SPATIAL VARIABILITY IN SLUG EMERGENCE PATTERNS—THIRD-YEAR RESULTS

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Introduction

Slugs remain widely viewed as serious pests of many Willamette Valley crops, including grasses grown for seed, especially during the establishment of new fall plantings. Objectives of this project were to monitor the timing of slug emergence and evaluate the feasibility of identifying areas within fields with highest populations of slugs to help focus control efforts on situations with the greatest risk of crop damage. Fall 2016 was the third year of ongoing research, and this report focuses on results from that year, along with comparisons among 2014, 2015, and 2016.

Material and Methods

Tests were conducted during grass seedling establishment of four major crop rotations (Table 1): red clover followed by conventional tillage fall planting of new perennial ryegrass (PR) stands, (2) white clover followed by no-till fall planting of PR, (3) winter wheat followed by conventional tillage fall planting of PR, and (4) canola followed by conventional tillage fall planting of PR.

Weekly counting of slugs, predatory beetles, and earthworms began just prior to crop emergence, except at site 1, where irrigation allowed the crop to emerge in mid-September, 3 weeks prior to our first counts. At all sites, slug blankets were placed in grid patterns spaced at approximately 1 acre per blanket, with a minimum of 36 locations per field. Ground chicken mash was applied beneath each water-soaked blanket on one day, and slugs, worms, and beetles were counted the next day. Plywood squares (16 inches x 16 inches) were used to cover the slug blankets to prevent disturbance by wind or water and to help maintain moisture within the blankets.

Slugs were counted weekly from October to December, and less frequently after that, for a total of 10, 9, 8, and 7 times at sites 1, 2, 3, and 4 (Table 1). In general, growers had fewer problems getting on their fields to apply slug bait in 2016 than they had in either of the 2 previous years. Timing of slug counts in this report refers to the number of weeks since early October, with week 1 being the period from October 2 to October 8, 2016. Experiments were terminated once crops were well established and final counts of crop stands and slug densities had been taken in late winter. Unusually heavy rainfall in October 2016 interfered with growers' plans for planting, with planting delayed until October 20 at site 3 and November 9 at site 4. Unusually warm weather lasted until the first week of December, facilitating vigorous growth of PR planted before the deluge. Late-planted stands suffered from the prolonged periods of cold weather in December and January.

Methods explored to quantify the spatial distribution of slugs and crop damage were similar to those used in previous years. The Gi-star hot spot analysis technique was chosen because it provided useful information on

Table 1. Slug emergence study site descriptions, fall 2016.

Site no.	County	Previous crop	Seedbed preparation	Planting date	Number of slug counts	Slug bait application dates
1	Linn	Red clover	Conventional tillage, irrigated up	Sep. 15	10	Oct. 28
2	Linn	White clover	No-till	Sep. 28	9	Oct. 18 Nov. 1 Nov. 15 Nov. 29
3	Polk	Wheat	Conventional tillage	Oct. 20	8	Nov. 8 Nov. 29
4	Polk	Canola	Conventional tillage	Nov. 9	7	Nov. 10 Nov. 29 Dec. 21

the statistical significance of slug populations. "Hot spots" denote locations with consistently higher-than-expected counts, and "cold spots" are those with lower-than-expected counts.

Soil moisture was measured gravimetrically using surface 2-inch-deep soil samples taken each time slugs were counted. Crop stands were evaluated by counting the number of missing 1-inch sections of row per 260 feet of row at each plot in a rectangle around the target flag, skipping the center 10 feet x 9 feet because of soil sampling disturbance and crop damage under the slug blankets. Slug baits were applied by growers based on their own experience and on information we provided to them regarding weekly slug counts.

Results and Discussion

Soil moisture content at the two early-planted sites (conventional tillage following red clover and no-till following white clover) was approximately 26% on October 12, resulting in rapid emergence of PR seedlings at site 2; those at site 1 had emerged even earlier due to use of irrigation in mid-September. Critical soil moisture content for PR emergence during the two previous falls had been a similar minimum of greater than 25%. All subsequent soil moisture readings in fall of 2016 were in a range of 35 to 40%, except at site 3, where the sandier soil was in a range of 31 to 34% soil moisture. The warm, moist conditions in October and November of 2016 not only encouraged rapid growth and development of PR seedlings, but also resulted in the appearance of more slug egg masses in the fields than in either of the 2 previous years.

