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# EVALUATING NEW INSECTICIDES TO MANAGE CLOVER SEED WEEVILS IN WHITE CLOVER SEED CROPS (2022)

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## Introduction

The clover seed weevil (CSW), *Tychius picirostris* Fabricius (Coleoptera: Curculionidae), is one of the primary factors limiting seed yield potential and economic sustainability in white clover (*Trifolium repens* L.) crops (Reeher et al., 1950). This species is a key insect pest in white clover seed production systems in Oregon’s Willamette Valley, benefiting from the close proximity of other white clover fields, a lack of alternative hosts to reduce pressure on clover seed fields, and high selection pressure of broad-spectrum insecticides used throughout the prolonged growing season. Other minor clover species grown in Oregon, including alsike (*Trifolium hybridum* L.) and arrowleaf (*Trifolium vesiculosum* L.), are also known to be susceptible to CSW feeding damage.

Clover seed weevil adults are gray, small (approximately 0.1 inch in length), and have a characteristic long snout and brushes of gray and white hair (Reeher et al., 1950). First-generation adults move into clover seed fields from overwintering areas and lay eggs within developing florets. Larvae hatch and feed on two to four developing seeds per floret, resulting in a considerable reduction in seed yield if not effectively managed (Chaudhri and Johansen, 1967). Since second-generation adult weevils exhibit dispersing behavior and do not feed on developing seeds or lay eggs, management recommendations should be focused on first-generation CSW populations.

This approach may vary with weather and crop variety and is not always a reliable indicator to appropriately time foliar insecticide applications targeting CSW in white clover (Chaudhri and Johansen, 1967).

In 2021, seven insecticides applied at BBCH 65–66 were evaluated for efficacy against CSW under field conditions (Mattsson et al., 2021). Grower standards used in that study (Brigade and Malathion 8 Aquamul) resulted in initial knockdown effects on adults but had minimal impact on larval counts throughout the growing season. Seed yield was not measured in this study.

We hypothesize that using more diverse modes of action applied at first larval detection targeting CSW larvae will reduce feeding damage and seed yield loss. The primary objective of this study was to evaluate the efficacy of newer insecticide chemistries for CSW management in commercial white clover seed fields when applied at first larval detection compared to a standard practice of applying pyrethroids (Brigade) at BBCH 65–66.

## Materials and Methods

### Experimental design

One large-scale field trial was conducted in a commercial white clover seed field in Linn County, OR, in 2022. Nine treatments, including an untreated control (Table 1), were evaluated for CSW control and

Chemical control of CSW in white clover seed crops poses several challenges. Current economic thresholds are based on adult activity and do not consider the severity of larval infestations. The current recommendation is to treat when an average of two or more adult weevils per single straight-line sweep (90°) are observed. However, the relationship between adult weevil densities and the crop-damaging larval stage during the mass influx of adults from overwintering habitat remains unclear. Past recommendations for insecticide timing were based on the crop stage reaching 20% flower brown-down (BBCH 65–66).

Table 1. Trade names, active ingredient, and application rate of treatments for a field trial in Linn County, OR, in 2022.

Trade name	Active ingredient (IRAC group)	Rate <sup>1</sup>
Untreated control	—	—
Brigade	Bifenthrin (3A)	6.4 <sup>2</sup>
Exirel	Cytraniliprole (28)	20.5 <sup>3</sup>
Exirel + Brigade	Cytraniliprole (28) + bifenthrin (3A)	20.5 <sup>3</sup> + 6.4 <sup>2</sup>
Harvanta	Cyclaniliprole (28)	16.4 <sup>3</sup>
Harvanta + Brigade	Cyclaniliprole (28) + bifenthrin (3A)	16.4 <sup>3</sup> + 6.4 <sup>2</sup>
Malathion + Brigade	Malathion (1B) + bifenthrin (3A)	20.0 <sup>3</sup> + 6.4 <sup>2</sup>
Steward	Indoxacarb (22)	11.3 <sup>3</sup>
Steward + Brigade	Indoxacarb (22) + bifenthrin (3A)	11.3 <sup>3</sup> + 6.4 <sup>2</sup>

<sup>1</sup>Rate in fl/oz/acre

<sup>2</sup>Applied at BBCH 65–66 (July 7)

<sup>3</sup>Applied at first detection of larvae (June 23)

seed yield. Plots were 29 feet wide x 300 feet in length. Insecticide treatments were arranged in a randomized complete block design with three replications. Insecticide treatments were applied with an ATV-mounted boom sprayer equipped with TeeJet 11002 VS nozzles calibrated to deliver 20 psi with at least 15 gpa. Newer chemistries targeting CSW larvae (Exirel, Harvanta, Steward) and malathion were applied at first larval detection on June 23, 2022. Brigade applications (Brigade only and Brigade combination treatments) were applied at BBCH 65–66 on July 7, 2022.

#### CSW abundance

Adult CSW populations were measured at 3, 7, 14, 21, and 28 days after treatment (DAT). Larval populations were estimated at 7, 14, 21, and 28 DAT. To measure larval abundance, developing inflorescences (seed heads) were collected from three random 1 ft<sup>2</sup> areas in each plot (approximately 30 inflorescences per plot). Inflorescences were placed in plastic bags, transported to the laboratory, and subjected to Berlese funnel extractions for 24 hours. Adult CSW abundance was estimated with two sweep net samples of five straight-line sweeps at two locations in each plot. The sum of sweep samples (ten total sweeps) was recorded for CSW adult abundance in each plot.

#### Seed yield

To determine clean seed yield, plots were combined using grower’s equipment and weighed using a Parkan weigh wagon on August 16, 2022. Subsamples of

harvested seed were collected and cleaned to determine clean seed yield.

#### Data analysis

Adult and larval CSW abundance data were fitted to a negative binomial distribution and analyzed using a generalized linear mixed model framework with treatment and DAT as fixed effects, block as random effects intercepts, and random slopes for DAT. Clean seed yield was analyzed using a linear mixed effects model with yield as fixed effects and block as random effects intercepts. Differences between treatments were determined using estimated marginal means, and the Tukey method was used to calculate *P*-values with a significance level of  $\alpha = 0.05$ . Degrees of freedom were approximated using Kenward-Rogers adjustment for seed yield analysis.

### Results and Discussion

#### Adult control

Both CSW adult and larval populations were detected throughout the bloom and seed fill periods. Adult CSW abundance using sweep net sampling was different among insecticide treatments across sampling dates (Figure 1A;  $\chi^2 = 6.4$ ,  $df = 8$ ,  $P < 0.001$ ), and there was an interaction between treatment and DAT factors (Figure 1C;  $\chi^2 = 1.6$ ,  $df = 32$ ,  $P = 0.02$ ). Across all sampling dates, CSW counts in Steward, malathion + Brigade, and Harvanta + Brigade plots were lower than in Brigade alone. When treatments were analyzed by DAT, insecticide treatments were different at 3, 7, and 14 DAT, with no differences detected at 21 and 28 DAT (Figure 1C). For 3 DAT, Steward and malathion had significantly fewer adults than the untreated control. At 7 DAT, fewer CSW adults were detected in Steward, malathion, and Harvanta treatments. Harvanta was the only treatment with significantly fewer adults than the untreated control at 14 DAT.

At 14 DAT, field plots reached BBCH 65–66, and Brigade applications were made for respective treatments. No differences were observed among treatments after Brigade applications. Adult CSW counts

Table 2. Insecticide treatment, mean number of CSW larvae per 30 inflorescences, and clean seed yield at harvest for a field trial in Linn County, OR, in 2022.

Treatment	----- Larvae -----				Yield ( $\pm$ SE) <sup>1</sup>
	--- Pre-Brigade ---		--- Post-Brigade ---		
	7 DAT	14 DAT	21 DAT	28 DAT	
Untreated control	1.7	12.3	1.7	8.0	539 (59)
Brigade	0.0	15.3	8.7	6.7	564 (83)
Exirel	0.7	9.0	1.7	8.0	591 (40)
Exirel + Brigade	0.3	6.0	0.3	3.7	635 (41)
Harvanta	5.7	3.0	8.0	15.0	550 (28)
Harvanta + Brigade	1.0	4.0	0.0	0.7	636 (68)
Malathion + Brigade	1.0	4.3	1.0	2.0	607 (73)
Steward	0.3	2.0	0.0	8.3	605 (50)
Steward + Brigade	1.0	6.0	0.0	2.7	659 (55)
<i>P</i> < 0.05	0.55	0.67	0.33	0.30	0.17

<sup>1</sup>Yield in lb/acre

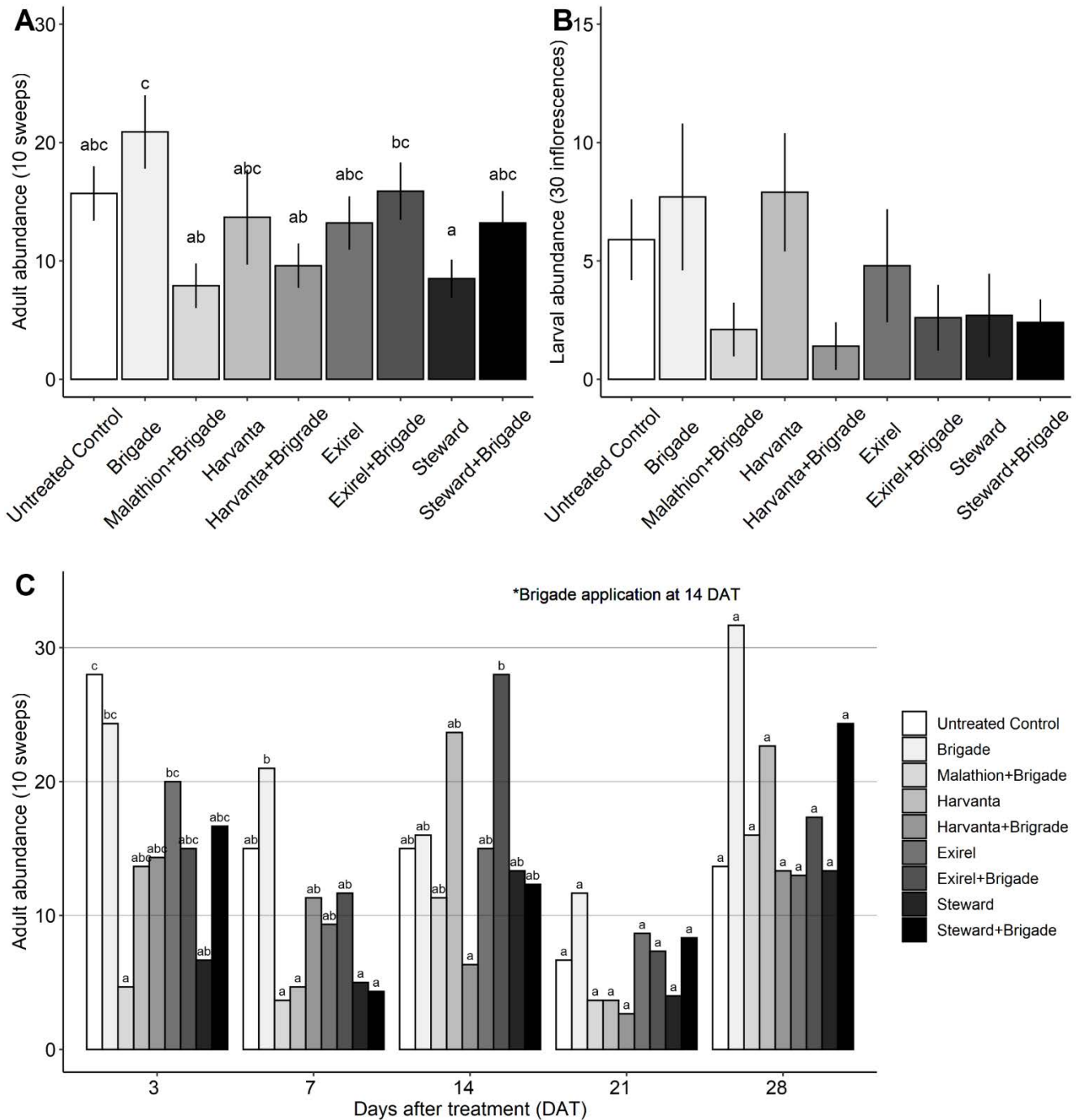


Figure 1. (A) Mean clover seed weevil (CSW) adult abundance ( $\pm$ SE) in straight-line sweep net samples (ten sweeps/plot) across all sampling dates. Treatment bars with the same letters are not significantly different ( $P < 0.05$ ) using Tukey separation. (B) Mean CSW larvae (30 floral heads) across all days after treatment (DAT). (C) Mean CSW adult comparisons among insecticide treatments at 3, 7, 14, 21, and 28 DAT. Bars with the same letters within DAT groups are not significantly different ( $P < 0.05$ ) using Tukey separation.

in the Brigade treatment were not different than the untreated control after application (DAT 21 and 28; Figure 1C). Phytotoxicity was not observed in any treatment.

#### Larval control

The number of larvae per 30 inflorescences was not different among treatments (Figure 1B;  $\chi^2 = 1.2$ ,  $df = 8$ ,  $P = 0.29$ ), and no differences were detected among treatments at each sampling date (Table 2). Brigade did not provide adequate control of adult or larval populations. In summary, limited efficacy of Brigade to reduce CSW adult and larval populations in a field trial aligns with preliminary laboratory assays suggesting high levels of pyrethroid resistance within local CSW populations using technical-grade chemistry and formulated product.

