Pacific Northwest Herbicide Resistance Initiative

2025 Annual Report













FOUNDATIONS

A strong tradition of collaborative research, teaching and extension focused on cereal and animal production exists in the PNW. Scientists from the region's land grant institutions (UI, WSU, OSU) and the ARS worked together with funding from the USDA, notably Solutions to Economic and Environmental Problems (STEEP) and Regional Approaches to Climate Change (REACCH). Currently, faculty and students from University of Idaho (UI), Washington State University (WSU) and Oregon State University (OSU) collaborate on a USDA-NIFA-CAP funded project, Landscapes in Transitions (LIT) that is focused on building adaptive capacity and soil health through crop diversity and cover crops. The PNWHRI is building on these previous collaborations and partnerships, incorporating true co-innovation.

THE PNWHRI

The PNWHRI is a collaboration among scientists from the region's land grant institutions in the PNW (Oregon State University, University of Idaho, Washington State University) and three USDA-ARS units (Columbia Plateau Conservation Research Center, NW Sustainable Agroecosystems, and Wheat Health, Genetics and Quality Research) to address herbicide resistance issues in the PNW cereal cropping systems.

STAKEHOLDERS/PARTNERS











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Executive Summary

The 2025 Annual Report for the Pacific Northwest Herbicide Resistance Initiative (PNWHRI) highlights significant advancements in tackling the growing issue of herbicide-resistant weeds within the region's cereal-based cropping systems. The initiative, a collaboration among the Agricultural Research Service (ARS), regional universities, and stakeholders, made important strides in research, stakeholder engagement, and the development of new weed management strategies. Below is a summary focusing on key achievements:

1. Collaborative Efforts and Team Expansion

PNWHRI has maintained regular coordination meetings, fostering a collaborative environment among researchers from ARS and regional universities. These discussions have helped define a clear set of objectives and research priorities. The first ARS weed scientist recruited (Dr. Olivia Landau) has built a strong collaboration with ARS and university scientists and is currently participating in several collaborative studies across the PNW. Plans are underway to recruit the remaining two positions. This expansion is critical for driving forward PNWHRI's mission of developing a regionally coordinated, science-based approach to herbicide resistance management.

2. Coordinated Systems and Regional Assessment

A notable achievement of the PNWHRI has been the establishment of an extensive inventory of long-term cropping systems trials across the Pacific Northwest. These trials assess the impact of various cropping rotations and management practices, and they allow for study of weed seedbanks and herbicide resistance. The initiative has collected baseline samples from multiple weed species, including downy brome, Italian ryegrass, kochia, Palmer amaranth, Russian-thistle, waterhemp, and wild oat, which are notorious for developing resistance. These samples have been integrated into a database that serves both researchers and stakeholders, offering valuable insights into the current state of herbicide resistance across the region.

3. Research Highlights

The Pacific Northwest Herbicide Resistance Initiative (PNWHRI) continues to make substantial progress toward understanding and mitigating herbicide resistance in regional cereal-based cropping systems. Through coordinated research across ARS, University of Idaho, Washington State University, and Oregon State University, the 2025 cycle produced major advancements in weed biology, integrated management, and technology-driven decision support.



1. Biology and Molecular Research

Herbicide Resistance Screening and Surveys

Comprehensive surveys across Washington, Idaho, and Oregon have revealed increasing resistance across multiple weed species. Russian thistle populations exhibited varying resistance to glyphosate but remained largely susceptible to 2,4-D and bromoxynil. In Idaho, 60% of common lambsquarters and 81% of kochia survived the labeled glyphosate rates, underscoring the urgency of diversified weed control. Redroot pigweed and barnyardgrass were effectively controlled by glufosinate and dicamba, whereas wild oat survival to Groups 1 and 3 herbicides remained concerning, reaching 68% for ethalfluralin and 52% for fenoxaprop.

Downy Brome Resistance and Adaptation

Research on herbicide-resistant downy brome revealed that ALS + PSII-resistant biotypes germinate faster and achieve higher cumulative germination at warmer temperatures (36°C) than other populations. These findings suggest that environmental interactions may influence the persistence and spread of resistant biotypes.

