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Sustainable management of slugs in commercial fields: assessing the potential for targeting control measures

By E FORBES[1], M BACK[1], A BROOKS[1], N PETROVSKAYA[2], S PETROVSKII[3], T POPE[1] and K F A WALTERS[1]

[1]*Harper Adams University, Newport, Shropshire TF10 8NB, UK*
[2]*University of Birmingham, Birmingham B15 2TT, UK*
[3]*University of Leicester, Leicester LE1 7RH, UK*
Corresponding Author Email: eforbes@harper-adams.ac.uk

Summary

Slug damage to cereal crops in the UK caused primarily by the grey field slug (*Deroceras reticulatum*) is of increasing concern to farmers following removal of methiocarb from the market and stewardship guidelines introduced for metaldehyde. This study assesses whether the discontinuous (patchy) distribution of slugs can be exploited by targeting control measures only at areas of fields with high slug densities, reducing the amount of pesticide used. Grey field slug numbers and crop damage were assessed throughout a growing season at spatially referenced points on a square grid in five cereal fields. The location of patches with high slug densities were found to be stable where populations were sufficiently large to allow detection using refuge traps. No consistent correlation between post-emergence plant damage and slug numbers within patches was recorded. It was concluded that although slug patches were sufficiently stable in time and space to support targeting of control measures, damage assessment may not offer a viable method of defining current location of patches.

Key words: *Deroceras reticulatum,* discontinuous distribution, patch stability, damage, sustainable molluscicide use

Introduction

Commercial and environmental considerations have led to increased pressure to reduce pesticide use in agricultural crops resulting in a growing interest in precision targeting and application of products. For many years slug control has relied on a limited number of active ingredients with methiocarb and metaldehyde dominating the market. Methiocarb was removed from the market in 2015 and metaldehyde, which now accounts for 84% of slug treatment in the UK (Garthwaite *et al*., 2015), is subject to restrictions and best practice guidelines aimed at protecting water courses (DEFRA, 2016). It is estimated that without effective control measures, damage to crop yield and quality could cost the industry £100 million per year for wheat, oilseed rape and potato crops alone (Nicholls, 2014; Twining *et al*., 2009).

The discontinuous distribution of *Deroceras reticulatum* (hereafter also referred to as “slugs”) in arable fields is widely reported (South, 1992; Bohan *et al*., 2000*a*; Archard *et al*., 2004) with patches of high slug density dispersed among areas of lower density, and may offer the potential for reducing molluscicide use in agricultural fields. If such patches are sufficiently stable in time and space, and a commercially viable method of identifying their location and dimensions can be established then control measures may be targeted at high slug density patches alone, leaving areas with lower slug numbers untreated. Various factors might be used to identify patch location including (but not limited to) crop damage or environmental factors such as soil moisture, soil pH or organic matter.

Methods of establishing the location of slug patches in the field have been investigated by Bohan *et al.* (2000*b*) who related the distribution of slugs to carabid beetle activity as a basis for conservation biocontrol strategies. In spite of this, few studies have addressed the stability of slug patches over time, or carried out detailed analysis of environmental factors influencing patch location. Mueller-Warrant *et al.* (2014) investigated patch location in relation to damage in Oregon, USA and found weak correlations between slug counts and damage in clover fields.

This study investigates whether patches of higher slug density, that persist in stable locations throughout the growing season, can be identified in commercial winter wheat fields. Where such patches occurred the hypothesis that location of patches can be identified from plant damage (caused by slug feeding) was investigated.

Materials and Methods

A standard experimental design was established in five commercial fields in Shropshire, UK each sown with winter wheat following a previous crop of oilseed rape (1. Uppington, cv. Horatio; 2. Adeney 1, cv. Reflection; 3. Lynn 1, cv. Reflection; 4. Lynn 2, cv. Reflection, 5. Adeney 2, cv. JB Diego). All fields were cultivated using a subsoiler and disc harrow followed by rolling. At each site crop husbandry followed normal farm practice at each site with between one and three applications of metaldehyde at standard rates early in the growing season.

