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SLUG DAMAGE AND NUMBER OF SLUGS (GASTROPODA: PULMONATA) IN WINTER WHEAT IN FIELDS WITH SOWN WILDFLOWER STRIPS

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ABSTRACT

Previous observations have shown that slugs found favourable conditions for reproduction in wildflower strips and that they caused high damage to oilseed rape adjacent to the strips. In the current study slug numbers and damage were estimated in wildflower strips and at different distances from the strips into winter wheat crops, from 1994 to 1996. Slug damage was estimated using an index of defoliation and slug numbers and activity were measured using wheat bran traps. Investigations began when winter wheat seedlings emerged and lasted for five weeks. Slug damage was never severe in any of the fields studied. In most fields, slug damage was higher close to the wildflower strips than at greater distances from the strips. The declining slug damage with increasing distances from the wildflowers strips was related to the distribution pattern of juvenile *Arion lusitanicus*, suggesting that this species was responsible for the higher damage near the strips. Other slug species (*Deroceras reticulatum, Arion fasciatus, Deroceras laeve*) were more or less evenly distributed over the field or were almost entirely confined to the wildflower strips. Results showed that winter wheat was not at risk from slug feeding in spite of the establishment of wildflower strips and that therefore the application of molluscicide along the strips is unnecessary.

INTRODUCTION

Slugs are the pests causing greatest concern to wheat growers in the United Kingdom (Glen, 1989). High slug damage in winter wheat is often observed, especially when rape was the previous crop (Glen, Spaull, Mowat, Green & Jackson, 1993). In Switzerland, however, high slug damage occurs very rarely in winter wheat (Högger, 1995). Therefore, molluscicide is usually not used in Swiss winter wheat fields.

However, winter wheat crops sown in fields where wildflower strips have been established were thought to be possibly at risk from slug damage. Wildflower strips (a synonymous term for weed strips) are sown inside fields or on the edges of fields with mixtures consisting of about twenty-five herbaceous species (Heitzmann, 1994). One purpose of establishing wildflower strips is to create semi-natural habitats in order to enhance the biodiversity of animals and plants in the agricultural landscape (Frank & Nentwig, 1995a & b). Another purpose is to increase the number of beneficial arthropods in the fields, as a result of movement of beneficials from the wildflower strips into the adjacent crop (Lys & Nentwig, 1992; Jmhasly & Nentwig, 1995; Hausammann, 1996).

Although wildflower strips have been sown on Swiss fields since 1989, there is little information on the impact of wildflower strips on slug numbers and damage in adjacent crops except for oilseed rape. In rape, complete crop failure was observed in field areas bordering on wildflower strips (Frank, 1996). This investigation further showed, that slugs found favourable conditions in the wildflower strips due to the lack of tillage, a plentiful supply of food plants and moist refuges. This resulted in high slug densities in and very close to the strips in the rape crop. In the study reported in this paper, slug numbers and slug damage in wildflower strips and adjacent winter wheat fields were studied, from 1994 to 1996, in order to investigate whether this crop is also at risk from slug feeding in areas near the strips.

MATERIALS AND METHODS

Study areas

The investigation took place between the end of October and mid-December 1994, 1995 and 1996 in six winter wheat fields at three locations near Bern, Switzerland. Wheat fields F1, F2 and F4 lay at Belp, 7 km south-east of Bern. Field F3 was located at Uettligen, 7 km north-west of Bern. Wheat fields F5 and F6 were at Hindelbank, 14 km and 12 km northeast of Bern (Table 1). Research was done on fields with loamy soils in the Swiss plateau, where the largest area of cereal fields is situated. The investigation was started soon after seedlings of winter wheat appeared above ground, and lasted for the following five weeks, during growth stages 11 to 13 (Zadoks, Chang & Konzak, 1974) when young wheat plants are most vulnerable to slug attack. All wheat fields were cultivated according to the Swiss guidelines for integrated production. All fields were ploughed before winter wheat was sown. Molluscicide was not applied in any of the fields studies. Details of all wildflower strips are given in Table 2.

