						13.6				-
	12 August[2]						3.4				-
	6 Sept[5]						-				0
Gelnhausen, Geislitz (Reduced tillage)	20 July[1]						17.2				0.3
	12 August[2]						0				0.2
	13 Sept[5]						-				0.4
Gelnhausen, Alten-Hasslau (Ploughed)	20 July[1]						0				1.3
	12 August[2]						0				0.6
	13 Sept[5]						-				-

[1]Standing cereals; [2]Cereal stubble, no cultivation;
[4]After drilling oilseed rape; [5]Oilseed rape at cotyledon stage

Table 2d. Mean numbers of slugs/m^2 extracted from soil by rapid soil sampling and by trapping in field sites 1-4, Southern Germany (Baden-Württemberg), sown with oilseed rape in 2004.

Field site	Date & cropping stage	% Soil moisture		Mean number of slugs in soil samples, per m^2				Mean number of slugs per trap			
		0-2 cm	2-10 cm	*Deroceras*	*Arion*	Milacid	All species	*Deroceras*	*Arion*	Milacid	All species
1. Waldshut-Tiengen (Reduced tillage)	29 June[1]	18.1	15.0	0	0	0	0	0	0	0	0
	9 August[2]	12.8	22.9	10.3	0	0	10.3	0.7	0	0	0.7
	30 Sept[4]	23.0	22.8	10.3	0	0	10.3	0.4	0	0	0.4
2. Plienzhausen (Reduced tillage)	29 June[1]	18.5	15.4	17.2	0	0	17.2	0.1	0.6	0	0.7
	20 July[2]	16.1	18.9	0	0	0	0	0	0	0	0
	1 Sept[4]	16.0	21.4	3.4	0	0	3.4	0	0	0	0
	9 Sept. [5]	15.8	23.5	-	-	-	-	0	0	0	0
3. Übrighausen (Reduced tillage)	15 August[1]	-	-	-	-	-	-	0	0	0	0
	16 August[1]	16.6	22.2	0	0	0	0	0.7	0.4	0	1.1
	25 August[2]	-	-	0	0	0	0	0	0	0	0
	16 Sept[4]	22.6	23.6	3.4	0	0	3.4	0.4	0	0	0.4
4. Berolzheim (Reduced tillage)	21 July[1]	-	-	0	0	0	0	-	-	-	-
	3 August[2]	19.3	29.5	3.4	0	0	3.4	0	0	0	0
	23 August[4]	24.4	29.7	0	0	0	0	0.6	0	0	0.6
	7 Sept[5]	16.0	24.7	0	0	0	0	0.2	0	0	0.2

[1]Standing cereals; [2]Cereal stubble, no cultivation;
[4]After drilling oilseed rape; [5]Oilseed rape at cotyledon stage

Table 2e. Mean numbers of slugs/m^2 extracted from soil by rapid soil sampling and by trapping in field sites 5-8, Southern Germany (5 & 6, Baden-Württemberg; 7 & 8, Bayern), sown with oilseed rape in 2004.

Field site	Date & cropping stage	% Soil moisture		Mean number of slugs in soil samples, per m^2				Mean number of slugs per trap			
		0-2 cm	2-10 cm	*Deroceras*	*Arion*	Milacid	All species	*Deroceras*	*Arion*	Milacid	All species
5. Hohenstadt (Reduced tillage)	6 July[1]	18.8	15.3	0	0	0	0	0.1	0.2	0	0.3
	27 July[2]	14.6	19.0	0	0	0	0	-	-	-	-
	25 August[4]	21.6	25.3	0	0	0	0	0.2	0	0	0.2
6. Eubigheim (Reduced tillage)	12 July[1]	18.8	15.3	0	0	0	0	0	0.9	0	0.9
	2 August[2]	19.2	19.5	0	0	0	0	0	0	0	0
	8 Sept[4]	15.8	23.5	0	0	0	0	0	0	0.2	0.2
7. Oberthulba (Reduced tillage)	19 July[1]	-	-	3.4	0	0	3.4	0	0	0	0
	30 July[1]	-	-	0	0	0	0	0	00.9	0	0.9
	13 August[2]	-	-	3.4	0	0	3.4	0	0	0	0
	27 August[4]	-	-	0	0	0	0	0.1	0	0	0.1
8. Burghausen (Reduced tillage)	12 July[1]	-	-	0	0	0	0	0	0.2	0	0.2
	30 July[1]	-	-	0	0	0	0	0	0	0	0
	13 August[2]	-	-	0	0	0	0	0	0	0	0
	15 Sept[5]	-	-	-	-	-	-	0.4	0	0	0.4

[1]Standing cereals; [2]Cereal stubble, no cultivation;
[4]After drilling oilseed rape; [5]Oilseed rape at cotyledon stage

Table 2f. Mean numbers of slugs/m^2 extracted from soil by rapid soil sampling and by trapping in field sites in south-west England sown with oilseed rape in 2004.

Field site	Date & cropping stage	% Soil moisture		Mean number of slugs in soil samples, per m^2				Mean number of slugs per trap			
		0-2 cm	2-10 cm	*Deroceras*	*Arion*	Milacid	All species	*Deroceras*	*Arion*	Milacid	All species
Eight Acres (Reduced tillage)	15 July[1]	23.7	23.6	29.9	0	0	29.9	3.7	0.1	0	3.8
	23 July[1]	-	-	-	-	-	-	15.7	0.6	0	16.3
	3 August[1]	23.8	21.2	9.2	0	0	9.2	33.6	5.9	0	39.5
	21 August[2]	28.4	27.6	87.4	2.6	0	90.0	4.9	0.8	0	5.7
	20 Sept[4]	22.5	26.2	4.6	2.6	0	8.0	2.1	0.2	0	2.3
	7 October[5]	24.3	27.1	9.2	2.6	0	11.8	0.8	0.1	0	0.9
	20 October[6]	-	-	-	-	-	-	4.6	0.4	0	5.0
	10 Nov[7]	-	-	-	-	-	-	0.8	1.2	0	2.0
Langmead (direct-drilled)	16 July[1]	20.0	18.8	0	5.1	0	5.1	1.4	0	0	1.4
	1 Sept[2]	24.3	23.8	12.8	15.3	2.6	30.7	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-

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

Table 2g. Mean numbers of slugs in soil and traps in Hanse Agro field sites, northern Germany, going from oilseed rape to winter wheat in 2004.

Field site	Date & cropping stage	% Soil moisture		Mean number of slugs in soil samples, per m^2				Mean number of slugs per trap			
		0-2 cm	2-10 cm	*Deroceras*	*Arion*	Milacid	All species	*Deroceras*	*Arion*	Milacid	All species
Lohndorf V1	20 August[2]	21.6	17.5	230	0	0	230	5.9	0	0	5.9
	17 Sept.[2]	14.5	17.9	703	0	0	703	72.7	0	0	72.7
	30 Sept.[5]	20.3	19.8	195	0	0	195	49.3	0	0	49.3
Lohndorf V12	20 August[2]	20.8	17.5	377	0	0	377	11.9	0	0	11.9
	17 Sept.[2]	15.1	17.9	278	0	0	278	45.9	0	0	45.9
	30 Sept.[5]	21.2	20.6	21	0	0	21	7.8	0	0	7.8

[2]Oilseed rape stubble; [5]Winter wheat

The highest slug populations of all (up to 703/m^2 in soil samples and up to 73/trap) were recorded in oilseed rape stubble at field sites in northern Germany (Table 2g), even although soil moisture levels were below 20% on most dates. There was some reduction following drilling of winter wheat in late September.

Studies were also made, from Stuttgart, in oilseed rape stubble at Merklingsen in Northrhine Westphalia (NRW), (Fig.2, M1), located 500 km North-west of Stuttgart. Soil samples and trap catches were compared on nine plots on this date: only *D. reticulatum* were recorded and the mean slug density in soil samples was 134/m² (equivalent to just over 4 slugs/sample), compared to a mean catch of 36.5 slugs/trap.

The percentage of soil samples without slugs was negatively correlated with slug density in soil as shown by Fig. 4, which shows this relationship for the soil samples collected from south west England. It would be much quicker to record the presence or absence of slugs in soil samples than to estimate slug density.

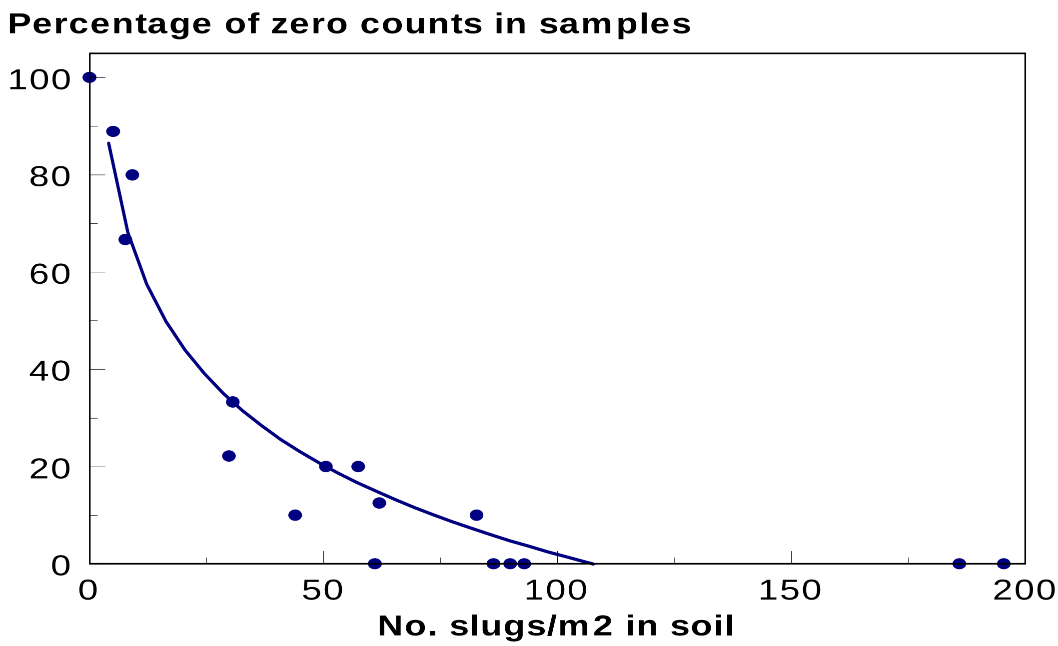


Figure 4. Percentage of soil samples with zero slug counts in relation to the density of slugs in soil.

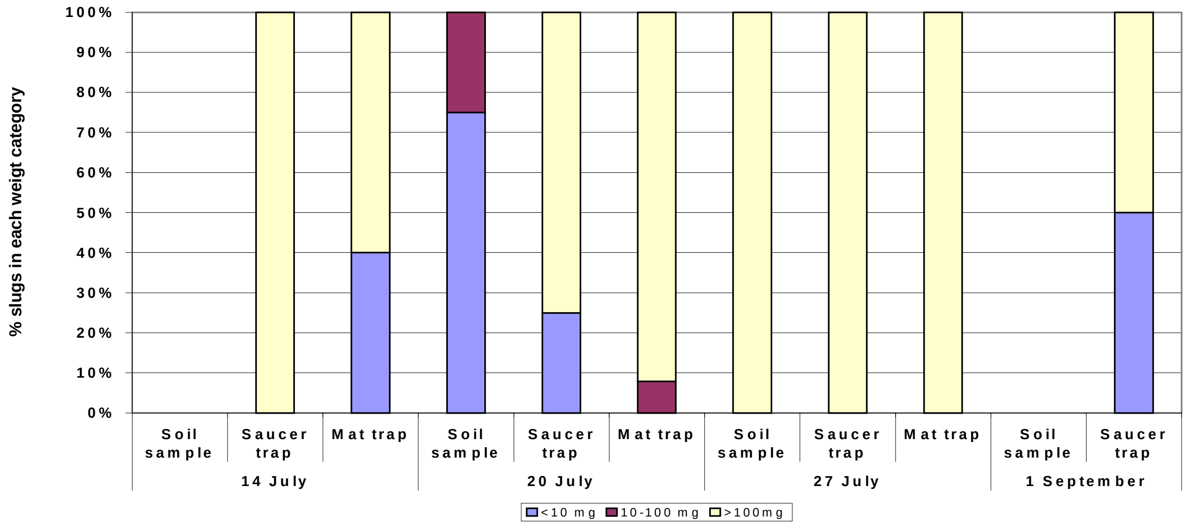
Size structure of the slug population

Table 3 shows the number of slugs in the different size classes in the three trial fields at Braunschweig. Small slugs (1-10 mg) were recorded only from soil samples on 2 August. Slugs in the Wülperode test field were all in size classes M and L. Their average weight was lower than at Sickte, because all were of the smaller *Arion* species. The directly sown field in Sickte had all size classes of *Deroceras* slugs, but large slugs (which were recorded from traps) made up the great majority. The presence of small slugs, which were found in central test plots, shows that slugs were probably reproducing in the field and that the population was obviously not only immigrant.