Experimental design and slug assessments

Refuge traps consisting of upturned 18 cm diameter, plastic plant pot saucers (LBS Horticulture Supplies, Lancashire, UK) were placed in a 10 × 10 grid with 10 m between nearest traps. Grids were established at a minimum of 20 m from the nearest field edge. The number of slugs under each refuge trap was counted at approximately 14 day intervals between 30 November 2015 and 18 February 2016, and thereafter monthly until 25 May 2016.

Damage assessments

The percentage leaf area damaged by slugs (slug damage identified following the descriptions of AHDB (2014)) was recorded from 20 randomly selected leaves located within a circle (50 cm radius) centred on each refuge trap. The mean leaf damage was calculated for each trap at each sampling visit.

Analysis of slug distribution and crop damage

Maps of slug numbers and damage distributions were produced using the "\contourf" function of MATLAB® (The MathWorks Inc., Massachusetts, USA), which is essentially a polynomial interpolation between the grid nodes. The correlation between the maps of trap counts obtained at different dates, and between maps of trap counts and those of leaf damage were quantified using the Pearson product-moment correlation coefficient also referred to as the Pearson correlation coefficient (PCC) or Pearson's r. Statistical analysis comparing slug population size in different fields, and the relationship between population size and feeding damage was conducted using R version i386 3.3.0 (Crawley, 2013), and analysis of variance or linear modelling respectively.

Results

Deroceras reticulatum *populations*

The number of slugs recorded in refuge traps varied both between assessment visits within fields, and between different fields. Between 30 November and early December 2015 slug numbers generally increased with time in the winter wheat fields investigated. The mean of the total number of slugs recorded in the sampling grid at each visit was similar in fields 1–3 (156.5 144.0 and 158.0 respectively). Significantly higher numbers were recorded over the same period in field 4 (412.0, F=9.98, $P<0.01$, d.f.=7), and lower numbers in field 5 (47.0, F=11.35, $P<0.01$, d.f. =6).

Slug numbers in fields 1–4 increased again after 4 January 2016 (peaking for a second time between late February and late April), with a mean total number of slugs recorded in the sampling grid between 4 January and 29 April 2016, of 283.3 in field 1 and corresponding figures of 359.8 (field 2), 264.2 (field 3), and 994.1 (field 4). Slug populations in field 5 remained low throughout this period with mean total numbers recorded in the 100 refuge traps of 72.8. Within each field, the maximum number of slugs recorded during an individual assessment visit was 663 in field 1 (week 22, 29 April), with corresponding maxima in field 2 of 667 (week 22, 26 April), field 3 of 400 (week 12, 18 February), field 4 of 1796 (week 16, 15 March) and field 5 of only 133 (week 5, 5 January). Due to the low number of slugs recorded in field 5, no further analysis of the data collected was undertaken.