#### Seed yield

No differences in total clean seed yield were observed among treatments in 2022 (Table 2). Similar field trials will be conducted in 2023 to further evaluate insecticide treatments on seed yield and to determine the best recommendations regarding insecticide chemistry selection for CSW control in Oregon white clover seed production.

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# DO NEWER PESTICIDE CHEMISTRIES PROVIDE ENOUGH SYMPHYLAN CONTROL IN GRASS SEED CROPS? (YEAR 1)

A.R. Willette, N. Kaur, N.P. Anderson, and S.J. Dorman

## Introduction

Symphylans are a soil pest with a broad host range, affecting numerous specialty crops, ranging from strawberry to grass seed to vegetable crops to mint (as many as 100 crops have been reported) in western Oregon, Washington, and California (Umble and Fisher, 2003; Shimat, 2015). Garden symphylan, *Scutigera immaculata* (Newport) is a soil arthropod, less than 10 mm long, white, centipede-like, and having 15 to 22 body segments. Symphylans feed on plant roots, resulting in stunted growth due to the reduction in the plant's ability to acquire nutrients and water (Burden, 2004). High infestation levels of symphylans can cause poor germination, stunted growth, seedling death, and reduced vigor, resulting in poor stands and reduced yields. Although few estimates of crop yield loss due to symphylans are available, a vast majority of western Oregon grass seed growers report challenges from mitigating symphylans every year, particularly during seedling/stand establishment (personal communication, agricultural industry professionals).

Symphylan control is managed using preventative insecticide application as preplant incorporation (PPI). Limited chemical control options exist for practical management of symphylans after the Lorsban (chlorpyrifos) phaseout. Sampling for symphylans using potato bait or soil sampling methods can indicate whether treatment should be administered (Umble and Fisher, 2003).

Efficacy trials for symphylan control in grass seed production have not been performed until this study. Efficacy data are needed to determine whether the newer pesticide chemistries are viable tools against symphylans. Our research objective was to evaluate the efficacy of new and existing pesticide products representing diverse modes of action for the management of symphylans in tall fescue, *Schedonorus phoenix* (Scop.) Holub, and perennial ryegrass, *Lolium perenne* L., grown for seed.

## Materials and Methods

A symphylan-infested site was identified using the potato bait method at the Oregon State University (OSU) Hyslop Research Laboratory near Corvallis, OR.

Treatments included five insecticidal products and an untreated control (Tables 1 and 2) during spring and fall of 2022. Spring-planted tall fescue (var. 'Titanium G-LS') and fall-planted perennial ryegrass (var. 'Fastball 3GL') plots were used in this study. Plots were 12 feet x 30 feet and were arranged in a randomized complete block design with four replications each. Each replication was bordered by 30 feet of nontreated buffer planted in the same crop. Treatments were applied PPI.

Spring treatments were made on April 8, 2022, using a CO<sub>2</sub> backpack sprayer calibrated to deliver 20 gal/acre at 22 psi through TeeJet 8002VS nozzles. Treatments were incorporated into the top 2 inches of soil, using a tractor-mounted rotavator, immediately prior to planting tall fescue variety 'Titanium G-LS' at a 9 lb/acre seeding rate with 13-inch row spacing. Seeding depth was approximately 0.5 inch.

Symphylan counts were taken from two randomly deployed potato bait stations per plot. Each bait station consisted of half a potato longitudinally cut, placed cut side down on the soil surface and covered with an 8-inch-wide plastic flowerpot without drain holes. Bait stations were deployed approximately 1 week after insecticide treatment and were checked 24 to 48 hours after placement by lifting the potato bait and counting symphylans under the potato on the soil surface and then counting the number of symphylans on the potato. The total number of symphylans per plot (two bait stations) was recorded at 10, 14, 25, 32, and 39 days after treatment (DAT). After final data collection, plant density was taken for each plot by randomly selecting a 1-meter length of one row within each plot and counting total germinated seeds unaffected by symphylans.

During fall 2022, a nematicidal (Nimitz) and a fungicidal (Velum Prime) product were included along with the three insecticidal chemistries that outperformed the control in the spring trial (Bateman et al., 2023). Fall insecticide application was made on October 20, 2022, using a CO<sub>2</sub> backpack sprayer calibrated to deliver 20 gal/acre at 22 psi through TeeJet 8002VS nozzles. Treatments were incorporated into the top 2 inches of soil, using a tractor-mounted rotavator, immediately prior to planting perennial ryegrass var. 'Fastball

3GL' with a seeding rate of 9 lb/acre and 13-inch row spacing. Seeding depth was approximately 0.5 inch.

Symphylan counts were performed according to the above-mentioned procedure and were recorded at 8, 13, and 33 DAT. No counts were taken between 14 and 30 DAT due to rain events that flooded this site. Plant density counts were taken at 50 DAT for each plot according to the above-mentioned methodology.

Data were analyzed by ANOVA, and means were separated using Fisher's protected LSD ( $P \leq 0.05$ ) (SAS Institute Inc, 2016).

## Results and Discussion

### Spring 2022

At 10 DAT, symphylans were not detected in plots containing treatments Capture LFR and Torac, indicating significant suppression compared to untreated control plots (an average of 9.25 symphylans) and Vantacor treatments (an average of 4.25 symphylans) (Table 1). At 14 DAT, a similar trend emerged for Capture LFR and A21377X, with no symphylans present and significant suppression compared to Vantacor (an average of three symphylans). At 25, 32, and 39 DAT, no treatment differences were detected compared to the control.

At the end of the spring trial, there was no difference in plant density among treatments (Table 1). However, there seemed to be a weak negative correlation between

higher plant densities and lowest symphylan densities in plots treated with Capture LFR (data not shown).

### Fall 2022

At 8 DAT, Capture LFR, Warrior II, Velum Prime, Torac, and the untreated control had comparable symphylan counts, and no difference in the mean symphylan counts was observed (Table 2). At 13 DAT, all pesticide treatments suppressed symphylans when compared to that of the untreated control (an average of 10.3 symphylans) and Nimitz plots (an average of 7 symphylans). No differences in mean symphylan counts were found at 33 DAT. At 50 DAT, plant densities of all insecticide treatments were comparable to the untreated control except Nimitz, indicating its poor performance in symphylan control.

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Table 1. Trade names, active ingredients (IRAC group), rate in fl oz/acre, mean number of symphylans, and plant density, spring 2022.<sup>1</sup>

Trade name	Active ingredient	Rate/a (fl oz)	Symphylan count per plot <sup>2</sup>					Plant density
			10 DAT <sup>3</sup>	14 DAT	25 DAT	32 DAT	39 DAT	
Capture LFR	Bifenthrin (Group 3A)	6.50	0.0 b	0.0 b	0.5 a	0.0 a	0.0 a	17.7 a
Torac	Tolfenpyrad (Group 21A)	21.00	0.0 b	0.3 ab	3.0 a	0.3 a	0.8 a	9.5 a
Vantacor	Chlorantraniliprole (Group 28)	2.50	4.3 ab	3.0 a	5.5 a	0.0 a	8.5 a	4.5 a
BAS4007I	Broflanilide (Group 30)	2.40	0.8 b	0.7 ab	5.8 a	1.5 a	9.8 a	7.2 a
A21377X	(Group 30)	10.27	2.5 ab	0.0 b	2.3 a	0.3 a	0.3 a	13.2 a
Untreated control	—	—	9.3 a	0.3 ab	4.3 a	0.5 a	3.5 a	14.0 a
$P > F$			0.006	0.031	0.545	0.582	0.092	0.092

<sup>1</sup>Means within a column followed by the same letter are not significantly different ( $P = 0.05$ ). Treatments were applied prior to planting on the same day.

<sup>2</sup>Symphylan counts were collected from two potato bait stations per plot at 10, 14, 25, 32, and 39 DAT.

<sup>3</sup>DAT = days after treatment



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Table 2. Trade names, active ingredients (IRAC group), rate in fl oz/acre, mean number of symphylans, and plant density, fall 2022.<sup>1</sup>

Trade name	Active ingredient	Rate/a (fl oz)	--- Symphylan count per plot <sup>2</sup> ---			Plant density
			8 DAT <sup>3</sup>	13 DAT	33 DAT	
Capture LFR	Bifenthrin (Group 3A)	6.50	0.0 b	0.3 b	0.0 a	131.0 a
Warrior II	Lambda-cyhalothrin (Group 3)	1.92	0.3 b	0.5 b	0.5 a	101.5 ab
Velum Prime	Fluopyram (Group 7 fungicide)	6.84	0.3 b	0.8 b	0.3 a	95.5 ab
Torac	Tolfenpyrad (Group 21A)	21.00	0.5 ab	1.3 b	1.5 a	99.5 ab
Nimitz	Fluensulfone (nematicide)	84.00	2.5 a	7.0 ab	1.0 a	60.3 b
Untreated control	—	—	1.0 ab	10.3 a	2.0 a	92.5 ab
<i>P &gt; F</i>			0.173	0.055	0.078	0.005

<sup>1</sup>Means within a column followed by the same letter are not significantly different ( $P = 0.05$ ). Treatments were applied prior to planting on the same day.

<sup>2</sup>Symphylan counts were collected from two potato bait stations per plot at 8, 13, and 33 DAT.

<sup>3</sup>DAT = days after treatment

# QUANTIFYING VOLE DAMAGE WITH AERIAL IMAGERY

*K.C. Tanner*

## Introduction

The gray-tailed vole (*Microtus canicaudus*) can cause substantial yield losses in Willamette Valley grass seed crops (Verhoeven and Anderson, 2021). Historically, high vole population numbers occurred every 4–8 years, followed by population crashes (Gervais, 2007). Recently, populations have remained elevated, with reports of severely damaged fields every year since 2019. Beyond the Willamette Valley, other species of voles are known to damage many crops.

Few control options are available for vole control in grass seed fields. Chemical control is limited to zinc phosphide baits. Above-ground application of zinc phosphide baits is limited to the period between early May and September 15 to protect migratory geese. Between September 15 and when migrating geese have left the valley in the spring, bait applications may only be made below ground by placing bait in the entrances of vole burrows. In one survey, only 26% of growers reported that zinc phosphide baits provided satisfactory control (Verhoeven and Anderson, 2021). Tillage can reduce vole populations, but it is used only as a last resort because it requires removing an established crop, which is a significant financial loss. Birds of prey and other predators feed on voles, but owl boxes and raptor poles have not provided detectable reductions in vole damage.

There is a clear need for improved vole control options, but evaluating new control practices is difficult and costly. The most rigorous method of measuring vole populations is to tag and release individuals, but this method requires labor-intensive live trapping programs. Gervais (2010) studied whether indicators of vole activity such as burrows and fresh droppings could be used to estimate populations, but none of these signs of vole activity was a good predictor of vole populations. An alternative approach is to measure crop damage, but this method has not been evaluated.

Voiles live in colonies with extensive networks of burrows and runways. During the vegetative growth period of grass seed crops, grazing damage is concentrated in the area immediately surrounding the colony. These patches of damage range from 1 to more

than 10 feet across, and they are irregular in shape. The severity of damage can differ among patches within a field, among fields, and over the course of the growing season. Variability in the size, shape, and severity of damage patches can complicate damage assessments. Nearby patches of damage are easy to see when walking in a field, but it is difficult to see damage at a distance because it is blocked from view by taller, undamaged plants.

Aerial imagery collected with unmanned aerial systems (UAS or drones) has been increasingly used in agricultural settings to evaluate crop health and nutrient and water status (Hassler and Baysal-Gurel, 2019). A drone can capture data on every square inch of a field in a relatively short time, something that would not be feasible on foot. This study tested whether aerial imagery captured with a drone can be used to quantify vole damage in grass seed fields.

## Materials and Methods

### Field sites

This study was conducted in two established tall fescue fields with severe vole infestations: a turf-type field, variety ‘Renegade DT’, approaching its third harvest, and a forage type, variety ‘Goliath’, approaching its eighth harvest. The turf type had distinct crop rows, while rows were not visible in the forage-type field. Tall fescue fields can differ in appearance, depending on variety and stand age, and these two fields were selected to represent the range of visual characteristics that tall fescue fields might exhibit.

### UAS

The aerial imaging system used in this study consisted of a DJI Matrice 210 v2 quadcopter drone outfitted with two cameras. A Micasense RedEdge MX camera captured five-band multispectral imagery (blue, green, red, red-edge, and near infrared), and a MicaSense downwelling light sensor (DLS2) recorded ambient light levels. A Sony a6000 camera captured high-resolution natural color (RGB; red, green, and blue) imagery. Both cameras were set up to capture one image per second.

### Georeferencing

Accurate location information for all data collected ensured that data collected on the ground could be matched to the corresponding location in the aerial imagery. Global navigation satellite system receivers capable of real-time kinematic positioning (RTK GPS, the technology used for tractor positioning) were used to collect accurate location information. A base station (Emlid Reach RS+) was set up prior to data collection and was set to record satellite observations throughout data collection. A rover module (Emlid Reach M+) was installed on the drone to record its location when photos were taken, and a second module was installed on a survey pole and was used to record locations on the ground. Ground control points (markers that are visible in drone imagery) were placed in the field prior to each flight, and their locations were recorded with the ground rover. Log files from the GPS modules were processed using Emlid Studio software. The location of the base station was determined using data from the closest continuously operating reference station (CORS).