Table 3. Distribution of slugs over the size classes small (S), medium (M), and large (L) and average weight of slugs in each test field.

Trial field	Sample type	Class S 1-10 mg	Class M 11-100 mg	Class L >100 mg	Average weight [mg]
Sickte Dir	Soil	3	0	2	300 (*Deroceras*)
	Trap	0	0	90	
Sickte	Soil	0	0	0	323 (*Deroceras*)
	Trap	0	0	20	
Wülperode	Soil	0	1	0	145 (*Arion*)
	Trap	0	4	5	

At Göttingen, there was a clear tendency for the small and medium slugs to be predominately found in soil samples, whereas large slugs, and to a lesser extent medium slugs, predominated in trap catches (Fig. 5). Average weights in soil samples and traps are shown in Table 4.



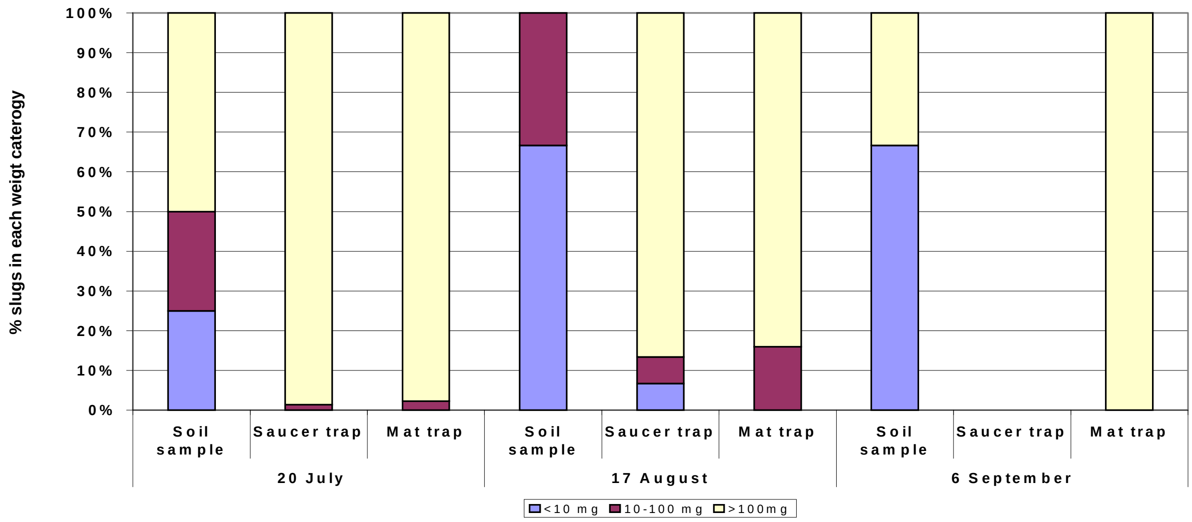


Figure 5. Percentages of the slug population in three size categories in soil samples and two types of trap at Torland (above) and Am Tannenberg (below), Göttingen, 2004.

In south west England, small slugs were found in soil samples on all sample dates, as shown in Fig. 6 for Eight Acres Field. Numbers of small and medium slugs peaked in cereal stubble in late August. This indicates that slugs were hatching during the summer, with strong evidence of successful breeding in the wet weather of July-August (Fig. 21). In traps, the slugs, predominantly *D. reticulatum*, were almost all in the large size categories at both sites with mean weights as shown in Table 5.

Table 4. Mean body weight of slugs collected by flooding soil samples, and by refuge trapping on two consecutive days, Göttingen 2004.

TORLAND

Sampling date	*Soil samples* (mg/ind. *)	Mat traps (50 x 50 cm) (mg/ind. *)		Saucer traps (27 cm Ø) (mg/ind. *)	
		Day 1	Day 2	Day 1	Day 2
20 July	279.5 (4)	298.9 (82)	235.2 (45)	301.1 (58)	220.9 (26)
17 August	5.1 (3)	224.8 (58)	288.0 (5)	188.1 (14)	205.5(4)
6 September	221.2 (3)	216.0 (1)	0	0	98.7 (1)

( ) = total no. of slugs, * including all species except *A. ater*

AM TANNENBERG

Sampling date	*Soil samples* (mg/ind.)	Mat traps (50 x 50 cm) (mg/ind.)		Saucer traps (27 cm Ø) (mg/ind.)	
		Day 1	Day 2	Day 1	Day 2
14 July	0	301.6 (5)	nd	248.4 (3)	nd
20 July	9.9 (4)	199.7 (15)	250.4 (4)	183.7 (4)	168.0 (5)
27 July	237.1 (3)	0.89 (2)	386.2 (3)	127.9 (2)	230.6 (3)
1 September	0	nd	nd	138.3 (2)	74.4 (1)

( ) = total no. of slugs

Near Kiel, in northern Germany, (Fig, 7), where high densities of *D. reticulatum* were recorded in oilseed rape stubble, the size structure of the slug population in late August (KW 34) was remarkably similar to that at the same time in south west England (Fig. 6), with 62-76% small slugs and 22-37% medium slugs. This is clear evidence of successful breeding during July-August in northern Germany. The presence of small slugs on all sampling dates shows that breeding continued into the autumn.

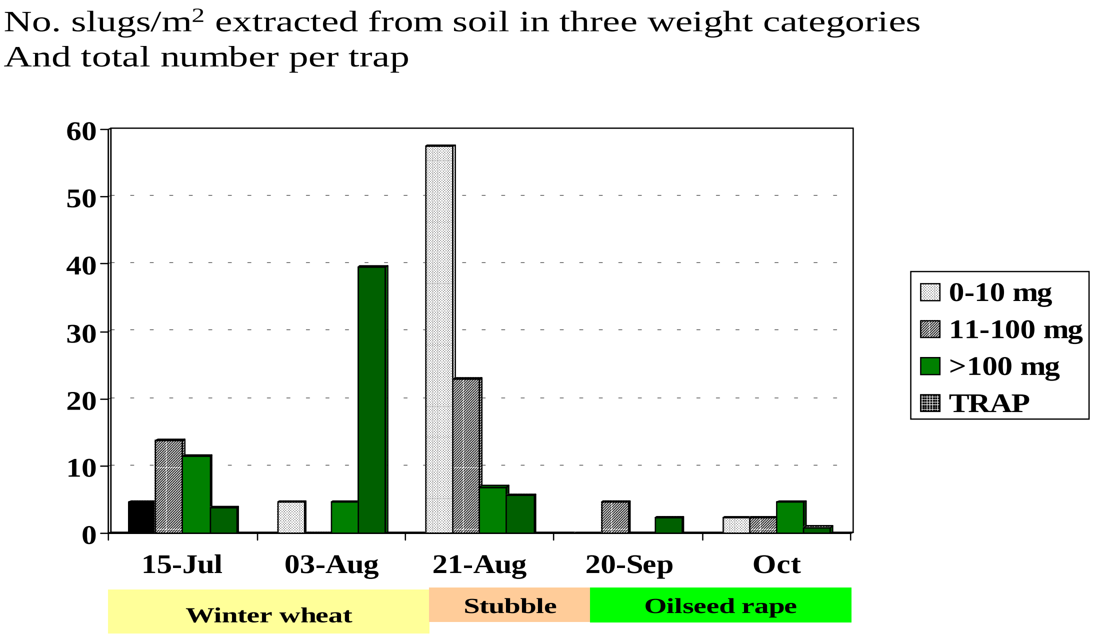


Figure 6. Numbers of slugs/m^2 in three size categories in soil samples and numbers in traps at Eight Acres Field, south west England, 2004.

Table 5. Mean weights of slugs (mg) recorded in traps at two field sites in south west England (n = number of slugs weighed). The percentage of *D. reticulatum* >100mg are shown. *Arion* spp. were all >100mg.

Field site	Slug species	Sampling date					
		15.07	23.07	4.08	21.08	18.09	7.10
Eight Acres	*D. reticulatum*	559	483	410	280	261	238
	(n)	(20)	(20)	(19)	(20)	(18)	(8)
	% >100mg	100%	100%	100%	100%	89%	88%
	A. subfuscus	-	2075	1830	1525	1969	-
	(n)		(4)	(20)	(3)	(2)	
	A. ater	-	11214	10651	-	-	-
	(n)		(2)	(3)			
Lang-mead	*D. reticulatum*	564	-	-	-	-	-
	(n)	(14)					

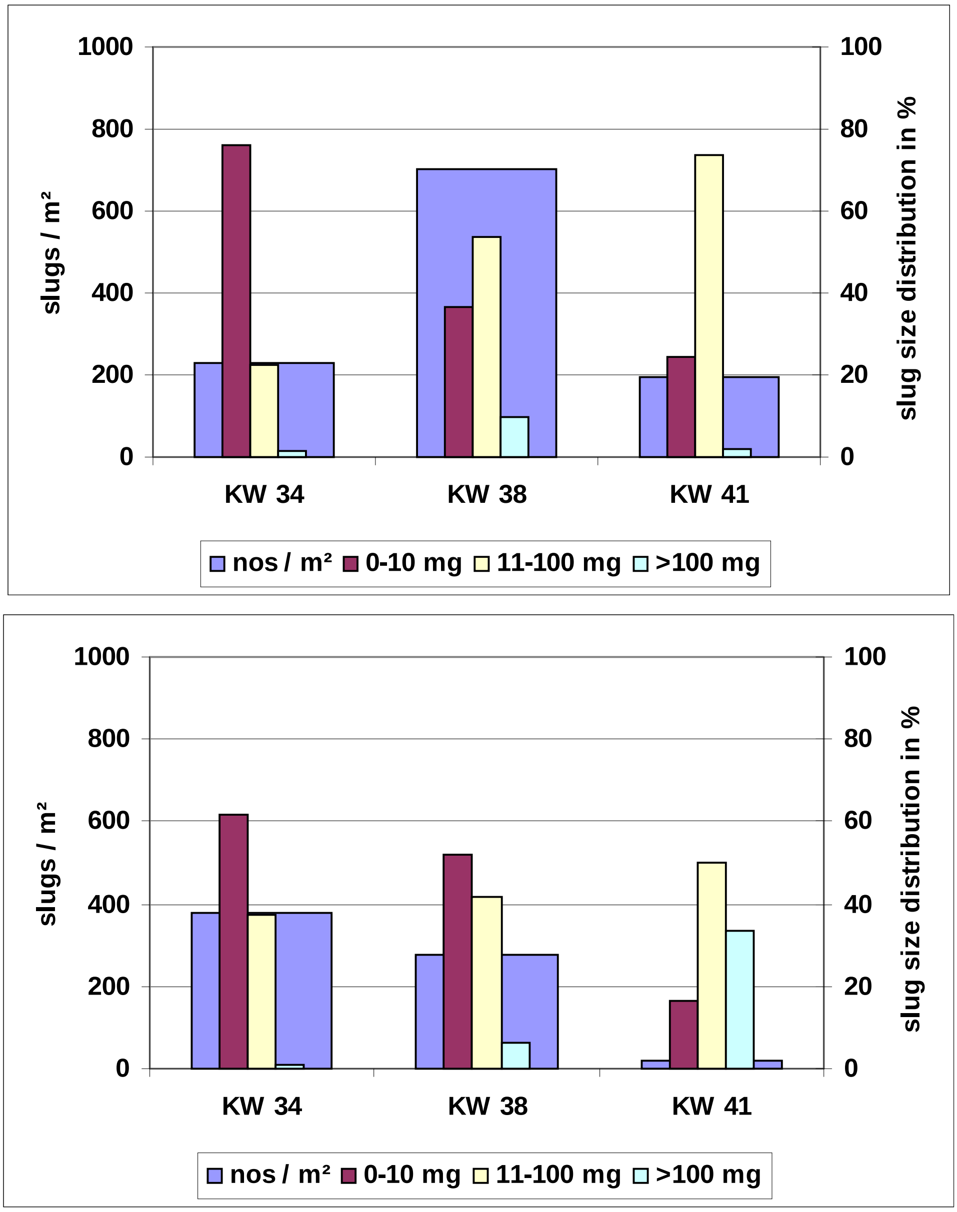


Figure 7. Numbers of slugs/m^2 and the percentages of slugs in each of three size categories in soil samples from V1 and V12, Löhndorf, northern Germany, 2004.

