Introduction
Nearly all published data on research of the gray field slug has been conducted in countries or states with weather patterns that differ markedly from that of the Willamette Valley. Data from the Midwest U.S. come from the Dakotas, Ohio, Michigan, while that from the east was derived in Maryland, and New York. These areas experience cold winter freeze followed by rapid thaw springs and wet, warm summers. Western Europe including the United Kingdom, Ireland, France, and Germany, along with parts of New Zealand and Australia experience cold winter freeze, or if more temperate, receive consistent rainfall year round (southern U.K. and parts of Ireland, 5.0 cm monthly). Researchers have shown that slug activity in the Mediterranean region of Israel is concentrated into the winter rainy season October to December because gastropods there spend the whole of the hot summer in aestivation. This is the only record found in the literature that records similar mollusk behavioral traits as those encountered in western Oregon. These observations led us to conclude that the biology and agro-ecology of this and other species in western Oregon need careful re-examination to understand the dynamics of slug activity within this environment and to better understand why our efforts to control slugs sometimes fail. This report and others like it will build a framework to help develop a new management protocol for growers.

A long-term study conducted in western Oregon quantified the effects of tillage, residue, drainage and rotation, on seed yield and dry matter residue (Steiner et al., 2006). Activity of the gray field slug Derocerus reticulatum Mueller, was observed one week per month during the duration of the study, 1992-2002. Data presented here substantiate earlier work on the initial seasonal emergence of slugs. After slug emergence has occurred, local weather events dictate vertical distribution in the soil and surface activity patterns (Cook, 2001). Soil moisture and vertical distribution and abundance based on three years of field data collected at Hyslop Farm Research Station is presented in this paper. The performance of slug baits was reduced by soil temperatures <12°C, with most baits performing well at >17°C. Slug emergence activity was delayed 4-5 days after a freeze event, even when followed by warm, wet conditions that other-wise were appropriate for slug activity (see also Cook, 2001).

Methods

Study Sites. Monitoring of slugs was done at three locations as a part of a 10-yr experiment investigating the effects of conservation practices on perennial grass seed production.

Weather Data. Weather data was attained on-site using complete Campbell weather station telemetry including; soil temperature (1.5 cm, 5 cm, 20 cm, and 30 cm depths); air temperature; water content reflectometer (15 cm and 30 cm depths); and rain fall. Any missing days of data were obtained from the National Weather Service Field Station, Hyslop Farm Research Station, in Corvallis, Oregon.

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Egg Data. Egg pits were dug on irregular schedules as time permitted, measuring 0.25 m² and 20 cm in depth, with egg number, species, and position recorded. Only the gray field occupied all sites during the course of this study.

Vertical Distribution. Soil cores were taken at one site in 1996, 1997, and 1998, to depths of 30 cm at the Hyslop Farm location. Cores were removed with a narrow shovel at 5 cm intervals, using a 30 cm x 30 cm square metal frame as a quadrate. All cores were taken from plots with active populations of the gray field slug from September thru the end of January. Two pits were dug in the summer of 1998 to a depth of 100 cm using a back-hoe and by excavating into the side walls using knives.

Growth Chamber Tests
In order to separate the effects of temperature on control of the gray field slug, tests were conducted in growth chambers that were programmed to provide four contrasting environmental schedules. The warmest temperature (21°C, 15 h day length (DL)) simulating soil temperatures and photoperiod in late August to mid September during the time of the year some grasses are planted; mid-level temperatures (15.5°C, 11 h DL; 10°C, 9 hours DL) simulating conditions encountered in late
September thru mid-November during the remainder of planting season and at the time of peak initial emergence of slugs; and the coolest (4.5°C, 7.5 hours DL) simulating mid-November thru mid-February soil temperatures when slugs remain active in the upper 5.0 cm of soil.

Ten gray field slugs (GFS) were tested in round arenas (26.5 cm diameter) covered with screened lids, and partially filled with native soil (Dayton / Woodburn, 25% soil moisture). Slugs were field collected and maintained in growth chambers at each temperature schedule for three weeks before use in experiments. Slugs were fed lettuce twice per week. Arenas were established on growth chamber shelves and rotated every three days to give equal cooling and lighting, replicated eight times. Pre-moistened cotton felt pads (3mm thick) were used in each arena as slug rests. Baits were removed after seven days simulating the number of baits left in field environments when earthworms are present. Slugs were observed for an additional 14 days to evaluate long term poison effects.

**Results and Discussion**

**Initial Fall Emergence.** The onset of initial seasonal emergence occurs during a period of falling air and soil temperatures in late August thru early October with little rainfall (Figure 1). This phenomenon was studied in the laboratory in the U.K. and substantiated in field conditions in our studies (Dainton, 1954; 1985). Unknown internal mechanisms in slugs trigger activity and hunger responses stimulated by cooling nighttime temperatures. Control efforts concentrated at this time benefit from low bait loss due to earthworm removal, planting schedules, and some spray programs that could utilize liquid admixtures.

**Vertical Distribution.** With initiation of cooler temperatures in late September and early October, slugs began leaving roosting sites in the soil, correlated to season and soil moisture (Figure 2). Slugs were found as deep as 100 cm in the soil during the dry season of August, using cracks, vertical earthworm burrows (Lumbricus terrestris L.) and horizontal vole runways (Microtus canicaudus). A greater number of slugs may be more evenly dispersed throughout the vertical soil profile early in the season until sub-soil moisture drives them to the surface. We found slugs more evenly dispersed throughout the soil profile during dry, hot summer months and less dispersed (greater densities) in the upper 7.5cm during cool, wet months. Yearly variances in precipitation and temperature will affect the location and density of slugs available for effective control.

