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LABORATORY AND GREENHOUSE TESTS TO DETERMINE THE PRESENCE OF RESISTANT SEEDS TO GLYPHOSATE IN ANNUAL RYEGRASS SAMPLES

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Introduction

Annual ryegrass (*Lolium multiflorum*, ARG) is among the most important cool season crops planted for forage, pasture, hay, cover crops, and turf. Oregon is the largest producer of annual ryegrass in the US with the Willamette Valley region in Oregon producing nearly 2/3 of the nation's cool season grasses. The high-quality Oregon grass seeds are traded nationally and internationally.

Concerns have been expressed by ARG seed end-users that ARG has evolved resistance to glyphosate and ARG seed lots may contain glyphosate-resistant seed. Although glyphosate-resistant Italian ryegrass has been identified in Oregon grass seed fields (Bobadilla, 2021; Ribeiro et al., 2024), no bioassays are currently available to seed testing labs to determine the level of glyphosate-resistance within ARG seed lots. The development of a standardized bioassay is needed to determine whether or not glyphosate-resistant ARG is present within seed lots. Such a tool would benefit the ARG seed market by enabling the seed lab to issue test reports with vital information that indicates whether or not an ARG seed lot contains glyphosate-resistant seeds.

The objective of this study was to: 1) develop laboratory and greenhouse bioassays that can identify and quantify the presence of glyphosate-resistant seeds in ARG samples; and 2) determine which bioassay is the most effective and economical test to perform on commercial seed lots.

Materials and Methods

Seed samples: seed samples representing eight ARG varieties were used in the study and were anonymized as variety 1 through 8.

Sample sizes of 4 replications of 100 seeds each were used in the laboratory test, and 4 replications of 50 seeds each in the greenhouse test.

Initial quality: Standard germination tests were conducted according to the Association of Official Seed Analysts (AOSA, 2025) rules for testing seeds to determine the initial quality of samples representing the eight varieties used in the study.

Study 1. Develop laboratory procedures to detect and quantify glyphosate-resistant seeds in ARG samples.

Two methods were tested: 1) the seed soaking method (SSM); and 2) the substrate imbibition method (SIM). Seed samples, planting methods, herbicide concentrations, and seedling evaluation criteria were the same in both methods, except that glyphosate was applied to the seeds in the SSM and to the substrate in the SIM. Each treatment was repeated four times.

The Seed Soaking Method (SSM)

For each variety of the ARG, 4 replications of 100 seeds each were imbibed for 16 h in a glyphosate solution before planting. Concentrations tested were 0.24, 0.49, 0.98, and 1.46% a.i. in the solution, i.e., 0.5, 1, 2, and 3% solution of glyphosate (48.7% a.i.), respectively (Bayer, St. Louis, MO). At the end of the soaking period, the seeds were blotted dry with paper towels and planted on germination paper (Anchor Co. St. Paul, MN) moistened with tap water. Non-treated seeds of each variety were planted as control to compare with the treated seeds. Seeds were germinated at 15-25°C for 14 days according to the AOSA, 2025.

The Substrate Imbibition Method (SIM)

Same experimental methods as those in the SSM were used, except that instead of imbibing the seeds in glyphosate solution, seeds were placed directly on germination paper moistened with the four concentrations of glyphosate.

Evaluation and Reporting: Seedlings were evaluated 14 days after planting, and were classified into resistant, susceptible, and dead seeds which had no growth at all. Results were reported as percentage of resistant seeds in each sample. Dead seeds were excluded from the calculations.

$$\% \text{ Resistant seedlings} = \frac{\% \text{ Normal seedlings}}{(\% \text{ Normal} + \text{ susceptible seedlings})} \times 100$$

Where *% Resistant seedlings* is the **percentage** of seedlings in a sample that developed healthy plants after spraying with glyphosate.

Normal seedlings are the total **number** of resistant seedlings in a sample with healthy root and shoot systems.

Susceptible seedlings are total **number** of seedlings in a sample that exhibit glyphosate toxicity symptoms (deformed root and shoot systems).

Study 2. Develop greenhouse procedures to detect and quantify the number of glyphosate-resistant seeds in ARG samples.

Four replications of 50 seeds each from the same eight ARG varieties were planted in 50-cell greenhouse trays for 21 days. Optimum greenhouse conditions were maintained with 75°F, 16 h light, water applied using a capillary irrigation system (bottom flat). Postemergence applications of glyphosate were made day 21 after planting. Plants were sprayed with glyphosate solution at rates of 8, 16, 32, and 64 fl. oz/a. The rate of 64 fl. oz/a is the most used dose among the growers who

use ARG as a cover crop to control ARG plants in the spring before planting the main crop. Seedlings were evaluated 14 days after the spray and the percentage of resistant seedlings was recorded. Four replications of 50 seeds were planted as a check control without the application of glyphosate.

For the bioassay studies, recording the number of plants with toxicity symptoms induced by herbicide is the most critical observation to detect the presence of plants susceptible to glyphosate in a sample. It is important to note that the rates of glyphosate used in the studies did not always result in complete death of seedlings, but rather it caused chemical damage such as deformed root and shoot structures in some cases. The number of glyphosate-resistant seedlings in each treatment was recorded. The percentage of resistant seedlings to glyphosate in each variety were calculated.

Results and Discussion

Study 1. The Laboratory Tests

The initial germination percentage of the eight samples used in the study ranged between 98.00 - 99.25%.

The Seed Soaking Method (SSM)

The seed soaking method failed to cause obvious chemical damage or toxicity symptoms to the ARG samples at any level of concentrations used, i.e., 0.5, 1, 2, and 3%, of the glyphosate (48.7% a.i.). This is probably because seeds did not imbibe the herbicide solution long enough to cause chemical damage. Using higher rates of glyphosate than what were tested or increasing soaking time is not desirable. Using high rates comes with safety and environmental concerns and a longer soaking period will extend the test duration. Thus, SSM method was removed from further consideration.

Laboratory seed bioassay protocols differ based on individual herbicide chemical properties. For example, the substrate imbibition method (SIM) is used to screen Clearfield® winter wheat varieties, whereas, the seed soaking method (SSM) is used to screen CoAXium® wheat varieties.

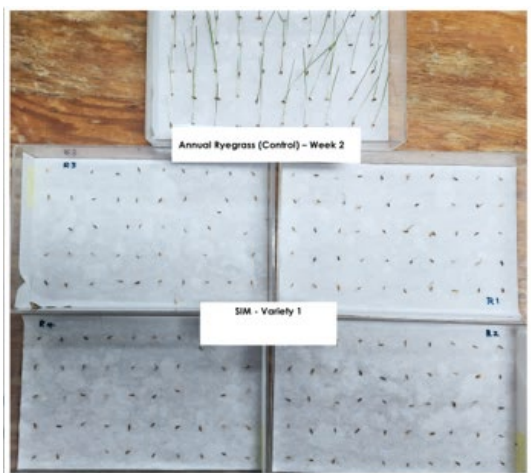


Figure 1. Substrate imbibition method (SIM), seeds planted on germination paper moistened with 0.5% (48.7% a.i.) glyphosate solution (lower two rows) vs. control (upper plate). Seeds were germinated at 15-25°C for 14 days.

The Substrate Imbibition Method (SIM)

The SIM was more effective than the SSM in inducing the toxicity symptoms caused by glyphosate in the developing seedlings. The effect of 0.5% glyphosate (48.7% a.i.) on seedlings 14 days after planting compared to the non-treated control is shown in Figure 1. At concentrations of 1%, 2%, and 3% seeds showed no sign of growth. At 0.5%

concentration of glyphosate solution, all seedlings of the eight varieties showed herbicide toxicity symptoms ranging from no seedling growth to some seedlings (10-30) with very short leaves (1.0-2.5 cm) and/or roots (0.5-1.5 cm). Symptoms of chemical injury differed among varieties, from no germination to missing, shredded, pale leaves, and missing or defective stubby roots. The nontreated control samples had well developed shoot (13-15 cm), and root (10-12 cm) systems, with an average of 97% germination.

Seven days after planting, signs of toxicity symptoms started to appear. After 14 days, the manifestation of the chemical damage was clear. The untreated control seedlings had healthy root/shoot systems (Figures 1 and 2).

Study 2. The Greenhouse Study

ARG plants were sprayed at day 21 after planting. Concentrations of 8, 16, 32 and 64 fl. oz./a. of glyphosate (48.7% a.i.) solutions were used. Plants were evaluated 14 days after the spray. At a concentration of 8 fl. oz./a, plants showed some toxicity symptoms, but not enough to cause significant chemical damage to all varieties. At a concentration of 16 fl. oz., plants started to turn yellowish, and the chemical injuries were more apparent than those at 8 fl. oz./a, but the effect was not completely and uniformly clear. Although



Figure 2. Symptoms of herbicide toxicity on annual ryegrass seedlings, evaluated 14 days after planting seeds on germination paper moistened with 0.5% solution.



Figure 3. Annual ryegrass plants sprayed on day 21 after planting with glyphosate at a rate of 32 fl. oz./a. Susceptible plants died within 14 days after spraying.

most growers who are using ARG as a cover crop use glyphosate at the concentration of 64 fl. oz./a. in the fields, it was found that 32 fl. oz./a. was sufficient and ideal to observe evidence of glyphosate damage. At this rate, most of the plants among the eight varieties turned greenish-brown to brown seven days after the spray. At 14 days, all plants of seven out of the eight varieties tested turned brown and died (Figure 3), indicating complete susceptibility to glyphosate. Only one variety showed some natural tolerance to glyphosate with a 3.5% survival rate. In this particular variety, seven seedlings out of 200 planted remained green. However, the length of these seven seedlings was about half the size (11-13 cm) of the non-treated control (22-28 cm)

(Figure 4). This indicates that even when a variety possesses natural tolerance to glyphosate, the growth of plants would be affected as both the root and shoot structures were stunted (Figure 4). Future studies are warranted to let seedlings that survived the glyphosate spray continue to grow in order to observe whether they can develop normal plants and produce viable seeds.

Different varieties respond to glyphosate differently, and the symptoms were clearly evident in the leaf color, i.e. greenish-brown to complete brown in susceptible seedlings. The various degrees of the discoloration correlated with the level of chemical injury caused by glyphosate and the level of natural tolerance of each individual seed in the sample. Each seed lot of any ARG variety should be tested independently to determine the presence and quantify the number of resistant seeds to glyphosate, if present. In this study, only one out of eight varieties showed some degree (3.5%) of resistant seeds.

Conclusions

Both the laboratory bioassay SIM at 0.5% concentration and the greenhouse test at 32 fl. oz./a. of (48.7% a.i.) were effective in detecting and quantifying the glyphosate resistant seeds in ARG samples. The

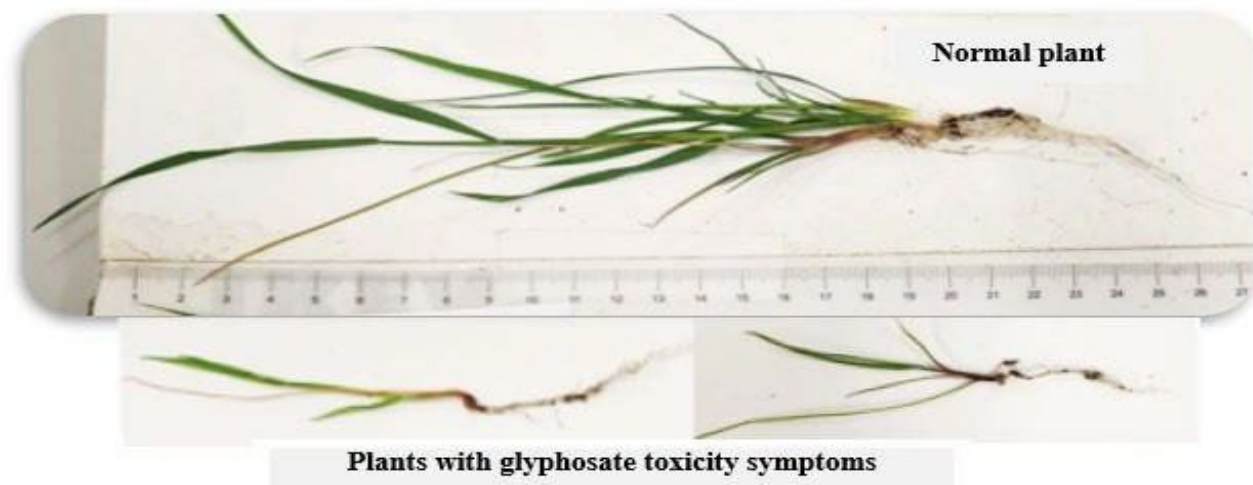


Figure 4. Lower row: Resistant annual ryegrass plants (small and weak) sprayed with glyphosate at a concentration of 32 fl. oz./a.i. Plants were sprayed on day 21 after planting and evaluated 14 days later. Upper row: Non-treated control annual ryegrass plant (normal plant).

laboratory test (SIM) has the advantage of a short testing period (2 weeks). The greenhouse test shows clearly the toxicity effect of glyphosate on the plants as they turn brown, but it takes five weeks.