### Data collection

Two UAS flights were conducted in each field. The turf-type field was flown on March 22 and April 27, 2022, and the forage-type field was flown on March 23 and April 22, 2022. The UAS was flown at 164 feet above ground level, resulting in a ground sample distance of 1.38 and 0.49 inches per pixel for the multispectral and RGB cameras, respectively. A multispectral photo was taken of a MicaSense calibrated reflectance panel (CRP) before and after each flight.

Ground-truth data were collected after each flight for 20 patches of vole damage and 20 undamaged areas distributed throughout the study area. Ground-truth points were identified as damaged if there were clear signs of vole activity such as droppings, runways, fresh signs of digging, or freshly clipped leaves and stems. Burrows alone were not considered sufficient evidence of vole damage because burrows can persist for several months without vole activity. Undamaged areas had vigorous crop growth with no evidence of vole activity. Observations, photographs, and RTK GPS location information were recorded for each ground-truth point. Evidence of other causes of poor crop growth was looked for but not observed.

### Data analysis

Drone pictures were processed using Pix4D Mapper software, which stitched the images collected during each flight into large images covering the entire flight

area. The locations of ground control points were entered during this processing step to ensure the images were accurately georeferenced. To correct for any differences in lighting conditions between flights, a radiometric calibration was performed, which converted raw multispectral image data to reflectance values. Reflectance is the fraction of ambient light (measured using the CRP photos and the DLS2) that was reflected by the surface in the photo and captured by the camera sensor. Data outputs also included digital surface models (DSM), which showed the elevation of the crop canopy, and a normalized differential vegetation index (NDVI) map.

ArcGIS Pro software was used for further analysis. Using elevation data from the DSM, relative canopy height was calculated as the difference in elevation between each pixel in DSM and the average elevation of the surrounding area (40.8-foot radius). Next, data were extracted from the aerial imagery at the locations of ground-truth points. At each ground-truth point, a circular area with a radius of 5.9 inches was defined, and summary statistics (average and standard deviation) were calculated for pixels in that area for the NDVI and relative canopy height images. ANOVA and Wilcoxon rank sum tests (when assumptions of normality were not met) were used to compare the NDVI and relative canopy height values of damaged versus undamaged ground-truth points.

Image classification was performed for each flight using a combination of all multispectral image bands, plus DSM and NDVI, via the image classification wizard in ArcGIS Pro. Training data for the classification model were created by manually marking areas of damaged plants, undamaged plants, and soil, based on appearance in the imagery. Prior to classification, the image was divided into objects, or groups of adjacent pixels with similar spectral characteristics (object-based classification). The model assigned objects to one of the three classification categories (soil, damaged plant, or undamaged plant). A previous attempt at image classification did not include a soil category and did not produce an accurate classification result.

The accuracy of the image classification model was evaluated by assessing whether the computer classification produced by the model was consistent with the human classification made for each ground-truth point. This was done by determining the percentage of the area within a radius of 5.9 inches of each ground-truth point that was assigned to each classification category.

## Results and Discussion

Both fields had extensive vole damage that was distributed throughout the study area. Areas with vole damage were easily distinguishable from undamaged areas in imagery from all four flights. Small plants and large areas of visible soil characterized damaged areas, while undamaged areas had larger plants with little to no visible soil.

There was notable crop growth between the March and April flights in both fields. In the March imagery, the turf-type field had narrow strips of visible soil between the crop rows in undamaged areas, but no soil was visible in the April imagery. While the forage-type field

had little visible soil in undamaged areas in the March imagery, vigorous crop growth was evident in the April imagery as many damaged areas decreased in size.

Figure 1 shows relative canopy height and NDVI standard deviation measured for both damaged and undamaged ground-truth points. Plants in damaged areas were significantly shorter ( $P < 0.05$ ) than plants in undamaged areas, based on relative canopy height. Average NDVI values were lower ( $P < 0.05$ ), and NDVI standard deviations were higher ( $P < 0.05$ ), in damaged areas compared to undamaged areas, likely due to the presence of visible soil. Damaged points are clustered in the bottom or bottom right of the graphs,

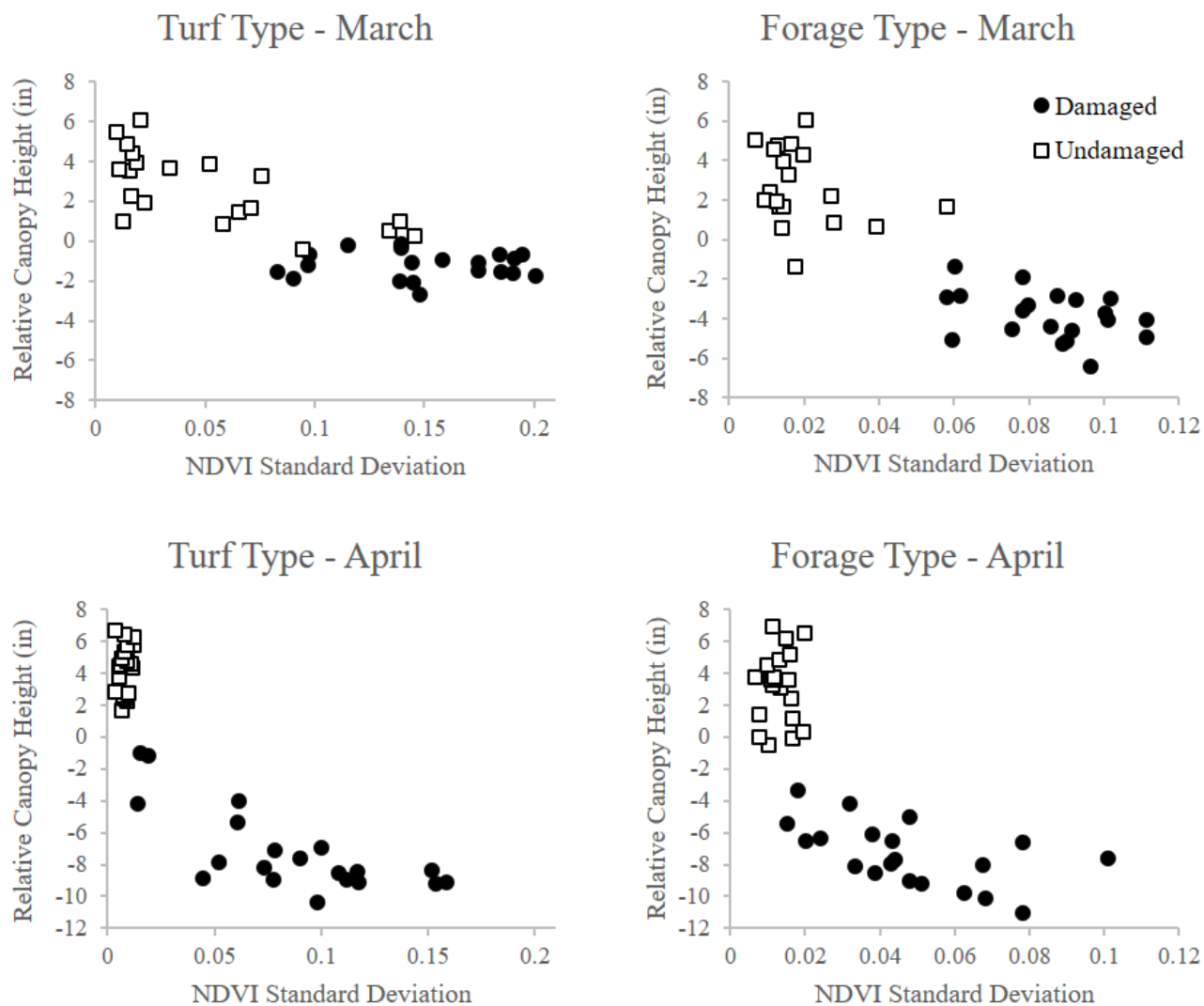


Figure 1. Aerial imagery values for locations that were observed from the ground. Relative canopy height is derived from the digital surface model and is shown on the y-axis. NDVI standard deviation is shown on the x-axis. Each point represents one ground-truth that was determined to be damaged (black circles) or undamaged (empty squares). Each panel shows data from one field and flight date.

and undamaged points are clustered in the top left. The clear separation between damaged and undamaged points suggests that vole damage can be detected using automated methods.

Image classification results are shown in Figure 2. Most of the area surrounding undamaged ground-truth points was classified as undamaged plants by the computer. The majority of the area surrounding damaged ground-truth points was classified as either damaged plants or soil.

The aim of this study was to differentiate between damaged and undamaged areas, so accuracy assessments focused on the damaged plant and undamaged plant classification categories. Soil was clearly visible in damaged areas in the aerial imagery,

so areas surrounding a damaged ground-truth point that were classified as soil were considered to be correctly classified. Three undamaged ground-truth points had some area classified as soil, and a visual inspection of the aerial imagery showed that this classification was an accurate representation of that location. Therefore, an undamaged ground-truth point was considered correctly classified if the surrounding area was assigned to the undamaged plant or soil categories. A damaged ground-truth point was considered correctly classified if the surrounding area was assigned to the damaged plant or soil categories.

Out of 160 ground-truth points, the area surrounding 123 points was 100% correctly classified. Ten points showed major classification errors, meaning that more than 50% of the surrounding area was classified

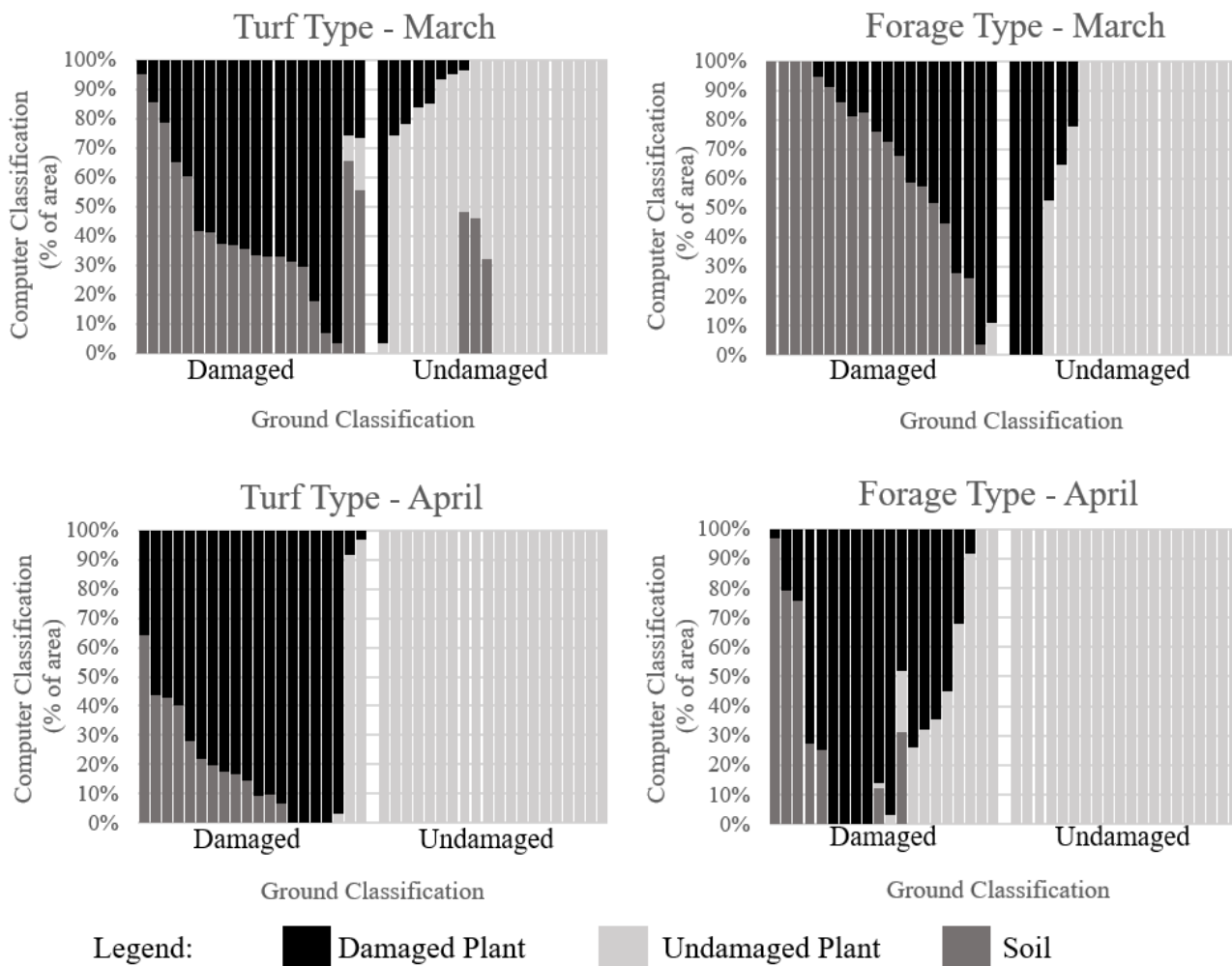


Figure 2. Classification results for the area surrounding each ground-truth point. Each bar represents the area immediately surrounding (within a radius of 5.9 inches) one ground-truth point. The shading of the bar shows what percentage of that area was assigned to each category by the image classification algorithm. Damaged points are grouped on the left side of each panel, and undamaged points are on the right. Each panel shows data from one field and flight date.

incorrectly. An additional 27 points had less than 50% of the surrounding area classified incorrectly.