Slug sampling

Slug numbers (activity-density) were estimated using bait stations containing wheat bran, cat food and water in a ratio of 1:1:5 by weight. Each bait station consisted of a petri dish (140 mm diameter) filled with 20–25 g bait. In each wildflower strip, eight petri dishes with bait were placed 1 m from the edge of the adjacent field. In the adjacent fields, bait stations were located at 1, 3, 5 and 18 m from the wildflower strips with eight stations at each distance. In each wildflower strip and at each distance from the strips, the bait stations were located 7 m apart. Slug numbers were recorded weekly. Petri dishes with bait were placed on the soil surface at dusk; four hours later, slugs on the dishes were counted and identified to species. Immediately afterwards, the petri dishes with baits were removed and the slugs were returned to the field.

Evaluation of slug damage

Every day after slug numbers were estimated, slug damage was evaluated using a defoliation index from zero to four: 0 = no damage; 1 = 1–25% defoliation; 2 = 26–50% defoliation; 3 = 51–75% defoliation; 4 = 76–100% defoliation. Slug damage was evaluated 1, 3, 5 and 18 m from the wildflower strips, in ten randomly chosen places at each distance from the wildflower strips. Defoliation scores were based on slug damage on ten plants in each place. Means were calculated for each distance and week.

In March, the density of wheat plants at each distance from the wildflower strips was assessed visually, to monitor whether there were areas with conspicuously low density of wheat plants, representing crop losses. This monitoring was also done on six fields of three additional farms near Bern in 1994 and on six fields of four additional farms in 1995. The wildflower strips on these additional fields were between one and three years old, comparable to the age of the study strips (Table 2).

Data analysis

For data analysis, slug damage scores were analysed using untransformed values. Slug numbers were transformed to square roots to stabilize the variance; actual data are presented in the figures. ANOVA was used to evaluate whether there were significant differences in slug numbers or slug damage between the different distances on each date. Tukey's HSD-test was used to determine significant differences.

Table 1. Details of the research fields

Field	Location	Year of research	Sowing date of wheat	Previous crop	Soil type	Cropped area (ha)
F1	Belp	1994	10.10.94	oats	gley	1.7
F2	Belp	1995	19.10.95	sugar beet	gley	2.0
F3	Uettligen	1995	25.10.95	maize	brown earth	2.8
F4	Belp	1996	14.10.96	sugar beet	gley	4.1
F5	Hindelbank	1996	16.10.96	potato	brown earth	1.3
F6	Hindelbank	1996	22.10.96	maize	brown earth	1.6

Table 2. Details of the investigated sown wildflower strips.

Wildflower strip	Location	Year of research	Sowing date of strip	Length (m)	Width (m)
strip 1	Belp	1994	3.5.94	170	3
strip 2	Belp	1995	3.4.95	145	4
strip 3	Uettligen	1995	10.4.95	261	3
strip 4	Belp	1996	29.4.94	139	3
strip 5	Hindelbank	1996	30.4.94	200	3
strip 6	Hindelbank	1996	8.4.95	235	3

RESULTS

In all wheat fields studied between 1994 and 1996, slug damage was very low with extremely low defoliation scores (Fig. 1). Moreover, no areas with low density of wheat plants were detected in March after winter wheat was sown. This also applied to the twelve additional fields monitored in 1994 and 1995. In fields F2, F4, F5 and F6, damage at 1 m from the wildflower strips was higher than at greater distances from the strips throughout the investigation. In field F1 in 1994, an opposite tendency was observed with significantly higher slug damage at 18 m than at 1 m from the wildflower strip in the third and fourth weeks. Damage in field F3 in 1995 was especially low and differences between distances from wildflower strip 3 were never significant (Fig. 1).

The composition of the slug population recorded on the bait stations differed among the research fields (Table 3). In field F1, *Deroceras reticulatum* (Müller) and *Arion fasciatus* (Nilsson) were dominant. *D. reticulatum* and *Arion lusitanicus* (Mabille) were the most abundant slugs in field F6, a field where numbers of slugs were generally low during the time of research. *A. lusitanicus* was predominant in fields F4 and F5, whereas *A. lusitanicus* and *A. fasciatus* were the most abundant species in field F2. *Deroceras laeve* (Müller) was recorded in great numbers only in field F1 and *Arion distinctus* Mabille and *Boettgerilla pallens* Simroth were only rarely recorded. Bait stations in field F3 contained almost no slugs, with none recorded on three study dates.