**Slug Activity.** After initial autumn emergence, local climatic events and innate biological rhythms regulate surface activity. During freeze cycles lasting 2-3 days or more, slugs entered a short physiological dormancy requiring 4-5 days of warming temperatures before activity resumed (Figure 3). These data have been substantiated by eight observations (7- >3 days; 1 > 6 days) of freeze/activity cycles during the past two years. Slugs consume little food during this late autumn / early winter period, as seen in the slug biomass data (Table 1). Conversely, hot dry conditions in late spring early summer may not decrease feeding in dry land farming situations if canopy conditions and nutritional composition are appropriate as in white clover (Trifolium repens L.) fields. Slugs continued to feed during hot periods (>35°C), as seen in the leaf damage data, until crop harvest (Figure 3). In high residue fields, many slugs remained at the soil surface - residue interface where moisture from dew was adequate to germinate volunteer grass and weed seeds (Gavin, unpublished observations). Attracting slugs to the surface when adequate food is available under this protective layer can be difficult. When soil moisture is low in tillage - low residue fields, drybaits may not be as attractive as those applied when soil moisture is greater.

**Egg Data.** In New Zealand pastureland D. reticulatum approximated two generations per year, with intervals between consecutive generations ranging from 4 to 7 months and maximum life span from 8 to 12 months (Baker, 1990). In western Oregon, the largest output of egg production occurs in autumn stimulated by innate physiological changes in adult slugs, followed by another spring-early summer period. Periods of egg hatching are delayed two to three months when soil temperatures remain near 6-8°C (Gavin, unpublished data), followed by a phase of slow juvenile growth. Under greenhouse conditions at 10°C, we found the onset of initial egg production was high in October - early November, and decreased with time through early February. Late autumn early winter eggs required a chilling period (3°- 4°C) for several weeks followed by warming temperatures before further development occured (Kingston, 1963; Gavin, unpublished data). This probably explains the seasonal differential in size classes found throughout the seasons and between years. Spring laid eggs apparently do not require chilling and juvenile development is very rapid until soils moisture declines.

**Temperature and Bait Efficacy.** It was evident that the efficacy of baits in cool (>10°C), moist (>25% soil moisture) conditions was poor, never exceeding 54% mortality, also verified by others (Fisher, personal communication). The dehydration advantage of metaldehyde is lessened when conditions are wet, allowing slugs to recover (30-50%) after a meal of the bait (Briggs and Henderson, 1987). Contact bait alternative products not requiring slug consumption, such as SlugFest AWF or granular Durham 7.5, showed less recovery. The assimilation of iron phosphate does not follow this characteristic as shown in the differences in performance of the two baits (Figure 5). If growers do not meet the narrow window of early baiting opportunity (>15.5°C soil temperature), than bait performance and effectiveness will be diminished.

**Conclusions**

Initial slug emergence in late summer - early autumn begins as soil temperatures start to fall and stimulate innate behavioral responses for feeding and egg-laying. Early baiting controls slugs easier if adequate moisture from dew activates dry baits. Early baiting will find slugs vertically dispersed in the soil,
however, as soil moisture increases slugs become concentrated near the surface. As soil temperatures decline control becomes more problematic due to an apparent decrease in slug metabolism and activity and weathering effects on the bait. Two generations of the gray field slug are possible in dryland farming in western Oregon based on observed weight class distributions, egg production limitations, and seasonal drying effects. The delayed emergence of slugs after short freeze cycles requires close observations by field representatives and growers so control efforts are not wasted.

![Graph showing rainfall, soil temperature, and slug emergence over time.](image)

Figure 1. Falling soil temperatures and minimal precipitation stimulate late-summer early-autumn emergence of the gray field slug. (Data based on 1992-2002 weather and slug observations from Benton, Linn, and Marion counties)

Table 1. Weight gain data from two age classes of slugs in white clover (*Trifolium repens* L.) showing little weight accumulation throughout late autumn / early winter months.

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</table>

1SEM=Standard error of the mean.
Figure 2. Control attempts in early season are more effective when soil temperatures are warm, however, vertically dispersed distribution of slugs at this time lessen contact with poisons. When soil temperatures reach their minimum and soils become saturated, more slugs are available as control becomes more problematic. (data from Hyslop Research Farm, 1996, 1997, 1998)

Figure 3. Slug surface activity is interrupted by cold or freezing temperatures and resuming activity requires 4-5 days of warming soil temperatures.
Figure 4. Slugs continue to feed through hot temperatures and very low soil moisture cover is adequate and nutritional status of its food source is high. [Data from white clover (Trifolium repens L.), June / July, 2006].

Figure 5. Slugs exposed to progressively cooler soil temperatures exhibit poor bait and non-bait performances. Recovery rates from metaldehyde products (DMP and Durham) increases as temperatures decrease. The physiological reaction of slugs to iron phosphate (Sluggo) does not allow slugs to recover.
Acknowledgements

We thank the growers Brian Glaser, Dave Goracke, Mark Macpherson, and Don Wirth for the use of their land, insights on slugs, and helpful suggestions; Bob Schroeder, Bob Spinney, and Curt Dannen from Western Farm Service for products and helpful suggestions; Glenn Fisher for his encouragement and helpful insights; and Rick Caskey for helpful design and research concepts, equipment design and construction, and field and laboratory help.

Literature