Testing results will help seed producers select the appropriate (susceptible) ARG variety to be marketed as a cover crop and will help seed buyers make informed purchasing decisions. This testing would also verify the claims of whether or not a seed lot contains glyphosate-resistant ARG, thus avoiding potential disputes or litigations between seed buyers and producers.

Issuing a laboratory report showing whether ARG samples contain glyphosate-resistant seeds will facilitate the trade of annual ryegrass nationally and internationally. Oregon ryegrass growers will benefit greatly from these herbicide bioassays as Oregon is the largest producer of this crop in the US. The tests will increase the confidence of consumers when buying US and Oregon produced ARG.

A proposal will be submitted to AOSA to include these bioassays in the Cultivar Purity

Testing Handbook.

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BRISTLY HAWKSBEARD SEED GERMINATION RESPONSE TO ALTERNATING TEMPERATURES

Renan N. D. Favera, Carol A. Mallory-Smith, and Victor H. V. Ribeiro

Introduction

Belonging to the sunflower family (*Asteraceae*), bristly hawksbeard (*Crepis setosa* Haller f.) is a non-native and fast-growing annual broadleaf weed species identified by its yellow flowers. These plants frequently exhibit biennial characteristics, as seeds can germinate and develop rosettes during nearly any season of the year (Favera et al., 2025).

Concerns are increasing for white clover (*Trifolium repens* L.) seed producers in Oregon, where its presence can lead to significant seed cleaning costs or lot rejection. This is particularly critical in Oregon's Willamette Valley, where clover seed production serves as a cornerstone of the agricultural economy. The state maintains a dominant position in the national industry, producing approximately 96% of red clover (*T. pratense* L.) and 97% of white clover seed in the United States (ODA, 2023), together with a strong industry infrastructure and more than 34,000 acres of clover seed production (Oregon State University, 2026a). In 2025, Oregon's total clover seed production was more than 28 million pounds. White clover accounted for more than 3 million pounds, representing approximately 11.22% of the total (Oregon Clover Commission, 2025).

Competition from weeds for resources such as water, light, and nutrients can negatively impact crop productivity and quality, and to meet market standards, harvested seed with high levels of weed seed contamination may require additional cleaning or face seed lot rejection. Effective management is currently hindered by a lack of empirical data

regarding bristly hawksbeard biology including germination phenology. The objective of this study was to investigate the germination response of two bristly hawksbeard populations to alternating day/night temperatures, with implications for optimizing the timing of management practices to improve control.

Materials and Methods

Bristly hawksbeard seeds were collected from two commercial white clover fields in Linn County, Oregon, and were labeled as Pop 1 and Pop 2. The seeds were harvested at maturity in mid-July 2025, cleaned, weighed, and confirmed to have over 90% viability through preliminary testing.

Growth chambers were used to test germination under four alternating temperatures: 59/41, 68/50, 77/59, 77/59, and 86/68 °F, with a 12-hour photoperiod. Each treatment included four replications of 20 seeds placed on moist filter paper in Petri dishes. Germination was recorded every 48 hours for 14 days to estimate the maximum germination and the time required to reach 50% germination. The study was repeated.

Results and Discussion

An ANOVA was used to test for differences between populations. No significant differences were found ($P > 0.05$) except at the 68/50 °F regime. Additionally, a Levene's test showed no significant differences between experimental runs, so the data were pooled for the final analysis.

Temperature influenced the germination speed of bristly hawksbeard, but maximum germination remained consistently high,

exceeding 97.3% across all treatments regardless of population origin (Table 1). As the alternating temperatures increased from cooler to warmer regimes, the time required to reach 50% germination (T_{50}) decreased. The fastest germination occurred at 86/68 °F, where both populations reached 50% germination in approximately 2 days. Conversely, the slowest germination occurred at 59/41 °F with T_{50} values of 5.1 days and 4.9 days for Pop 1 and Pop 2, respectively. These results indicate that bristly hawksbeard can germinate under cool early spring and mid-to-late fall (October/November) conditions, but germination accelerates as temperatures increase.

These findings are particularly striking when compared to recent climate data from the Hyslop Weather Station. In 2025, the mean maximum temperatures for February and March were 49.3 and 57.2 °F, respectively (Oregon State University, 2025). For February 2025, the mean early morning temperature recorded at 8 AM was 32.4 °F, with observations ranging from a low of 25.0 °F to a high of 45.0 °F. In March 2025, the mean 8 AM temperature rose to 43.6 °F, with a recorded low of 36.0 °F and a high of 58.0 °F. (Oregon State University, 2025). These averages aligned with the cooler 59/41 °F regime, where bristly hawksbeard germination was relatively slow.

However, data from early 2026 show a shift toward even more favorable conditions for rapid establishment. In February 2026, daily maximums frequently exceeded previous averages, reaching up to 63.0 °F, followed by a significant spike to 68.0 °F in early March. Regarding diurnal temperatures, the mean early morning temperature recorded at 8 AM for February 2026 was 39.0 °F, with observations ranging from a low of 31.0 °F to a high of 50.0 °F. In early March 2026,

the mean 8 AM temperature rose to 45.3 °F, with a recorded low of 40.0 °F and a high of 48.0 °F (Oregon State University, 2026a).

For clover producers, increase in early spring or mid-to-late fall temperatures is critical. While 2025 conditions might have allowed a 5-day window for T_{50} , the warmer 2026 spikes push the biological response closer to the accelerated rates seen in warmer alternating temperature regimes, suggesting that as early spring temperatures trend higher, proactive monitoring and earlier intervention will become necessary to prevent bristly hawksbeard establishment.

Conclusion

This study confirms that bristly hawksbeard possesses the ability to germinate across a wide spectrum of alternating day and night temperatures, ensuring its persistence in the varied climate of the Pacific Northwest. While the species maintains high overall germination regardless of the temperature regime, the rate of germination is accelerated under warmer conditions (above 68/50 °F) where the time to reach 50% germination was reduced to around 3.1 days at 77/59 °F and 2.2 days at 86/68 °F. The data suggests that germination behavior tracks closely with ambient air temperatures and even brief periods of elevated air temperatures in early spring can trigger rapid germination. As temperatures rise, the time to reach peak germination is cut nearly in half.

The high max. germination observed at the cooler 59/41 °F regime indicates that bristly hawksbeard might be capable of establishing during late fall or over mild winter months. This potential for winter establishment is a concern that warrants further investigation, as it could shift the focus of management strategies toward earlier monitoring or late season control to prevent robust seed bank

development before the primary spring growing season. For growers, these findings indicate that the available window for applying pre-emergence herbicides or preparing stale seedbeds can become extremely narrow during warm spring intervals. Because germination can occur within just a few days of favorable weather, proactive monitoring and rapid intervention are essential. To maintain the quality and profitability of seed crops, management strategies must account for this rapid biological response to prevent the widespread establishment of this problematic weed.

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Table 1. Days to reach 50% germination (T₅₀) and maximum germination with standard error (SE) for two bristly hawksbeard populations across varying alternating temperature regimes.

Population	Parameters	59/41 °F	68/50 °F	77/59 °F	86/68 °F
		Germination estimate ± SE			
Pop 1	Max. germination	100 (1.49)	100 (1.94)	99.9 (1.36)	99.1 (1.66)
	T ₅₀	5.1 (0.08)	5.4 (0.11)	3.1 (0.09)	2.2 (0.08)
Pop 2	Max. germination	99.8 (1.47)	100 (2.19)	99.8 (1.35)	97.3 (1.79)
	T ₅₀	4.9 (0.08)	4.7 (0.12)	2.9 (0.09)	2.2 (0.09)

MATING DISRUPTION FOR SOD WEBWORM MANAGEMENT IN PERENNIAL GRASS SEED SYSTEMS

Navneet Kaur and Seth J. Dorman

Introduction

Sod webworm, *Chrysoteuchia topiaria* (Zeller) (Lepidoptera: Crambidae), is a persistent and economically damaging pest in Oregon grass seed production systems, particularly in fine fescue, perennial ryegrass, and tall fescue. Larval feeding on grass crowns reduces stand vigor and seed yield, yet effective management remains challenging because larvae are protected within the soil–crown interface, and insecticide efficacy depends heavily on rainfall timing. Concerns about environmental impacts, insecticide resistance risk, and limited chemical control options underscore the need for alternative management strategies.

Sex pheromones of *C. topiaria* were identified in 1979 by Kamm and McDonough (1979). Since then, pheromone traps have been widely used to monitor adult flight. However, their use has largely been limited to decision support rather than direct control. Mating disruption, which deploys high concentrations of synthetic pheromones to interfere with mate finding, is a promising nonchemical tactic that has not been fully evaluated in grass seed systems. This study assessed the efficacy of pheromone-based mating disruption to suppress adult male *C. topiaria* activity under commercial production conditions.

Materials and Methods

Field trials were conducted in 2025 to evaluate the efficacy of pheromone-based mating disruption for *C. topiaria* in Oregon grass seed production systems. Three commercial chewing fine fescue (*Festuca rubra* ssp. *commutata*) seed production

fields in Marion County, OR, were selected based on historical records of *C. topiaria* infestation and pheromone trap captures.

Mating disruption treatments were established before the onset of peak adult flight, predicted to occur at approximately 1,575 degree-days (base threshold = 42°F) starting 1 January, based on the developmental model established by Kamm and McDonough (1980). Dispensers were deployed on 12 June at Sites 1 and 2 and on 16 June at Site 3, with an accumulation of approximately 1,200 degree-days. Each site contained two 208 × 208 ft (64 × 64 m) plots: a control plot (no pheromone) and a mating disruption plot that were at least 3 acres apart to avoid wind effects. Dispensers (X-mate; AlphaScents Inc., Canby, OR) contained synthetic blends of the *C. topiaria* sex pheromone components (Z)-11-hexadecenal and (Z)-9-hexadecenal. Forty-two dispensers per acre were installed in a uniform 6 × 7 grid pattern at 32-foot spacing, providing consistent pheromone coverage.

Adult male moth activity was monitored weekly using four UniTraps® (Great Lakes IPM, Vestaburg, MI) baited with *C. topiaria* pheromone lures. The pheromone traps were placed in the middle of each treatment plot. Trap catches were recorded on 23 and 30 June 2025. Mating disruption efficacy was quantified using percent inhibition (PI) of trap catch between treated and control plots, calculated as $(1 - T/C) \times 100$, where T is the mean number of moths captured in the disruption plot and C is the mean number in the control plot. Trap counts were analyzed using a negative binomial generalized linear

model (GLM) with treatment, week, site, and the treatment \times week interaction as fixed effects. Analyses were performed in R (R Core Team 2024).

Results and Discussion

Adult male *C. topiaria* captures were consistently lower in pheromone-treated plots than in untreated controls across all three field sites and both sampling weeks (Figure 1). During the first sampling period (Week 1), mean trap catches in treated plots were inhibited by 86.7% relative to controls, while the second sampling period (Week 2) showed 71.7% inhibition. Percent inhibition values among individual sites ranged from 53.8 to 100% (Figure 1).

The generalized linear model indicated a main effect of treatment ($\chi^2 = 9.71$; $df = 1$; $P = 0.0018$), confirming that male moth activity was suppressed in pheromone-treated plots. The effect of week was also significant ($\chi^2 = 6.10$; $df = 1$; $P = 0.0135$), reflecting increased overall moth abundance later in the season. Neither site ($\chi^2 = 3.29$; $df = 2$; $P = 0.193$) nor the treatment \times week interaction ($\chi^2 = 2.25$; $df = 1$; $P = 0.134$) was significant, indicating that treatment efficacy was consistent across locations and sampling periods. Trap count data indicated a 97% reduction in male captures during the first week and 77% reduction during the second week. No field-level evidence of trap competition or lure degradation was observed during the two-week trial period.

Although absolute trap catches differed among sites, treatment efficacy remained consistent, suggesting that the technique is robust across variable field environments and pest densities. From an IPM standpoint, mating disruption represents a viable nonchemical tactic that could reduce reliance on insecticides such as chlorantranilprole and lambda-cyhalothrin,

which are constrained by rainfall-dependent performance and limited registration options in seed crops. By reducing mating success, pheromone-based disruption targets the pest population before egg laying and larval establishment, thereby complementing existing management tools.

Future work should assess dispenser longevity, pheromone release rates, optimal deployment density, and integration with cultural and biological controls. Economic analysis of device costs and damage reduction will further guide adoption in the grass seed industry. Collectively, these results support pheromone-mediated mating disruption as a promising addition to sustainable *C. topiaria* management programs in Oregon's perennial grass seed systems.