In fields F2, F4 and F5, where *A. lusitanicus* was the most abundant species, numbers of slugs were greatest in the wildflower strips, with decreasing numbers in the wheat crops from 1 m to 18 m from the strips. This trend of decreasing numbers of slugs with increasing distance from the wildflower strips was especially distinct in weeks three and five (field F2) as well as weeks one to three and week five (fields F4, F5; Fig. 2). This rapid decline in number of individuals from 1 m to the centre of the fields was primarily distinct in *A. lusitanicus*, whereas other species (*D. reticulatum, A. fasciatus, D. laeve*) were almost entirely confined to the wildflower strips or were more or less evenly distributed over the whole crop area (Figs. 3, 4). Although *A. lusitanicus* was relatively abundant at 1 m from the wildflower strips, many more individuals populated the wildflower strips. A similar distribution pattern of slugs in field F6, which was mainly populated

Table 3. Total number (=N) and percentage of slug species recorded on bait stations in each field (data for the crop and the adjacent wildflower strip are pooled).

Species	F1 Belp 1994		F2 Belp 1995		F3 Uettligen 1995		F4 Belp 1996		F5 Hindelbank 1996		F6 Hindelbank 1996	
	N	%	N	%	N	%	N	%	N	%	N	%
Arion lusitanicus	128	7.3	146	40.4	5	29.4	357	87.9	345	74.4	35	41.7
Deroceras reticulatum	881	50.5	72	19.9	10	58.8	4	1.0	94	20.0	35	41.7
Arion fasciatus	517	29.6	142	39.3	1	5.9	3	0.7	0	0.0	0	0.0
Deroceras laeve	217	12.4	0	0.0	1	5.9	38	9.3	27	5.6	14	16.6
Arion distinctus	0	0.0	0	0.0	0	0.0	4	1.0	0	0.0	0	0.0
Boettgerilla pallens	1	0.2	1	0.3	0	0.0	0	0.0	0	0.0	0	0.0