Distribution of Deroceras reticulatum *within fields*

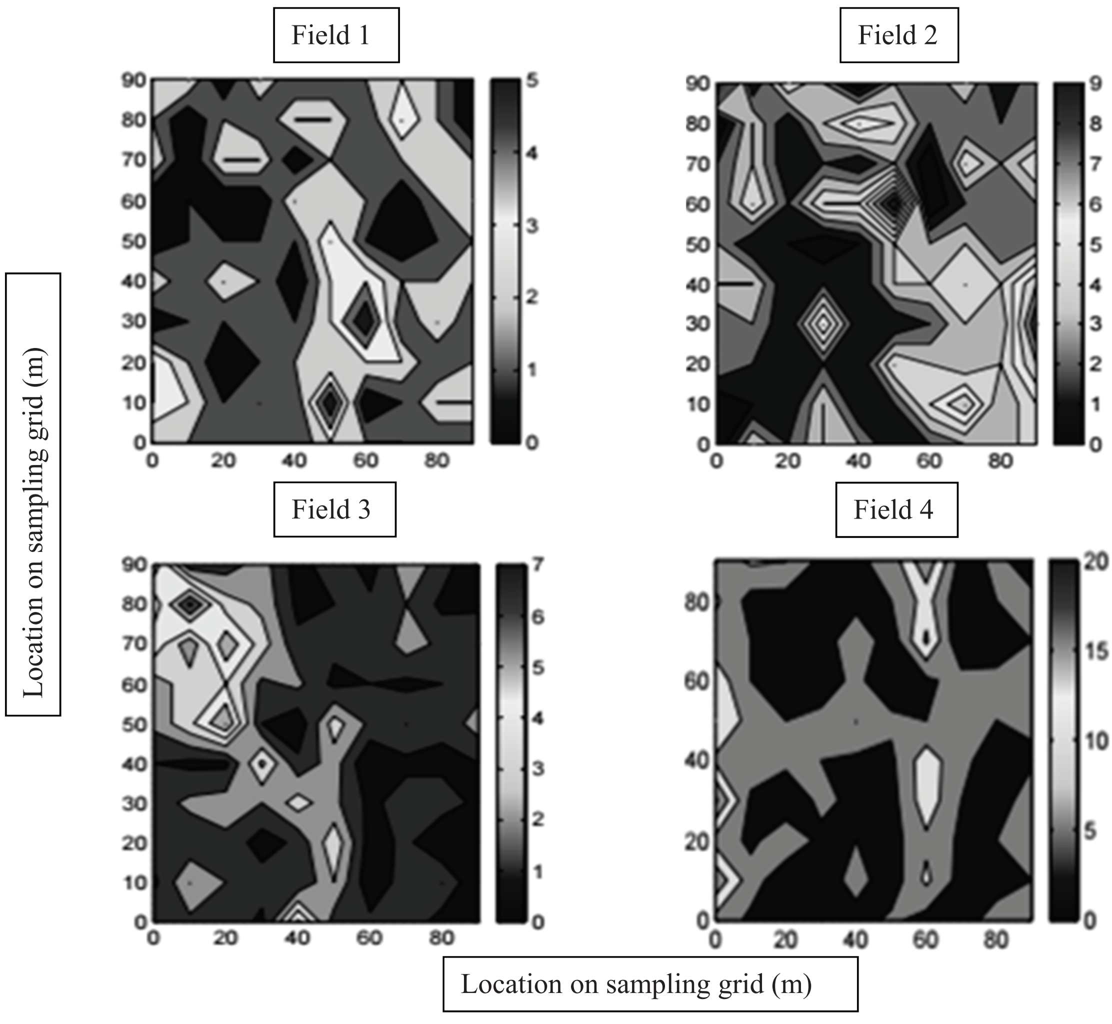

Fig. 1. The distribution of *D. reticulatum* in commercial winter wheat fields sampled in week 6 of the study (4–10 January 2016). Axes = distance (metres) from the common reference point of the sampling grid (lower left corner); Shading represents number of slugs caught per trap.

Irrespective of the variable population levels in different fields, discrete areas of higher slug densities developed following crop establishment within all the fields investigated (Figs 1 & 2). Subsequently, variation between assessment visits in numbers of slugs that were active on the soil surface (reflected in refuge trap records) resulted in a corresponding disappearance of slug patches when very low catches were recorded and their reappearance as trap catches increased (Fig. 2).

This variability in slug numbers may have been in part the result of responses to environmental conditions such as temperature, moisture and others that both vary during the growing season of the crop, and influence the relative proportions of the slug population that are active on or beneath the soil surface. Despite this, the location of the major slug patches was stable over time, reappearing in similar positions in the sampling grid (Fig. 2; Table 1).