Seedbank Microbiome Characterization

A new pipeline for microbiome characterization was developed to assess both soil and weed seed microbial communities in irrigated dryland wheat systems. Using DNA extraction and sequencing protocols, this study confirmed the recoverable microbiomes from Russian thistle, green foxtail, and knotweed, laying the groundwork for exploring the effects of microbes on seed dormancy and decay.

Preemergence Herbicide Efficacy and Seed Placement

Greenhouse trials have demonstrated that seed burial depth significantly affects preemergence herbicide activity. Pyroxasulfone (Zidua) was most effective within the top 2 inches of soil, whereas trifluralin (Treflan) efficacy decreased sharply with deeper seed placement, highlighting the need for precision in seedbed preparation for optimal weed control.

Digital Phenotyping for Dose-Response Assays

The PNWHRI validated the use of digital phenotyping via the Phenospex TraitFinder, which showed a high correlation ($r \ge 0.97$) with manual biomass measurements. This innovation allows for a faster, non-destructive assessment of herbicide sensitivity and facilitates the preservation of resistant plants for genetic analyses.

2. Integrated Cropping and Soil Management

Weed Management in Wheat-Fallow Systems

Field trials in Oregon evaluated integrated weed management strategies during the fallow phase of wheat rotation. The results indicated that mechanical weed control (summer sweep tillage) improved crop yield and water retention compared with



chemical-only fallow management, suggesting that occasional tillage can enhance sustainability without compromising soil health.

Soil Acidity and Weed Pressure

Experiments in Idaho revealed higher weed populations and lower chickpea yields in unlimed acidic soils than in lime-amended plots, confirming that soil pH management plays a key role in crop competitiveness and long-term weed suppression.

Tillage and Seedbank Dynamics

Long-term tillage studies have shown slightly higher weed densities in tilled systems (4 plants/ft²) than in no-till systems (3 plants/ft²). However, chickpea yields were greater under no-till, reinforcing the agronomic and environmental benefits of reduced soil disturbance.

Bioherbicides and the Use of Light-Based Technology for Weed Control

Sorgoleone, a bioactive compound derived from sorghum, has been shown to suppress the germination and growth of several key weeds, including Russian thistle and downy brome, indicating its potential as a natural herbicide. Complementary experiments with infrared and blue light treatments demonstrated reduced weed seed viability and enhanced crop vigor, whereas high-intensity light exposure in canola showed limited yield benefits.

3. Socioeconomic and Technological Innovation

Producer Perspectives and Management Trends

A regional survey of 81 producers from Idaho, Oregon, and Washington revealed that herbicide resistance ranks as the third most critical threat to production, behind equipment cost and low commodity prices. Most respondents reported more problematic weed species today than a decade ago, emphasizing the growing regional challenges.

Machine Learning and Decision Support Tools

Researchers successfully developed a prototype data pipeline for fine-tuning a large language model (LLaMA 3–8B) using 1,426 herbicide resistance resources from WSU University's Small Grains database. The model demonstrated domain-specific accuracy and formed the basis of a public-facing decision aid for producers in the Inland Pacific Northwest.

4. Extension, Outreach, and Impact

The PNWHRI's outreach network, anchored at WSU's Wilke Research and Extension Farm, hosted demonstrations on integrated weed control strategies, combining chemical, mechanical, and biological tools. Large-scale field days showcased the economic and ecological benefits of diversified herbicide programs and targeted tillage.



Additional extension initiatives have focused on biological control (Battalion Pro) and long-term planning for herbicide-resistant downy brome and Italian ryegrass.

Summary

Collectively, the accomplishments of the PNWHRI advance the region's ability to manage herbicide resistance through integrated, evidence-based strategies. The initiative's work, from molecular research and microbiome exploration to digital technology and on-farm demonstrations, provides a comprehensive foundation for building resilient, profitable, and sustainable cereal production systems across the Pacific Northwest.