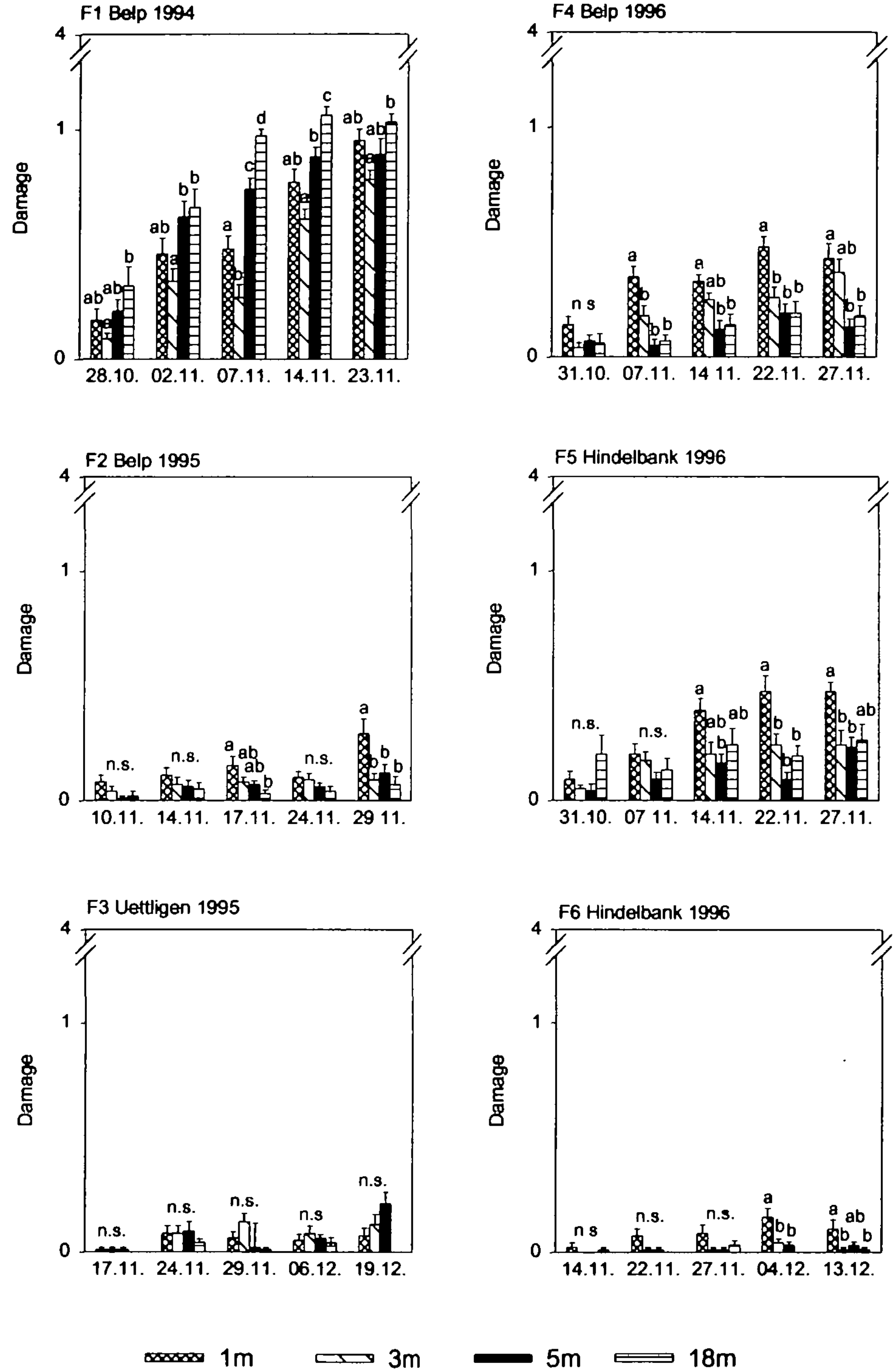

Figure 1. Slug damage score (Mean ± SE) in winter wheat fields at different distances from wildflower strips. Different letters mean significant differences within each date (Tukey; $P < 0.05$). n.s. = not significant.