The direction of classification errors differed between flights. In March, the most common error was undamaged ground-truth points classified as damaged plants. In April, undamaged ground-truth points were 100% correctly classified, while the area around damaged ground-truth points was sometimes classified as undamaged plants. Overall, more than 90% of the combined area surrounding ground-truth points was correctly classified (Table 1).

This study demonstrated that vole-damaged areas in tall fescue fields can be differentiated from undamaged areas by drone aerial imagery collected in March and April. This approach can be used to test vole control practices in the future and may also be adapted as a scouting tool prior to canopy closure.

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Table 1. Classification accuracy summary. Percentage of the area surrounding damaged and undamaged ground-truth points that was assigned to each classification category by the image classification algorithm.

Ground-truth classification	Computer classification		
	Undamaged plant	Damaged plant	Soil
----- (%) -----			
Undamaged	91.0	7.5	1.6
Damaged	9.4	54.0	36.0



# THE EFFECT OF SUBSURFACE DRAINAGE IN GRASS SEED FIELDS ON SOIL CARBON STOCKS

*L.C. Breza, J.M. Moore, A.A. Tomasek, and K.M. Trippe*

## Introduction

Approximately 14% of U.S. cropland has subsurface tile drainage to help mitigate saturated soil conditions by lowering the water table below the crop rooting zone. As a result, growers can achieve higher yields in poorly drained soils because saturated conditions no longer limit crop performance. In Oregon's Willamette Valley, poorly drained soils, combined with long rainy seasons, lead to unique farming challenges, and tile drainage helps alleviate some of these issues.

Farmers began installing tile drainage systems in the Willamette Valley as early as the mid-1800s and continue to install tile drains today. Subsurface drainage in the region has allowed farmers to lengthen the growing season by extending access to their fields. Studies have shown that tile drainage helps warm the soil faster than untilled fields (Jin et al., 2008). Warmer soils promote plant and microbial growth, providing crops a "head start" in the growing season. Because of the extended growing season, tile drainage also allows growers to plant a more diverse selection of crops and thus provides increased economic opportunity and flexibility.

It is well established that tile drainage impacts nutrient cycling, soil chemistry, biological activity, greenhouse gas (GHG) emissions, and water quality (Blann et al., 2009; Grenon et al., 2021). However, the degree to which drainage may positively or negatively influence these essential biological processes and resources is largely dependent upon soil type, farming practices, crop selection, and climate. Most existing studies on subsurface drainage were conducted in the Midwest and provide a limited scope of research and application for Willamette Valley growers.

Although there are extensive studies on the impact of tile drainage on biogeochemical processes, almost no research explicitly examines its impact on soil carbon (C) storage dynamics, especially at lower soil depths. The Willamette Valley can serve as a model system for studying C stocks in response to drainage because its soils tend to be deep mineral soils with naturally high soil C content. Additionally, there is an age gradient of tile drainage systems across the

Willamette Valley, which can provide insight into short- and long-term drainage effects on soil C. Constant saturation during the winter, followed by a long drying period in the summer, provides stable conditions for extended observation. Finally, grass seed crops that define the region's largest agricultural industry have the potential to add C inputs into the soil via deep rooting depths. Taken together, the above-mentioned regional characteristics allow us to study the impact of tile drainage on C storage dynamics and investigate potential mechanisms driving these dynamics.

Understanding C cycling dynamics in the Willamette Valley will help us determine how local agricultural management can aid in C sequestration under a changing climate. Therefore, our research aims to investigate the fate of soil C in response to tile drainage in Willamette Valley soils. We expect that soil C can respond in one of two ways: (1) tile drainage may *decrease* soil C by creating aerobic conditions and increasing microbial degradation of existing soil C, which microbes respire to the atmosphere, or (2) drained fields may facilitate crop root growth and stabilization of microbial byproducts, resulting in a net *increase* of soil C.

## Materials and Methods

### *Soil collection*

Soils were collected July through August 2022 from 15 grass seed production fields throughout the Willamette Valley between Corvallis and Eugene. We targeted Dayton silt loam soil (fine, smectitic, mesic Vertic Albaqualfs) by identifying Dayton zones within each field and then confirming the presence of Dayton soil through standard classification procedures.

Field treatments included newly tiled (< 5 years post-tile drain installation, n = 5), old tile (> 15 years post-tile drain installation, n = 5), and untilled (no history of tile drainage, n = 5). All fields have a history of grass seed crops, primarily consisting of tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort.), perennial ryegrass (*Lolium perenne* L.), and annual ryegrass (*Lolium multiflorum* L. Husnot).

Three 50-m transects were established within each Dayton soil zone within each field. We sampled soil to a depth of 1 m at the 0-, 25-, and 50-m points along each transect with an ATV-mounted hydraulic soil probe (Giddings Machine Company, Inc.) and used plastic liners within a stainless-steel soil probe (4.25 cm diameter) to extract intact soil cores. The intact soil cores were removed from the stainless-steel probe, capped on either end to prevent soil loss, and placed immediately on ice packs to keep cores cool. We stored intact soil cores at 4°C immediately after returning from the field.

#### Soil processing and analysis

Intact cores were removed from the plastic liners and laid out in trays for horizon delineation. A distinctive characteristic of the Dayton series is a Malpass clay layer (i.e., argillic horizon) that begins at or above 38 cm and can end as deep as 74 cm (Figure 1, Table 1). Because of variability in the depth of the Malpass clay, the abrupt textural change would likely alter the physical and chemical characteristics of the soil if standard soil depths (e.g., 0–15 cm, 15–30 cm, etc.) were used. Instead, we opted to segment the soil based on horizons, as this would maintain a consistent texture class across all samples. We identified the Ap/E (above the Malpass clay), Bt (Malpass clay), and BC (below the Malpass clay) horizons and recorded the depth and mass for each. Subsamples from each horizon from each core were analyzed for total C and nitrogen (N) (LECO CN282).

#### Equivalent soil mass calculations

To accurately estimate organic C stocks, we quantified the equivalent soil mass for each sample. This approach calculates the cumulative soil mass and organic C mass based on the depth, volume, and mass of different reference layers (i.e., horizons) within a soil core. Then, a cubic spline curve is fit to the cumulative soil mass and organic C down the soil profile (Wendt and Hauser, 2013). This approach provides the equivalent soil mass (ESM) C for each horizon and the cumulative soil C (i.e., summed incremental ESM-C) for the entire profile. We also used ESM calculations to determine cumulative and incremental N content within the soil profile.

#### Statistical analysis

To assess the overall accumulation of soil C in response to drainage, we modeled the cumulative soil C values, determined via the ESM approach, as a function of tile drainage. We used a mixed-effects model (R package lme4), with tile drainage age defined as the fixed

effect and transect defined as the random effect. To determine the effect of drainage treatment on soil C within horizons, we used the mixed-effects model previously outlined within each horizon. We defined incremental soil C values as the response variable instead of cumulative soil C. For both statistical models, we excluded one of the untilled fields (n = 4) from analysis because it was determined that many of the cores obtained from that field were not of the Dayton series and thus could not be compared to the other soil samples.

We tested for Gaussian distributions for each response variable and, subsequently, examined the distribution of model residuals for normality. Response variables (except for the Bt incremental C variable) did not meet the assumptions of the model. Therefore, we performed

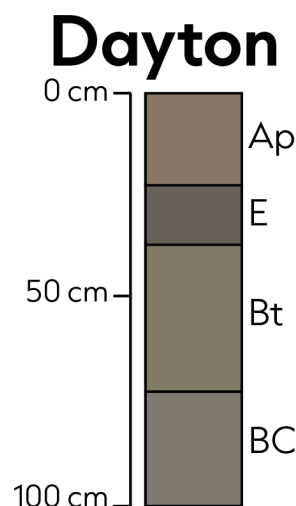


Figure 1. Illustration depicting the Dayton series soil profile up to 100 cm and the location of each horizon with respect to depth. Horizon descriptions are presented in Table 1.

Table 1. Dayton soil series horizon depths and texture.

Horizon	Description
Ap/E	0–30 cm. Silt loam texture with 15–30% clay.
Bt	38–74 cm. Clay or silty clay texture with 40–50% clay.
BC	74–100 cm. Clay or silty clay with 40–50% clay in the upper part and silty clay loam or silt loam with 20–35% clay in the lower part.

log transformations of the non-normal response variables, which allowed the data to meet the model's assumptions.

### Results and Discussion

The primary objective of this study was to assess whether tile drainage encourages C storage or depletes existing C stocks. We targeted the Dayton soil series because it is poorly drained and likely to be impacted the most by subsurface drainage compared to other soil types in the Willamette Valley.

We found no differences in cumulative soil C between newly tiled, old tile, and untilled fields (Figure 2,  $P = 0.35$ ). We also measured soil C within each horizon to determine whether this trend persisted throughout the soil profile. Consistent with known organic C values for different horizons within the Dayton series, we found that the Ap/E horizon contained the most soil C and that soil C declined with depth. Additionally, there were no differences between drainage treatments in the Ap/E horizon and the Bt horizon. However, we found the BC horizon in old tile fields contained more soil C than the newly tiled and untilled treatments (Figure 3,  $P < 0.001$ ).

We found similar patterns in soil N concentrations across treatments and horizons. Like soil C, there were no differences in cumulative soil N (Table 2,  $P = 0.24$ ) between newly tiled, old tile, and untilled fields. There were also no differences in soil N between treatments in the Ap/E and Bt horizons. Within the BC horizon, old tile fields had less soil N than the newly tiled and untilled fields ( $P < 0.0001$ ).

Maintaining C:N ratios that promote biological activity is essential for regulating C and N cycling in agroecosystems, especially in the upper regions of the soil profile where roots can capture vital nutrients released from the decomposition of crop residues. Our results show that soil C:N ratios generally decreased with depth in the soil profile, meaning there were fewer parts of C to N at lower depths compared to shallower depths. Drainage affected C:N ratios within the Ap/E and Bt horizons, with old tile fields having lower C:N ratios than the newly drained and undrained fields (Ap/E,  $P < 0.001$ ; Bt,  $P < 0.01$ ). However, the differences in C:N ratio between drainage treatments, while statistically different, may not be meaningfully

different within the larger context of agricultural processes. The C:N ratios in the Ap/E horizon were all roughly 10:1, and the C:N ratios in the Bt horizon were approximately 6:1 (Table 2). There were no differences in C:N ratios in the BC horizon between drainage treatments.

Fields with older drainage have potentially had higher diversity of crop plantings than newer fields. This extended cropping history likely has allowed more cumulative root biomass inputs. The production of new roots and death of old roots provides substrates for microbial colonization and an energy source (e.g., C) for microbial activity. Root turnover and C incorporation into microbial biomass can lead to C stabilization

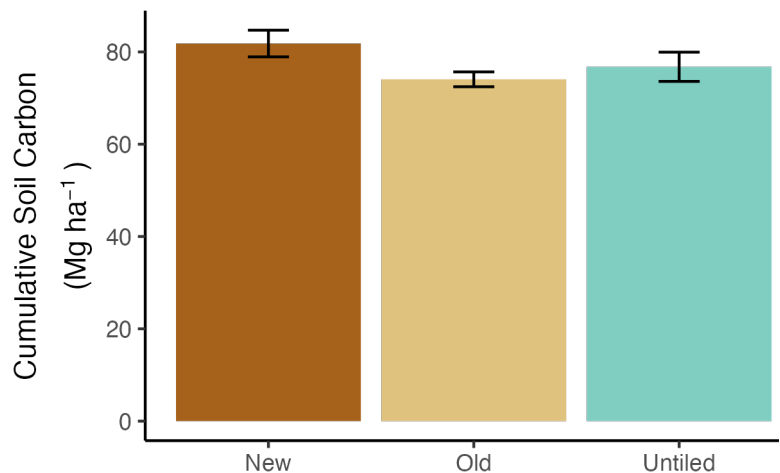


Figure 2. Cumulative soil C across drainage treatments. Differences between treatments were not significant. Bars represent standard error of the mean. Statistics are presented in Table 2.

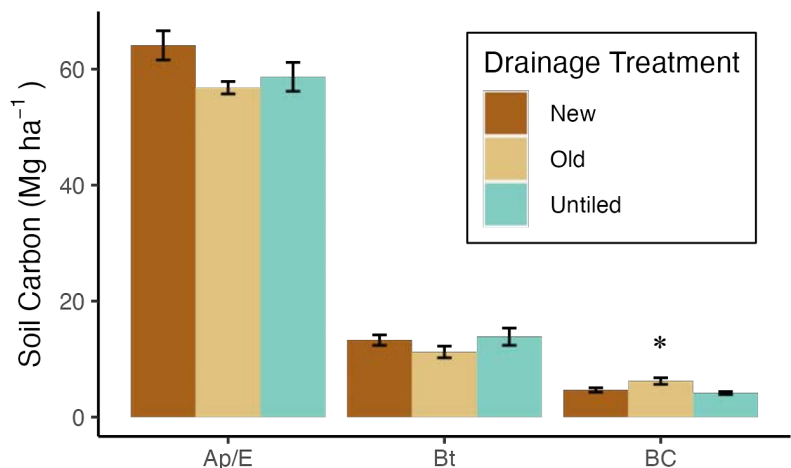


Figure 3. Incremental soil C for each horizon. Asterisk denotes differences between treatments within a soil horizon. Bars represent standard error of the mean. Statistics presented in Table 2.