Predatory beetle populations were highest in the first few weeks of counting at any site, declining slowly until the arrival of snow and freezing temperatures in December (Table 2). Numbers of predatory beetles varied widely among the sites, perhaps responding to prior crops or differences in insecticide use patterns. Earthworm counts were lower than in either of the 2 previous years. The no-till site had low numbers of predatory beetles and high numbers of earthworms, while numbers of beetles and earthworms varied widely among the three conventionally tilled sites.

As in previous years, slugs were not uniformly distributed across any of the sites on any single date. Counts varied from 0 to 76 slugs per blanket. There were, however, fewer differences over time in 2016 than in 2015. In general, counts were also more stable over time in 2015 than in 2014. Consistent spatial patterns in slug counts occurred at all four sites in 2016.

At site 1, the earliest planted field, both hot spots and cold spots were statistically significant, with consistently higher-than-average slug counts at two hot spots and consistently lower-than-average counts at three cold spots (Figure 1). The cold spots all occurred along the east edge of the field and may represent border effects. Although the two hot spots were both on the north edge of the field, nothing else stood out as unique about those locations.

There were three statistically significant hot spots at site 2, all near the southeast corner of the field and close to the base of a large, nearby hill (Figure 2). This suggests the possibility that subsurface moisture flow over the summer draining from the adjacent hillside could have facilitated more vigorous growth by the white clover crop, thereby benefiting the slugs. Slug counts over time were more uniform at this site than

Table 2. Slug emergence, predatory beetle, and earthworm results for each study site, fall 2016.

Site no.	Average weekly slug count, entire fall season	Highest weekly average slug counts: Week[1]	Highest weekly average slug counts: Average number	Slug counts from period most likely related to crop loss: Weeks included	Slug counts from period most likely related to crop loss: Average number	Average counts of other organisms[2]: Predatory beetles (weeks 3–9)	Average counts of other organisms[2]: Earthworms (weeks 4–9)
1	3.5	4	11.3	3–4	8.8	0.03	0.9
2	7.4	7	8.8	2–7	7.2	<0.01	4.3
3	1.4	7	3.2	5–8	1.9	0.52	4.5
4	8.4	8	18.2	7–10	9.8	2.73	0.3

[1]Week 1 of fall establishment season was defined as October 2–8, 2016, even though the crop had emerged 3 weeks earlier at site 1 due to use of irrigation.
[2]Counts did not begin until weeks 5 and 7 at sites 3 and 4, respectively, due to delayed planting.

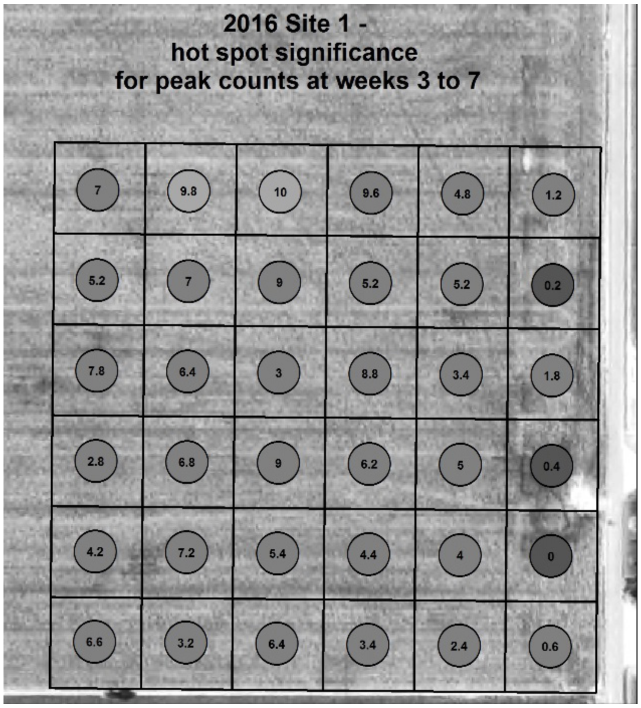

Figure 1. Hot and cold spots for slug counts at site 1.