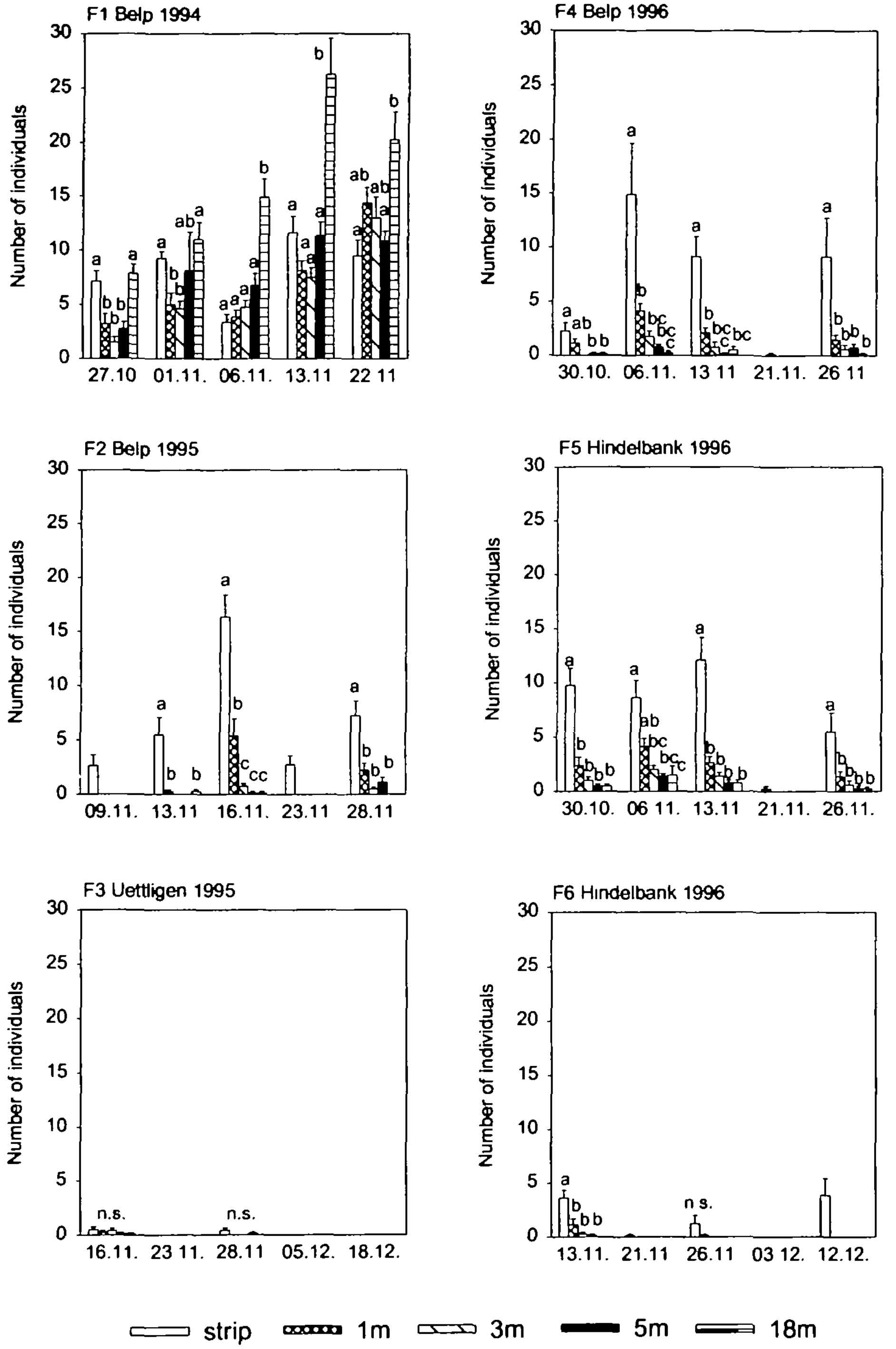

Figure 2. Number of all slugs (Mean ± SE) in wildflower strips and in winter wheat fields at different distances from strips. Different letters mean significant differences within each date (Tukey: $P < 0.05$). n.s. = not significant.