Table 2. Cumulative and equivalent soil mass values for each horizon for carbon (C) and nitrogen (N) content.<sup>1</sup>

		Soil C			Soil N			----- C:N ratio -----		
		----- (mg ha <sup>-1</sup> ) -----			----- (mg ha <sup>-1</sup> ) -----					
		Mean ± SE	F	P	Mean ± SE	F	P	Mean ± SE	F	P
Cumulative	New	81.8 ± 2.9	1.86	0.16	8.5 ± 0.2	1.45	0.24	—	—	—
	Old	74.1 ± 1.6	—	—	8.6 ± 0.2	—	—	—	—	—
	Untiled	76.8 ± 3.2	—	—	8.2 ± 0.2	—	—	—	—	—
Ap/E	New	64.1 ± 2.5	2.50	0.09	5.9 ± 0.2	1.69	0.19	10.8 ± 0.2	10.48	< 0.001
	Old	56.8 ± 1.1	—	—	5.7 ± 0.1	—	—	10.0 ± 0.1	—	—
	Untiled	58.7 ± 2.5	—	—	5.5 ± 0.2	—	—	10.7 ± 0.1	—	—
Bt	New	13.3 ± 0.9	1.29	0.28	0.9 ± 0.0	0.06	0.94	7.3 ± 0.2	6.10	< 0.01
	Old	11.3 ± 1.0	—	—	1.2 ± 0.1	—	—	6.7 ± 0.2	—	—
	Untiled	13.9 ± 1.4	—	—	0.8 ± 0.0	—	—	7.6 ± 0.2	—	—
BC	New	4.7 ± 0.3	8.90	< 0.001	1.8 ± 0.1	13.36	< 0.0001	5.4 ± 0.2	0.33	0.72
	Old	6.3 ± 0.5	—	—	1.7 ± 0.1	—	—	5.2 ± 0.2	—	—
	Untiled	4.2 ± 0.2	—	—	1.8 ± 0.1	—	—	5.3 ± 0.2	—	—

<sup>1</sup>SE = standard error

within the soil matrix. Furthermore, the accumulation of microbial necromass can also contribute to aggregated masses of soil and organic matter. However, this aggregation process is confined to upper soil horizons and may not be the primary contributing factor of C accumulation at lower depths. Our results show that C content in the Ap/E horizon is nearly 6 times higher than that in the Bt and BC horizons, regardless of drainage treatment. The translocation of soil C as dissolved organic matter (DOM) may be a more likely avenue for deep C accumulation.

Increased subsurface drainage may aid in the movement of DOM over long durations, which may eventually become stabilized in deeper horizons via chemical bonding. When microbes decompose organic matter (e.g., crop residues) in the upper horizons of the soil profile, a portion of the organic matter is broken down into lightweight molecular structures that become soluble. These dissolved organic compounds can move freely in the soil and, because of the charged nature of these compounds, can form organomineral complexes within the soil matrix. Past research suggests that DOM derived from organic matter in the upper horizons is the primary source of DOM in percolating water in lower

horizons (Rothstein et al., 2018) and thus may explain the translocation of DOM into the BC horizon within our study.

### Conclusion

In summary, we did not detect differences in soil C stocks in fields with new, old, or no tile drainage, except in the deepest horizon (BC horizon). We found that old tile fields contained more soil C within the BC horizon than the newly tilled or untilled fields. As such, we can partially accept the hypothesis that drainage supports C accumulation, but only in deep horizons within old tile-drained fields.

Our early findings are promising because they indicate that in Willamette Valley soils, tile drainage does not negatively impact soil C storage and may promote soil C at lower depths in the long term. Understanding the exact mechanism for C accumulation in old tile-drained fields will be crucial for providing growers with best practice recommendations. The continuation of this work will investigate potential linkages between microbial community structure and activity and C cycling to understand further how tile drainage affects C stocks in the Willamette Valley.

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# RESISTANCE TO ACCASE INHIBITORS IN DOWNY BROME POPULATIONS FROM FINE FESCUE SEED FIELDS

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## Introduction

In the United States, Oregon is the largest fine fescue (*Festuca* L. spp.) seed-producing state. Species produced include Chewings fescue (*F. rubra* L. ssp. *commutata* Gaudin), creeping red fescue (*F. rubra* L. ssp. *rubra* Gaudin), and hard fescue (*F. brevipila* Tracey), with an estimated 26,800 harvested acres in 2021 (Oregon State University, 2021b). About 60% of fine fescue seed production in Oregon occurs in the foothills of the Cascade Mountain Range in the Willamette Valley, and an additional 40% of seed production is in the Grande Ronde Valley and the Columbia Basin in the northeastern part of the state (Oregon State University, 2021a).

Weed management, particularly of grass weeds, represents one of the biggest challenges fine fescue growers face in Oregon. Among the several weed species that can negatively impact fine fescue grown for seed, downy brome (*Bromus tectorum* L.) is one of the most difficult species to control in the northeastern region. Preemergence herbicide options are limited and often do not provide effective downy brome control in the fall because of a lack of sufficient rainfall or irrigation to activate them; therefore, additional herbicide applications are required to reduce downy brome infestation levels after emergence. There are only two postemergence (POST) grass herbicides (fluzifop and sethoxydim) registered for use in fine fescue seed production in Oregon, and both herbicides are acetyl-coenzyme A carboxylase (ACCase) inhibitors (Group 1). Previously, one ACCase-resistant downy brome population was confirmed in fine fescue seed production systems in northeastern Oregon (Ball et al., 2007).

Since 2007, fine fescue seed growers in northeastern Oregon have reported diminished downy brome control with ACCase inhibitor herbicides. These reports raised concerns that multiple downy brome populations have evolved resistance to this group of herbicides. Therefore, the objective of this study was to evaluate downy brome populations for resistance to the ACCase inhibitors sethoxydim, clethodim, fluzifop-P-butyl, and quizalofop-P-ethyl, and the acetolactate synthase (ALS) inhibitor sulfosulfuron.

## Materials and Methods

Ten downy brome plants were collected at physiological maturity from nine commercial fine fescue seed production fields in the Grande Ronde Valley, Union County, OR, in 2020. Fields were selected based on grower observations of poor control of downy brome populations with ACCase inhibitor herbicides. Panicles were hand threshed for seed collection, and seeds were stored in envelopes at room temperature until the screenings were initiated.

The experiment was conducted at Oregon State University greenhouses, Corvallis, OR (44.56°N, 123.28°W) using a randomized complete block design with six replications. The experiment was repeated. Plants were grown at 75°F (day) and 59°F (night), and artificial lighting was provided using 400-watt high-pressure sodium light bulbs to ensure a 12-hour photoperiod.

Herbicide rates of 0, 1, and 2 times the recommended labeled rate were tested (Table 1). Application rates

Table 1. Herbicides, trade names, and rates used in the study.

Herbicide	Trade name	Rate <sup>1</sup>	
		---- (oz a <sup>-1</sup> ) ----	
		1X	2X
Clethodim <sup>2</sup>	Select MAX	16	32
Sethoxydim <sup>2</sup>	Poast	40	80
Fluzifop-P-butyl <sup>2</sup>	Fusilade DX	8	16
Quizalofop-P-ethyl <sup>2</sup>	Assure II	12	24
Sulfosulfuron <sup>3</sup>	Outrider	0.66	1.32

<sup>1</sup>Rate based on label recommendation, where 1X = labeled rate. Clethodim and quizalofop-P-ethyl label rates were based on the recommendation for alfalfa. Sulfosulfuron label rate was based on the recommendation for winter wheat.

<sup>2</sup>COC (crop oil concentrate [1% v/v]) was added to the spray solution.

<sup>3</sup>NIS (nonionic surfactant [0.25% v/v]) was added to the spray solution.



for herbicides (clethodim, quizalofop-P-ethyl, and sulfosulfuron) not registered for use in fine fescue seed production were determined by the recommended rate for representative rotational crops grown in the Grande Ronde Valley. Herbicides were applied with appropriate adjuvants using a research cabinet sprayer delivering 15 gpa spray volume through a single 8002E nozzle at 40 psi to individual downy brome plants at the two- to three-leaf stage.

Downy brome plants were visually assessed as dead or alive 21 days after treatment. Plants were considered alive if green tissue was observed in growing plants, whereas completely necrotic plants were considered dead. Survival was expressed as the proportion of surviving individuals compared to the total number of treated seedlings.

### Results and Discussion

Results confirmed that most downy brome populations tested were resistant to the ACCase inhibitors sethoxydim, clethodim, fluazifop-P-butyl, and quizalofop-P-ethyl (Figure 1). Survival levels varied among the populations for each herbicide tested. The populations were cross-resistant to the ACCase-inhibitors clethodim and quizalofop-P-ethyl in fine fescue. Although these herbicides are not labeled for use in fine fescue, they may be used in many other crops grown in the area, such as canola, peas, mint, alfalfa, and sunflower.

### Clethodim

Downy brome survival ranged from 9 to 58% when treated with the labeled rate of clethodim (16 fl oz a<sup>-1</sup>) (Figure 1). Populations UDB-1, UDB-2, UDB-3, and UDB-4 had greater than 50% survival. Populations UDB-6, UDB-7, UDB-8, UDB-9, and UDB-10 had less than 45% survival. All populations were sensitive to two times the labeled rate of clethodim (32 fl oz a<sup>-1</sup>).

### Sethoxydim

All populations had greater than 80% survival when treated with the labeled rate of sethoxydim (40 fl oz a<sup>-1</sup>), except population UDB-9 (Figure 1). Downy brome plant survival was slightly reduced when treated with two times the labeled rate of sethoxydim (80 fl oz a<sup>-1</sup>), but still was greater than 50%.

### Fluazifop-P-butyl

All downy brome populations were resistant to fluazifop-P-butyl (Figure 1). Downy brome plant survival was greater than 90% when treated with either the labeled rate (8 fl oz a<sup>-1</sup>) or two times the labeled rate (16 fl oz a<sup>-1</sup>).

### Quizalofop-P-ethyl

All downy brome populations were resistant (100% survival) to the labeled rate of quizalofop-P-ethyl (12 fl oz a<sup>-1</sup>) (Figure 1). All downy brome populations except UDB-9 had greater than 75% survival when

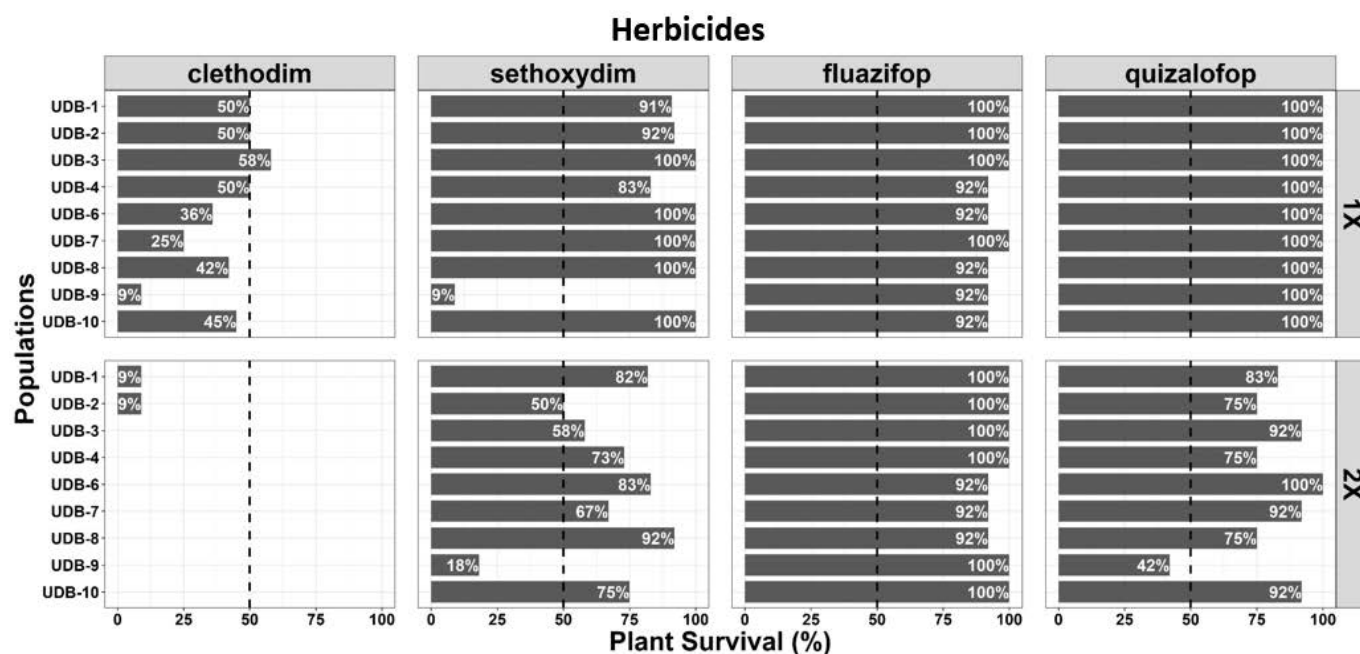


Figure 1. Downy brome survival to clethodim, sethoxydim, fluazifop-P-butyl, and quizalofop-P-ethyl at the labeled rate (1X) and two times the labeled rate (2X) of each herbicide.

treated with two times the labeled rate (24 fl oz a<sup>-1</sup>). Population UDB-9 was controlled (42% survival) with two times the labeled rate, indicating different levels of resistance.