The weights of 229 individuals (all *D. reticulatum*) collected from traps after one night (28/29 September 2004) at Merklingsen in Northrhine Westphalia (NRW),are shown in Fig. 8. The great majority of slugs were >100 mg.

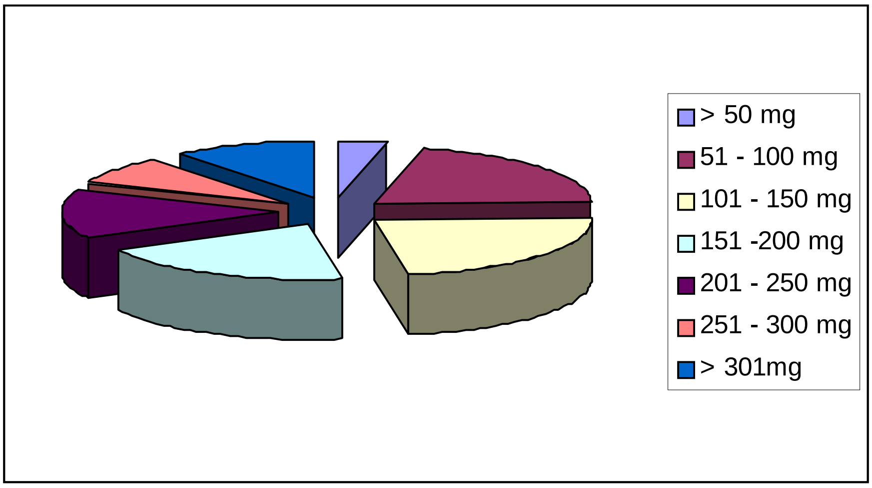


Figure 8. The weights of 229 slug weights trapped in oilseed rape stubble, 28/29 September 2004 at Merklingsen/NRW.

Ease of use of the rapid method of soil sampling

The rapid method of soil sampling used for monitoring slug populations in 2004 required more effort than slug trapping. The main problem with the method was the need to remove soil samples from the field. Some consultants did not have a suitable vehicle for this.

During the flooding process, the great majority of slugs were recorded on the kohlrabi slices, on the container lid or sides (Table 6).

Table 6. Places where slugs were recorded during rapid flooding, 2004.

Place where slugs were found	No.	%
Container lid	252	32.1
Container sides, above water level	155	19.7
Container sides, below water level	31	3.9
Kohlrabi slices	285	36.3
Soil surface	62	7.9
Cereal stalks	0	0
Soil below water	0	0
Total recorded	136	100

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

Plant numbers and slug damage

Slug damage (Table 7a, 7b & 7c) was estimated at 17 of the 19 field sites. Damage 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. Slug damage data were not available for two fields, one in Bayern where there was herbicide damage to the crop and one in south west England where slug pellets were accidentally applied to the whole field. Low levels of damage were recorded on fourteen of the seventeen fields.

Substantial damage was recorded on three fields. The first of these was the Sickte direct-drilled field at Braunschweig (Table 7a), where a 23% decrease in plant numbers was recorded, with 33% of the surviving plants showing signs of slug damage. Soil sampling revealed that there were 19 slugs/m^2 in the cereal stubble on 2 August. However, no slugs were recorded in soil after drilling and emergence and only low numbers were recorded in traps in cereal stubble and at oilseed rape establishment. Direct-drilled crops are known to be at especially high risk of slug damage because of the absence of cultivation which otherwise reduces slug populations (VOSS *ET AL.*, 1998; GLEN & SYMONDSON, 2003). The second site was a field with reduced tillage, Plienzhausen, Baden Württemberg (Table 7b), where a 28% reduction in plant numbers was recorded. However, in contrast, there was only 1% of damage to the surviving plants at this field site. This pattern of a substantial reduction in plant numbers but with only a small amount of damage to the surviving plants is not typical of slug damage to oilseed rape, as recorded in this project over the three years from 2002 to 2004. It therefore seems likely that some other factor was probably responsible for the decrease in plant numbers at this site. The third site with substantial damage was Eight Acres Field, south west England (Table 7c) where, after reduced tillage, a 36% decrease in plant numbers was recorded, with 92% of the surviving plants showing slug damage. At this site, slug numbers had built to a peak of 90/m^2 by late August in cereal stubble. Soil sampling after drilling indicated that numbers were reduced by about 87-92% following cultivation (Table 7c).

The pattern of damage through the establishment phase at Eight Acres Field is shown in Fig. 9. Because of late drilling (16 September) the oilseed rape seedlings grew slowly through the establishment phase. Conditions were wet and suitable for slug activity throughout establishment, thus slug attack became progressively more severe, both in the reduction in plant numbers and the percentage of plants with damage. It is important to remember that these figures for damage are average figures and that some patches of crop were severely damaged, with unacceptably low numbers of plants/m^2, considerably less than the average figures for plants/m^2 might suggest.

Table 7a. Slug damage to oilseed rape in nine fields in northern Germany (see Fig. 1 for locations), 2004, together with slug infestation, estimated using the rapid soil sampling method and the numbers of slugs per trap.

Location	Site & method of cultivation	Slug 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
Braunsch-weig	Sickte (Direct drilled)	No./m^2 Soil	-	19.3	0	0	-	22.9	32.5
		No./trap	-	0.5	1.8	0.6	-		
	Sickte (Reduced tillage)	No./m^2 Soil	-	0	0	0	-	0	5.8
		No./trap	-	0.6	0	0	-		
	Wülperode (Reduced tillage)	No./m^2 Soil	-	3.9	0	0	-	9.1	2.4
		No./trap		0.1	0	0.2			
Göttingen	Torland (Reduced tillage)	No./m^2 Soil	13.7	10.3	-	10.3	-	0	0
		No./trap	9.8	7.8	-	0.1	-		
	Am Tannenberg (Ploughed)	No./m^2 Soil	13.7	10.3	-	0	-	0	0
		No./trap	1.7	0.2	-	-	-		
Aurich	Loquard (Ploughed)	No./m^2 Soil	4.4	0	-	-	-	0	0
		No./trap	-	-	-	0	-		
	Pewsum (Ploughed)	No./m^2 Soil	13.6	3.4	-	-	-	0	5.1
		No./trap	-	-	-	0	-		
Geln-hausen	Geislitz (Ploughed)	No./m^2 Soil	17.2	0	-	-	-	0	2.8
		No./trap	0.3	0.2	-	0.4	-		
	Alten-Hassloch (Ploughed)	No./m^2 Soil	0	0	-	-	-	0	5.9
		No./trap	1.3	0.6	-	0	-		

Table 7b. Slug damage to oilseed rape in eight fields in southern Germany (see Fig. 2 for locations), 2004, together with slug infestation, estimated using the rapid soil sampling method and the numbers of slugs per trap.

State	Site & method of cultivation	Slug 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
Baden-Württem-berg	1. Waldshut (Reduced tillage)	No./m^2 Soil	0	10.3	10.3	-	-	0	1
		No./trap	0	0.7	0.4	-	-		
	2. Plienz-hausen (Reduced tillage)	No./m^2 Soil	17.2	0	3.4	-	-	28.1	1
		No./trap	0.7	0	0	0	-		
	3Übrig-hausen (Reduced tillage)	No./m^2 Soil	0	0	3.4	-	-	0	0
		No./trap	1.1	0	0	-	-		
	4. Berolzheim (Reduced tillage)	No./m^2 Soil	0	3.4	0	0	-	0	0
		No./trap	-	0	0.6	0.2	-		
	5. Hohenstadt (Reduced tillage)	No./m^2 Soil	0	0	0	-	-	0	0
		No./trap	0.3	-	0.2	-	-		
	6. Eubigheim (Reduced tillage)	No./m^2 Soil	0	0	0	-	-	0	0
		No./trap	0.9	0	0.2	-	-		
Bayern	7. Oberthulba (Reduced tillage)	No./m^2 Soil	0	0	0	-	-	*	*
		No./trap	0.9	0	0.1	-	-		
	8. Burghausen (Reduced tillage)	No./m^2 Soil	0	0	-	-	-	0	0
		No./trap	0.2	0	-	0.4	-		

*Slug damage data not available as a result of herbicide damage to crop.

Table 7c. Slug damage to oilseed rape in two fields in south west England, 2004, together with slug infestation, estimated using the rapid soil sampling method and the numbers of slugs per trap.

Site & method of cultivation	Slug 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
Eight Acres (Reduced tillage)	No./m^2 Soil	29.9	90.0	7.2	11.8	11.8	36.2	91.7
	% Decrease	-	-	**92.0**	**86.9**	**86.9**		
	No./trap	39.5	5.7	2.3	0.9	2.0		
Langmead (Direct drill)	No./m^2 Soil	5.1	30.7	-	-	-	*	*
	No./trap	1.4	-	-	-	-		

*Slug damage data not available as a result of overall treatment with slug pellets.

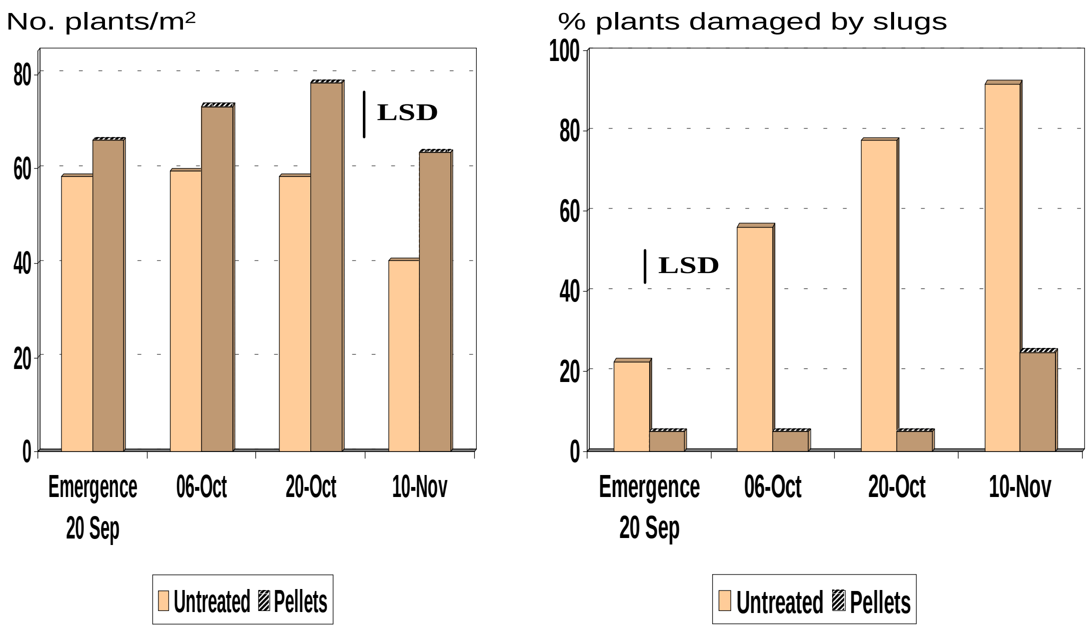


Figure 9. Numbers of plants/m^2 and the percentages of plants damaged by slugs from emergence to the 4-6 true-leaf stage on Eight Acres Field, south west England, 2004.