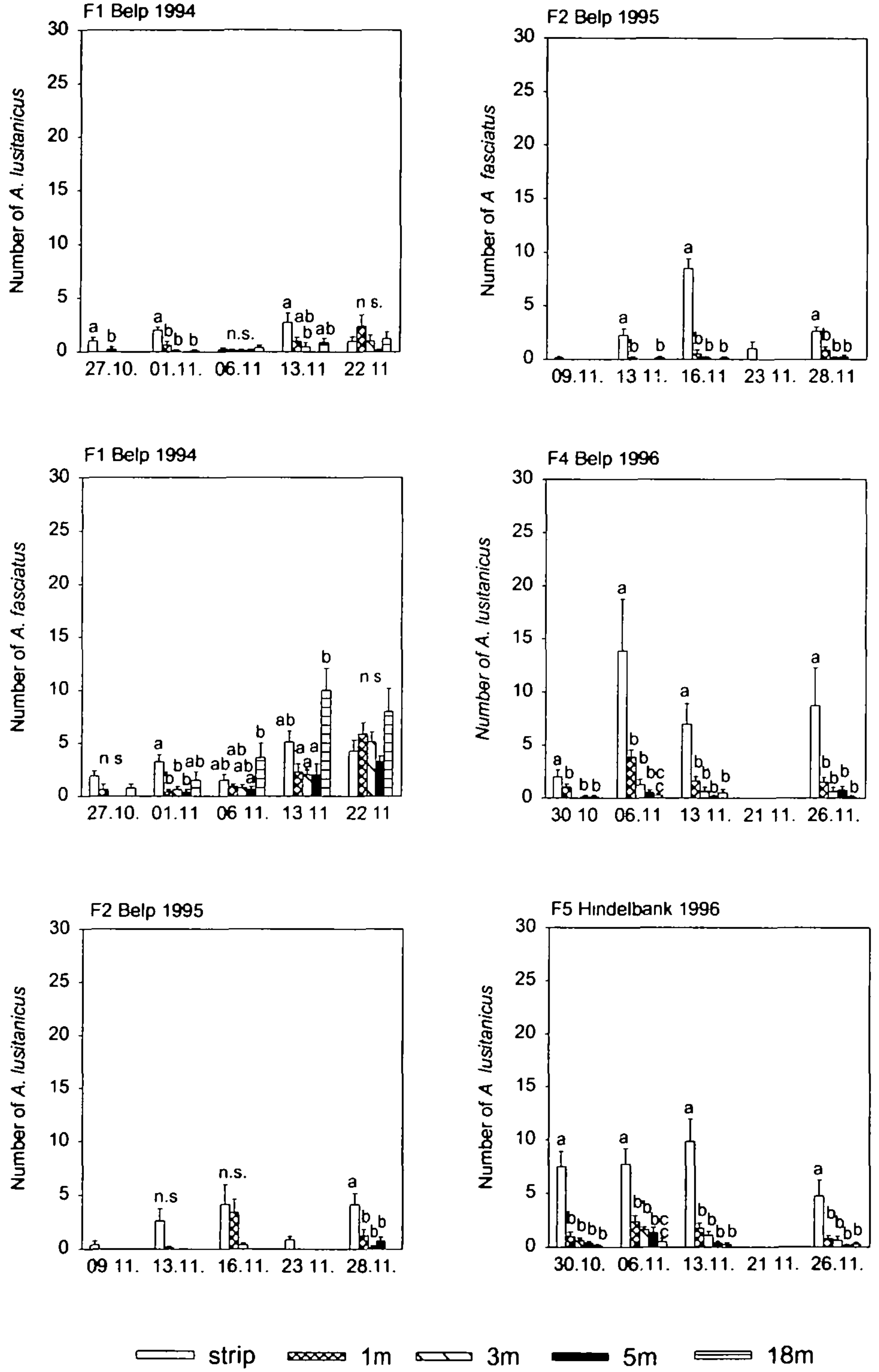
F1 Belp 1994
Number of A. lusitanicus
27.10. 01.11. 06.11 13.11 22 11
F2 Belp 1995
Number of A fasciatus
09.11. 13 11. 16.11 23 11. 28.11
F1 Belp 1994
Number of A. fasciatus
27.10. 01.11 06 11. 13 11 22 11
F4 Belp 1996
Number of A. lusitanicus
30 10 06.11 13 11. 21 11. 26.11.
F2 Belp 1995
Number of A. lusitanicus
09 11. 13.11. 16.11. 23 11. 28.11.
F5 Hindelbank 1996
Number of A lusitanicus
30.10. 06.11. 13.11. 21 11. 26.11.
strip
1m
3m
5m
18m

Figure 3. Number of *Arion lusitanicus* and *A. fasciatus* (Mean ± SE) in wildflower strips and in winter wheat fields at different distances from strips. Only locations with a total number of more than 70 individuals were included (see Table 3). Different letters mean significant differences within each date (Tukey: $P < 0.05$). n.s. = not significant.

by *A. lusitanicus* and *D. reticulatum*, was only observed in the first week of the investigation (Fig. 2). In four of the six wheat fields, almost all *A. lusitanicus* recorded were juvenile individuals of about 5 mm. Over all fields the percentage of juvenile *A. lusitanicus* was between 73 (field F1) and 100% (field F6) of all *A. lusitanicus* recorded. In contrast to the other wheat fields studied, fields F1 and F3 did not have higher numbers of slugs in the wildflower strips than in the adjacent crop (Fig. 2). Whereas field F3 contained extremely few slugs, field F1 had the highest number of slugs of all fields. In this field, the number of slugs was highest at 18 m from the wildflower strip. The particularly high density of slugs at 18 m from the wildflower strip was due to *D. reticulatum*, *A. fasciatus* and *D. laeve*. In contrast to these three species, *A. lusitanicus* was much less abundant at 18 m from the wildflower strip in field F1 (Figs. 3, 4). In addition, no decrease in slug numbers was observed from 1 m to 5 m from the wildflower strip in field F1.

