GROWING KNOWLEDGE

Series content is coordinated by Dr. Jay Pscheidt, professor of botany and plant pathology at Oregon State University in Corvallis, Oregon.

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The Milky Slug (*Deroceras reticulatum*), or the Grey Fieldslug, is a major pest in Willamette Valley agriculture and horticulture.
PHOTO COURTESY OREGON STATE UNIVERSITY

A slimy scourge

Researchers seek effective biological controls against invasive North American slugs

BY CASEY H. RICHART, DANA K. HOWE, DEE R. DENVER AND RORY J. MCDONNELL

THE MILKY SLUG (*Deroceras reticulatum*) is probably the most economically damaging species of terrestrial slug or snail species in the world. This holds true for Oregon, where it is a major pest in Willamette Valley agriculture and horticulture (where it is often called the gray field or gray garden slug).

A 2012 study by the Oregon Seed Council concluded that slugs alone cost the Oregon grass seed industry about $60 million a year, factoring in direct crop loss, molluscicide cost, and additional labor.

Milky slugs are about 1.5–2 inches long, but they are often numerous and have healthy appetites for a very wide variety of plants, including ornamentals such as hostas, marigolds, and gardenias. They also live in a wide range of places, including nurseries, garden centers, personal gardens, small farms, parks, adjacent forests, pastures, and other agricultural fields.

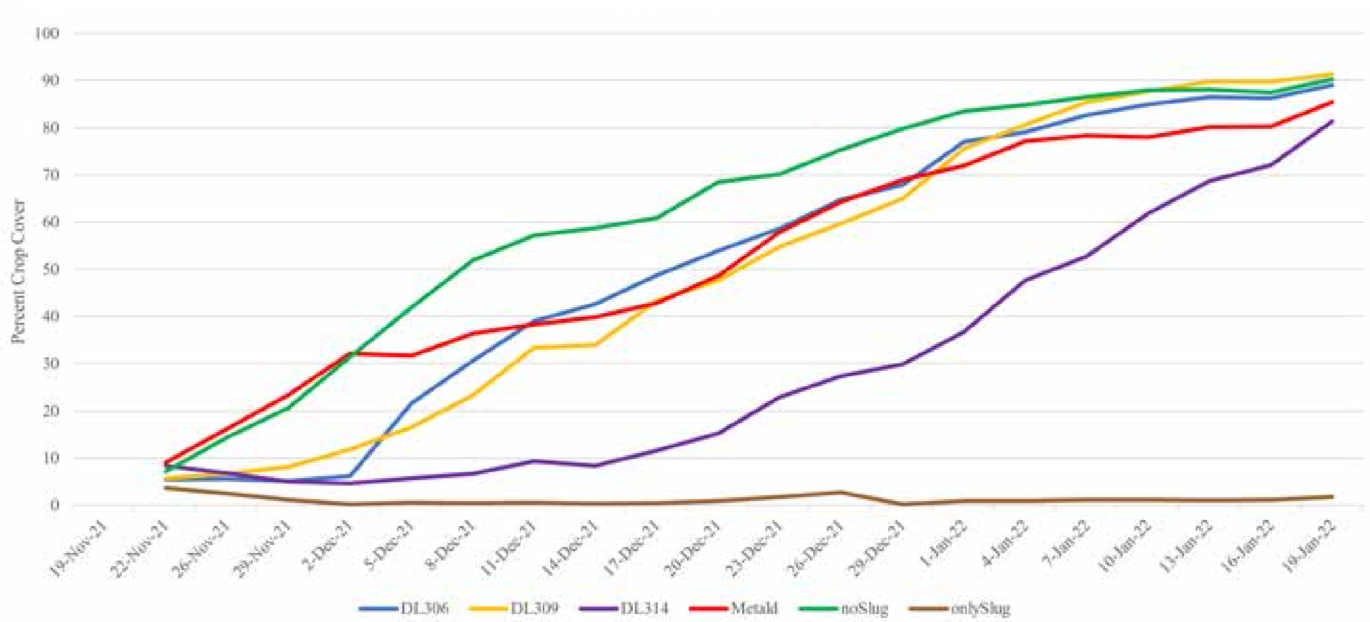
The milky slug gets its name from the white defensive mucus it secretes when harried. Their coloration ranges from light to dark gray, with a darker gray mottling throughout the body.

Chemical remedies

The most used management strategy in Oregon agriculture for pest slugs and snails is chemical molluscicides. However,

Crop protection

Researchers compared three species of *Phasmarhabditis* nematodes: 1) *P. papillosa* DL306, 2) *P. hermaphrodita* DL309, 3) *P. californica* DL314, to 4) liquid metaldehyde, 5) no management strategy (slugs only, a negative control), and 6) no slug pressure (a positive control). They placed 10 milky slugs into each microcosm (excepting the positive control), and all six treatments had three replicates. We assessed mortality daily and assessed crop protection by taking images of the containers every three days.



these compounds come with many challenges. Farmers, for example, report considerable variation in efficacy of the active ingredients, which include metaldehyde, iron phosphate, sodium ferric EDTA, and methiocarb.