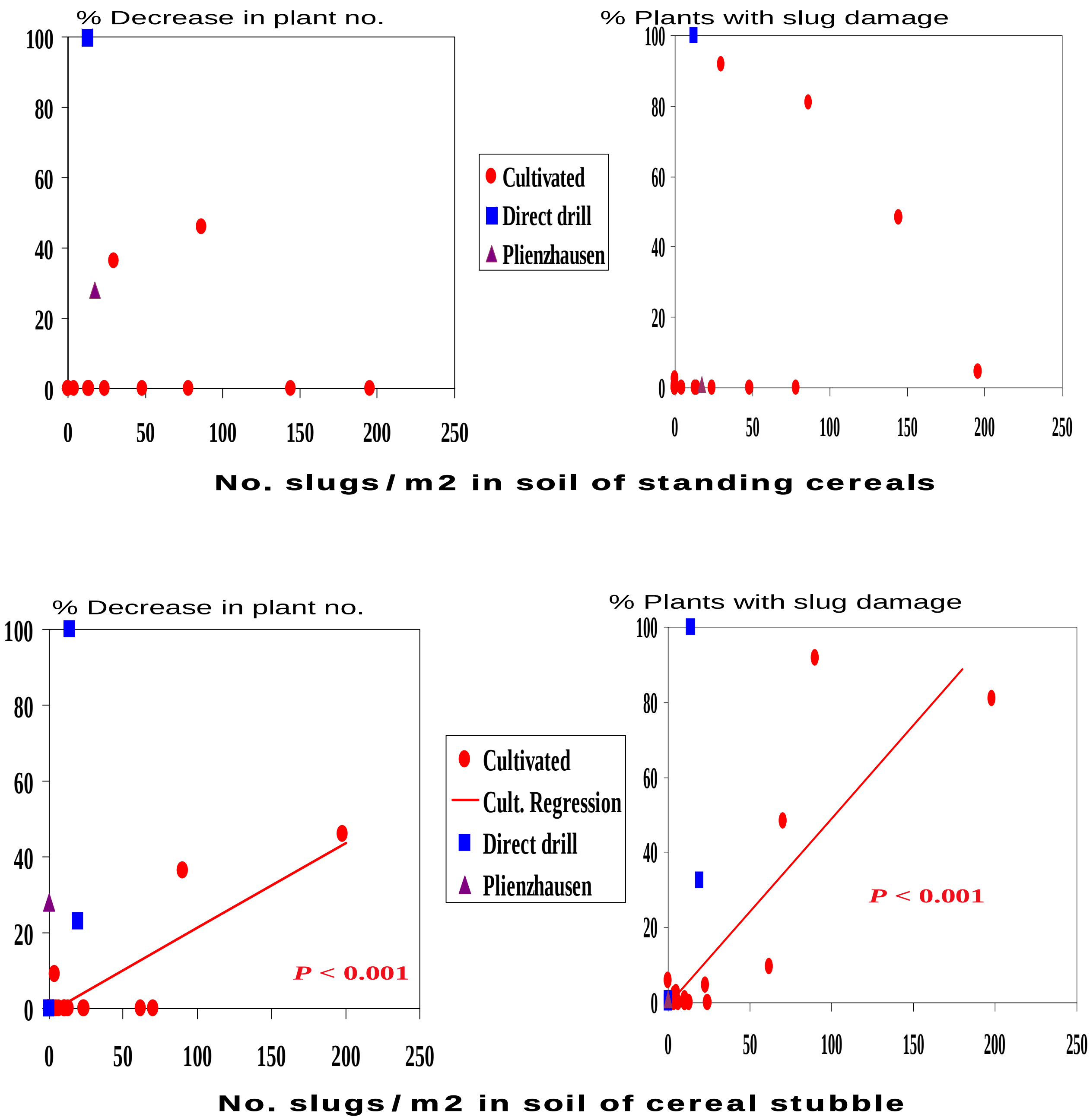


Figure 10. Percentage decrease in density of oilseed rape seedlings (left) and the percentage of surviving plants with slug damage (right) in relation to slug density in soil of the preceding standing cereal crop (above) and the slug density in the soil of cereal stubble (below), 2002-2004. Separate relationships are shown for fields that were cultivated before drilling, or direct drilled, because of the known effect of cultivation in reducing slug numbers. One atypical site, Plienzhausen, in 2004 is also shown separately.

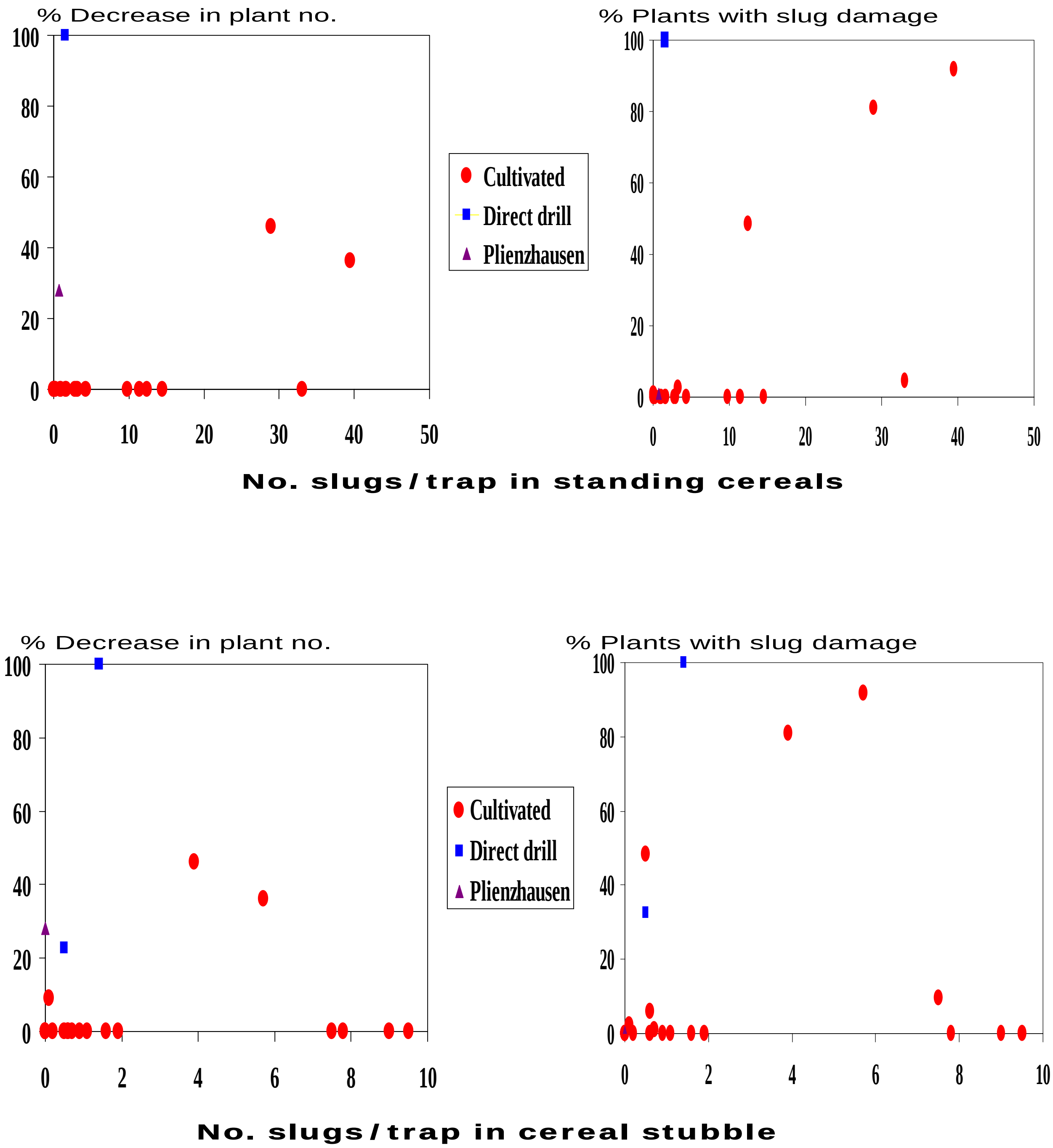


Figure 11. Percentage decrease in density of oilseed rape seedlings (left) and the percentage of surviving plants with slug damage (right) in relation to the slug numbers per trap in the preceding standing cereal crop (above) and the slug numbers per trap in cereal stubble (below), 2002-2004. Separate relationships are shown for fields that were cultivated before drilling, or direct drilled, because of the known effect of cultivation in reducing slug numbers. One atypical site, Plienzhausen, in 2004 is also shown separately.

In order to assess the value of soil sampling and trapping in standing cereals and stubble for estimating the risk of slug damage to a following crop of oilseed rape, we are now able to draw on three years of data. These results are summarised in Fig. 10 and Fig. 11.

The best predictor of the severity of slug damage was the density of slugs recorded in the soil of the cereal stubble shortly before drilling, which was significantly ($P < 0.001$) related to the % decrease in plant density and the % of surviving plants with slug damage, in cultivated fields (Fig. 10). The relationship suggests that 10% of plants would be lost when the slug density in cereal stubble reaches about $50/m^2$, which is an average of just under 2 slugs/soil sample for samples dug with a standard sized spade. However, it is important to remember that most data points for slug damage were at or close to zero and that only 2-3 points contributed to the positive and highly significant regression lines in Fig. 10. Thus more data are needed from fields with severe slug damage. With only 2-3 points for direct-drilled fields, it is not possible to draw firm conclusions about the relationship between slug numbers and damage but, as expected, there appears to be a much steeper slope than for cultivated fields (due to the lack of the effect of cultivation in reducing slug numbers).

The relationships between slug damage and the density of slugs in soil of the preceding standing cereal crop were much more variable (Fig. 10) than the relationships for slug density in the soil of cereal stubble and, therefore, the slug density in the soil of standing cereals does not appear to be suitable for damage prediction.

All relationships between slug damage and trap catches were also highly variable (Fig. 11) indicating that slug traps are unlikely to provide an accurate prediction of the risk of slug damage. In particular, a low catch in traps in cereal stubble was followed by severe damage in one case. There is, however, a possible indication that traps in standing cereals may have some value in predicting the severity of slug damage, even though they sometimes greatly overestimated the risk (Fig. 11).

Slug populations and damage going from oilseed rape to winter wheat

Slug densities were greatly reduced in plots cultivated twice or three times compared to uncultivated plots or plots that were cultivated once only (Fig. 12). Slug densities on plots where metaldehyde pellets were applied were similar to those on untreated plots (Fig. 13), whereas cultivated plots showed lower slug densities than either of these treatments. Plots where fertiliser (Kalkstickstoff) was applied showed reduced slug numbers (which were similar to cultivated plots) compared to the untreated (Fig. 14). The density of winter wheat plants recorded in early October (Fig. 15) showed clearly the value of cultivation and possibly a benefit from fertiliser. However, because of lack of replication in this experiment, these conclusions must be treated with caution.