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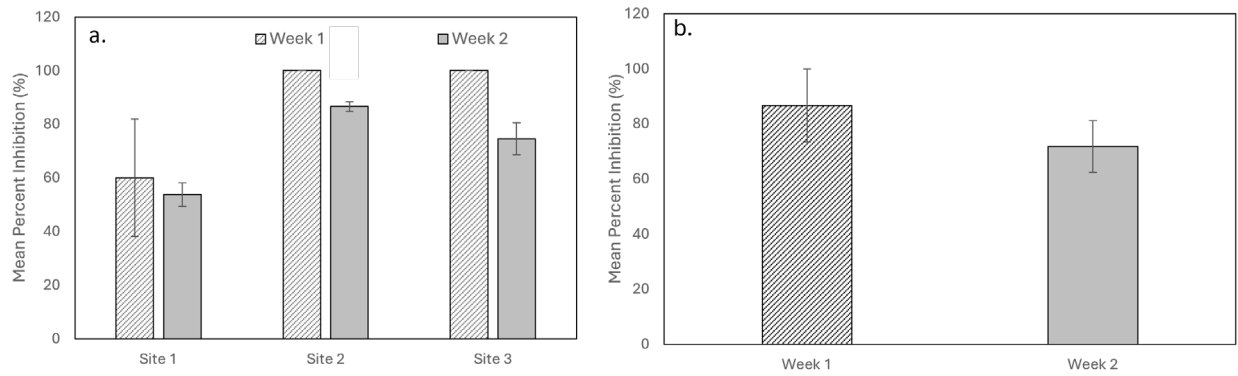


Figure 1. Percent inhibition of *Chrysoteuchia topiaria* male trap captures in pheromone-treated plots compared with untreated controls in fine fescue seed fields (a). Percent inhibition by site and sampling week (b).

TILE DRAINAGE EFFECTS ON SOIL NITROGEN DYNAMICS

Jennifer M. Moore, Kristin M. Trippe, and Lauren C. Breza

Introduction

Tile drainage is used globally in agroecosystems to improve crop productivity on poorly drained mineral soils by lowering the water table to create an improved environment for germination and root growth. In the Willamette Valley (WV) of Oregon approximately 28% of cropland has tile drainage (USDA NASS 2022 Ag Census), ranging from 5.5% in Lane, the southernmost county, to nearly 50% in Washington county in the north. While a benefit for agricultural productivity, tile drainage creates pathways for losses of nitrogen (N) from fields. These losses can occur as gases – primarily nitrous oxide (N₂O) and N₂– and in dissolved organic and inorganic N forms, especially nitrate-N (NO₃⁻-N), which is highly mobile in water. Losses of N increase production costs by wasting fertilizer, reducing crop yield and quality, and degrading water and air quality.

Most studies evaluating C and N losses from tile drainage have focused on croplands in the six states making up the U.S. Cornbelt (IL, IN, IA, MI, MN, OH). This is because 84% of all tile-drained cropland in the U.S. exists in this region (USDA NASS 2022 AgCensus), where tile drainage accounts for 40-60% of cropland. Typical NO₃⁻-N losses via tile drainage range from 8.9–35.7 lb N ac⁻¹ yr⁻¹ under conventional management. Direct soil emissions of N₂O are generally in the range of 2.7–7.1 lb N ac⁻¹ yr⁻¹. These values are representative of intensively managed row-crop systems on mineral soils in the U.S., excluding peat or organic-rich soils.

Although tile drainage’s impact on nutrient cycling and water quality is well studied in

midwestern soils, its effect on soil carbon (C) and nitrogen (N) cycling in WV croplands remain poorly understood. The objective of this study was to evaluate the impact of tile drainage on gaseous and soluble losses of N in a poorly drained field used for annual ryegrass seed (*Lolium multiflorum* Lam., ARG) production. This study was a component of our larger, previously reported soil C study (Breza et al., 2022 and 2023).

Materials and Methods

Study area and soil characteristics

The field used for this evaluation was selected because it contained three distinct sections representing different tile-drainage histories: tile drainage installed within three years of our initial sampling (“New”), tile drainage installed more than 30 years earlier (“Old”), and an area with no history of tile drainage (“Untiled”). Within the tile drainage sections, sampling was restricted to a single soil type (Dayton soil series; fine, smectitic, mesic Vertic Albaqualfs).

Although the surface horizon of this poorly drained silty clay loam soil is aerobic in the dry season, the lower depths can maintain hydric conditions year-round. Poorly drained soils are common throughout the WV where, in the absence of artificial drainage, prolonged seasonal saturation limits the growth of mesophytic crops. One exception to this is annual ryegrass (ARG) which can tolerate wet conditions; however, yields of ARG are typically lower than in well-drained or artificially drained soils.

Soil sampling and N₂O monitoring

Within each tile drainage system, three 50-m (164 ft) transects were established and

within each transect, three sub-sampling areas were marked by GPS for soil collection and installation of soil chambers for trace gas collection. In August 2022, soil cores were collected to a depth of 39 inches and split into three genetic soil horizons (Ap, Bt, and BC). Soil bulk density was determined by taking the dry mass of each horizon and dividing it by the volume of the core. Samples were analyzed for total C and N content by dry combustion using a LECO CN828 analyzer. Soil pH was measured in a 2:1 water:soil ratio and soil nitrate-N (NO_3^- -N) and ammonium-N (NH_4^+ -N) were measured after 2 M KCl extraction using colorimetric methods.

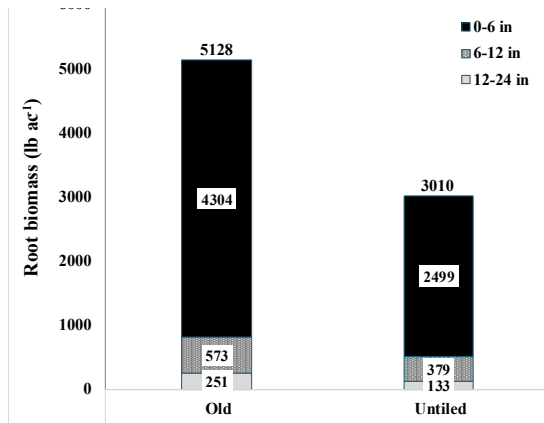


Figure 1. Annual ryegrass root biomass (lb ac^{-1}) by depth for Old and Untiled drainage areas.

Soil properties were determined on composite samples by combining the three samples across each transect. Each soil C and N stock (lb C or N ac^{-1}) was calculated on an equivalent soil mass basis by multiplying composite concentrations by a common reference soil mass (300 kg m^{-2} or 61.4 lb ft^2) equal to the lower mean soil mass of the compared composites. This soil mass translates to approximately 12-15 inches for each horizon (i.e., Ap = 0-12", Bt = 12-24", and BC = 24-39").

Fluxes of nitrous oxide (N_2O) were measured using a LI-7820 analyzer

connected to a LI-8200 smart chamber, which allows for in-field measurements. For each tile drainage area, nine measurements were collected each sampling date (three per transect). Flux measurements were collected for a total of 45 days spanning a total of 365 days between Spring 2022 and Spring 2024 (Table 1). On each sampling day, 27 readings were taken resulting in 1,215 maximum observations over the 45 total sampling days. After removing any duplicate or erroneous readings, a total of 1,063 observations were used for analysis.

Vegetation sampling and processing

Yield data were collected via GPS yield monitoring in the 2023 harvest year. The area mapped was restricted to the region of our sampling area to align with soil and trace gas measurements; thus, replication was not possible. Seed N content was estimated as 2% as reported by Hart et al. (2012).

We used a Giddings hydraulic probe to collect root cores in the same manner as that described for soil samples except root cores were extracted using a 3" diameter steel core that was 39" long. Due to extreme soil hardness during the summer sampling, we were unable to get three cores per field. Despite these major challenges, our team was able to retrieve one core from New and three each from Old and Untiled areas. To simplify root processing, samples were separated into 0-6-, 6-12-, and 12-24-inch depths. Roots were separated from soil using a Gilson Hydropneumatic Elutriation System Rootwasher. Following washing, the root samples were dried at 40°C , weighed, ground, and analyzed for C and N content by dry combustion.

Results and Discussion

Tile drainage history influenced yield. In 2023, seed yield in the New and Old tile

drained areas were 23.2% and 13.7% greater, respectively, than in the Untiled area (Table 2). Since yield data were not replicated, the yield patterns shown here should be taken as general observations, not firm conclusions. Based on the assumed seed N content of 2% (Hart et al., 2012), the New tile area accumulated 10 lb N ac⁻¹ more in seed than the Untiled area, while the Old tile area accumulated 3.6 lb N ac⁻¹ more. Approximately 83% of ARG roots were in the top 6 inches of the soil (Table 1). Although root biomass below this depth was lower overall, the Old tile area had 61% greater total root biomass than the Untiled area, supporting the hypothesis that drainage increases root biomass and rooting depth. Straw was assumed to have twice the biomass as seed with an average N content of 1% (Hart et al., 2012).

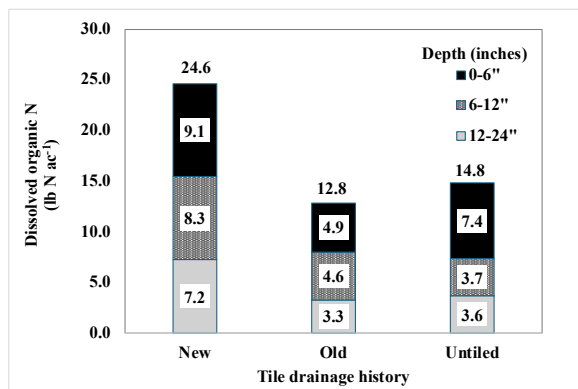


Figure 2. Dissolved organic N stocks by depth for the three tile areas in a Willamette Valley annual ryegrass field.

We measured root biomass and N content from cores collected in Old and Untiled areas. Because our coring instrument failed during sampling, root cores could not be collected from the New tile area. Over 80% of root biomass was found in the top 6" of soil, regardless of drainage history (Figure 1). Total root biomass, however, was 1.7 times greater overall in Old compared to Untiled and nearly 2 times greater at the lowest depth measured (12-24"). To estimate

above- and below-ground stocks in all drainage histories, we assumed a root biomass of 5,000 lb ac⁻¹ with a conservative root N concentration of 1.5%. Although not directly measured, we expect root biomass in the New area to exceed that of both Old and Untiled areas, given that seed yield and dissolved organic N (DON) levels were higher in New than Untiled (Table 1 and Figure 2). While nutrient and carbon allocation to roots can decline as above-ground yield increases, the higher DON in New is consistent with greater root biomass. Moreover, DON was twice as high in New compared to Untiled at the deeper sampling depths (Figure 2). Overall, total plant N uptake decreased in the order New > Old > Untiled (Table 2). Relative to Untiled, plants in New and Old took up nearly 38 and 23 lb more N per acre, respectively.

Postharvest sampling in August 2022, revealed that soil NO₃⁻-N was lowest in New, followed by Old, and was highest in Untiled (Figure 3). This pattern was consistent across all soil horizons. Across the full 40-inch profile, the New tile area contained roughly half the NO₃⁻-N of the Untiled area, and the Old tile area contained 25 lb N ac⁻¹ less than Untiled. Residual NO₃⁻-N in the New area was within the range reported for other grass seed production systems, whereas levels in the Old and Untiled areas were relatively high.

Explaining the 106% reduction in soil NO₃⁻-N in the New area relative to Untiled is challenging given the multiple N loss pathways, including leaching to groundwater or through tiles, plant uptake, and gaseous losses via denitrification. Losses from denitrification were most pronounced in spring and were associated with fertilization events while soil moisture remained high. N₂O spikes were short lived (less than one to two weeks), and fluxes

decreased to near zero once soil dried in late spring (Figure 4). To estimate an average cumulative annual N₂O emission, we summed fluxes for the growing season from the fall of one year to late spring in the following year (i.e., the first Spring 2022 samples were ignored). From September 2022 to May 2023, cumulative values were 1.8, 3.4, 4.7 lb N₂O-N ac⁻¹ for New, Old, and Untiled, respectively, but high spatial and temporal variability resulted in no significant difference between Tile Age History. From October 2023 to May 2024, cumulative values were 0.77, 0.71, 8.2 lb N₂O-N ac⁻¹ for New, Old, and Untiled, respectively. In 2023-2024 period, New and Old were significantly lower than Untiled. Our annual estimates align with studies from the Midwest for moderately well drained (2.3 lb N₂O-N ac⁻¹) and poorly drained (>5 lb N₂O-N ac⁻¹) soils (Lawrence et al., 2021). Despite limited temporal coverage, winter N₂O fluxes were low to near zero (Figure 4). This was unexpected because heavy rain during this period usually promotes anaerobic soil conditions and higher gaseous N losses through denitrification. These results suggest that the postharvest soil NO₃⁻ is not denitrified with the returns of winter rains. In contrast, more than 90% of annual N₂O loss occurred during the spring fertilization period, consistent with patterns commonly reported in the literature (Figure 4).

Greater plant N uptake in the New, compared to Untiled tile area, accounts for an estimated 70% of the difference in soil NO₃⁻-N between the New and Untiled areas (53.8 lb N ac⁻¹). The relatively high residual soil N in Untiled, especially deeper in the profile (Figure 4) is more susceptible to leaching losses. These findings suggest that N cycling is more efficient in the New tile drained area relative to the Untiled area.