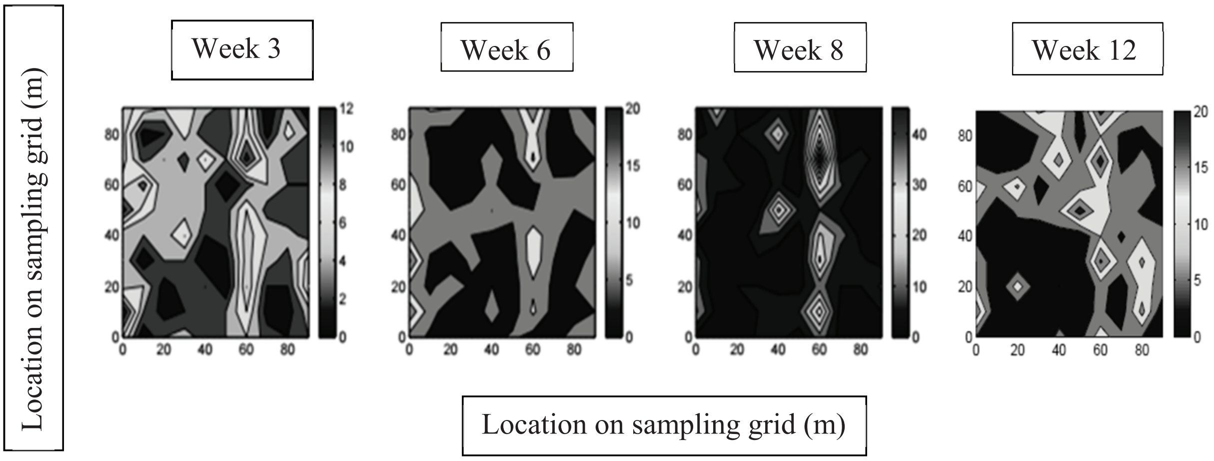

Fig. 2. The distribution of *D. reticulatum* in a single commercial winter wheat field (Field 4) on four representative assessment dates: Weeks 3 (18 December 2015), 6 (6 January 2016), 8 (21 January 2016) and 12 (18 February 2016). Axes = distance (metres) from the common reference point of the sampling grid (lower left corner); Shading represents number of slugs caught per trap.

Correlation between location of damage and slug counts

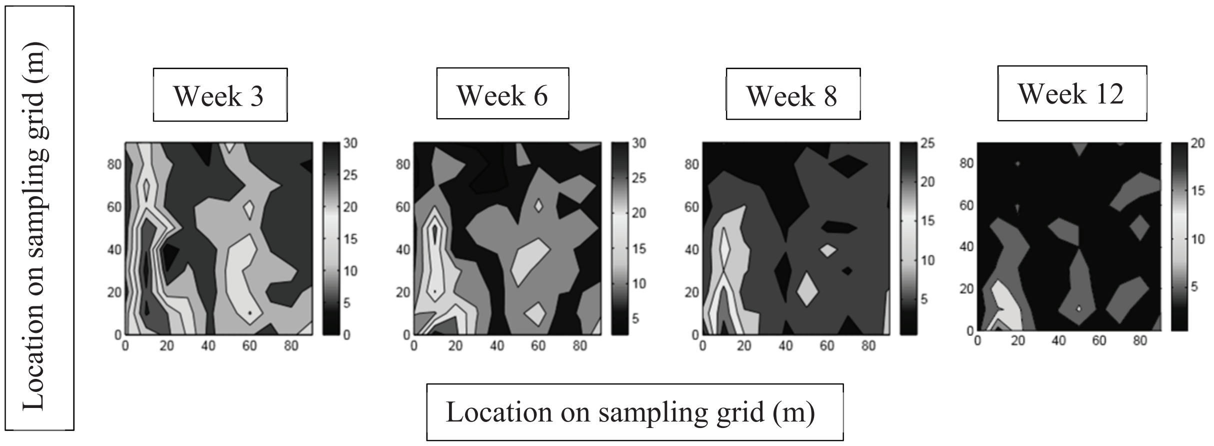

Fig. 3. The distribution of damage caused by *D. reticulatum* feeding in a single commercial winter wheat field (Field 4) on four representative assessment dates: Weeks 3 (18 December 2015), 6 (6 January 2016), 8 (21 January 2016) and 12 (18 February 2016). Axes = distance (metres) from the common reference point of the sampling grid (lower left corner); Shading represents percentage damage to crop plants.

Slug feeding damage varied between fields. Highest percentage leaf damage was recorded in Field 4, reflecting the high slug numbers recorded in refuge traps, and lowest damage levels in Field 5. Damage scores decreased in all fields following crop establishment when the rate of growth exceeded the rate at which slug feeding reduced leaf area (e.g. Fig. 3).

Clear correlations between the percentage feeding damage recorded on plants and slug catches in refuge traps at each grid point were not found in any field or assessment date (Figs 4 & 5). The weak relationship between apparent slug damage and numbers of slugs caught in refuge traps suggests that visible slug damage is a poor indicator of the location of patches of higher slug densities, even in winter wheat fields with higher slug populations.