Löhndorf Herbst 2004

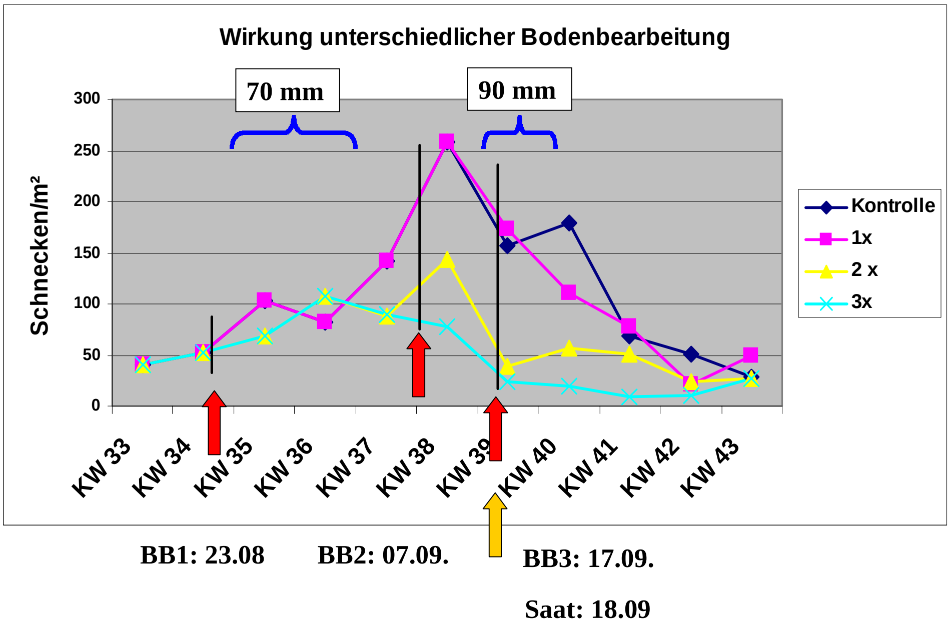


Figure 12. Slug density in oilseed rape stubble and winter wheat, drilled on 18th September, in plots without cultivation (Kontrolle) or cultivated once, twice or three times, Kiel.

Löhndorf Herbst 2004

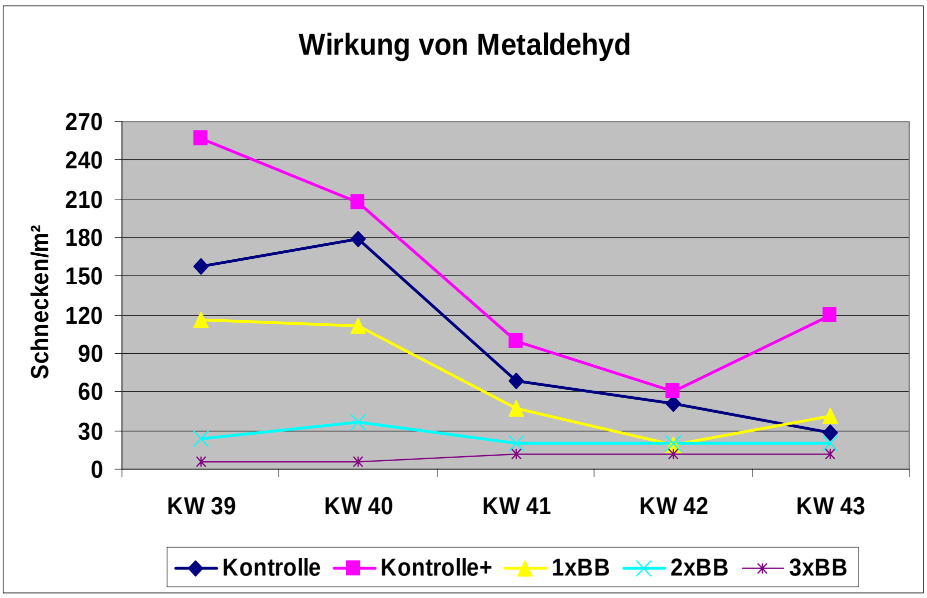


Figure 13. Slug density in oilseed rape stubble and winter wheat, in plots without metaldehyde pellets and without cultivation (Kontrolle), with metaldehyde pellets and without cultivation (Kontrolle+), or without metaldehyde pellets and cultivated once (1xBB), twice (2xBB) or three times (3xBB), Kiel.

Löhndorf Herbst 2004

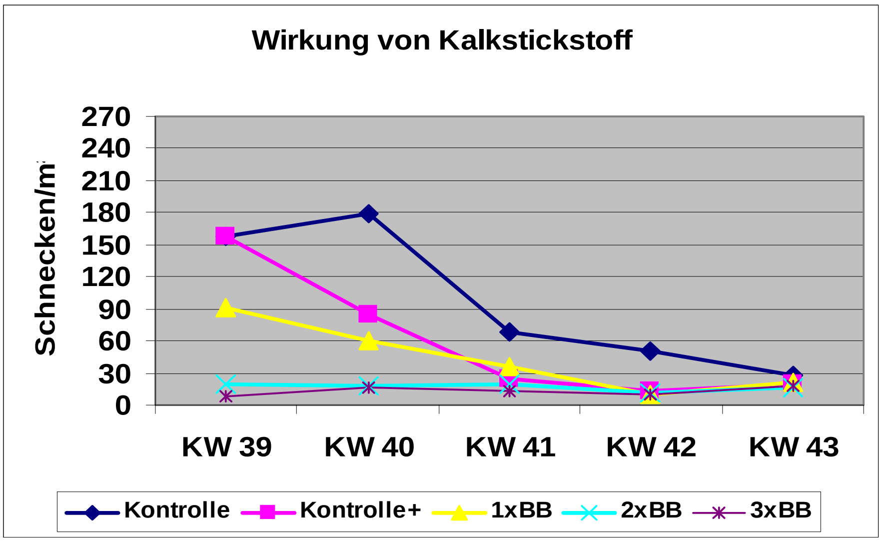


Figure 14. Slug density in oilseed rape stubble and winter wheat, in plots without fertiliser and without cultivation (Kontrolle), with fertiliser (Kalkstickstoff) and without cultivation (Kontrolle+), or without fertiliser and cultivated once (1xBB), twice (2xBB) or three times (3xBB), Kiel.

Löhndorf Herbst 2004

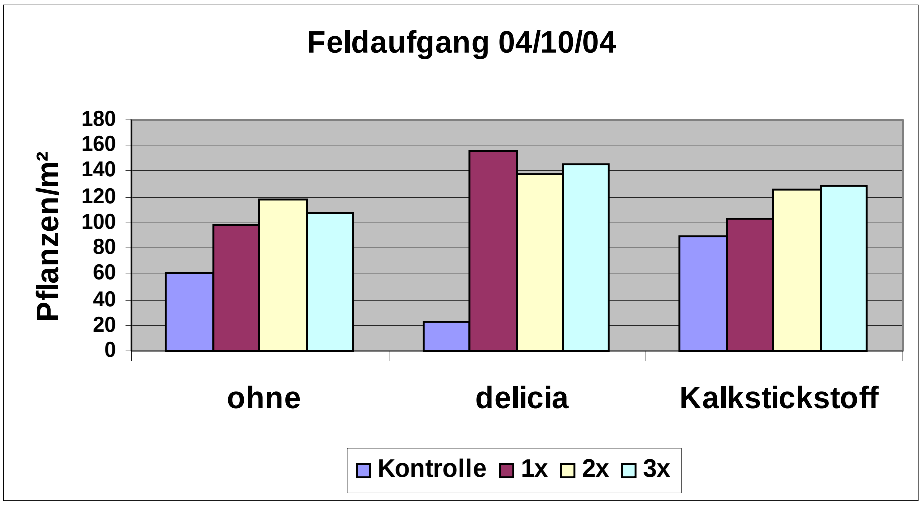


Figure 15. Number of wheat plants/m^2 on plots without treatment (ohne), or with metaldehyde pellets (delicia) or with fertiliser (Kalkstickstoff). In all three treatments, plots were without cultivation (Kontrolle), or cultivated once (1x), twice (2x) or three times (3x), Kiel.

Examination of cereal roots

At Braunschweig, as well as in southern Germany and south west England, no slugs or eggs were recorded from cereal root samples collected in cereal stubble.

At Göttingen, small number of active slugs and egg batches were found by pulling up cereal roots shortly before harvest (Table 8). Two large *D. reticulatum*, one large *Arion* sp. and one small *Arion* were found. In addition, two egg batches were recorded on the root samples of winter wheat collected from Torland on 21 July. In comparison, a total of 4 slugs were detected by flooding 9 soil samples which had been collected from these fields on the same day.

Table 8. Slug species and number of individuals collected from cereal root samples, Göttingen, 2004.

Sampling site	**Kuhwiese** (winter wheat)	**Am Tannenberg** (winter barley)	**Am Tannenberg** (winter barley)	**Torland** (winter barley)
Sampling date	16 July	16 July	21 July	21 July
No. of slugs and weight per 90 root samples	0	1 *A. fasciatus* (371 mg)	1 *Arion* sp. (4.1 mg) 1 *D. reticulatum* (557 mg)	1 *D. reticulatum* (911 mg)
Egg batches/90 roots	0	0	0	2

In Kiel, root samples were collected in late August and September from oilseed rape stubble (Table 9). Here, more slugs and eggs were recorded (up to 47 eggs and 12 active slugs were recorded per 100 roots). Thus, sampling of oilseed rape roots could be a possible method to detect potential risk of slug damage to a following winter wheat crop. However, the numbers recorded were quite small in comparison to the large numbers of slugs recorded from soil samples at these sites (Table 2g and Fig. 7).

Table 9. Slug species and number of individuals collected from root samples in oilseed rape stubble, Kiel, 2004.

Field site	**Löhndorf V1**	**Löhndorf V1**	**Löhndorf V12**
Precrop	Oilseed rape stubble	Oilseed rape stubble	Oilseed rape stubble
Sampling date	20 August	17 Sept.	20 August
No. of individuals per 100 roots	12	3	9
Eggs	47	9	18

Table 10. The number of slug eggs/m² extracted from each of 20 soil samples taken either in plant rows or in the inter-row spaces of both wheat and oilseed rape fields at two occasions in 2004 at Boxberg/ Germany.

Field 1: Winter wheat																						
Samples taken:	In the plant rows																					
BBCH		Sample-No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Mean**
43	Date	28.05.2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
77		21.07.2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Samples taken:	In the interrow spaces																					
BBCH		Sample-No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Mean**
43	Date	28.05.2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
77		21.07.2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**

Field 2: Oilseed Rape																						
Samples taken:	In the plant rows																					
BBCH		Sample-No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Mean**
67	Date	28.05.2004	0	0	0	0	0	**796**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**39,8**
75		21.07.2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0*	0	0	0	0	**0**
																*1 *Deroceras r.* (juv.)							
Samples taken:	In the interrow spaces																					
BBCH		Sample-No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**Mean**
67	Date	28.05.2004	0	0	0	0	0	0	0	0	0	0	0	0	**1393**	0	0	0	0	0	**1194**	0	**129,35**
75		21.07.2004	0	0	0	0	0	0	0	0	0	0	0	0*	0	0	0	0	0	0	0	0	**0**

Washing soil samples for slugs and eggs

In order to improve the probability of egg detection, instead of pulling out plant roots from soil, soil samples were taken either in the plant rows or in the inter-row spaces at two different field sites at Stuttgart, one site with winter wheat and the other with oilseed rape harvested in 2004. 20 single cores were taken at random at the same occasions as the uprooting of the cereal plants. A sampling corer of 8 cm in diameter and 15 cm depth was used in these additional studies. The single soil samples were kept in a PVC-container covered with a slug-proof lid. The soil samples were washed and slug eggs were recovered from the sieves. The results are summarised in Table 10. No eggs were found in the soil samples from the wheat field. In contrast, an average of ca. 40 eggs/ m² was found in soil samples taken from the rows of oilseed rape plants, whereas 130 eggs/m² were regained from washing soil samples taken from the inter-row spaces in the same field. The differences between plant-row and inter-row samples are unlikely to be significant due to the rather low frequency of samples with eggs, which did not exceed 5-10% of the total samples. All eggs were identified as *D. reticulatum*. The July sampling date did not reveal any eggs in any of the washed soil samples. This is likely to highlight that the earlier sampling date (at BBCH 43 for wheat and BBCH: 67 for oilseed rape) is the most promising one.