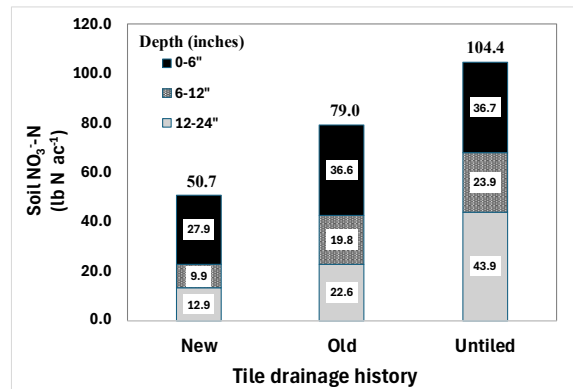


Figure 3. Soil nitrate-N (NO₃⁻-N) stocks by depth for the three tile areas in a Willamette Valley annual ryegrass field.

Summary

Overall, our results demonstrate that tile drainage substantially alters N distribution, root development, and crop productivity in ARG systems. The New tile drained area exhibited higher seed yields, greater estimated N uptake, and lower residual soil NO₃⁻-N compared to the Untiled area, indicating more efficient N cycling and improved synchronization between N availability and crop demand. Enhanced root biomass in the Old tile drained area, together with indirect indicators of greater root investment in the New area, suggests that drainage not only increases aboveground productivity but also promotes deeper and more extensive rooting. This improved root system likely contributes to more efficient N scavenging due to higher root surface area and reduced postharvest soil NO₃⁻-N accumulation. Despite uncertainties related to missing root core measurements and the limited temporal resolution of N₂O flux data, the consistency across yield, N uptake, DON patterns, and soil profile NO₃⁻-N supports the conclusion that tile drainage enhances both agronomic performance and nutrient-use efficiency. Collectively, these findings highlight the potential of drainage improvements to reduce environmental N losses while simultaneously increasing crop productivity, underscoring its importance as

a management practice in poorly drained grass seed production systems.

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Acknowledgements

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Table 1. Seasonal sampling dates, total days in sampling period, and number of days of soil N₂O-N flux measurements.

Season	Sampling period	Total days in period	Sampling days
Spring 2022	4/29/2022 - 6/8/2022	41	5
Fall 2022- Winter 2023	9/16/2022 - 1/11/2023	118	15
Spring 2023	3/18/2023 - 5/28/2023	72	9
Fall 2023- Winter 2024	10/7/2023 - 11/28/2023	53	5
Spring 2024	3/17/2024 - 5/29/2024	81	11

Table 2. Cumulative N stocks (lb N ac⁻¹) in New, Old, and Untiled areas summed across the 60'' soil profile. Changes (Δ) in yield (Y), NO₃-N, and total N (TN) represent the difference between New or Old and Untiled.

Tile Age	Yield (Y)	Δ Y from UT	Straw (est.)*	Root biomass	
----- lb ac ⁻¹ -----					
New	2,658	504.0	5,316	5,000 [†]	
Old	2,337	183.0	4,674	4,575	
Untiled	2,154	na	4,308	2,685	
	Seed N	Straw N (est.)*	Root N	Total N uptake	Δ TN from UT
----- lb ac ⁻¹ -----					
New	53.2	53	75 [†]	181.3	37.9 [†]
Old	46.7	47	73	166.2	22.8
Untiled	43.1	43	57	143.4	na

* Straw content was estimated as 2x seed amount with a 1%N content (Hart et al., 2012).

[†]New root biomass, N content, and total N uptake were estimated because root cores were not possible given the sampling instrument broke during sampling.

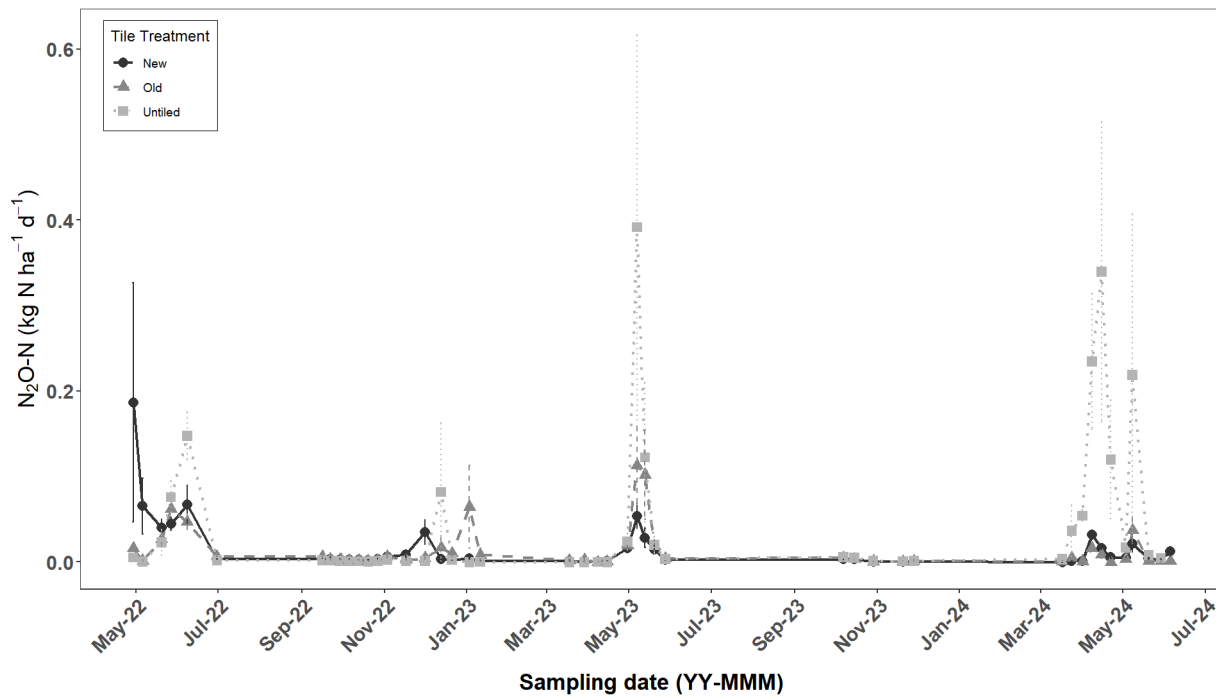


Figure 4. Measured fluxes of N as N₂O-N (kg N ha⁻¹) in the three tile drainage age groups.

Note: 1 kg ha⁻¹ = 0.89 lb ac⁻¹.

BICYCLOPYRONE + BROMOXYNIL (TALINOR) AND FLUMETSULAM (PYTHON) CROP SAFETY IN GRASSES GROWN FOR SEED

Victor H. V. Ribeiro and David Maliszewski

Introduction

Herbicide evaluation is a key component of the Extension Weed Science program at Oregon State University, as part of ongoing efforts to improve weed management in grass seed crops (Ribeiro, 2025). Identifying new herbicides and potential candidates for future registration is critical for developing effective strategies to manage herbicide resistance, sustain crop yields, and ensure the longevity of the grass seed industry. Field trials were initiated in the fall of 2024 to evaluate the crop safety of bicyclopyrone + bromoxynil (Talinor) and flumetsulam (Python) in perennial ryegrass (*Lolium perenne* L.) and tall fescue (*Festuca arundinacea* Schreb.) grown for seed. These herbicides provide control of a variety of broadleaf weeds, including mayweed chamomile (*Anthemis cotula* L.), a challenging weed in agricultural production systems in the Pacific Northwest (Adhikari et al., 2020). These herbicide evaluations are for experimental purposes only and should not be considered a recommendation for commercial use.

Material and Methods

In the fall of 2024, two field trials were established at the Oregon State University Hyslop Experimental Farm near Corvallis, OR: one in newly planted perennial ryegrass and one in established tall fescue. Plots measured 10 ft wide x 40 ft long. Experiments were arranged in a randomized complete block design with four replications.

Herbicide treatments and rates are included in Table 1. Applications were made at two timings (April 23, 2025, and May 9, 2025)

using a CO₂-backpack sprayer equipped with six Teejet AIXR11003 nozzles calibrated to deliver 20 GPA. At the time of application, perennial ryegrass was at the jointing stage (Feekes growth stage 7) and approximately 8 and 10 inches tall at the first and second applications, respectively. Tall fescue was also at the jointing stage (Feekes growth stages 7 and 8) and approximately 15 and 20 inches tall at the first and second applications, respectively. Weather conditions during application are summarized in Table 2.

Monthly precipitation and minimum, mean, and maximum air temperatures during the growing season were obtained from the Hyslop Weather Station in Corvallis, OR (Figure 1). Weed pressure in these fields was low.

Crop injury was visually evaluated on a scale from 0% to 100%, where 0% indicated no injury and 100% indicated crop death. Evaluations were conducted at 7, 14, 21, 28, and 42 days after treatment (DAT). Plots were swathed on July 3, 2025, and seed was harvested on July 10, 2025, using a small plot combine. Harvested seed was cleaned, and clean seed yield was recorded. Seed viability was determined using the OSU Seed Laboratory standard germination test, conducted in the OSU Weed Science Laboratory, using 400 randomly selected seeds per treatment (100 per plot).

Crop injury, clean seed yield, and seed viability data were subjected to analysis of variance (ANOVA). When ANOVA indicated significant treatment effects ($P \leq 0.05$), means were separated using Fisher's

protected least significant difference (LSD) test.

Results and Discussion

No crop injury was observed in perennial ryegrass or tall fescue for any herbicide treatment, regardless of application timing, at 7, 14, 21, 28, or 42 DAT. Seed yield did not differ significantly among treatments for perennial ryegrass ($P = 0.06$) or tall fescue ($P = 0.87$) (Table 1), and seed germination remained high across all treatments, ranging from 86% to 95% for perennial ryegrass and from 91% to 97% for tall fescue (Table 1).

Conclusion

These results indicate that bicyclopyrone + bromoxynil and flumetsulam were safe for use in newly planted perennial ryegrass and established tall fescue under the conditions evaluated. No crop injury was observed, and seed yield and germination were not negatively affected. The findings provide

important crop safety and clean seed yield data to support registrant needs and contribute to the local knowledge base for Oregon grass seed growers.

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Acknowledgments

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Table 1. Clean seed yield and seed germination of perennial ryegrass and tall fescue at Hyslop Farm, Oregon, 2024-2025.

Treatment	Rate	Timing	Perennial ryegrass		Tall fescue	
			Seed yield	Seed germination	Seed yield	Seed germination
			lb/A	% control	lb/A	% control
Untreated control		-	628	-	604	-
bicyclopyrone + bromoxynil ^a	13.7	April 23, 2025	644	94	547	97
bicyclopyrone + bromoxynil ^b	18.2	April 23, 2025	798	94	653	97
flumetsulam ^c	0.66	April 23, 2025	710	92	496	95
flumetsulam ^c	1.33	April 23, 2025	589	94	611	93
pyrasulfotole + bromoxynil	15	April 23, 2025	850	94	505	97
bicyclopyrone + bromoxynil ^a	13.7	May 9, 2025	654	86	569	91
bicyclopyrone + bromoxynil ^b	18.2	May 9, 2025	757	93	491	96
flumetsulam ^c	0.66	May 9, 2025	724	90	567	97
flumetsulam ^c	1.33	May 9, 2025	710	91	536	92
pyrasulfotole + bromoxynil	15	May 9, 2025	694	95	570	95
<i>P</i> -value			0.06	0.16	0.87	0.13

^aCoAct+ (2.75 fl oz/A) + COC (1% v/v) was added to the spray solution.

^bCoAct+ (3.6 fl oz/A) + COC (1% v/v) was added to the spray solution.

^cNIS (0.25% v/v) was added to the spray solution.

Table 2. Weather information during herbicide application.