#### Sulfosulfuron

All downy brome populations tested in this study were susceptible to sulfosulfuron (data not shown). Sulfosulfuron is labeled for downy brome control in wheat and other crops, but it is not registered for use in fine fescue grown for seed.

#### **Conclusion**

The results of this study confirmed a high percentage of ACCase-resistant downy brome populations collected from multiple fine fescue seed production fields in northeastern Oregon. The ALS inhibitor sulfosulfuron effectively controlled these ACCase-resistant populations, but it is not labeled for use in fine fescue. Therefore, herbicides with different sites of action, including ALS inhibitors, are needed to control downy brome in fine fescue fields and rotational crops and to reduce the selection pressure of ACCase inhibitors in this system. Further study is needed to determine the extent and prevalence of ACCase-resistant downy brome in the region and to investigate integrated downy brome management strategies in local fine fescue seed cropping systems.

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#### **Acknowledgments**

The authors thank the fine fescue seed growers in Union County, OR, for allowing collection of downy brome populations in their fields, the Oregon Fine Fescue Commission for funding this research, and Joan Campbell, University of Idaho, for supplying susceptible downy brome seed.

# INDAZIFLAM HERBICIDE USE IN STAND ESTABLISHMENT OF KENTUCKY BLUEGRASS GROWN FOR SEED (YEAR 2)

*J.F. Spring and D.L. Walenta*

## Introduction

Grass weed control during the establishment or seedling year of Kentucky bluegrass (*Poa pratensis* L.; KBG) grown for seed is a persistent problem in eastern Oregon. Herbicides currently registered for use in seedling and established KBG stands generally provide less-than-adequate control of key grass weeds when applied as stand-alone treatments. Grass weed control can be improved with the use of multiple herbicides in sequential application programs, but poor weed control and crop injury are still fairly common. In addition, several of these herbicides have long-term soil residual properties that may cause injury to rotational crops.

A multiyear project is underway to investigate the utility of the active ingredient indaziflam (Alion) as a potential herbicide for use in both seedling and established KBG in eastern Oregon seed production systems. Indaziflam is a preemergent herbicide with broad-spectrum weed control activity and excellent safety on established perennial grass plants. The mode of action for indaziflam is inhibition of cellulose synthesis (Herbicide Resistance Action Committee Group 29), and it has activity on germinating seedlings of both grass and broadleaf plants. Currently, there are no Group 29 herbicides registered for use in KBG grown for seed, and it could provide a new mode of action to combat ALS- and/or ACCase-resistant grass weed (e.g., downy brome) infestations.

Alion (Bayer Crop Science) is currently registered for use in carbon-seeded or established perennial ryegrass and tall fescue seed crops in western Oregon and for use in established perennial ryegrass, tall fescue, smooth brome grass, and wheatgrass seed crops in eastern Oregon. Indaziflam used in Willamette Valley grass seed production has acceptable crop safety if adequate time is allowed between application and subsequent rainfall or irrigation events. Adequate crop safety has been documented from dormant fall applications made to spring-planted perennial ryegrass seedlings in western Oregon (Curtis et al., 2016). Initial testing of indaziflam applied after harvest to established KBG demonstrated acceptable crop safety in irrigated production in the Grande Ronde Valley in northeastern Oregon (Walenta, 2016).

The use of indaziflam in fall- or spring-seeded KBG stands has potential to substantially improve warm- and cool-season grass weed control during the critical period it takes a stand to become well established. Soil surface conditions after seeding a new stand facilitate more direct and uniform contact with the soil compared to postharvest applications in established stands. The long residual activity of indaziflam means that a single application has potential to provide durable preemergence grass weed control into subsequent years of the stand. While safety of indaziflam on well-established perennial grasses has been thoroughly demonstrated, previous evaluation of indaziflam safety on perennial grass seedlings is limited. Recent research in KBG (Spring and Walenta, 2021) demonstrated potential for this use pattern.

The objective of this study was to conduct a second year of crop safety evaluation of indaziflam applied at early crop growth stages during stand establishment of irrigated KBG seed crops in central Oregon and in the Grande Ronde Valley.

## Materials and Methods

Field trials were located in two commercial stands of seedling KBG, one in Wheeler County near Clarno, OR, and one in Union County near La Grande, OR. Weed-free sites were selected for the trials. The Clarno trial was in a stand of 'Rockstar' in a loam soil under wheel-line irrigation, seeded in August 2021. In La Grande, the trial was located in a stand of 'Gaelic' in a sandy loam soil under center pivot irrigation, seeded in April 2021. All other production inputs were applied across the trial by the hosting grower using common production practices.

Trials were established in a randomized complete block design with four replicates and an individual plot size of 10 feet x 30 feet (Clarno) or 8 feet x 25 feet (La Grande). Indaziflam was applied as Alion at 1, 2, and 3 oz/acre at each of three growth stages of KBG using CO<sub>2</sub>-powered backpack sprayers delivering 15 (Clarno) or 21 (La Grande) gal/acre. Growth stages of KBG were three- to five-leaf, three- to five-tiller, and 10+ tiller. At the La Grande site, the 3 oz/acre Alion rate was omitted at the three- to five-leaf application stage, due to severe injury observed in this treatment in

2021. Applications were made in Clarno on October 5, 2021, November 16, 2021, or March 25, 2022, and in La Grande on May 26, 2021, June 25, 2021, or September 1, 2021.

Crop injury was rated periodically throughout the season using a percent scale from 0 to 100, with no effect at 0 and plant death at 100. At crop maturity, a 6-foot-wide swath in the center of each plot was windrowed and allowed to dry in the field prior to threshing with a small-plot combine. Seed was then rethreshed with a stationary thresher and cleaned with an air-screen cleaner to approximately 98% purity and a bushel weight of 18 lb for calculation of clean seed yield. Kentucky bluegrass test weights were reduced by 2–4 lb/bu in many eastern Oregon fields in 2022, and we were unable to clean samples to standard bushel weight (21 lb/bu), even at extremely high cleanout percentages (50% plus in initial tests).

### Results and Discussion

At the La Grande location, visually apparent crop injury in early May was minor (< 10–15%) at the earlier application timings and increased slightly with increasing Alion rate (Figure 1, bottom). No crop injury was observed in 10+ tiller treatments. Seed yield was equivalent to the nontreated check at 1 oz/acre Alion applied to three- to five-leaf KBG but showed a moderate reduction (estimated 200–300 lb/acre loss) at 2 oz/acre. The 3 oz/acre rate was not tested at this application timing in this trial.

For three- to five-tiller applications, seed yield was equivalent to the nontreated check at 1 oz/acre Alion, equivalent or slightly less at 2 oz/acre, and considerably reduced at 3 oz/acre. For all Alion rates applied to 10+ tiller KBG, seed yields appear equivalent to the nontreated check at the level of precision the somewhat variable data from this site can support. Overall results from this spring-seeded stand are consistent with those seen in two fall-seeded stands in 2021 (Spring and Walenta, 2021).

At the Clarno location, no crop injury was apparent in May for any rate of Alion applied at the three- to five-leaf stage (Figure 1, top). At the three- to five-tiller stage, minor crop injury (< 10%) was apparent and appeared to increase slightly with increasing Alion rate. Applications made to 10+ tiller KBG in the spring caused the highest levels of injury observed in the trial at the 2 and 3 oz/acre rates (Figure 1). At the 3 oz/acre rate, very few seedheads were produced (data

not shown). Rate did not influence injury level for treatments applied at the three- to five-leaf stage, but there appears to be a pattern of slightly increasing injury with increased rate at three- to five-tiller applications.

Although visible crop injury at earlier application timings was minor (three- to five-tiller treatments) or nonexistent (three- to five-leaf treatments), all Alion rates applied at these timings appear to have resulted in slight to moderate seed yield reduction relative to the nontreated check. Considerable variability is evident in the data, which prevented precise estimation of yield reduction, but losses ranged from approximately 200 to 400 lb/acre. This level of yield loss is similar to that observed from the same treatments in trials conducted in 2021. Yield reductions were of similar magnitude at 1 and 2 oz/acre rates applied at the 10+ tiller stage and were very high at the 3 oz/acre rate.

The pattern of crop injury at Clarno (i.e., good safety, relatively minor yield reduction from applications made to early growth stages, and much higher injury observed from the last application timing made to well-established seedlings) is opposite that observed at the La Grande trial in 2022 and in both trials conducted in 2021. In all of these trials, Alion applications made to small KBG seedlings were most injurious, and safety generally increased with KBG growth stage at time of application. We suspect that differing soil water dynamics between trials may be the cause of this difference. Alion is known to require adequate binding time to dry soil (at least 48 hours is recommended on the label) in order to “fix” to the upper profile and be resistant to downward leaching with water, which can otherwise result in crop root damage.

At the Clarno site, relatively good crop safety was obtained from early applications (three- to five-leaf and three- to five-tiller) made to a dry soil surface with at least 3 days elapsing prior to the next irrigation. However, at the 10+ tiller application timing, an application window with dry surface soil was not possible due to consistent rains and cool spring conditions that prevented soil drying. Thus, the 10+ tiller application was made to a partially moist soil surface. With subsurface recharge from wet soil deeper in the profile, the soil was not able to remain dry for an extended time period.

We presume that this lack of upper soil drying prevented the herbicide from binding to the soil and allowed movement into the crop root zone when the



first irrigation of the year occurred about 5 days after application. In contrast, very dry spring conditions in 2021 allowed for adequate binding time on dry soil at this application timing, and relatively minor injury was observed in 2021 trials. At all other sites, the soil surface was at least somewhat moist at three- to five-leaf application timing and dry following the 10+ tiller application.

The unexpected reversal of crop safety versus KBG developmental stage at time of application observed at the Clarno trial has potentially important implications. It suggests that soil surface moisture at, and shortly after,

application may play an important role in crop safety of indaziflam applications. Under certain conditions (such as at the Clarno site), soil moisture conditions may be more important than the expected pattern of increasing crop safety on larger, better-established seedlings that was observed at the other three trial locations to date. We presume that soil moisture conditions are the controlling factor, although this hypothesis requires further investigation. If application to dry soil does increase crop safety independent of seedling growth stage as speculated, it may be possible to develop refined use guidelines that reduce the risk of crop injury from indaziflam applications to small seedling KBG.

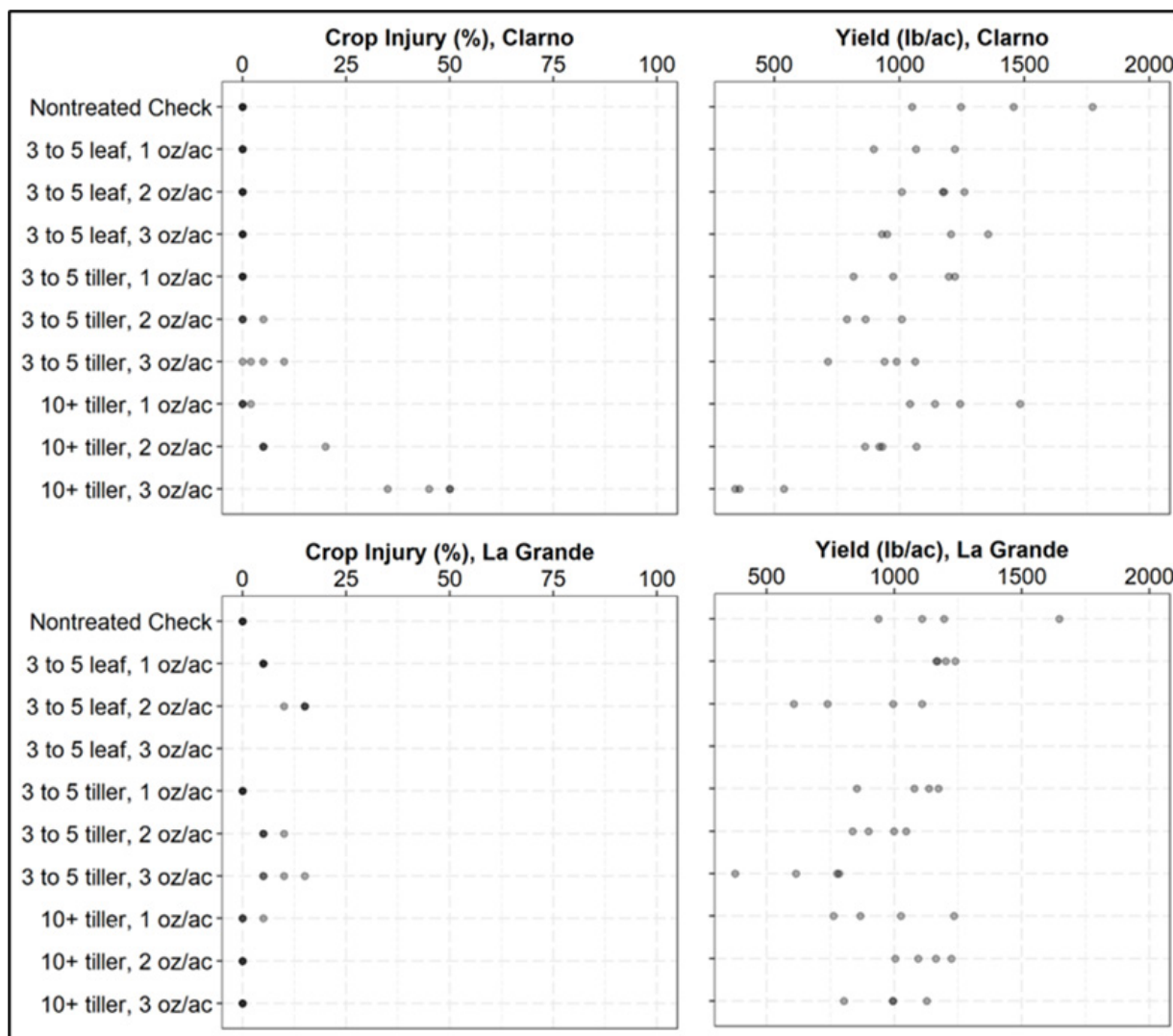


Figure 1. Crop injury at the onset of rapid stem elongation following second node emergence in early May 2022 (scale of 0 to 100%, with no injury at 0 and plant death at 100) and first-year clean seed yield (approximately 98% purity and 18 lb bushel weight) following treatment of seedling Kentucky bluegrass stands with experimental applications of indaziflam (Alion). Each point represents response of an individual plot, with four replicate plots per treatment at each site.