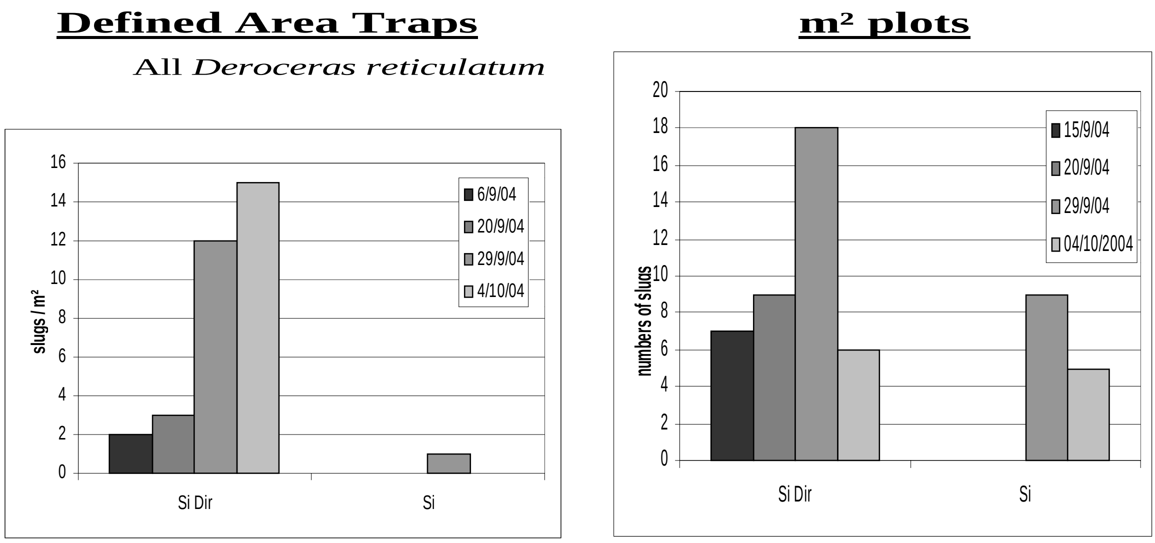


Figure 16. Number of slugs/m^2 in the Sickte Direct Drilled Field (Si Dir) and the Sickte Field with reduced tillage (Si), in defined area traps put in place after oilseed rape drilling and examined at intervals until 4th October, or in square-meter plots treated with metaldehyde pellets and examined at intervals until 4th October.

Comparison of defined area traps (DATS) and square-meter plots

At Braunschweig, slug numbers were monitored in defined-area traps (DATs) set up in both fields in Sickte after sowing of oilseed rape and after the last main sampling date and monitored until early October. Slug numbers increased markedly in the period between 6 September and 4 October 2004 (Fig. 16). While only one slug of the genus *Deroceras* was detected in the Sickte field with reduced tillage, on 29 September 04, slug densities in the Sickte direct-drilled field increased to 15/m². That is, they reached close to the value of 19.3 slugs/m² which was calculated on the basis of soil samples taken on 2 August.

All slugs caught in the DATs belong to the genus *Deroceras* and the large size class (>100 mg). However, the average weight of slugs caught in DATs (246 mg) was about 100 mg less than those in the square-meter plots set up in each test plot at the same time (345 mg). The average weight of slug populations neighbouring the Sickte Direct-drilled field, determined using one-square-metre plots (351 mg), was also much heavier than that of slugs in DATs. The weight difference between animals caught in DAT and those counted in one-square-metre plots was also noted in the 2003 study.

The weight difference suggests that it is quite possible that slugs moved to the soil surface because of optimal surface conditions in dark DATs. Considering the square meter plots (Figure 16), there was a striking increase in densities towards 29 September. So, high slug densities in DATs coincided with increased slug density in the meter square areas. An increase in slug densities owing to wet environmental conditions in autumn was also noted in 2003. It is still unclear whether catches in DATs reflect the autochthonous slug population in these areas or comprised individuals which had immigrated from outside. However, the latter is rather unlikely given that the traps reached 10 cm into the soil and were sealed on top with black cloth.

Comparison of trap types and times of exposure

At Göttingen, the numbers of slugs foraging on the soil surface were recorded by two different types of refuge traps, standard mat traps and saucer traps, put out at the same time and examined on two successive days.

The number of slugs captured by refuge trapping in July and August 2004 at Torland was substantially higher than the number extracted from soil samples (Table 11). Particularly *D. reticulatum* was found in high numbers under the mat traps and saucer traps. However, when densities/m² in soil samples were calculated, these values were similar to the number of slugs/trap on Day 1 in both types of trap (Table 12). In contrast, at Am Tannenberg low numbers of slugs (mainly *Arion* spp.) were captured in mat traps and saucer traps in July, ranging between 2 and 15 individuals per 9 traps (Table 11). A higher density of slugs/m² was detected in the soil samples than in the traps on 20 July and 27 July (Table 11). However, on 14 July and 1 September, up to 0.6 individuals/trap were recorded, whereas no slugs were found in soil samples. At Torland, a high percentage of slugs recorded in soil samples and refuge traps was *D. reticulatum*, whereas *Arion* spp. were predominant (> 80%) in refuge traps at Am Tannenberg (Table 11).

Table 11. Slug species and total number of individuals collected from each set of nine samples by flooding of soil samples and by refuge trapping (Göttingen 2004)

TORLAND

Sampling date	**Soil samples**	**Mat traps (50 x50 cm)**		**Saucer traps (27 cm Ø)**	
		Day 1	**Day 2**	**Day 1**	**Day 2**
20 July	2 *D. reticulatum* 2 *Arion sp.*	77 *D. reticulatum* 3 *A. fasciatus* 1 *A. distinctus* 7 *A. ater*	44 *D. reticulatum* 1 *A. fasciatus* 12 *A. ater*	54 *D. reticulatum* 4 *A. fasciatus* 12 *A. ater*	26 *D. reticulatum* 8 *A. ater*
17 Aug	3 *Deroceras sp.*	54 *D. reticulatum* 4 *A. fasciatus* 12 *A. ater*	2 *D. reticulatum* 3 *A. fasciatus*	12 *D. reticulatum* 2 *A. fasciatus* 1 *A. ater*	2 *D. reticulatum* *2 A. fasciatus*
6 Sept	1 *D. reticulatum* 2 *Deroceras sp.*	1. *D. reticulatum*	0	0	1 *D. reticulatum*

AM TANNENBERG

Sampling date	**Soil samples**	**Mat traps (50 x50 cm)**		**Saucer traps (27 cm Ø)**	
		Day 1	**Day 2**	**Day 1**	**Day 2**
14 July	0	2 *A. fasciatus* 1 *A. distinctus* 2 *Arion sp.*	nd	1 *D. reticulatum* 2 *Arion sp.*	nd
20 July	4 *Arion sp.*	2 *D. reticulatum* *2 A. distinctus* *10 A. fasciatus* 1 *Arion sp.*	4 *A. fasciatus*	3 *A. fasciatus* *1 Arion sp.*	1 *D. reticulatum* 4 *A. fasciatus*
27 July	1 *A. distinctus* 3 *A. fasciatus*	2 *Arion sp.*	2 *D. reticulatum* 1 *Arion sp.*	1 *D. reticulatum* *1 Arion sp.*	1 *D. reticulatum* 4 *A. fasciatus*
1 Sept	0	nd	nd	2 *Arion sp.*	1 *A. distinctus*

nd = not determined

Table 12. Number of slugs/m² collected by flooding of soil samples and by refuge trapping on two consecutive days (Göttingen 2004).

TORLAND

Sampling date	Soil samples (No. of ind./m^2)	Mat traps (50 x50 cm) (No. of ind./m^2)		Saucer traps (27 cm Ø) (No. of ind./m^2)	
		Day 1	**Day 2**	**Day 1**	**Day 2**
20 July	13.7 (3)	9.8 (9)	6.3 (9)	7.8 (9)	3.8 (8)
17 Aug	10.3 (2)	7.8 (9)	0.6 (4)	1.7 (7)	0.4 (3)
6 Sept	10.3 (2)	0.1 (1)	0	0	0.1 (1)

( ) = total number of soil samples or traps yielding slugs

AM TANNENBERG

Sampling date	Soil samples (No. of ind./m^2)	Mat traps (50 x50 cm) (No. of ind./m^2)		Saucer traps (27 cm Ø) (No. of ind./m^2)	
		Day 1	**Day 2**	**Day 1**	**Day 2**
14 July	0	0.6 (4)	nd	0.3 (3)	nd
20 July	13.7 (2)	1.7 (7)	1.8 (3)	0.5 (4)	0.6 (4)
27 July	10.3 (3)	0.2 (2)	1.3 (3)	0.2 (1)	0.3 (2)
1 Sept	0	nd	nd	0.2 (2)	0.1 (1)

( ) = total number of soil samples or traps yielding slugs
nd = not determined

At Torland, the number trapped after overnight exposure (Day 1) was higher than the number trapped on Day 2. At Am Tannenberg, the numbers trapped on Day 1 and Day 2 were rather low. The number of slugs captured by saucer traps and mat traps showed little difference in July at Torland indicating that both types of traps were equally effective, but in August, more were recorded in mat traps than saucer traps (Table 12).

4. Discussion

The weather in summer and early autumn 2004 was wetter than 2002 and, especially, wetter than the very dry year of 2003. However, despite this, slug numbers were relatively low in the standing cereal crops and cereal stubble in all 17 study fields going from cereals to oilseed rape in Germany in 2004. It seems likely that slug numbers had been reduced to very low levels by the drought of 2003 and that slug populations had insufficient time to recover by summer and early autumn 2004. The highest recorded density in Germany was $19/m^2$ in cereal stubble in early August at the direct-drilled field at Sickte (Table 2a). Higher densities (31 and $90/m^2$) were recorded in cereal stubble in two field in south west England (Table 2f).

The soil in the upper 10 cm layer was relatively dry at the sites in Germany (Table 2a-2e), with typically less than 20% moisture during this period at most sites. This contrasted with higher moisture levels at the field sites in England (Table 2f) where higher slug densities were recorded, except on 2 August. On this date, slug numbers dropped to $9/m^2$ at a time when the soil in the 2-10cm layer fell to 21%. It seems likely that, at this site on 2 August, the slugs had moved deeper into the soil: numbers recovered and showed a strong increase by late August (Table 2f, Fig. 6). This drop in numbers in the surface 10 cm in response to dryer soil conditions could perhaps indicate that, in Germany, the soil in the upper 10 cm layer was too dry to be suitable for slugs, so that slugs were not detected because they were hiding at greater depths. However, the highest slug densities in all the study fields in this project were recorded in oilseed rape stubble in northern Germany, where the soil moisture (Table 2g) was similar to several other sites in Germany.

This suggests that the reason that low slug numbers were recorded at sites going from cereals to oilseed rape in Germany was that slug densities were low in these fields. This conclusion is supported by the low levels of damage to oilseed rape recorded at 14 of 16 sites in Germany where slug damage was measured (Table 8).