	April 23, 2025	May 9, 2025
Air temperature (°F)	37	58
Wind speed (mph)	4	3.5
Relative humidity (%)	34	49
Cloud cover (%)	0	20
Foliage moisture	dry	dry
Soil moisture	dry	dry
Soil temperature (°F)	60	60

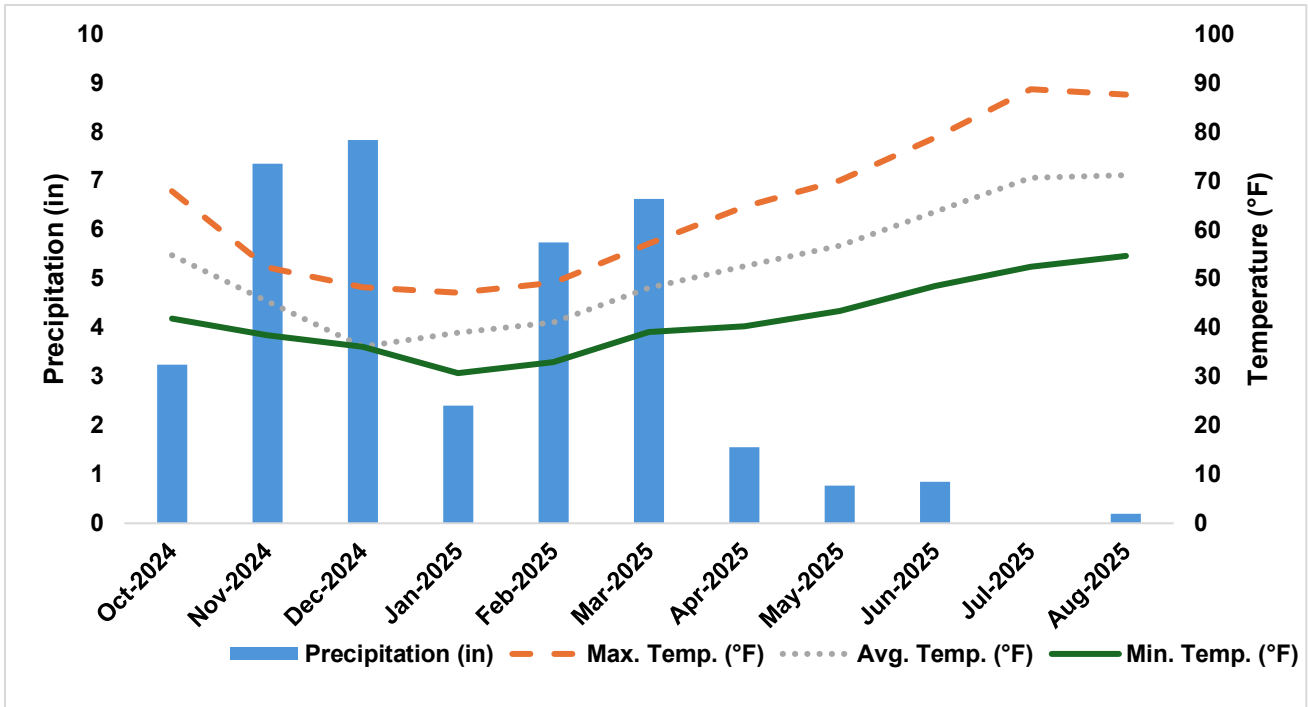


Figure 1. Monthly accumulated precipitation and minimum, mean, and maximum air temperatures during the growing season.

TOLPYRALATE + BROMOXYNIL (TOLVERA) CROP SAFETY IN PERENNIAL RYEGRASS GROWN FOR SEED

Victor H. V. Ribeiro and David Maliszewski

Introduction

A premix herbicide containing tolpyralate (a HPPD inhibitor; Group 27) and bromoxynil (a PSII inhibitor; Group 6), developed by Corteva Agriscience, is now registered for use in the United States under the trade name Tolvera® (Reddy et al., 2025). This herbicide is labeled for postemergence weed control in spring and winter wheat, durum wheat, and barley. Tolpyralate represents a new mode of action in cereal grains and provides control of both broadleaf and certain grass weed species (Jhala et al. 2023). With its recent registration in cereals, there is an opportunity to further evaluate this herbicide in grass seed systems. Therefore, the objective of this study was to assess the crop safety of tolpyralate + bromoxynil in newly planted perennial ryegrass. This product was evaluated for research purposes only, and the results should not be interpreted as recommendations for commercial use.

Material and Methods

A field study was established in fall 2024 in newly planted perennial ryegrass at the Oregon State University Hyslop Experimental Farm, near Corvallis, OR. Plots were 10 ft wide x 30 ft long. The experiment was arranged in a randomized complete block design with four replications.

The study included 10 herbicide treatments plus an untreated control (Table 1). Herbicide applications were made on May 5, 2025, using a CO₂-backpack sprayer equipped with six Teejet AIXR11003 nozzles calibrated to deliver 20 GPA. At the time of application, the crop was at the

jointing stage (Feekes growth stage 7) and approximately 10 inches tall.

Monthly precipitation and minimum, mean, and maximum air temperatures during the growing season were obtained from the Hyslop Weather Station in Corvallis, OR (Figure 1). Weed pressure across the study area was minimal and inconsistent, with only a few scattered plants present in some plots. Weather conditions during application are presented in Table 2.

Crop injury was visually assessed using a scale from 0% to 100%, where 0% represented no injury and 100% represented crop death. Evaluations were conducted at 7, 14, 21, 28, and 42 days after treatment (DAT). Plots were swathed on July 1, 2025, and seed was harvested on July 9, 2025, using a small plot combine. Harvested seed was cleaned, and clean seed yield was recorded. Seed viability was determined using the OSU Seed Laboratory standard germination test, conducted in the OSU Weed Science Laboratory, using 400 randomly selected seeds per treatment (100 per plot).

Crop injury, clean seed yield, and seed viability data were subjected to analysis of variance (ANOVA). When significant treatment effects were detected ($P \leq 0.05$), means were separated using Fisher's protected least significant difference (LSD) test.

Results and Discussion

No crop injury from any treatment was observed at 7, 14, or 21 DAT (data not shown). However, tribenuron caused 7%

injury at 28, 35, and 42 DAT (Table 1). Injury consisted of crop stunting, which is a typical symptom of ALS-inhibiting herbicides.

Differences in perennial ryegrass clean seed yield were detected among treatments ($P = 0.01$; Table 1). Tribenuron resulted in the lowest yield (854 lb/A), which was lower than most other treatments. Perennial ryegrass is known to be more sensitive to tribenuron than other grass species, and its use may result in crop stunting and reduced seed yield. The treatment 2,4-D + florpyrauxifen + MSO (945 lb/A) did not differ from tribenuron, although its yield was similar to 2,4-D + florpyrauxifen alone (1,100 lb/A). The remaining treatments produced yields ranging from 1,093 to 1,259 lb/A.

Seed germination differed among treatments ($P < 0.01$; Table 1). Germination was highest (96%) with clopyralid + fluroxypyr, bromoxynil + MCPA, and pyrasulfotole + bromoxynil, whereas 2,4-D + florpyrauxifen + MSO resulted in the lowest germination (87%).

Conclusion

Under the conditions of this study, tolpyralate + bromoxynil at both rates (11 and 14.7 fl oz/A) did not cause crop injury or reduce seed yield in newly planted perennial ryegrass, indicating potential suitability for use in grass seed production

systems based on their crop safety profile. The results generate valuable information on crop tolerance and clean seed yield that can assist product registration efforts and strengthen the regional knowledge base for grass seed production in Oregon. The reduced seed yield and germination observed with 2,4-D + florpyrauxifen + MSO warrant further investigation to clarify its potential impact on seed yield and viability. The inclusion of MSO, which is required by the product label, may have contributed to the observed effects, particularly under conditions that could influence crop tolerance, and should be considered in future evaluations.

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Acknowledgments

The authors thank Corteva Agriscience for funding this study.

Table 1. Crop injury, clean seed yield, and seed germination of perennial ryegrass at Hyslop Farm, Oregon, 2024-2025.*

Treatment	Rate oz/A	Crop injury			Seed yield lb/A	Seed germination % of control
		28 DAT	35 DAT	42 DAT		
Untreated control		-	-	-	1134 ab	-
tolpyralate + bromoxynil ^a	11	0 b	0 b	0 b	1093 ab	90 bc
tolpyralate + bromoxynil ^a	14.7	0 b	0 b	0 b	1199 a	94 ab
2,4-D	16	0 b	0 b	0 b	1149 a	94 ab
clopyralid + fluroxypyr	16	0 b	0 b	0 b	1213 a	96 a
bromoxynil + MCPA	12.8	0 b	0 b	0 b	1154 a	96 a
tribenuron ^b	0.28	7 a	7 a	7 a	854 c	94 ab
florasulam + fluroxypir	13.5	0 b	0 b	0 b	1259 a	94 ab
2,4-D + florprouxifen ^a	24	0 b	0 b	0 b	945 bc	87 c
2,4-D + florprouxifen	24	0 b	0 b	0 b	1100 ab	90 bc
pyrasulfotole + bromoxynil	13.5	0 b	0 b	0 b	1181 a	96 a
P-value		<0.01	<0.01	<0.01	0.01	<0.01

*Means within a column followed by the same letter are not significantly different according to Fisher's LSD test ($\alpha = 0.05$).

^aMSO at 1% v/v was added to the spray solution.

^bNIS at 0.25% v/v was added to the spray solution.

Table 2. Weather conditions during herbicide application (May 5, 2025).

Air temperature (°F)	64
Wind speed (mph)	2-4
Wind direction	South
Relative humidity (%)	40
Cloud cover (%)	0
Foliage moisture	dry
Soil moisture	dry
Soil temperature (°F)	60

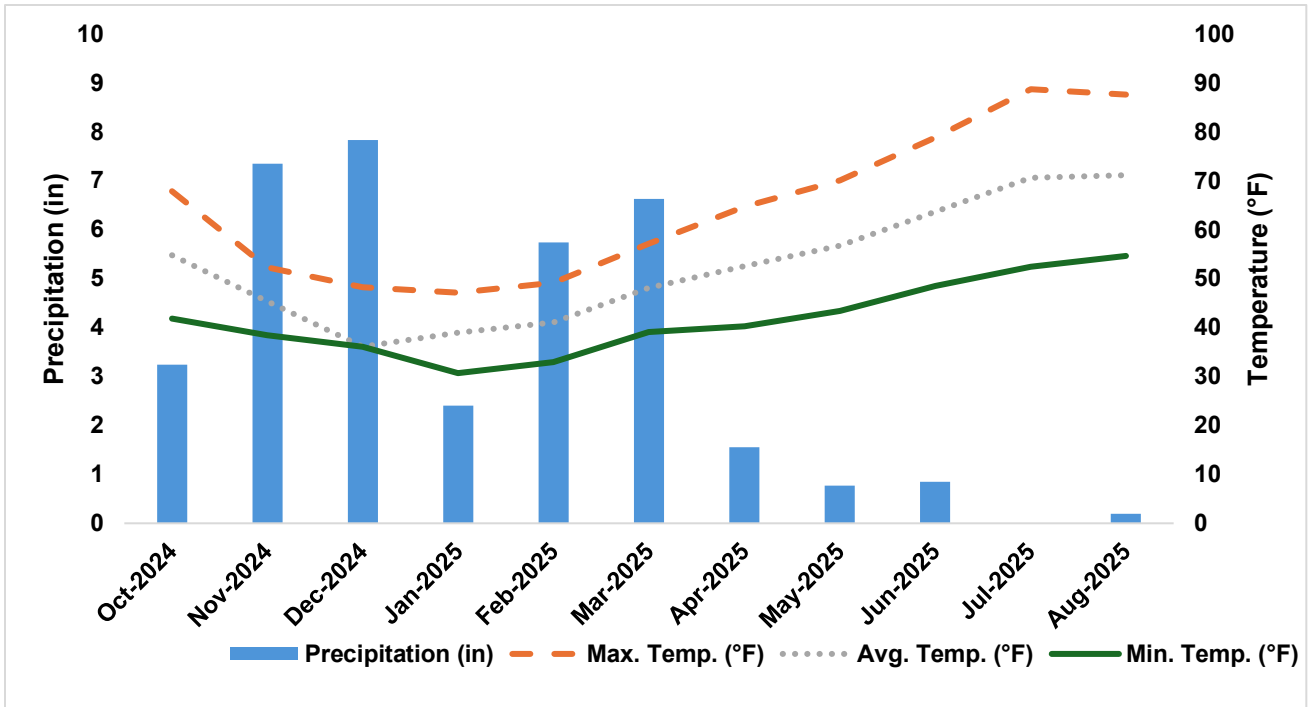


Figure 1. Monthly accumulated precipitation and minimum, mean, and maximum air temperatures during the growing season.

PRE-EMERGENT HERBICIDE APPLICATIONS FOR DOWNY BROME CONTROL IN ESTABLISHED KENTUCKY BLUEGRASS GROWN FOR SEED

Darrin L. Walenta

Introduction

Downy brome (*Bromus tectorum* L.) management typically begins late summer/early fall soon after Kentucky bluegrass (KBG) seed harvest. The process begins in late July/August with post-harvest residue management activities that include the removal of straw by baling followed by reduction of stubble height with propane-flaming. Timely residue management strongly influences KBG seed yield potential the following year because the plant crown needs to be opened up to allow tiller development in the fall. In KBG, reproductive tillers need to develop 8+ leaves before they are receptive to vernalization stimuli (low temperatures and short photoperiod) which induce flowering the following spring (Chastain et al., 1997; Parker-Clark et al., 1996). Key agronomic management practices (e.g. post-harvest residue, fall fertilization, irrigation, pest control) deployed during this time frame also influence management of downy brome infestations with pre-emergent herbicides.

The main challenge in established KBG is to apply a pre-emergent herbicide in early fall prior to downy brome emergence and achieve effective herbicide activity at the soil surface. Herbicide efficacy is strongly influenced the amount of fine residue and/or ash remaining on the field surface in both burn and no-burn post-harvest residue management. Fine residue is defined as any crop residue remaining on the field surface after baling. As KBG stands age, rhizomes spread and fill-in the inter-row space. In either residue management strategy, surface conditions allow for the interception of the applied pre-emergence herbicides. Propane-

flaming is not completely effective at burning all fine residue in older KBG stands and often requires additional harrowing and re-flaming the field. In situations where propane-flaming is not utilized, the fine residue and KBG stubble remain intact (Figure 1). Mechanical techniques to disperse fine residue/ash more effectively and reduce rhizomatous spread need to be investigated further in order to improve pre-herbicide contact with the soil surface. Irrigation timing may also improve herbicide movement to the soil surface and incorporation into the soil where germinating downy brome seed can take up the herbicide.