There is scientific evidence to suggest that gastropods can develop a tolerance to metaldehyde, which is the most widely used active ingredient. In baited form, metaldehyde is also attractive to dogs and can be fatal if ingested. Additionally, it persists in waterways, which may result in further non-target poisoning. Due to these non-target concerns, this chemical has been banned in the United Kingdom, as have some forms of applications in California.

Another chemical molluscicide, methiocarb, is a restricted use material with the DANGER-POISON signal word. It is neurotoxic to humans, and highly toxic to birds, bees, and aquatic species, particularly fish. Methiocarb has been banned in Europe because of its damaging non-target effects.

Iron phosphate and chelated iron are stomach poisons and there is evidence to suggest that they can be harmful to earthworms. Ideally, an optimized integrated pest management (IPM) strategy would allow for better pest control while reducing negative impacts on non-target systems.

Dana Howe from the Dee Denver lab adding nematodes to the microcosm containers in the OSU greenhouses.

PHOTO COURTESY OREGON STATE UNIVERSITY

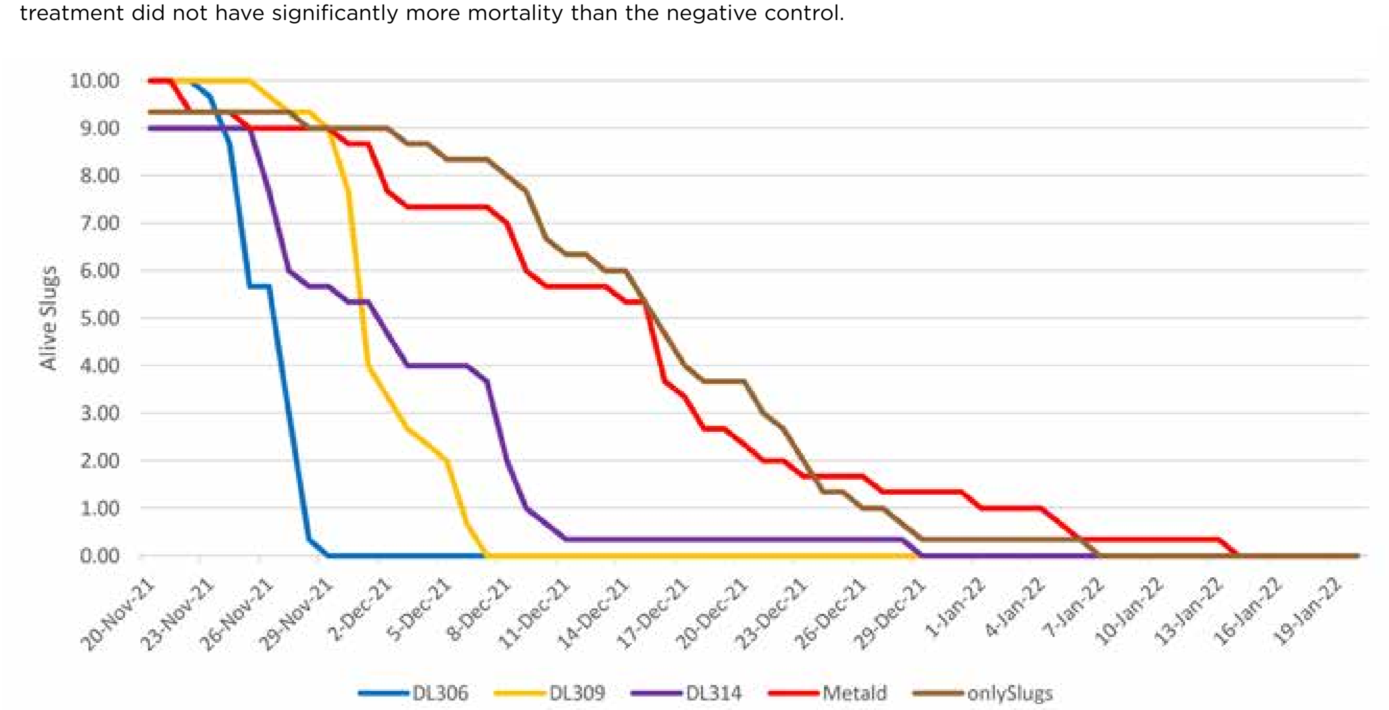
In search of IPM solutions

Much of our research focuses on developing IPM strategies for pest slugs and snails, including using essential oil plant extracts as biorational molluscicides, assessing the effectiveness of natural enemies of the pests as biological control agents, and developing attractants for use in both trapping and attract-and-kill strategies.

Also, we aim to better understand the natural history and life history character-

Average mortality by treatment

The containers treated with nematodes resulted in significantly higher slug mortality than metaldehyde. The metaldehyde treatment did not have significantly more mortality than the negative control.