Project Justification

Our overarching goal is to create a PNW Herbicide Resistance Initiative (PNWHRI) to identify and overcome risks associated with herbicide resistance in cereal-based cropping systems, reduce production losses and reduce or eliminate pressure on trade limits due to contamination.

The PNW region includes some of the most productive wheat, barley, and grain legume production systems in the nation. In 2021, nearly 5 million acres of wheat and barley were harvested from Idaho, Oregon, and Washington. This constitutes 12% of the U.S. small grain acreage and 14% of the total national production. The region exports roughly 80% of its production, which makes small grains enormous contributors to the economies of the three states and the viability of the region's rural and urban communities.

The significant achievements in market development, soil conservation, water quality improvement, and sustainability that have occurred in the PNW through the adoption of no-tillage or low-tillage systems are fundamentally threatened by **herbicide-resistant weeds.** Key points along the production pathway are adversely affected by weeds, including crop yield and quality losses, farming practices, grain handling practices, transport and storage, import/export requirements, and end use of grain in the country of destination.

- Weed seeds present in crop fields at harvest affect crop quality, yield, and export suitability.
- Herbicide-resistant weeds fundamentally alter farming practices, forcing less profitable and often less reliable crop rotations, or the use of tillage, which is known to impact soil health and increase erosion.
- Blending grain with weed seeds can contaminate other grains from the region along the export pathway.
- Overseas importers use weed seed contamination limits as leverage to block the import of PNW wheat.
- PNW wheat, barley, and pulses are typically consumed by people.

Sustained research and extension actions, in coordination and collaboration with farmers, are critically needed to mitigate herbicide resistance and overcome barriers to the adoption of alternative methods of weed management, resulting in more resilient systems.

USDA-ARS and regional land-grant scientists require new funding in addition to that provided by regional commodity commissions and industry stakeholders to develop new tools and knowledge to address this emerging problem. Our vision for managing



herbicide resistance is centered on collaborative, multi-stakeholder, region-wide coordinated action integrating multiple situation- and location-specific management practices. This initiative plans a multidisciplinary, multitactical approach that utilizes applied and fundamental agronomic and genetic research, in collaboration with economic and social scientists, resulting in farm practices supported by the NRCS, with the goal of providing farmers with economically viable weed-resilient systems.

Weed management strongly affects the long-term environmental and economic sustainability of PNW farming systems. Investing in the improvement of agricultural technology, conservation of soils and soil health, and adaptation to climate variability, including changes in the timing and availability of precipitation and water for irrigation, are all examples of critical areas impacted by weed management. Alternative cropping systems that include incremental (introduction of new cash and cover crops) and transformational (integration of crop and livestock production) approaches are required to achieve these goals in the future. All of these interconnected issues can be best addressed through a coordinated, interdisciplinary, systems-based approach that is regional and long-term.



SUMMARY OF OBJECTIVES

Weed seeds present in crop fields at harvest affect crop quality, yield, and export suitability. Herbicide-resistant weeds fundamentally alter farming practices, forcing less profitable and often less reliable crop rotations, and may force the use of tillage, which is known to impact soil health and increase erosion. Blending grain with weed seeds can contaminate other grains from the region along the export pipeline. Overseas importers use weed seed contamination limits as leverage to block the import of PNW wheat.

The goal of the PNW Herbicide Resistance Initiative is to reduce the overall importance of weeds in PNW production systems such that they are not considered a primary threat to the system.

To achieve the primary goal, the initiative will conduct research to improve weed management by identifying new options and improving existing options by characterizing 1) weed biology, physiology, biochemistry, and molecular biology; 2) weed ecology and spread; 3) weed-crop interactions; 4) impact of biotic and abiotic factors on the weed seed bank; 5) crop and soil management that reduces the seed bank; 6) the frequency of herbicide resistance occurrence and evolution; and 7) practical and social constraints on the use of integrated weed management methods.