DISCUSSION

Slugs are major pests in winter wheat, being capable of causing severe yield loss in different countries (Glen, 1989; Barratt, Byers & Bierlein, 1994; Ester & Nijenstein, 1995). This contrasts with the overall situation in Switzerland where winter wheat is rarely attacked by slugs (Högger, 1995). Even though slug damage was generally low in the wheat fields studied, in four fields out of six, slug damage at 1 m from the wildflower strips was significantly higher than at greater distances from the strips. In these fields, the declining slug damage with increasing distances from the wildflower strips was related to the distribution pattern of the slugs in several weeks of the investigation. Thus, in fields F2, F4, F5 and F6 slug damage at 1 m was higher than at greater distances from the wildflower strips, because at 1 m slugs were more abundant than at greater distances from the strips. *A. lusitanicus* was very abundant in the wildflower strips and declined rapidly with increasing distance from 1 m to the centre of the fields. This distribution pattern suggests that *A. lusitanicus* was primarily responsible for the higher slug damage at 1 m than at greater distances from the wildflower strips.

A similar distribution pattern with large numbers of *A. lusitanicus* in wildflower strips and at 1 m from the strips was also observed in oilseed rape (Frank, 1996). However, in those parts of the rape fields where no molluscicide was applied, there was complete crop loss within distances up to 2 m from the wildflower strips. Oilseed rape was sown five to seven weeks earlier than winter wheat. At that time *A. lusitanicus* had just finished its egglaying period and many adult slugs were still alive. Each night, many adult *A. lusitanicus* moved from the wildflower strips into the adjacent rape fields where they fed on rape seedlings and caused complete crop loss there. In late October and November, the time when winter wheat was susceptible to slug damage, almost all adult *A. lusitanicus* had already died. Therefore, dispersal of adult *A. lusitanicus* between wildflower strips and the adjacent wheat crop was very rare. Thus, adult *A. lusitanicus* were unable to cause high damage in wheat close to the wildflower strips. *A. lusitanicus* preferred to lay its eggs in and close to the wildflower strips. This was the reason for the higher numbers of juvenile *A. lusitanicus* found in the wildflower strips and also 1 m from the strips than at greater distances from the strips in all wheat fields. Since these small juveniles are not able to cover great distances, they probably did not move between the wildflower strips and the adjacent wheat crop. Moreover, juvenile *A. lusitanicus* eat much less than adults, thus their damage did not harm the wheat crop. High slug damage close to wildflower strips or similar semi-natural habitats might occur in winter cereals that are sown earlier than winter wheat. For example, high slug damage and slug numbers were found in those areas of a winter rye field which were close to a grassland strip (Speiser & Niederhauser, 1997).

The particularly high damage in field F1 at 18 m from the wildflower strip was probably due to the relief of the ground surface, which was slightly lower in that part of field F1 than in the rest of the field. This area of the field most likely provided particularly high surface moisture content, explaining the higher activity-densities of *D. reticulatum*, *A. fasciatus*