The objective of this study was to evaluate the impact of heavy harrowing and irrigation management on pre-emergent herbicide activity for downy brome control in established KBG. The irrigation management strategy was to apply approximately one inch of irrigation water within 48 hours of pre-emergent herbicide application to move the applied herbicides through remaining unburnt fine residue on

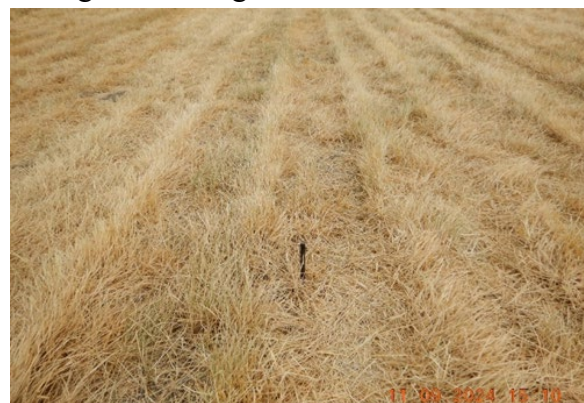


Figure 1. Established Kentucky bluegrass stand after raking and baling but prior to heavy harrowing.

field surface (Clark et al., 2019). The study is part of an on-going effort to develop sequential pre- and post-emergent herbicide programs as part of an effective strategy to mitigate Group 1 herbicide resistant downy brome populations. The herbicides utilized in the trial represent herbicides that are registered for use in established KBG, as well as, a new herbicide (Alion®) recently registered for use in established KBG seed crops.



Figure 2. Established Kentucky bluegrass stand after post-harvest residue management (rake + bale only) and heavy harrowing 2x (angled second pass).

Materials and Methods

The study was initiated in Sept 2024 in a commercial seed production field of KBG variety “Gnome” located in Union Co. near La Grande, OR. Following the third seed harvest in July 2024, post-harvest straw was baled and removed from the field. Rows of established KBG were distinguishable even though rhizomatous spread had filled in much of the area between the rows (Figure 1). The study site was heavy harrowed 2x at different directions (first pass with KBG rows then at an angle) prior to pre-herbicide treatment application (Figure 2). The heavy harrow used was a 70-foot wide Degelman Strawmaster® with 7 rows of 26” x 5/8” spring-mounted tines with hardened tips (Figure 3). The study design was a randomized complete block with 4 replications.

Environmental conditions at time of herbicide application are summarized in Table 1. Herbicide treatment subplots were 10 ft x 30 ft. A 10-ft hand-held CO₂ sprayer calibrated to deliver 16 GPA at 30 psi was used to apply pre-emergent herbicides on 12 Sept 2024 and, within 48 hours, the field was center pivot irrigated with 0.9” water. Crop injury and downy brome control evaluations were made on 4 April and 23 May 2025. Crop injury and downy brome control were both visually assessed using a scale of 0% to 100%, where 0% represented no injury and 100% represented KBG plant death. Seed yield was not determined in this study. Analysis of variance was performed to determine pre-herbicide treatment effects on crop phytotoxicity and downy brome control. Herbicide treatment means were separated by Tukey’s all-pairwise comparison method at 5% level of significance.

Results and Discussion

Wildfire smoke intrusion caused poor air quality in August 2024 which prevented propane-flaming the field in a timely manner. Therefore, residue was only managed by mechanical means to reduce stubble height (rake and bale) which left an unquantifiable amount of fine residue on the study site. Rainfall events delivered below average rainfall from September through November 2024. The drier than normal conditions negatively impacted KBG re-growth and downy brome emergence in the fall of 2024. Downy brome did not emerge in the fall but did emerge over the winter. Unfortunately, downy brome had developed multiple tillers by late winter which rendered post-emergence herbicide applications in-effective at this growth stage.

Overall, the downy brome population was variable across the study site. Several pre-emergent herbicides applied as either stand-

alone treatments or tank mixed with another pre-emergent herbicide were not different from each other (Table 2, P-value = 33.6)). In this study, the most effective pre-emergent herbicide treatments included Alion (2 ounces/acre) which provided 85% to 87% downy brome control. Outlook, Prowl H2O + Outlook, and Norton provided downy brome control ranging from 67% to 71% which is considered unacceptable levels of control. Stand-alone treatments including Prowl H2O and Eptam 7EC provided poor downy brome control at 37% and 51%, respectively. Results from this study indicate that tank mixing pre-emergent herbicide partners may offer improved downy brome control in situations where thermal post-harvest residue management is not possible in established KBG stands and when substantial irrigation ($\geq 0.9''$) occurs soon after application to move herbicides through remaining residue to the soil surface. Future research efforts will



Figure 3. Degelman Strawmaster 70-foot wide heavy harrow with 26" spring-mounted tines.

continue to evaluate the effectiveness of post-harvest residue and irrigation management strategies to improve pre-emergent herbicide effectiveness and the application of Alion at the maximum labeled use rate (3 oz/a) in Kentucky bluegrass for downy brome control.

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Table 1. Crop/weed growth stage and weather conditions at time of herbicide application.

Application date/timing	12 September 2024, Pre-emergent (PRE)	
KBG growth stage	Minimal re-growth	
Downy brome growth stage	None emerged	
Air temperature (F)	61	
Relative humidity (%)	65	
Dew present?	No	
% Cloud cover	85% overcast sky	
Wind velocity (mph)	3 to 6 from NW	
Soil temp surface (F)	68	
Soil temp 1 inch (F)	64	
Soil temp 2 inch (F)	62	
Soil temp 4 inch (F)	62	
Soil moisture	Moist surface, wet to 1" then dry below. 0.11" rainfall received the night before.	

Table 2. Crop injury and downy brome control in established Kentucky bluegrass grown for seed following fall application of pre-emergent herbicides.

Tmt	Herbicide	Active Ingredient	Product Rate/A	Timing	23 May 2025	
					% Crop Injury	% Downy Brome Control
1	Check		untreated		0	0.0 d
2	Prowl H2O	pendimethalin	5 pt	PRE	0	37.5 c
3	Prowl H2O + Outlook	pendimethalin dimethanamid	3 pt 21 oz	PRE	0	71.2 ab
4	Eptam 7EC	EPTC	5 pt	PRE	0	51.2 bc
5	Nortron	ethofumesate	32 oz	PRE	0	68.7 abc
6 ^a	Alion	indaziflam	2 oz	PRE	0	83.7 ab
7	Alion + Prowl H2O	indaziflam pendimethalin	2 oz 3 pt	PRE	0	85.0 a
8	Outlook	dimethanamid	21 oz	PRE	0	67.5 abc
9 ^a	Alion	indaziflam	2 oz	PRE	0	87.5 a
LSD (0.05) ^b					ns	33.6

^aTreatments 6 and 9 were to be followed by different post-emergent herbicides but the sequential treatments were dropped from the study (see results and discussion).

^bMeans with the same letter are not significantly different from one another.

A NEW METHOD FOR RAPID DETERMINATION OF SEED MOISTURE CONTENT IN COOL-SEASON GRASSES

Jing Zhou, Nicole P. Anderson, Darrin L. Walenta, Jeremiah K.S. Dung, Thomas G. Chastain,

Introduction

Determining seed moisture content (SMC) prior to harvesting grass seed crops plays an important role in achieving optimum seed quality, seed yield, and harvest efficiency. Seed moisture content is a reliable indicator of physiological maturity and influences storage conditions and shelf life of grass seeds (Grabe et al., 1986; Silberstein et al., 2010; Szulc et al., 2020). Swathing within the recommended SMC range minimizes seed shattering losses and optimizes seed quality (Andrade et al., 1994; Silberstein et al., 2010). Seed shattering is lowest at high SMC and highest at low SMC. However, swathing when the SMC is too high can result in problems with poor seed germination. Thus, it is important that seed growers swath at the recommended SMC range for each cool-season grass species (Silberstein et al., 2010).

The traditional method for determining SMC is to dry seed at a temperature that causes water to be released from the seed and then calculating the difference between weight before and after drying (Hay et al., 2023). Current OSU recommendations for determining SMC in Oregon grass seed crops involve obtaining representative seed head samples from the field, stripping seed from the heads, and weighing seed before and after drying. The wet and dry weights are then used to calculate SMC expressed as a percentage (Silberstein et al., 2010). Historically, the stripped grass seed samples have been dried using one of several options, including the use of an oven, microwave, or Koster tester. This process is time consuming, requires travel to a central location for sample processing, and sometimes occurs after the SMC has already fallen below recommended levels

for swathing, or after long periods of transport which may influence accurate SMC estimation. There is a pressing need for a more efficient method for determining SMC in grass seed crops in the field so that timely harvest decisions can be made, especially when multiple fields need to be tested in a single day.

The aim of this project was to develop a new method for rapidly determining SMC, utilizing near-infrared reflectance (NIR) technology. In this project, we developed the Grady Sensor, which allows users to predict SMC in seconds. The sensor is a convenient and cost-effective means of SMC assessment in many economically important cool-season grass crop species.



Figure 1. Physical components of The Grady Sensor.

Materials & Methods

The physical design of the Grady Sensor, including the main device body, a seed cup, and calibration standards, is shown in Figure 1. The device consists of electrical components, including a microprocessor, battery power management circuit, NIR light-emitting diode (LED) circuit, and a photodiode circuit. The LED circuit includes a constant current LED driver that controls LEDs at two specific wavelengths (WLs), namely WL-1 and WL-2. Circuits were embedded into a custom-designed printed circuit board (PCB) with all

electronic components assembled onboard. A device enclosure was designed to house the PCB and other features that enable this device to be handheld and portable.

Calibration equations were established through regression analysis of wavelength readings provided by the sensor against reference gravimetric oven SMC across eight grass species, including tall fescue [*Schedonorus arundinaceus* (Shreb.) Dumort.], annual ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot], perennial ryegrass (*Lolium perenne* L.), orchardgrass (*Dactylis glomerata* L.), creeping red fescue (*Festuca rubra* L. subsp. *rubra*), creeping bentgrass (*Agrostis stolonifera* L.), Chewings fescue [*Festuca rubra* L. subsp. *fallax* (Thuill.) Nyman], and Kentucky bluegrass (*Poa pratensis* L.). Seed samples of all eight species were collected from commercial seed production fields and experimental plots located in Oregon in June-July 2025. In addition, samples of tall fescue, perennial ryegrass, annual ryegrass, and orchardgrass were collected in New Zealand in January 2025 to extend the range of environmental conditions and varietal diversity. Nine sensor prototypes (devices) were used for testing in New Zealand, and 13 prototypes were used for testing in Oregon.

Data collection began at the onset of externally visible seed fill (presence of an endosperm) and continued daily through harvest. Each day, representative samples were taken from each field by stripping seed from a minimum of 30 seed heads and storing them in an airtight container in a cooler until ready for sensor measurement. Sensor readings were taken and recorded after stripping seed from the seed heads. Immediately after sensor measurement, the samples were removed from the cup, placed in a drying tin and weighed prior to drying in a laboratory circulated-air oven at 266°F (130 °C) for two hours. After drying, samples were

cooled to room temperature and then weighed to allow for calculation of the SMC percentage.

The linear relationship between the sensor readings and oven SMC was assessed using the Coefficient of Determination (R^2) derived from linear regression analysis. Calibration equations for each grass species were developed based on oven SMC and sensor readings from the latest NIR sensor prototypes. The dataset was randomly divided into training (80%) and testing (20%) sets. A partial least squares regression (PLSR) model was trained on the training set and validated on the testing set of each species. Model performance for estimating SMC was evaluated using the R^2 and Mean Absolute Error (MAE) between the oven SMC and model predictions.

Results & Discussion

Linear regression results demonstrated a linear relationship ($p < 0.05$) between sensor readings at WL-1 and oven SMC values for all eight grass species (Figures 2a and 2c). Regression analyses of sensor readings at WL-2 revealed linear relationships ($p < 0.05$) for annual ryegrass, tall fescue, creeping bentgrass, Chewings fescue and Kentucky bluegrass, but not for orchardgrass, perennial ryegrass, and creeping red fescue (Figures 2b and 2d). This result is expected as WL-2 is designed as a reference wavelength to capture baseline reflectance and is less affected by SMC, thereby enabling normalization of WL-1 readings to account for seed-specific factors such as seed surface texture and size.

Performance of PLSR models in predicting SMC using readings from the latest NIR sensor prototypes is shown in Figure 3. Across the eight grass species evaluated, the PLSR models demonstrated robust predictive accuracy for SMC, with average prediction errors ranging from 1.2 to 4.6% when validated against gravimetric oven-

derived SMC values. Among the species tested, the sensor showed the best predictive performance for Kentucky bluegrass, achieving an R^2 of 0.94 and an MAE of 1.2%.