Hundreds of thousands of nematodes now occupy the spot where the infected *Deroceras reticulatum* slugs died.

PHOTO COURTESY OREGON STATE UNIVERSITY

istics of invasive slug and snail species to make control efforts more effective, while reducing non-target impacts.

In parts of Europe, there are a few species of nematode roundworms in the genus *Phasmarhabditis* (there is no common name) that have partnerships with a facultatively symbiotic species of bacteria. Together, they specialize in eating slugs and snails.

The nematodes penetrate the slug and vomit inside a cocktail that includes the bacteria. The bacteria are slug-eaters, and they reproduce rapidly, and the nematodes in turn feed on the bacteria and reproduce. This cycle continues until all that remains is a slug-shaped soup of parasitic worms, bacteria, and vomit.

The species that we are currently using in our research are *P. papillosa* DL306, *P. hermaphrodita* DL309, and *P. californica* DL314. The DL numbers signify different strains of the species, and they correlate to the graphs in this article. Our very preliminary data suggests that the primary hosts for *P. papillosa*, and *P. californica* is the milky slug or other slugs in the genus, whereas P. *hermaphrodita* has been found in a wide variety of terrestrial gastropod species, including snails.

In Europe two of these nematodes species are commercially available as biological control agents. The first, *Phasmarhabditis hermaphrodita*, was commercialized in 1994 as Nemaslug® and is now available in 15 countries.

Nemaslug® has a long history of protecting agricultural (e.g. winter wheat) and horticultural (e.g. orchids) crops from damage by a wide range of pest slug and also some pest snail species.

The second, *P. californica*, was commercialized in 2022 as Nemaslug 2.0® and is currently only available in England, Scotland and Wales. Users purchase these nematodes in packets and mix the contents with water and apply

An image through the microscope of *Phasmarhabditis* nematodes infecting a slug (*Deroceras reticulatum*).
PHOTO COURTESY OREGON STATE UNIVERSITY

immediately using a watering can or hose applicator, to already damp soil in their gardens.

Currently, there is no species of nematode roundworm native to North America that is known to specialize in terrestrial slugs and snails, and nematodes that target these pests are not currently commercially available to North American farmers and horticulturalists. This is due to a lack of information on potential impacts on non-target slugs and snails.

We recently conducted an experiment to assess if these nematode roundworms can protect annual ryegrass, an important crop in the Willamette Valley. To ensure the containment of the nematodes, we conducted this research in a microcosm — a small-scale representation of a field situation, in containers at the Oregon State University greenhouses.

We compared three species of *Phasmarhabditis* nematodes: 1) *P. papillosa*, 2) *P. hermaphrodita*, 3) P. *californica*, to 4) liquid metaldehyde, 5) no management strategy (slugs only, a negative control), and 6) no slug pressure (a positive control). We placed 10 milky slugs into each microcosm (excepting the positive control), and all six treatments had three replicates. We assessed mortality daily and assessed crop protection by taking images of the containers every three days. See the "Crop protection" figure (Page 42) for more information.

The containers treated with nematodes resulted in significantly higher slug mortality than metaldehyde. In fact, the metaldehyde treatment did not have significantly more mortality than the negative control. See the "Average mortality by treatment" figure (Page 43) for more information.

However, the slugs treated with metaldehyde were clearly poisoned, and for about two weeks they hardly moved, and they did not start eating the ryegrass until recovering from this poison. Conversely, the slugs in the nematode containers grazed freely for 10 days, before the nematodes started to cause rapid mortality and the slugs grazed grass no more. See the "crop protection by grass growth" figure to see more general trends on grass herbivory.

These differences in mortality rate resulted in different patterns of crop protection. The metaldehyde conferred great crop protection initially, with measurable grazing pressure not detected until after 2 weeks. In the nematode treatments however, for the first 10 days, crop protection tracked the negative control, with crops rebounding strongly after significant slug mortality had occurred.

These results suggest that integrating nematodes with a chemical molluscicide are likely to confer greater crop protection than either of these treatments alone. We are excited to test this hypothesis. We have already exposed a wide diversity of commercially available molluscicides to these three *Phasmarhabditis* species in laboratory studies, and we found that they do not cause mortality in these nematodes. Watch for future updates to be shared in Digger.

This research strongly suggests that nematode roundworms are a powerful tool in the IPM arsemnal against terrestrial slugs and snails. However, since at least two of these nematodes (*P. hermaphrodita* and *P. papillosa*) are native to Europe, it is possible that they could become a pest here as well.

The next step in our research is to test the lethality of these nematodes against the rich and unique terrestrial slug and snail fauna native to the temperate rainforests of the Pacific Northwest. For as in chemical pesticides, biological control of slugs and snails too has a long history of detrimental non-target effects.

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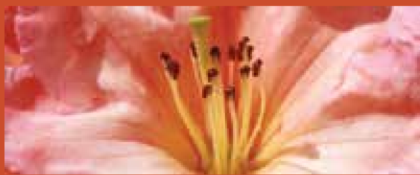


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