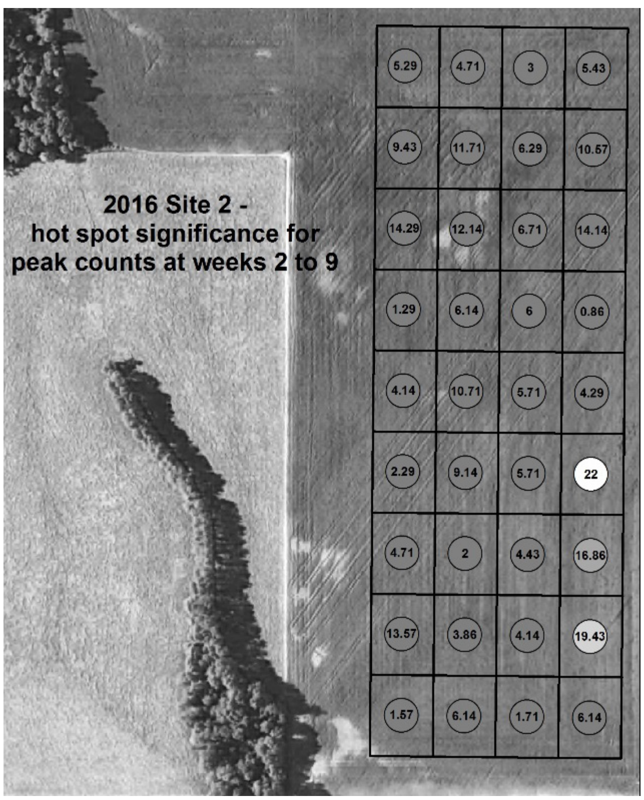

Figure 2. Hot spots for slug counts at site 2.

at the other three sites, likely due to the generally favorable conditions for slugs in no-till white clover, a phenomenon seen in the previous 2 years. Slug baits were applied by growers more often at site 2 than at the three other sites.

There were four statistically significant hot spots at site 3, with three of them occurring on the south side of our plots, a position in the field at which elevation dropped off markedly in the general slope from north to south (Figure 3). This lower elevation region of the field may have experienced greater subsurface moisture flow during the summer than the slightly higher elevation region to the north. No obvious cause for the hot spot in plot 313 could be discerned.

All four statistically significant hot spots at site 4 occurred on the south side of our plots in the lower elevation portion of the field (Figure 4). Complex water flow patterns were present in this field, with multiple small springs running throughout the period of slug counts. The prior crop of canola appeared to be quite favorable for slugs, and counts in some of the plots at this site were among the highest ever recorded in our research over the past 3 years.

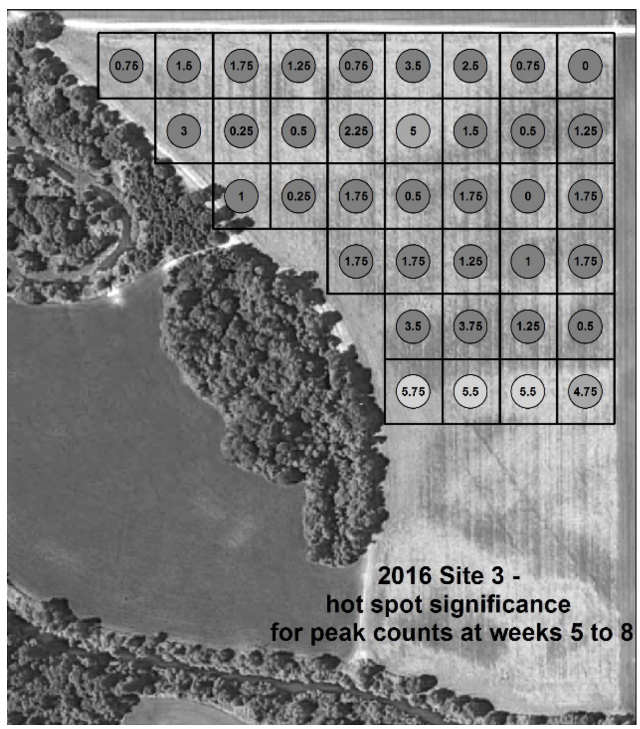

Figure 3. Hot spots for slug counts at site 3.

Note: For Figures 1–4, values within circles are the average peak slug counts, with statistical confidence levels of 99% for fully white circles (hot spots) or black circles (cold spots), 95% for mostly white or black circles, 90% for slightly white or black circles, and nonsignificance for neutral gray circles.