The PLSR models resulted in robust prediction accuracy across varieties or fields for all eight grass species. It highlights the Grady Sensor's ability to determine SMC in grass seed crops across varieties and environmental conditions, and reproducibility in the sensor's response to moisture variations. Notably, a small deviation in model agreement was observed for turf-type and forage-type tall fescue. The forage-type seed fields had greater prediction errors compared to the turf-type fields. The discrepancy suggests that varietal differences between forage-type and turf-type tall fescue may influence NIR reflectance properties. Consequently, the development of separate calibration equations for forage and turf-type varieties of tall fescue are underway to enhance model accuracy for this species.

The result of this work demonstrates the efficacy of the Grady Sensor as a method for rapid and reliable determination of seed moisture content in cool-season grass seed crops.

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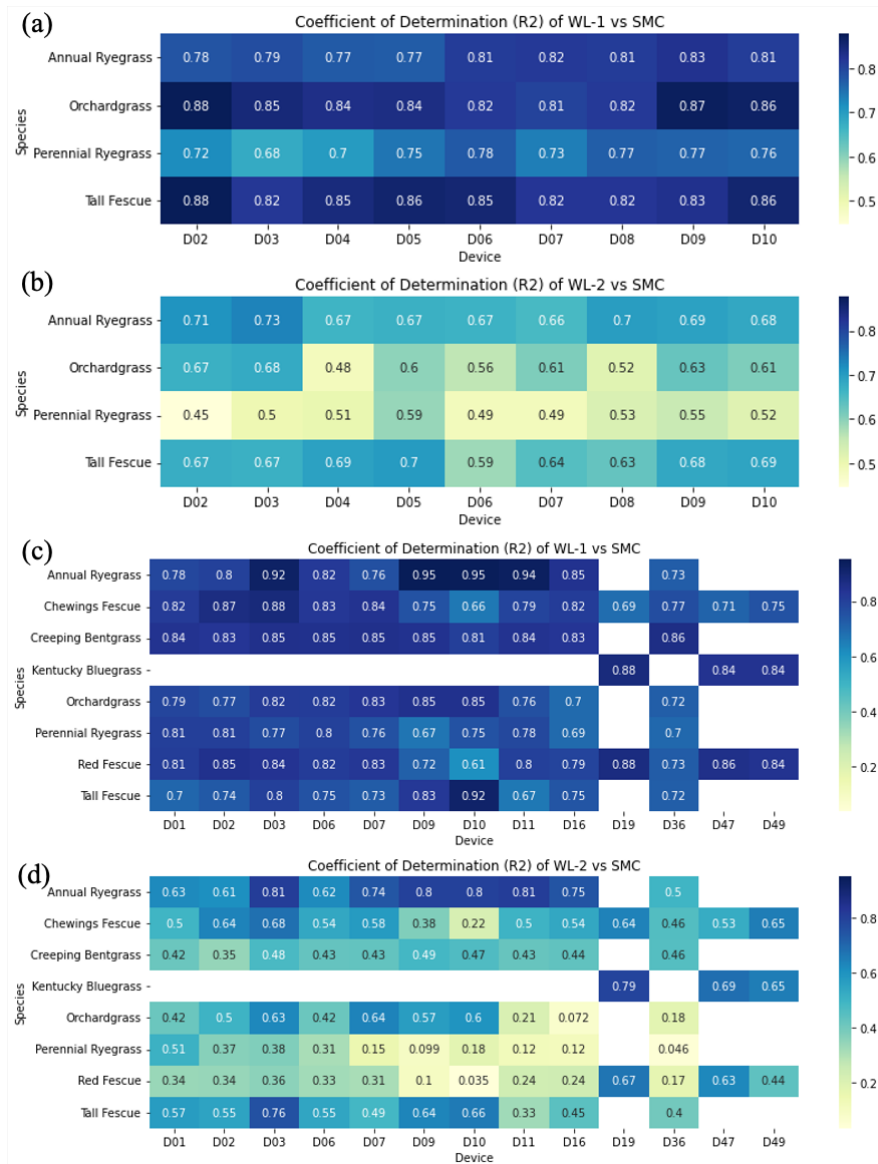


Figure 2. Heatmaps of Coefficient of Determination (R^2) between near-infrared (NIR) sensor readings and laboratory oven seed moisture content (SMC) across sensor devices for eight major cool-season grass species. (a) and (b) show data from nine sensor prototypes collected in New Zealand and (c) and (d) show from data collected in Oregon. Devices 19, 47, and 49 were tested in eastern Oregon while the other 10 devices were tested in western Oregon. (a) and (c) indicate the linear agreement between WL-1 and oven SMC while (b) and (d) indicate the linear agreement between WL-2 and gravimetric oven-derived SMC. A darker color means a stronger linear relationship between sensor readings and laboratory oven SMC, while a lighter color means a weaker relationship.

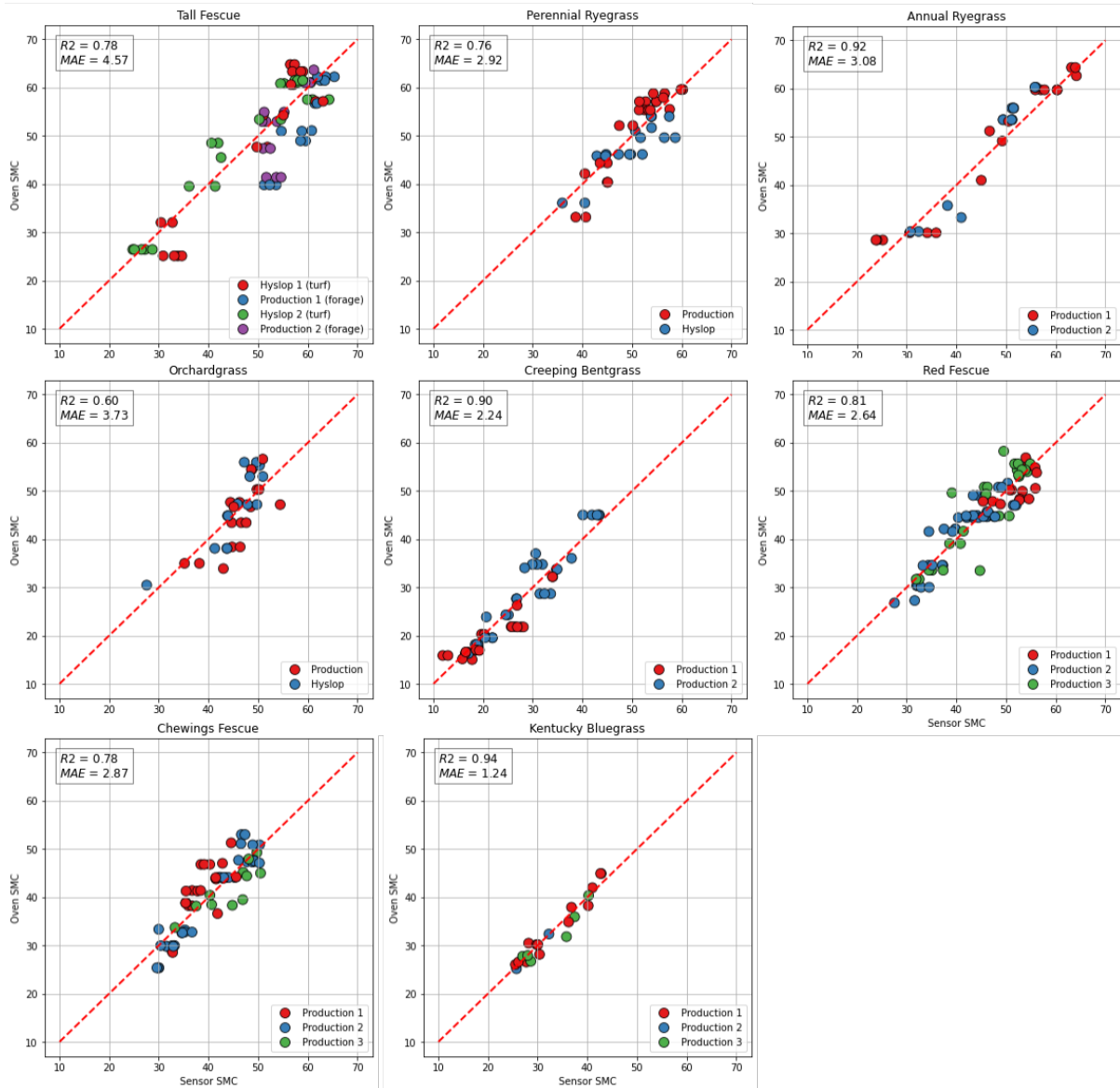


Figure 3. The relationship between near-infrared (NIR) sensor seed moisture content (SMC) and laboratory oven-derived SMC for tall fescue, annual ryegrass, perennial ryegrass, orchardgrass, creeping red fescue, creeping bentgrass, Chewings fescue, and Kentucky bluegrass. For each grass species, training data from all sampled varieties were combined and used to establish the estimation equation.

DETERMINING CARROT SEED MOISTURE CONTENT USING HYPERSPETRAL IMAGERY AND A NEAR-INFRARED SENSING DEVICE

Jing Zhou, Nicole P. Anderson, John Spring, and Jeremiah K.S. Dung

Introduction

Central Oregon is a major global producer of hybrid carrot seed crops, growing up to 60% of the seed for domestic carrot root crop production in the United States and as much as 30% of global stocks. Between 2017 and 2025, an estimated 2,500 to 5,000 acres of carrot seed were produced in central Oregon each year, with annual net value exceeding \$35 million USD (J. Spring, unpublished data).

In Oregon carrot seed production, determining moisture content (MC) of threshed crop material is critical for successful seed storage, cleaning, and germination. When harvesting carrot seed crops, it is difficult to capture relatively clean seed as is done in many other seed crops. Even with modern combine machinery, harvested crop material is generally a mix of 10-40% seed and 60-90% inert material in Oregon carrot seed fields. To avoid seed spoilage in storage, MC of this ‘field run’ material must be below 9% at threshing. In central Oregon, this is achieved exclusively through in-field drying of windrows. To achieve acceptable seed lot purity and avoid seed shatter losses after swathing, it is also highly undesirable to allow MC at threshing to fall below 7%.

Given the importance of MC at the time of threshing and the narrow range of acceptable values, current industry practice is to determine MC in each individual field each day when weather conditions are suitable for harvesting. It is not uncommon for MC to be re-measured multiple times in the same day as air temperature and humidity change. Field run samples are collected from combine harvesters at each (re-)start of threshing, then transported to a central facility for MC measurement with benchtop quick-drying moisture testers. Development of a field-portable moisture tester would allow major improvements in harvest efficiency and provide considerable cost savings to carrot seed growers and the industry.

Recently, a low-cost, field-portable near-infrared spectroscopy (NIR) sensing device – commercialized as the Grady Sensor – was validated to accurately predict seed moisture content (SMC) in multiple species of grass grown for seed (Anderson et al., 2026). The initial objective of this carrot seed work was to evaluate the potential for NIR to be used to measure MC of field run carrot seed crop material. However, after the first year of data collection (2024), it was apparent that the Grady Sensor could not accurately

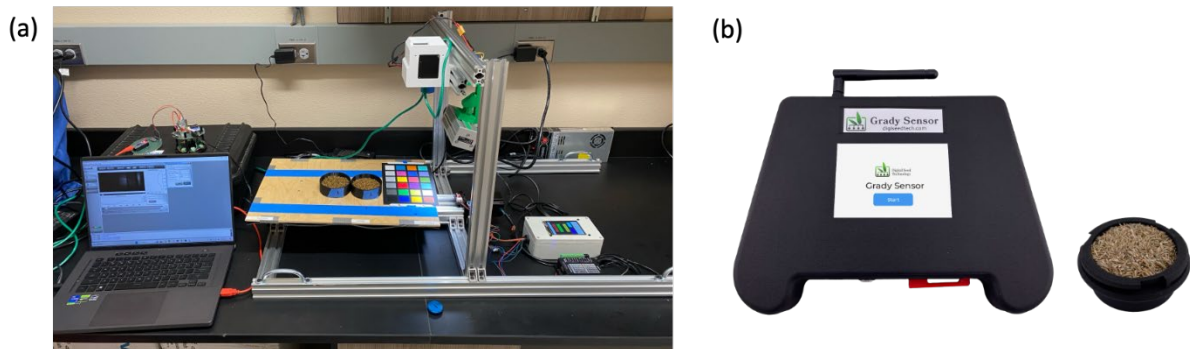


Figure 1. (a) The HyperIn imaging platform and (b) the near infrared (NIR) seed moisture sensor prototype.

predict MC of this highly variable and heterogenous field run material.

In grass seed, the Grady Sensor is not used to measure MC of harvested plant material. Instead, SMC of fresh, hand stripped grass seed samples has been established as a reliable proxy for seed maturity (Silberstein et al., 2010) and is used to inform proper harvest timing in these crops. While the suitability of SMC as an indicator of seed maturity in carrot seed crops has not been evaluated in Oregon, work in other growing regions (Brown and Spurr, 2006) suggests there could be potential. As in grass seed crops, determining proper swathing timing is challenging to determine in carrot seed but is crucial to obtaining good seed germination and maximized seed yield. Successful calibration of the Grady Sensor to measure SMC of hand-harvested carrot seed samples would greatly facilitate future research regarding SMC as an indicator of carrot seed maturity and proper swathing timing in Oregon. Currently, the potential relationship between SMC and carrot seed maturity is unknown in the central Oregon environment. For the second year of this project (2025), the objective was to evaluate the suitability of the Grady Sensor for SMC measurement of fresh hand-harvested carrot seed over a range of maturity and MC.