Table 1. *Correlation (Pearson's r) between numbers of slugs recorded in refuge traps at different locations within the sampling grid in Field 4 (field with highest observed slug densities), on different sampling occasions*

Date of assessment Sample 1	Date of assessment Sample 2	Variance explained (r^2)
18/12/15 (week 2)	22/12/15 (week 4)	0.46
22/12/15 (week 4)	06/01/16 (week 6)	0.51
22/12/15 (week 4)	02/02/16 (week 10)	0.58
22/12/15 (week 4)	15/03/16 (week 16)	0.56
06/01/16 (week 6)	18/02/16 (week 12)	0.53
06/01/16 (week 6)	11/01/16 (week 7)	0.63
11/01/16 (week 7)	14/01/16 (week 7)	0.83
14/01/16 (week 7)	21/01/16 (week 8)	0.85
21/01/16 (week 8)	26/01/16 (week 9)	0.73
26/01/16 (week 9)	02/02/16 (week 10)	0.59
02/02/16 (week 10)	18/02/16 (week 12)	0.68
18/02/16 (week 12)	15/03/16 (week 16)	0.71

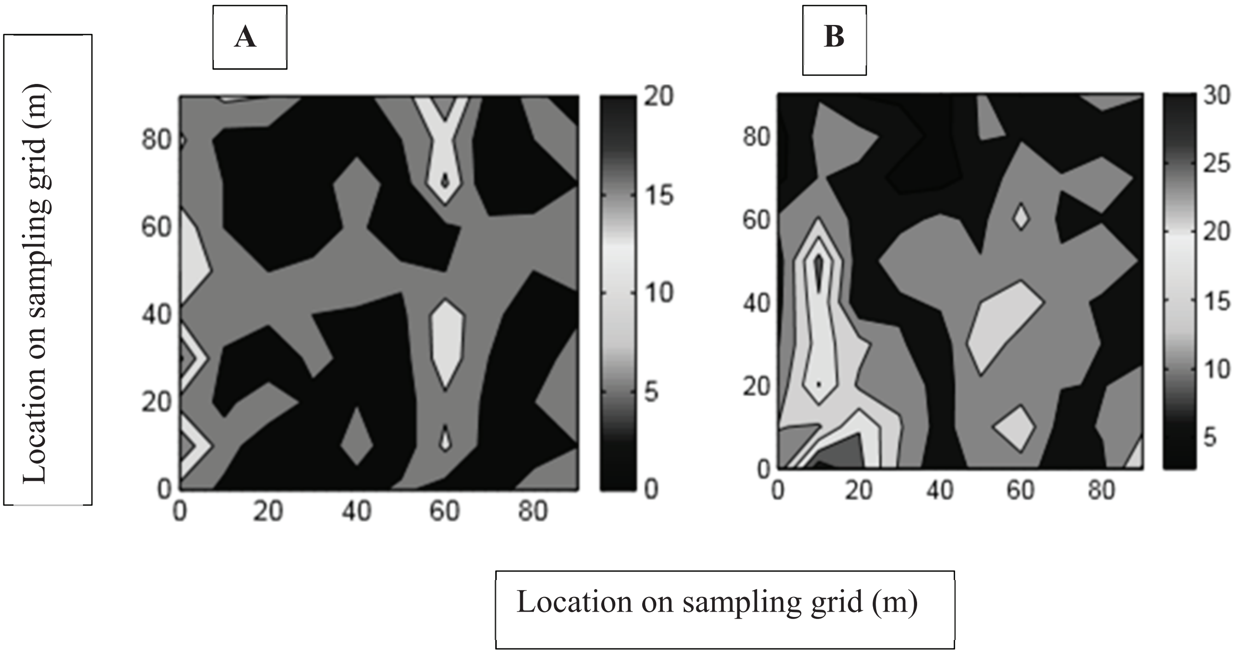

Fig. 4. The distribution of *D. reticulatum* (A) and of slug feeding damage (B) in Field 4 (week 6, 6 January 2016). Axes = distance (metres) from the common reference point of the sampling grid (lower left corner); Shading represents either number of slugs caught per trap) (A) or percentage damage to crop plants (B).