At the two sites in Germany where significant losses of oilseed rape plants were recorded, one site (Sickte) was direct-drilled. At this site, 19 slugs/m^2 were recorded by soil sampling in cereal stubble (Table 2a) and similar densities to this were estimated in oilseed rape at establishment using defined area traps and square-meter areas (Fig. 16). Thus, it appears that, in the absence of cultivation, slugs survived in sufficient densities to cause a 23% loss of oilseed rape seedlings at establishment. This conclusion is supported by the findings at Eight Acres Field in England where a 36% loss of plants was recorded and slug density at establishment was estimated as 12 slugs/m^2 (Table 7c). The greater severity of damage at the site in England, despite a lower slug density could be at least partly due to the slow growth of seedlings following late sowing (in mid September), coupled with moist conditions suitable for slug activity. The second site in Germany where significant loss of plants (28%) was recorded, Plienzhausen, showed a pattern that was not typical of slug damage, so it is believed that plant losses at this site were not due to slugs.

The decline in numbers at Eight Acres Field in England on 2 August corresponded with a marked increase in numbers recorded in traps, at a time when the surface soil was very moist and suitable for slug activity, in contrast to the drier conditions at 2-10cm depth.

There was a remarkable similarity in the size structure of the *D. reticulatum* populations in soil samples at the two sites where substantial numbers were recorded: in cereal stubble at Eight Acres, south west England (Fig. 6), and in oilseed rape stubble at Löhndorf, northern Germany (Fig. 7). The size structure of the slug populations at both sites showed strong evidence of breeding by *D. reticulatum* in late summer, with a large proportion of the population consisting of small (1-10mg) individuals by late August.

At all locations, the slugs recorded from soil samples were consistently smaller on average than those recorded from traps, as was also found in past years. In particular, soil samples were very efficient in detecting small (1-10mg) individuals, which were virtually absent from traps.

Comparisons of mat traps and saucer traps showed little difference in numbers per trap on the first date in July, but mat traps recorded more than saucer traps on a second date in August. Differences between trap types on different sampling dates were also found in UFOP project Nr. 521/031a in 2003, where on one occasion saucer traps recorded more slugs than mat traps, whereas the reverse was found on a later date. Results in 2004 showed that there was no advantage in leaving the traps out for more than one night.

Pulling up cereal roots after harvest did not reveal any slugs or eggs, although some were recorded at Göttingen when cereal roots were pulled before harvest. This method of root examination appeared to be more successful in oilseed rape stubble than in cereals, so it may perhaps be useful for assessing the risk of slug damage to a first winter wheat crop following oilseed rape.

The data from the field sites in 2004, together with the earlier projects in 2002 and 2003, provide valuable preliminary information on the relationships between the severity of slug damage to oilseed rape at establishment and the slug population density in soil, and slug numbers in traps, in standing cereals and in cereal stubble. From this, it is clear that flooding of soil samples taken from cereal stubble gave the best prediction of the risk of slug damage to oilseed rape. Soil samples from standing cereals were less useful for risk prediction, because slug numbers sometimes increased or decreased substantially between the sampling time and the time when oilseed rape was at risk.

Traps in stubble showed a poor correlation with risk and it was especially notable that trap catches in stubble were sometimes low when risk was high. It is thought that traps in stubble can underestimate risk for two main reasons. First, there is an abundant supply of food for slugs in cereal stubble in the form of shed grain and pieces of straw etc. This reduces the likelihood of slugs feeding on the bait in the traps. Second, the weather is hot in August and the traps are exposed to full sun when placed out in stubble, making them unfavourable places for slugs to rest.

Traps in standing cereal crops appeared to give a better estimate of risk than traps in stubble, presumably because (1) the crop canopy helps to maintain humid conditions suitable for slug activity when the soil surface is moist, (2) there is little food on the soil surface to compete with the trap bait and (3) traps in standing cereals are shaded from the sun by the crop canopy, so that the traps provide cool, moist resting places for slugs.

The finding that the percentage of soil samples with zero slugs was inversely related to slug density and that 20% of samples had zero counts when slug density was about 50/m^2 (Fig. 4) indicates that it may be possible to use the presence or absence of slugs in soil samples to provide a quick and simple estimation of risk. The relationship between slug density in the soil of cereal stubble and subsequent damage risk to oilseed rape (Fig. 10) indicates that a 10% loss of oilseed rape seedlings could be expected in a field where slug density reaches 50/m^2. Thus, in a field where 20% of soil samples, or less, showed zero slugs, this might indicate a risk of plant loss of 10% or more. Use of the frequency of zero counts for risk assessment would speed up the process of soil examination because, once a single slug had been detected in a sample, it need not be examined again. However, it is important to note that the relationship in Fig. 4 is for samples of a size (23/m^2) slightly larger than the samples taken with standard spade (31/m^2). Thus, the relationship will need to be investigated for samples taken with a standard spade.

In the assessment of damage risk, it is important to remember that, from 2002 to 2004, severe slug damage with significant plant loss has been recorded at only three sites, two of which were in England. It is also important to note that the low incidence of damage to oilseed rape has been typical of Germany in these years. Thus, the methods developed in this project have given a good reflection of the generally low level of risk of slug damage in Germany from 2002-2004. The only site in Germany where significant plant loss due to slugs has definitely been recorded is a direct-drilled field at Sickte, in 2002 and 2004. Direct drilling is known to be associated with a high risk for slug damage, because of the lack of cultivation which would otherwise reduce slug numbers substantially (VOSS *ET AL.*, 1998; GLEN & SYMONDSON, 2003). However, direct drilling is not typical of agronomic practice for oilseed rape in Germany, as the soil is normally cultivated by non-inversion (reduced) tillage or ploughing. Results in this project indicate that reduced tillage results in an 85-90% reduction in slug populations. Reduced tillage (particularly with two or three passes) in oilseed rape stubble was also shown to be valuable in diminishing slug numbers and damage to winter wheat.

Because we have had relatively few sites with slug damage to oilseed rape, 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.

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 more laborious than slug trapping. However, over the three years from 2002 to 2004, soil sampling in cereal stubble has provided a much better prediction of the risk of slug damage to oilseed rape than trapping. Because of its labour-intensive nature, soil sampling is perhaps suitable in its present form only for use by consultants to provide a true picture of the slug population in soil in the period leading up to establishment of oilseed rape crops. Nevertheless, the results indicate that the process of examination of soil samples could be simplified and speeded up by recording only the presence or absence of slugs.

Although not as accurate as soil sampling in stubble for risk assessment, slug trapping in standing cereal crops appears to have some potential. Further studies of slug trapping in standing cereals and soil sampling in stubble are certainly warranted to evaluate their potential.

Soil sampling - advantages

- Soil sampling in cereal stubble gives the best prediction of the risk of slug damage to oilseed rape, even in hot weather
- Presence or absence of slugs in soil samples could possibly provide a rapid evaluation of damage risk
- Relatively easy to dig samples from cereal stubble
- 10-cm depth of soil samples gives good result
- 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

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
- Trapping in cereal stubble can underestimate damage risk

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

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 continue to be validated for the purpose of risk assessment at several field sites and locations. The process of validation should again include crop consultants to give a practical perspective on the technology as well as to provide wider geographical cover of the regions of Germany. There is evidence that slug populations have recovered somewhat in autumn 2004 in Germany from the very low levels that resulted from the severe drought of 2003. Thus, the prospects are good for further investigations in 2005.

6. References

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7. Appendix of weather records

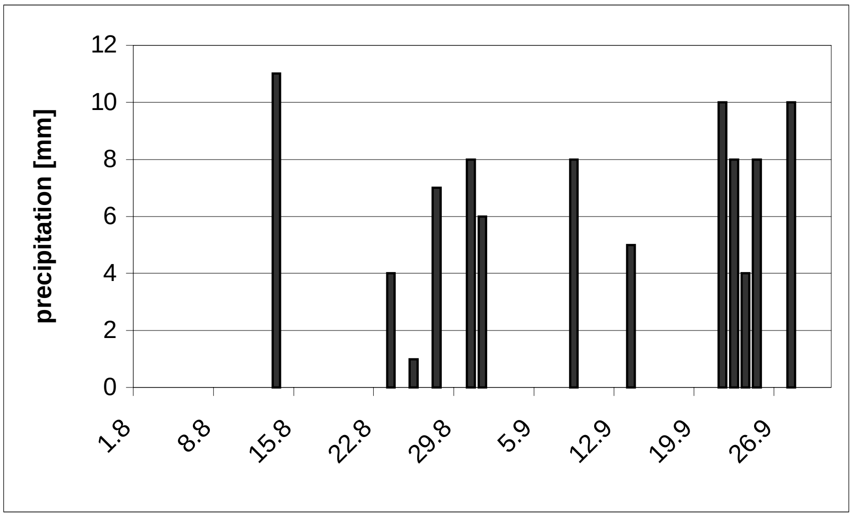

Figure 17. Daily rainfall in August and September 2004 at the Sickte Trial Site, Braunschweig.

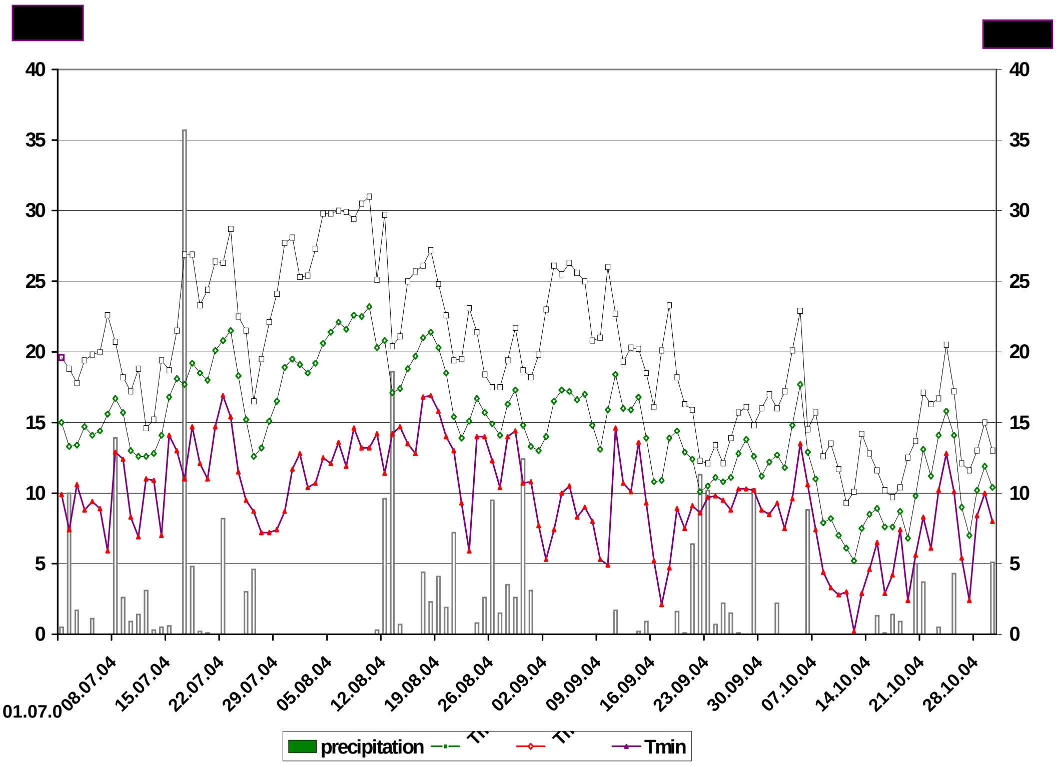

Figure 18. Daily maximum, minimum and average temperature and precipitation at Göttingen, July – September 2004.