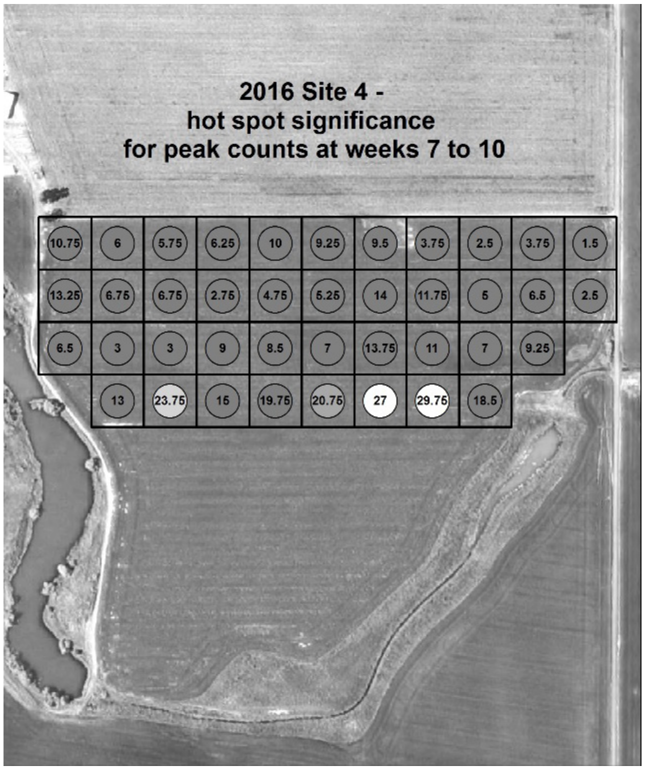

Figure 4. Hot spots for slug counts at site 4.

To test the hypothesis that shallow subsurface moisture was a critical factor in successful over-summer survival by slugs, we conducted deep soil sampling in late summer of 2016 at the site that had the strongest spatial patterns in slug counts in 2015. We sampled soil to a depth of 3 feet, compositing the soil into 6-inch increments. There were differences among plots in the moisture content of the two deepest depths (24–30 inches and 30–36 inches). However, these differences did not align meaningfully with the slug counts from 2015. It seems likely that favorable subsurface soil moisture may be a necessary but not sufficient condition for the presence of high slug counts. High among the other possible factors is simply how well the slugs did versus any slug bait applications in the recent past.

All evidence from the past 3 years of slug counts indicates that slugs tend to live out their lives within a few hundred feet of where they hatched, and that acre-size plots are large enough to be nearly independent of one another.

Crop damage by slugs was relatively mild during the fall of 2016, and ongoing counts of PR stands indicate that both fields planted before heavy rains in October established quite well.

Performance of slug bait applications varied widely among sites, with two-fold reductions in slug counts at site 2 (e.g., eight slugs per blanket the week before treatment and four slugs per blanket the week after treatment) and seven-fold reductions at site 1. Interactions between temperature, planting date, and timing of slug bait applications at the other two sites prevented us from estimating performance of slug bait applications.

The critical period for crop damage caused by slugs was spread over a wider period in the fall of 2016 than in previous years because of the range in planting dates caused by interruption of field work by heavy rainfall in October. As a result, only at site 2 was it possible to correlate crop damage with slug counts.

Summary

These findings have several important implications for management of slugs by grass seed growers. First, the absence of cold spots, except at a single site in 1 year (site 1 in 2016), means that entire fields will generally need to be treated at least once during the peak emergence of slugs after fall rains begin; there were no truly safe locations free of all slug danger. Second, the presence of several stable hot spots at each of the sites means that there will be areas needing repeated applications of slug bait. The simplest way to identify those areas would be to mark locations where high numbers of slugs have already been found. Third, the multiyear correlation between lower elevations and higher slug counts within fields suggests that it may be possible to predict where slug numbers will be highest within fields. Fourth, no-till establishment of PR into existing clover crops can succeed if growers are willing to apply slug bait multiple times over the fall (i.e., whenever more slugs appear at the soil surface ready to eat crop plants) and are diligent in their scouting for slugs. Fifth, the economic threshold for damage to PR seedlings remains very low, likely somewhere between two and four slugs per blanket for measurements made during active slug baiting. The threshold would likely be even lower if slug bait was never applied.

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