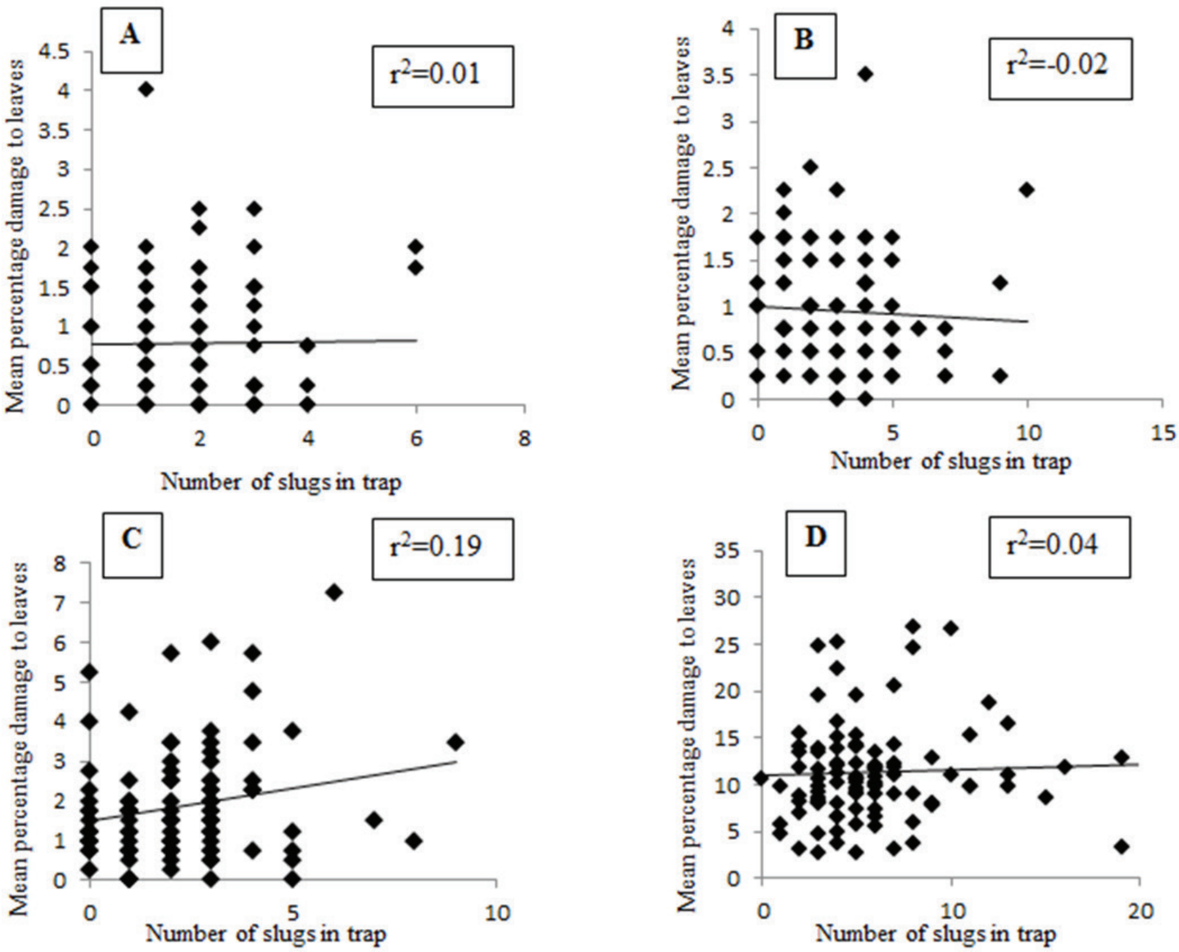

Fig. 5. The relationship between percentage leaf damage and number of *D. reticulatum* caught in refuge traps at each grid point in week 6 (A) Field 1, (B) Field 2, (C) Field 3 and (D) Field 4 (4, 5, 6 and 6 January 2016 respectively).

Discussion

Deroceras reticulatum causes damage to a wide range of agricultural and horticultural crops, leading to significant economic losses (Nicholls, 2014; Twining *et al*., 2009). The species is known to display two peaks of reproductive activity in arable fields, in the spring and autumn (Port & Port, 1986). In this study, raised slug activity during autumn was reflected in refuge trap catches between November and December and a second higher peak was recorded between late February and May. Thereafter catches remained low until the winter wheat crops were harvested in August. Slug numbers varied widely between fields with some exceeding recommended treatment thresholds (AHDB, 2016).