In summary, the combined observations of indaziflam applied to seedling KBG across four trial locations in two production regions suggest that Alion offers potential for early postemergence use, particularly at 1 or 2 oz/acre. The unexpected pattern of crop injury observed at the Clarno site in 2022, however, indicates that further investigation is needed to better understand the relative importance of soil moisture and KBG growth stage on crop injury. Trials are being repeated in central and northeastern Oregon in 2023.

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# IMPACT OF SLUG BAITS ON THE SURVIVAL OF *PHASMARHABDITIS* NEMATODES

*D.K. Howe, D.R. Denver, C.H. Richart, and R.J. Mc Donnell*

## Introduction

Slugs are among the most damaging pests of grass and clover seed production in the Willamette Valley. Control measures are limited and focus heavily on the use of molluscicidal baits, but growers report considerable variation in the efficacy of the most widely used active ingredients (metaldehyde, iron phosphate, and sodium ferric EDTA) (Mc Donnell and Anderson, 2017). Biological control—the use of a pest’s natural biological enemies to combat it in the field—offers a compelling option.

Nematode worms in the genus *Phasmarhabditis* are important natural enemies of slugs in many parts of the world. In fact, in Europe, a species called *Phasmarhabditis hermaphrodita* is currently being used as a commercially available biological control agent called Nemaslug to successfully manage slug pests in a wide range of crops (Rae et al., 2007). There is considerable interest from growers and industry for a similar product to be developed for the U.S. market, especially now that multiple *Phasmarhabditis* species have been discovered on the west coast, including in Oregon (Mc Donnell et al., 2018; Howe et al., 2020). Consequently, there is a need to determine whether current slug control strategies affect the survival of these nematodes so that an informed decision can be made on their potential in the Integrated Pest Management of slugs in vulnerable crops. Thus, the goal of this study was to investigate the impact of multiple slug bait products on the survival of the three candidate biological control agents *P. hermaphrodita*, *P. californica*, and *P. papillosa*.

## Materials and Methods

### Survival trials

Oregon-derived strains of *Phasmarhabditis hermaphrodita*, *P. californica*, and *P. papillosa* were maintained in the laboratory on standard nematode growth media (NGM) agar plates and fed bacteria that co-culture with the nematodes.

The impact of the most commonly used molluscicide active ingredients (metaldehyde, iron phosphate, and sodium ferric EDTA) on the survival of these species was assessed by sprinkling NGM agar plates with

25–28 mg of pulverized pellets, which equates to the recommended label rate. The following molluscicide treatments were used:

- Metaldehyde at 4% (Deadline M-Ps) and 7.5% (Durham Granules 7.5)
- Iron phosphate at 1% (GardenSafe) and 3% (IronWorxx)
- Sodium ferric EDTA at 2% (IronFist) and 5% (Ferroxx)
- Water control, i.e., no molluscicidal treatment (negative control)

Ten adult nematodes from one species were placed on each of five replicate plates per treatment, sealed with parafilm, and incubated at 18°C. After 4 days, the nematodes were gently poked with a platinum wire to check for movement/life.

### Statistical analysis

Differences in percentage nematode mortality between the different bait treatments and controls were investigated using the Kruskal-Wallis test. Posthoc analysis was completed using Dunn’s test incorporating the Bonferroni correction for multiple comparisons. All statistical analyses were carried out using IBM SPSS version 24.

## Results and Discussion

For *P. papillosa* and *P. californica*, there were no differences in percent nematode mortality between the different molluscicide treatments and the control (Figures 1 and 2). These results suggest that widely used active ingredients are not lethal to these nematode species.

However, for *P. hermaphrodita* (Figure 3), which has been commercialized in Europe as Nemaslug, GardenSafe caused greater ( $P < 0.001$ ) mean ( $\pm$ SE) percent nematode mortality ( $58.00 \pm 5.83$ ) than IronWorxx ( $2.00 \pm 2.00$ ) or IronFist ( $2.00 \pm 2.00$ ). This is a surprising result because, according to the GardenSafe label, the only active ingredient present in the product is iron phosphate at 1% concentration. Iron phosphate is a chemical compound that is Generally Recognized As Safe (GRAS) by the U.S. Food and Drug Administration (FDA). Also, given that IronWorxx

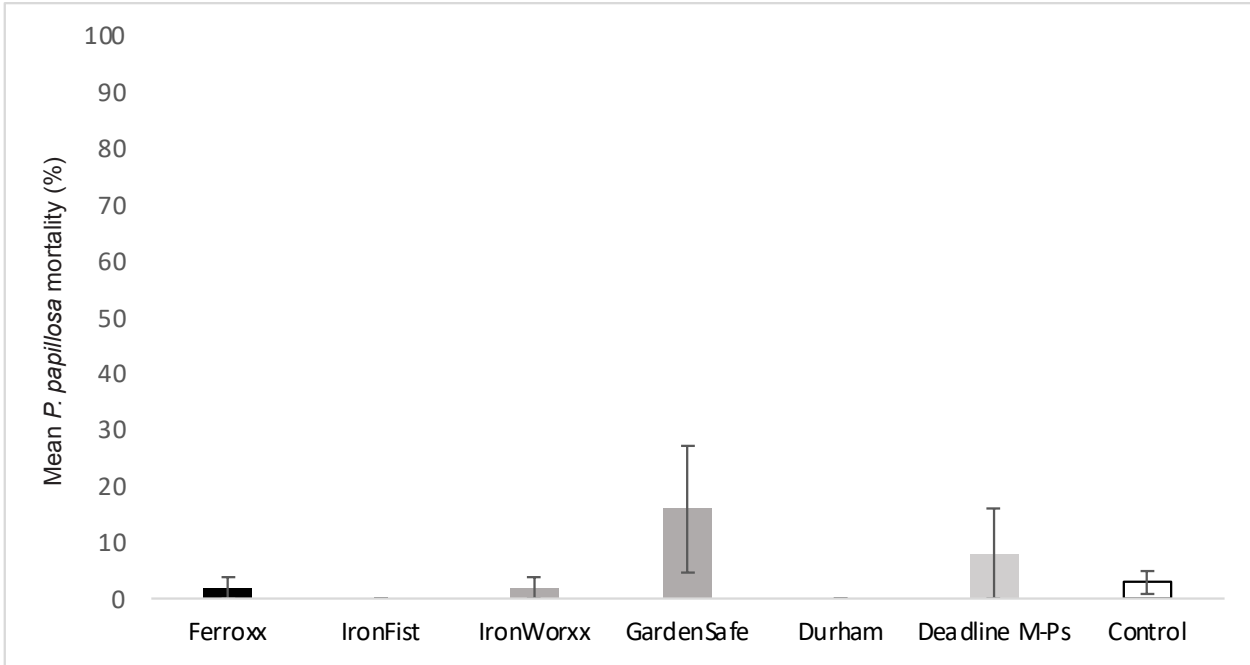


Figure 1. Mean ( $\pm$  SE) percentage *Phasmarhabditis papillosa* mortality when exposed to sodium ferric EDTA (Ferroxx and IronFist), iron phosphate (IronWorxx and GardenSafe), and metaldehyde (Durham Granules 7.5 and Deadline M-Ps) based slug baits. Controls were water only. There were no statistical differences between treatments ( $KW = 7.376$ ,  $P = 0.287$ ).

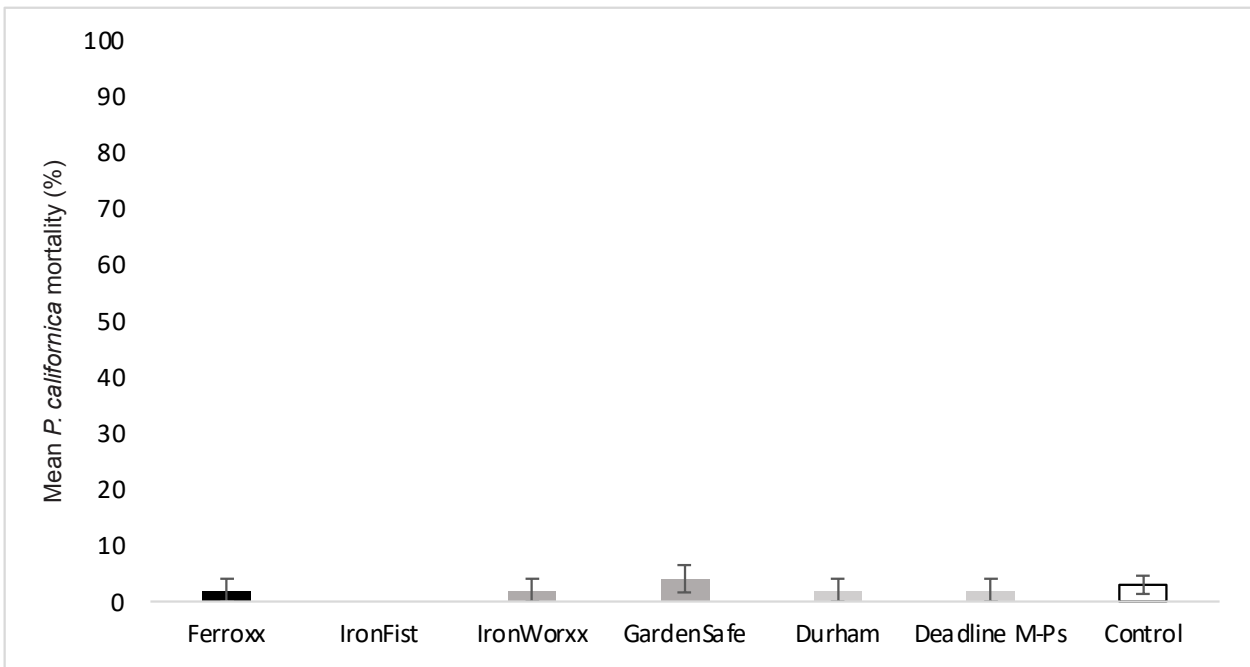


Figure 2. Mean ( $\pm$  SE) percentage *Phasmarhabditis californica* mortality when exposed to sodium ferric EDTA (Ferroxx and IronFist), iron phosphate (IronWorxx and GardenSafe), and metaldehyde (Durham Granules 7.5 and Deadline M-Ps) based slug baits. Controls were water only. There were no statistical differences between treatments ( $KW = 2.656$ ,  $P = 0.851$ ).

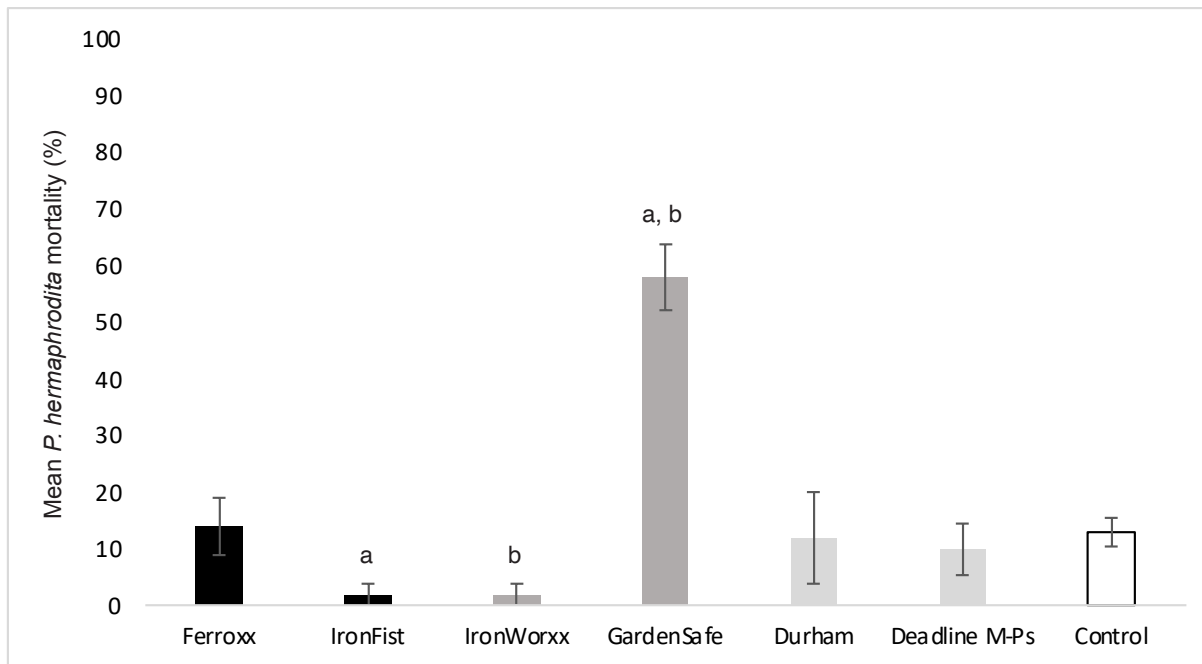


Figure 3. Mean ( $\pm$  SE) percentage *Phasmarhabditis hermaphrodita* mortality when exposed to sodium ferric EDTA (Ferroxx and IronFist), iron phosphate (IronWorxx and GardenSafe), and metaldehyde (Durham Granules 7.5 and Deadline M-Ps) based slug baits. Controls were water only. Statistical difference observed between certain treatments ( $KW = 20.662$ ,  $P = 0.002$ ). Bars with the same lowercase letter indicate significant differences in mortality between the treatment medians. a: test statistic = 27.30,  $P < 0.001$ . b: test statistic = 27.30,  $P < 0.001$ .

has an iron phosphate concentration of 3% and caused minimal nematode mortality ( $2.00 \pm 2.00$ ), it is unlikely that iron phosphate is lethal to *P. hermaphrodita*. It is likely that one of the other ingredients in GardenSafe is lethal to this nematode species but, because bait composition is largely proprietary information, it is difficult to determine what that ingredient could be.