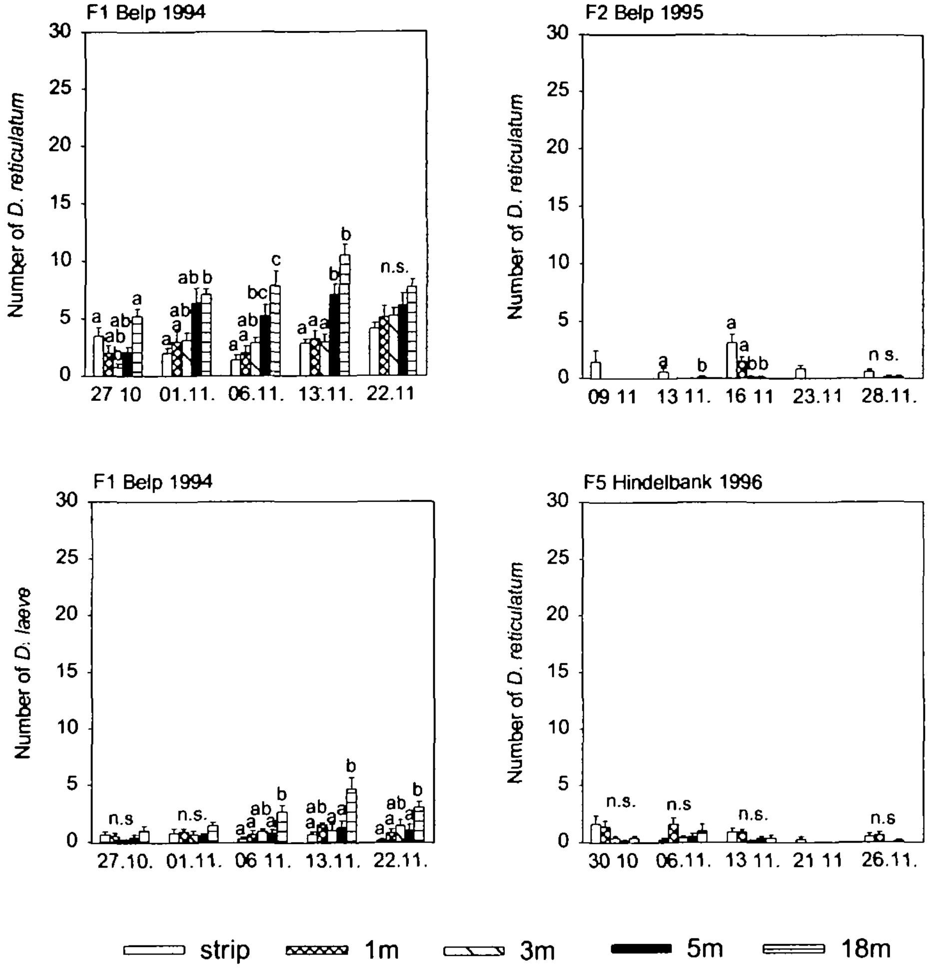

Figure 4. Number of *Deroceras reticulatum* and *D. laeve* (Mean ± SE) in wildflower strips and in winter wheat fields at different distances from strips. Only locations with a total number of more than 70 individuals were included (see Table 3). Different letters mean significant differences within each date (Tukey; $P < 0.05$). n.s. = not significant.

and *D. laeve* there than in other parts of the field (Young & Port, 1991). Therefore, these three species appeared to be responsible for the high damage at 18 m from the wildflower strip.

In some weeks of the investigation in 1995 and 1996, no slugs were found on the bait stations or slugs were exclusively restricted to bait stations in the wildflower strips. The nights in most of these weeks were particularly cold with surface temperatures below 0° C, leading to inactivity of slugs (Young, Port, Emmett & Green, 1991). In these cold nights the bait in the petri dishes in the wheat fields was frozen. However, the dense vegetation cover in the wildflower strips protected the soil surface from cooling and the baits were usually not frozen there. This was the reason why slugs were found exclusively in the wildflower strips in some weeks. The particularly low number of slugs found in field F3 cannot be explained by low temperatures, because at Uettligen night temperatures were above 0° C during weeks one to three. The low number of slugs at this location was probably due to a fairly fine soil surface with few crevices representing unsuitable conditions for slugs (Moens, Latteur & Fayt, 1992).

One reason why winter wheat in Switzerland is usually not attacked by slugs appears to be the climate. The time when young winter wheat plants develop (October to December) is often cold with snow-fall or frozen soil surface, conditions which are unfavourable to slugs. In England and the Netherlands, on the other hand, this time is generally milder with fewer frosty days (Müller, 1980) enabling slugs to cause severe damage to young winter wheat. A further reason for the low extent of damage in winter wheat crops in Switzerland is of course the tillage regime. Usually fields are ploughed before sowing winter wheat. Ploughing means soil disturbance with declining soil moisture and leads to bare ground. Such effects hinder slug survival. In contrast, conservation tillage generally favours slug survival in different crops (Dowling & Linscott, 1985; Hammond & Stinner, 1987; Tonhasca & Stinner, 1991; Hammond, 1996). Therefore, severe damage in winter wheat may often be observed when non-inversion tillage is used (Glen, Wiltshire, Wilson, Kendall & Symondson, 1994).

The low damage to winter wheat compared to oilseed rape alongside wildflower strips was explained by the absence of adult *A. lusitanicus* at the time when wheat seedlings emerged. Thus, the occurrence of high slug damage in winter crops adjacent to wildflower strips appears to be dependent on the presence of adult *A. lusitanicus*. Although it cannot be excluded that high damage to winter wheat might occur near wildflower strips, this appears to be unlikely as crop losses were never observed during three years in eighteen different fields. Thus, the creation of wildflower strips was shown to be no risk for adjacent winter wheat crops and wildflower strips can therefore be recommended to enhance the number of beneficial arthropods and the biodiversity of animals and plants in the agricultural landscape.

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