The discontinuous distribution of slugs in arable fields reported by Bohan *et al*. (2000*a*) and Archard *et al*. (2004) resulted in patches of higher slug numbers interspersed within areas of lower slug densities being readily detected in all fields investigated in this study, irrespective of the size of slug population or the pesticide application schedule. Refuge traps were used to assess slug activity on the soil surface where factors such as soil moisture and temperature, which vary throughout the growing season, can influence their behaviour (Choi *et al*., 2004). During periods of sub-optimal physical conditions, a significant proportion of the population retreats to a protected environment, below the soil surface (South, 1992) where they cannot be detected using refuge traps. Consequently the patches of high slug population densities were not recorded at every sampling visit, but critically were located in the same areas of the field when they were detected, suggesting that slugs either move vertically between the upper soil horizon and the soil surface, or return to the same locations in the field when conditions are favourable. Successful suppression of slug populations following application of metaldehyde slug pellets may have contributed to masking of the location of the field patches prone to harbouring higher slug numbers by significantly lowering trap catches across the field (including within the patches). Critically, however, as patches subsequently reappeared in the same areas when slug surface activity increased again, their location is likely to be dependent on spatially stable environmental characteristics. The spatial and temporal stability of the patches, if confirmed in fields in different years and regions of the country, support the proposal that molluscicide use in agricultural fields may be reduced by targeted application of control measures to areas of high slug densities within fields, provided a cost effective method of defining patch location at or before sowing of the crop can be developed.

In this study, the low efficiency with which refuge traps monitor slug activity below the soil surface, coupled with temporal variation in key physical conditions affecting the proportion of the slug population that was active on the surface, may have resulted in variation in the timing and frequency of patch detection during the growing season. In fields with low slug populations, patches were more difficult to detect using refuge traps during the critical period immediately after sowing, whereas when higher numbers of slugs were present patch location was determined earlier. Refuge traps are also labour intensive and they may not be an economically viable method of targeting treatments. It was hypothesised that crop damage may offer an alternative, cost effective approach for identifying areas of higher slug density in commercial crops.

The weak correlations between the percentage leaf area removed by slug feeding and refuge trap catches in winter wheat fields sampled in this study suggested, however, that this method of assessing damage could not be used as a reliable indicator of patch location. Stronger (but still weak) correlations between crop damage and slug population levels were reported from a study in North America in which crop emergence (post emergence plant densities) was assessed (Muller-Warrant *et al*., 2014). Significant reduction in winter wheat crop yields can be caused through damage to the germ of the seed, resulting in seed hollowing that prevents germination thus reducing plant density. In addition, slug feeding often results in seedlings being severed above the seed or at ground level, again affecting plant density (South, 1992). Such early feeding activity in patches with high numbers of slugs can result in very few plants being available and related dispersion of slugs to other areas in search of food; however, lowering the strength of correlations between plant density and slug numbers in later assessments. As wheat plants grow, the characteristic leaf shredding caused by slug feeding occurs. Percentage leaf area affected by shredding has been used to assess damage at this stage, but the ability of the plant to rapidly produce new leaves when actively growing limits its value as an indicator of slug activity.

Other slug species were present in all of the fields studied, although in much lower numbers than *D. reticulatum*. The presence of other slug species may, however, have been another contributing factor to the low correlation observed between the percentage leaf damage and slug densities as the damaged caused by different species is indistinguishable.

In summary, the demonstration of discrete and stable areas within commercial winter wheat fields in which higher slug numbers occur supports the proposal that reduced use of molluscicides can be achieved through targeting the treatments at such areas alone. Commercially viable approaches to defining the location of these patches remain to be established, but crop damage assessments have only limited potential. As assessment of crop emergence would occur too late to protect against seed hollowing, and subsequent leaf shredding has proven to be an inaccurate method of forecasting future crop damage, neither method can be used to locate and target treatments at the areas of the field at risk. A more effective approach may involve the characterisation of key factors of the physical environment that collectively lead to the formation of localised patches of high slug numbers, and development of cost effective approaches to their use in the field offers a focus for future work.

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