GardenSafe is largely used by home gardeners, and such growers should be mindful of the potential lethal effects of this product to *P. hermaphrodita*. However, the slug baits (e.g., Deadline M-Ps and Ferroxx) that are most widely used by growers in the Willamette Valley had minimal impact on the survival of the three candidate nematode species. This suggests that if these nematodes are commercialized for slug control, it will be possible to use slug baits as part of an Integrated Pest Management approach in grass and clover seed production.

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# EFFECT OF CHLORMEQUAT CHLORIDE PLANT GROWTH REGULATOR WITH AND WITHOUT SPRING MOWING IN ANNUAL RYEGRASS SEED CROPS

*N.P. Anderson and D.J. Maliszewski*

## Introduction

Forage grass seed crops, including annual ryegrass (*Lolium multiflorum* L.), are a vital part of seed production enterprises in Oregon. Like other cool-season grasses, annual ryegrass produces only 15 to 33% of its potential seed yield. Lodging of the crop during flowering and seed shattering are two of the major factors limiting maximum seed yield. Seed yield is reduced by lodging during anthesis and early seed fill as a result of self-shading in the canopy and reductions in pollination. Making better use of management practices that reduce stem length, decrease lodging, and/or reduce seed shatter are areas that should be further explored to address seed yield potential.

Plant growth regulators (PGRs) are widely used to reduce lodging and increase seed yield in many of Oregon's cool-season grass seed crops. One species widely grown in Oregon without use of PGRs is annual ryegrass. This has been a result of low seed prices and lack of previous research. However, recent work with trinexapac-ethyl (TE; tradename: Palisade EC) has shown that 400–600 g TE ha<sup>-1</sup>, combined with spring defoliation (mowing), can increase seed yields by 150% or more (Anderson et al., 2020, 2021).

A federal registration for a different PGR, chlormequat chloride (CCC), is being sought, but research is needed to evaluate its effect on annual ryegrass seed crops. Early work by Hebblethwaite et al. (1978) examined the effect of CCC on perennial ryegrass and found that it had little effect on tiller length or lodging. However, seed yield was increased in some years, likely due to improved assimilate transfer to the seed. Hampton (1986) also evaluated effects of CCC on perennial ryegrass and found that neither tiller length nor lodging was reduced, but seed yield increases resulted from improved survival of tillers. More recent work showed no effect on seed yield from CCC applications in dryland turf-type perennial ryegrass (Anderson and Maliszewski, 2021). The aim of this work was to determine whether CCC and tank mixes of TE + CCC can be used to further increase annual ryegrass seed yield under western Oregon conditions.

## Materials and Methods

Field trials were conducted on 'Gulf' annual ryegrass at Oregon State University's Hyslop Research Farm over two harvest years, 2021 to 2022. Plot size was approximately 14.5 m x 3.5 m. Spring defoliation by sheep grazing was simulated using a flail mower. The experimental design was a randomized complete block with a split-plot arrangement of treatments and four replications.

Main plots were spring defoliation, and subplots were PGR treatments. Subplots were randomly allocated within defoliation main plots. Defoliation treatments included an untreated control (no mowing) and mowing (2x) at the two-node stage (BBCH 32). Subplots included TE (0, 400 g ha<sup>-1</sup>), CCC (0, 600, 1,200, and 1,800 g ha<sup>-1</sup>), and TE + CCC tank mixes (600 g CCC ha<sup>-1</sup> + 400 g TE ha<sup>-1</sup>, 1,200 g CCC ha<sup>-1</sup> + 400 g TE ha<sup>-1</sup>, 1,800 g CCC ha<sup>-1</sup> + 400 g TE ha<sup>-1</sup>). All PGR applications were made at BBCH 31–32, except for a single CCC treatment, which was split over two timings (1,200 g CCC ha<sup>-1</sup> at BBCH 32 + 600 g CCC ha<sup>-1</sup> at BBCH 51).

At peak flowering (BBCH 65), two 0.1 m<sup>2</sup> samples of above-ground biomass were collected from each plot near crop maturity to determine total dry matter and seed yield components. Samples were placed in a dryer at 65°C for approximately 48 hours to determine above-ground biomass. Lodging ratings were recorded just prior to harvest on a scale of 0–100%.

Plots were swathed with a modified John Deere 2280 swather and combined with a Hege 180 plot combine. Subsamples of harvested seed were collected from each plot and cleaned using a Clipper M2B cleaner to determine clean seed yield. Seed weight was determined by counting two 1,000-seed samples with an electronic seed counter and weighing these samples on a laboratory balance.

Analysis of variance was conducted to test spring defoliation and PGR treatment effects and their interaction on seed yield, seed weight, seed number, and other characteristics for each trial. Spring defoliation and PGR treatment means for each trial were separated by Fisher's protected LSD values at 5% level of significance.

## Results and Discussion

There was a significant interaction between spring mowing and PGR for seed yield, seed number, harvest index (HI), and final lodging in both years (Tables 1 and 2). Most PGR treatments containing TE resulted in increased seed yield in both years. Applications of CCC alone had no effect on seed yield in either year, with or without spring mowing at BBCH 32. The combination of TE + CCC did not result in additional increases over TE alone.

In both years, there was a significant interaction for seed number. However, seed weight was affected by the interaction only in 2022. Lodging was affected by TE and TE + CCC when plots were mowed, but not when they were left unmowed. Similar results occurred for

HI. It is likely that any seed yield increases resulted from an increase in seed number that more than offset the decrease in seed weight, most likely caused by improved pollination conditions resulting from a reduction in lodging.

These results provide additional confirmation that annual ryegrass seed yields in Oregon are able to respond to more intensive spring crop management, including the use of TE PGR and spring mowing. However, application of CCC alone, or in a tank-mix with TE, is not likely to provide additional benefit to annual ryegrass seed crops grown in western Oregon. We recommend that spring mowing and TE continue to be utilized together to maximize annual ryegrass seed yields.

Table 1. Interaction effects of chlormequat chloride (CCC) and trinexapac-ethyl (TE) plant growth regulators on seed yield, yield components, harvest index, and lodging in ‘Gulf’ annual ryegrass with and without spring mowing, 2021.

Treatment	Yield	Seed weight	Seed number	Harvest index <sup>1</sup>	Lodging <sup>1</sup>
	(kg ha <sup>-1</sup> )	(mg seed <sup>-1</sup> )	(no m <sup>-2</sup> )	(%)	(%)
<b>No mow</b>					
Untreated control	1,536 a	2.966	51,968 a	12.0	100
400 g TE ha <sup>-1</sup>	2,399 bcd	2.843	84,936 bcdef	11.5	94
600 g CCC ha <sup>-1</sup>	1,531 a	3.091	50,000 a	7.6	99
1,200 g CCC ha <sup>-1</sup>	1,423 a	3.132	45,751 a	7.8	99
1,800 g CCC ha <sup>-1</sup>	1,297 a	3.024	43,038 a	8.0	96
600 g CCC ha <sup>-1</sup> + 400 g TE ha <sup>-1</sup>	2,541 cdefg	2.777	92,050 defg	14.1	93
1,200 g CCC ha <sup>-1</sup> + 400 g TE ha <sup>-1</sup>	2,453 cde	2.744	89,395 cdef	14.3	91
1,800 g CCC ha <sup>-1</sup> + 400 g TE ha <sup>-1</sup>	2,471 cdef	2.636	94,343 efg	17.4	88
1,200 g CCC ha <sup>-1</sup> + 600 g CCC ha <sup>-1</sup>	1,638 a	3.136	52,295 a	10.9	96
<b>2x mow</b>					
Untreated control	1,670 ab	2.953	56,698 ab	17.3	96
400 g TE ha <sup>-1</sup>	2,944 defg	2.676	109,908 fg	28.8	73
600 g CCC ha <sup>-1</sup>	1,856 abc	2.932	63,639 abcde	17.4	90
1,200 g CCC ha <sup>-1</sup>	1,564 a	2.925	53,748 ab	15.4	90
1,800 g CCC ha <sup>-1</sup>	1,796 abc	2.981	60,261 abc	15.3	93
600 g CCC ha <sup>-1</sup> + 400 g TE ha <sup>-1</sup>	3,229 efg	2.617	123,392 gh	32.1	74
1,200 g CCC ha <sup>-1</sup> + 400 g TE ha <sup>-1</sup>	3,247 fg	2.570	126,645 h	25.4	66
1,800 g CCC ha <sup>-1</sup> + 400 g TE ha <sup>-1</sup>	3,282 g	2.559	128,693 h	28.2	61
1,200 g CCC ha <sup>-1</sup> + 600 g CCC ha <sup>-1</sup>	1,803 abc	2.892	62,312 abcd	15.0	89
LSD = 0.05	<i>P</i> = 0.0294	0.2319	0.0066	0.0006	0.0003

<sup>1</sup>Homogenous group format cannot be used because of pattern of significant differences.



Table 2. Interaction effects of chlormequat chloride (CCC) and trinexapac-ethyl (TE) plant growth regulators on seed yield, yield components, harvest index, and lodging in ‘Gulf’ annual ryegrass with and without spring mowing, 2022.

Treatment	Yield	Seed weight	Seed number	Harvest index <sup>1</sup>	Lodging
	(kg ha <sup>-1</sup> )	(mg seed <sup>-1</sup> )	(no m <sup>-2</sup> )	(%)	(%)
<b>No mow</b>					
Untreated control	1,397 bc	2.851 f	49,401 bc	9.0	93 c
400 g TE ha <sup>-1</sup>	1,823 e	2.723 cde	66,958 efg	10.0	90 c
600 g CCC ha <sup>-1</sup>	1,379 bc	2.824 ef	48,801 bc	7.4	91 c
1,200 g CCC ha <sup>-1</sup>	1,579 cd	2.840 ef	55,722 cd	9.2	95 c
1,800 g CCC ha <sup>-1</sup>	1,557 cd	2.846 f	54,758 cd	8.8	94 c
600 g CCC ha <sup>-1</sup> + 400 g TE ha <sup>-1</sup>	1,693 de	2.661 c	63,838 def	9.8	93 c
1,200 g CCC ha <sup>-1</sup> + 400 g TE ha <sup>-1</sup>	1,576 cd	2.688 cd	59,192 de	8.7	91 c
1,800 g CCC ha <sup>-1</sup> + 400 g TE ha <sup>-1</sup>	1,577 cd	2.755 cde	57,584 cd	8.8	91 c
1,200 g CCC ha <sup>-1</sup> + 600 g CCC ha <sup>-1</sup>	1,213 ab	2.827 ef	43,003 ab	8.1	90 c
<b>2X mow</b>					
Untreated control	1,251 ab	2.788 cdef	44,883 ab	14.8	95 c
400 g TE ha <sup>-1</sup>	1,858 ef	2.501 b	74,470 gh	17.0	75 b
600 g CCC ha <sup>-1</sup>	1,179 ab	2.794 def	42,240 ab	8.9	89 c
1,200 g CCC ha <sup>-1</sup>	1,154 ab	2.840 ef	40,842 ab	9.8	95 c
1,800 g CCC ha <sup>-1</sup>	1,066 a	2.759 cdef	38,715 a	8.1	94 c
600 g CCC ha <sup>-1</sup> + 400 g TE ha <sup>-1</sup>	1,745 de	2.445 ab	71,307 fgh	18.6	58 a
1,200 g CCC ha <sup>-1</sup> + 400 g TE ha <sup>-1</sup>	1,880 ef	2.412 a	78,068 h	15.6	61 a
1,800 g CCC ha <sup>-1</sup> + 400 g TE ha <sup>-1</sup>	2,087 f	2.384 a	87,693 i	19.7	61 a
1,200 g CCC ha <sup>-1</sup> + 600 g CCC ha <sup>-1</sup>	1,217 ab	2.772 cdef	44,042 ab	10.5	93 c
LSD = 0.05	P = 0.0000	0.0000	0.0305	0.0014	0.0000

<sup>1</sup>Homogenous group format cannot be used because of pattern of significant differences.

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