Materials & Methods

Data were collected over two years from commercial irrigated carrot seed fields near Madras, OR. In 2024, combine run samples were collected from each field and brought to OSU's Central Oregon Agricultural Research and Extension Center (COAREC) where they were threshed with a stationary thresher (Winterstieger LD-350) and cleaned with a combination of hand screens and an air screen cleaner (Clipper Office Tester). A "dirty sample" (samples that were hand screened to remove large stem fragments only) and a "clean sample" (samples that were cleaned using a thresher and seed mills to $\geq 75\%$ seed purity), were drawn from each combine run sample. The seed samples were imaged using a Nano VNIR Hyperspec camera (400-1000 nm, Headwall Photonics), as shown in Figure 1a. Hyperspectral images were processed to extract mean reflectance values at each wavelength for each sample. Pearson correlation coefficient (r) values were calculated between SMC after oven drying and each of the hyperspectral bands to identify spectral regions sensitive to SMC changes.

In 2025, seed samples were hand-collected from four commercial carrot seed production fields near Madras, OR. Two fields had a common Nantes type hybrid female grown under seed-to-seed production, and the other two fields had a

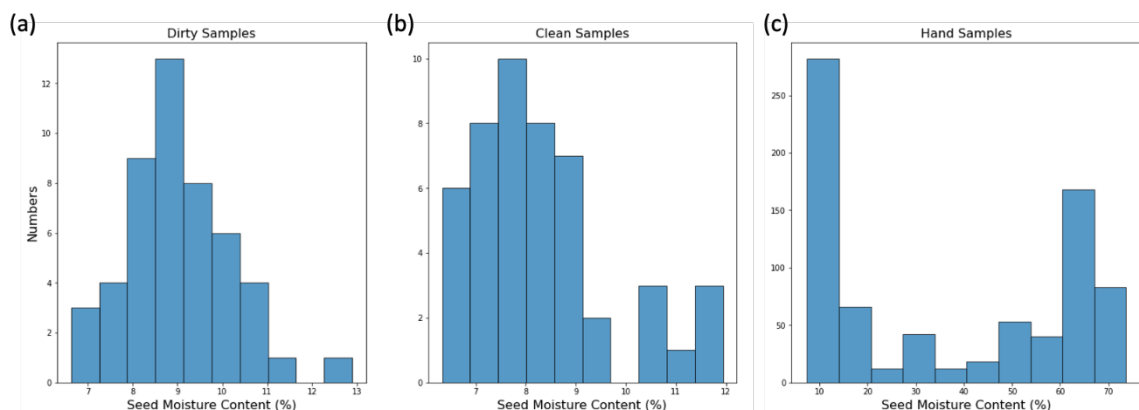


Figure 2. Distribution of the moisture of collected carrot seed samples. (a) and (b) show the collected seed moisture content (SMC) of dirty and clean samples, respectively, in year 1 (2024) and (c) shows the collected SMC of hand-harvested samples in year 2 (2025).

common Emperor cut-and-peel type hybrid female grown under root-to-seed production. Data collection started when seeds of tertiary umbels began to display visible endosperm (BBCH 8.3) and continued until combine harvest. Each day, representative samples were taken from each field and stored in an airtight container in a cooler until ready for hand separation of seed from umbels prior to sensor measurement. In each field, around 30-40 individual umbels were collected from different plants. The samples were measured using each of six duplicate Grady sensor prototypes (Figure 1b). Raw readings in the two spectral wavelengths (WLs), namely WL-1 and WL-2, from each prototype were recorded.

After imaging and sensor measurement, seed samples were weighed (wet weight) prior to drying in a laboratory circulated-air oven at 266°F (130°C) for 48 h. After drying, samples were cooled to room temperature in a desiccant-containing chamber and weighed (dry weight) to allow for calculation of SMC. The SMC was calculated by subtracting the dry weight from the wet weight, dividing that difference by the wet weight, and then multiplying by 100 to express it as a percentage.

Calibration equations were developed using oven-derived SMC values as the

reference and sensor readings from the Grady Sensor prototypes. The dataset was randomly divided into training (80%) and testing (20%) sets. A partial least squares regression model was trained on the training set and validated on the testing set. Model performance for estimating SMC was evaluated using the R^2 and Mean Absolute Error (MAE) between the oven-derived SMC and model predictions.

Results & Discussion

The distribution of SMC values collected in both years is shown in Figure 2. The hyperspectral data (Figure 3) indicated that the spectral region between 580 nm (red) and 810 nm (near infrared or NIR) correlates with MC of hand-threshed carrot seed samples. This result aligns with the well-established understanding that NIR spectral regions are highly sensitive to moisture due to their strong absorption by water molecules (Lin et al., 2019; Lobell & Asner, 2002). Additionally, changes in seed color caused by moisture loss were detected in the red spectral region.

In contrast, bands with a significant relationship to MC in dirty samples were found in the blue region (400 - 500 nm). This is likely because the dirty samples contained a mixture of seeds and inert material, with the proportion of each varying widely between samples. As the seeds dried, the inert material also

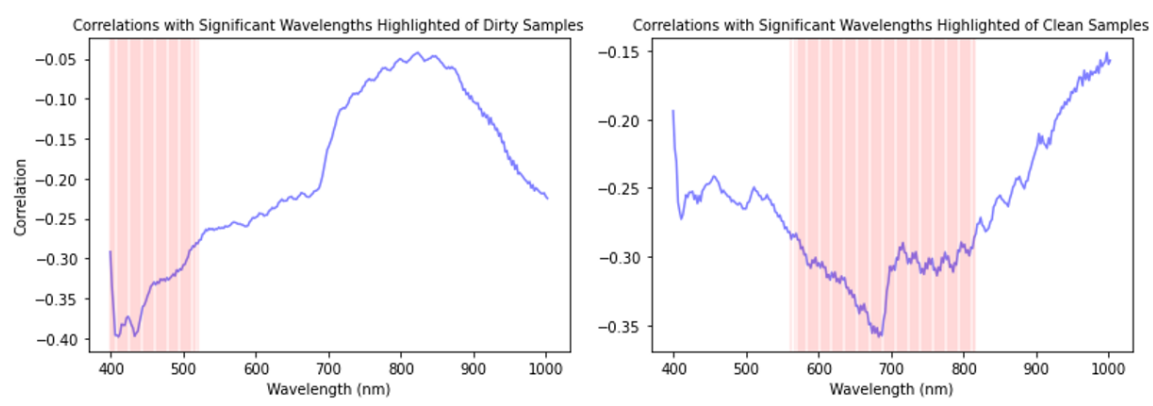


Figure 3. Pearson correlation between oven drying SMC in carrot seeds and hyperspectral bands. The bands with significant linear relationships are highlighted in red. Spectral regions in blue and green colors were significant for the dirty samples (left) and those in red to near infrared were significant for the clean samples (right).

underwent color changes, transitioning from green to yellow. These color changes, as detected by the hyperspectral sensor, served as indicators of MC variation in the samples. The relationship between oven drying SMC and hyperspectral reflectance in the three most correlated bands in both dirty and clean seed samples are shown in Figure 4. The predictive accuracy of this relationship was not high enough to reliably relate reflectance to MC for field run threshed material. However, predictive accuracy for clean seed samples was higher. Consequently, in the second year of the project (2025), the objective was changed to test the relationship between NIR reflectance and SMC of clean seed samples over a wider MC range.

For the Grady Sensor prototypes, a calibration equation was established using data from hand-harvested clean seed samples collected in 2025, covering a broad SMC range of 10 - 75%. This model achieved an overall predictive accuracy of 93% with an average error of 4.58% (Figure 5).

This model performance is comparable to that obtained in grass seed crops (Anderson et al., 2026), where the Grady Sensor is in commercial use to inform swathing timing decisions. Although SMC and seed maturity have not been experimentally linked in hybrid carrot seed grown in Oregon, preliminary work in other growing regions (Brown and Spurr, 2006) suggests that SMC within a similar range (25-60% SMC) may be used to inform swathing timing in carrot seed in a manner directly analogous to current use in grass seed. The existence of a low-cost field-portable NIR sensor providing nearly real-time measurements with minimal sample processing requirement (as compared to standard oven-drying protocols) would greatly facilitate future research investigating carrot SMC as a

predictor of seed maturity, and possible eventual adoption of the technique in actual production practice.

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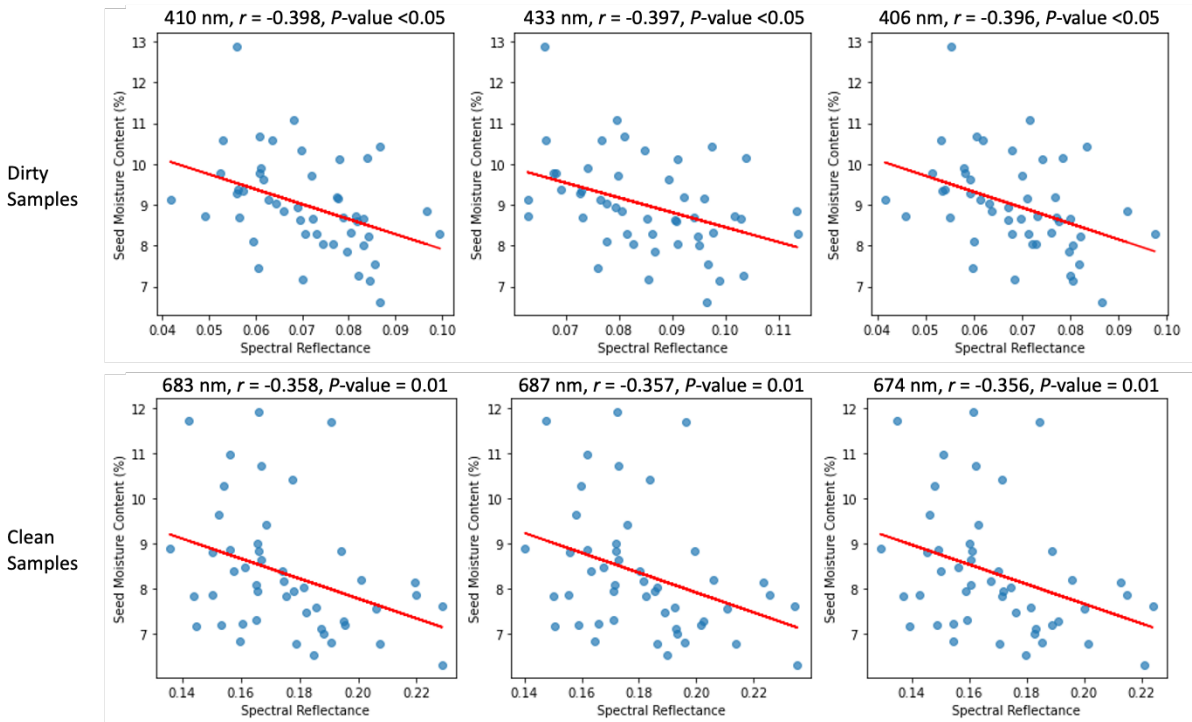


Figure 4. Scatterplots of the agreement between oven drying SMC in carrot seeds and hyperspectral reflectance in the three most correlated bands in both dirty (top) and clean (bottom) samples. The Pearson correlation and P -value are shown on top of each plot.

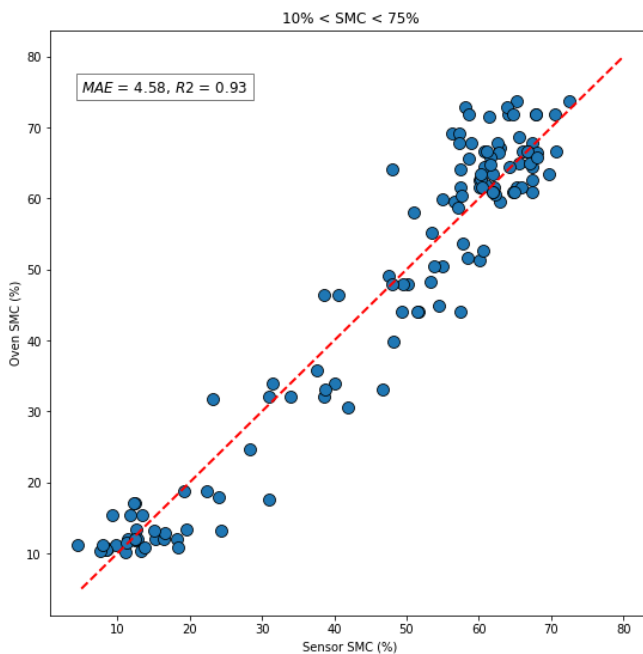


Figure 5. Scatterplots showing the relationship between near-infrared (NIR) sensor seed moisture content (SMC) of hand-harvested clean carrot seed samples and laboratory oven-derived SMC.

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