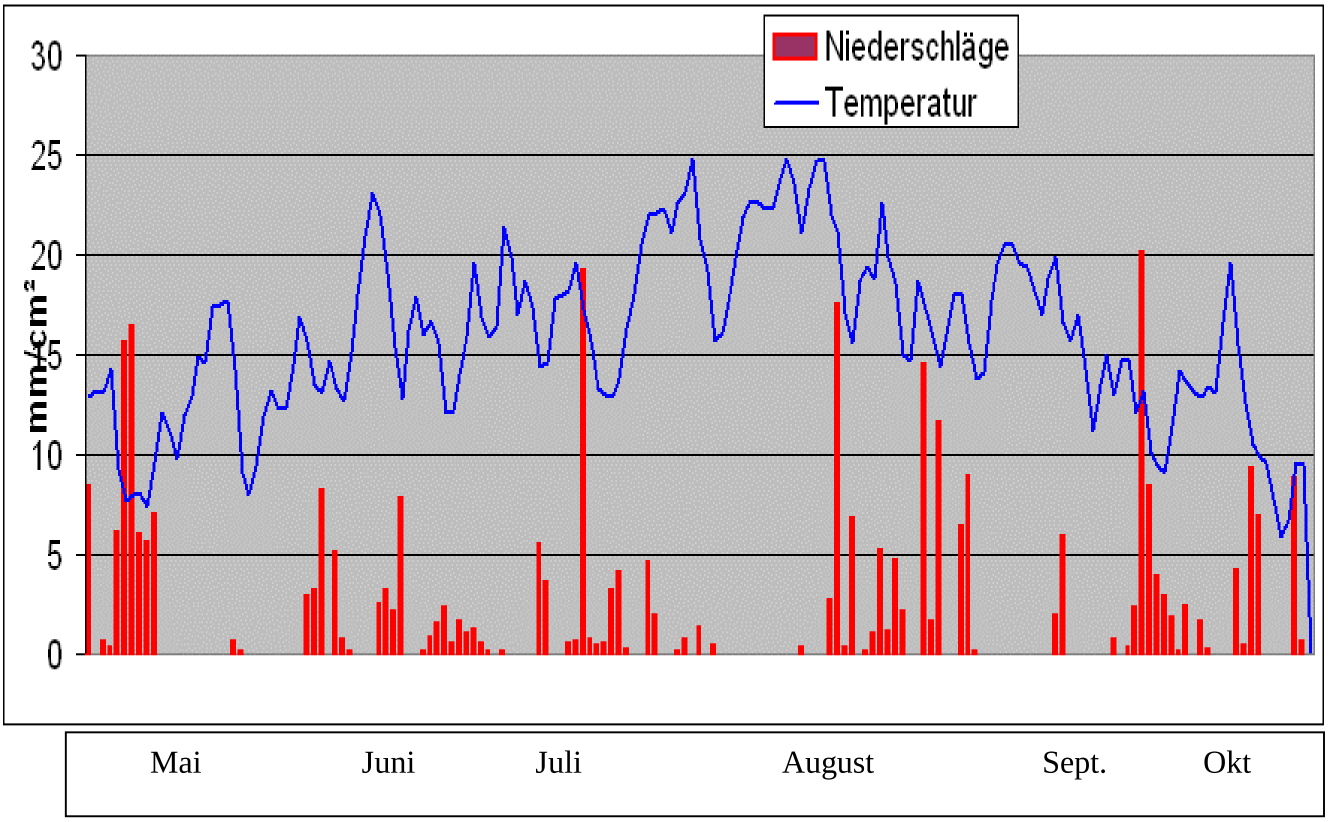

Figure 19. Average daily temperature and rainfall at Übrighausen, Baden-Württemberg, May to October 2004.

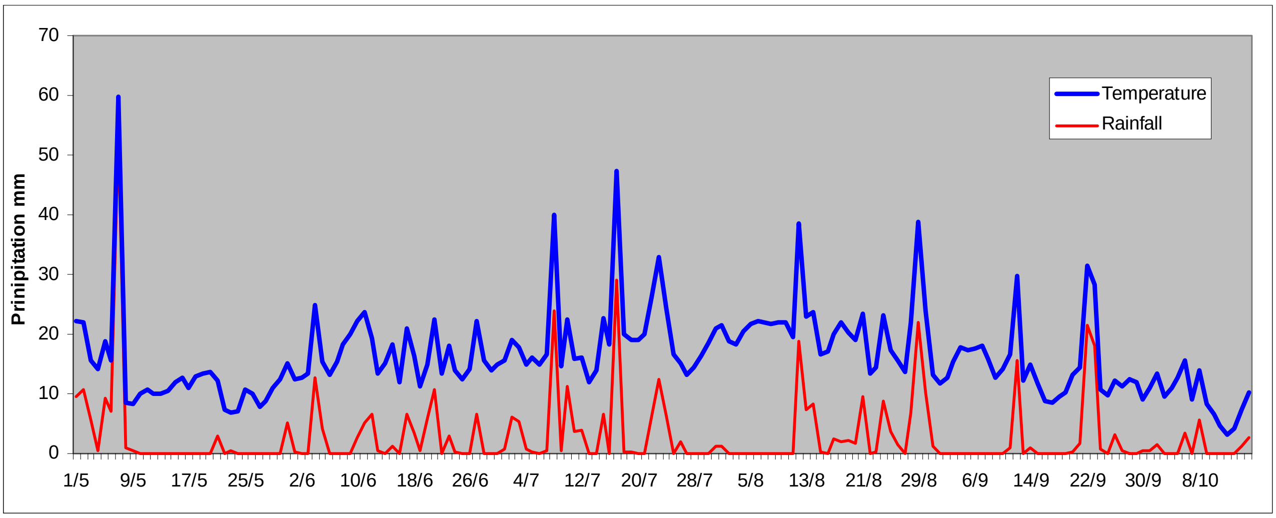

Figure 20. Average daily temperature and rainfall at Maria-Bildhausen, Bayern-Franken, May to October 2004.

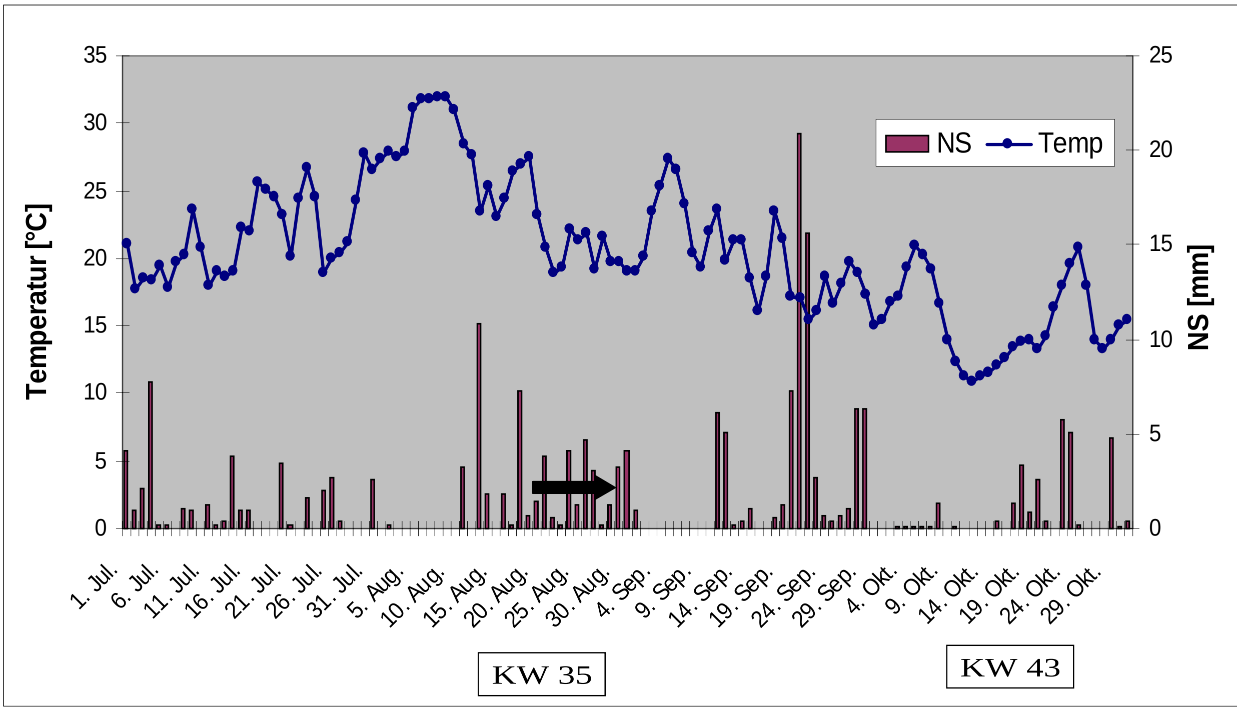

Figure 21. Average daily temperature and precipitation, Löhndorf, July to October 2004.

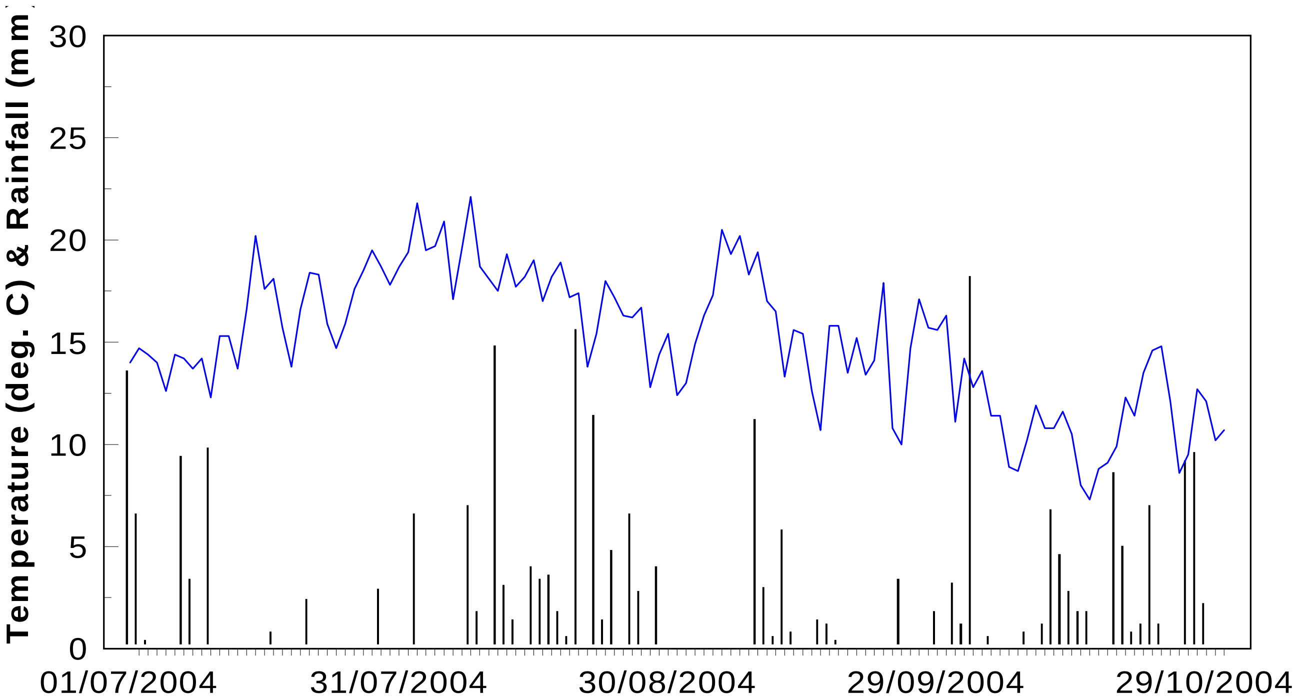

Figure 22. Average daily temperature and precipitation, Yeovilton, Somerset, July to October 2004.