The fundamental assumption underlying our goal is that climate variability and change that affect weed development and survival will be inherently accommodated by developing climate-based decision support systems. Our overarching goal is to develop a system adaptive capacity by refining best management practices based on the fundamental biology of weed species into a management toolbox that incorporates a real-time climate-based decision support system.

Objective #1: Biology, Ecology, and Crop Rotation

Refine best practices for weed management based on fundamental biology, ecology, and diversified crop rotations. This objective has three main themes: Crop Rotation Based Theme, Biology-Based Theme, and Cross-Cutting Theme

Crop Rotation Based Theme:

a) Evaluation of intensification and diversification of PNW cropping systems on weed populations at the practical and fundamental levels, utilizing existing and new intermediate- and long-term research field trials and novel methods based on emerging phenotypic and genomic resources. i. Refine best



- management practices associated with tillage systems (using long-term tillage trials)
- b) Augment existing rotational trials with intensive evaluations of weed populations, focusing on collecting longitudinal data on the effects of discrete traditional and novel management tactics, as outlined in the biology-based theme. Identifying gaps in existing short-, intermediate-, and long-term trials and working to fill those gaps.

Biology-Based Theme

The evaluation of herbicide resistance, weed seedling emergence (including patterns), seed longevity, seed retention timing of viable seed production based on timing of emergence, and the capacity to extract soil water after harvest if left uncontrolled. The focus is on problematic weeds in the PNW (Italian ryegrass, cheatgrass, wild oat, common lambsquarters, Russian-thistle, or other weeds based on stakeholder feedback or change in condition) and will use PNW-collected germplasm. Studies may include:

- Occurrence and extent of herbicide resistance in common weeds in the PNW, and an assessment of the genetic, physiological, biochemical, and evolutionary factors and mechanisms that facilitated the resistance and persistence of weed seeds.
- ii. Determine the relative importance of mutation, migration, selection, and random genetic drift for important traits, including traits that confer resistance, in weed species in wheat cropping systems in the PNW
- iii. Determine minimum, maximum, and optimal temperature requirements for germination under different moisture regimes for use in decision-support tools.
- iv. Response to soil- and foliar-applied herbicides at various temperatures.
- v. Response of weed seeds to light quality (red, far-red, and blue light).
- vi. Develop a hydrothermal model of weed emergence timing using field and laboratory data.
- vii. Determine how the soil microbiome (fungi and bacteria), microfauna, and soil invertebrates affect the longevity and survival of seeds in the seed bank.

Cross-Cutting Theme

- a) Develop innovative and high-throughput or automated pipelines to enhance data collection and assess weed populations at all stages of their lifecycle.
- b) Incorporate novel technology as opportunity presents, including automation to acquire relevant biological data, harvest weed seed control, robotics, precision field management, or other technologies.



Objective #2: Socio-economic

Determine the socio-economic and policy-related opportunities and barriers to adopting integrated weed management systems within traditional and aspirational wheat-based systems that impact resilience to weeds.

- a) Develop and administer a regional survey of grower perceptions on herbicide resistance, barriers to adoption of integrated weed management tactics or best management practices.
- b) Provide support for interested communities to establish and maintain a cooperative weed control zone.
- c) Develop a co-innovation structure to facilitate grower integration into the initiative and evaluate social aspects of co-innovation.

Objective #3: Extension and Outreach

Develop an active and engaged extension and outreach program built around fundamental and applied aspects of the Initiative.

- a) Foster cooperation through a precision farming network, utilizing innovative or new approaches for co-innovation and co-production.
- b) Evaluate and report outcomes and impacts to stakeholders using traditional and novel methods, including surveys.
- c) Develop decision support tools to integrate climate, biology and control tactics. Logistical considerations – probability assessment to apply an input as part of the data distribution service (DDS), windows of opportunity for inputs, and consequences of improper timing of input application incorporated into the DDS.



RESEARCH ACCOMPLISHMENTS

Objective#1: Biology Based Theme

Herbicide resistance surveys and screening for resistance to commonly used herbicides in PNW wheat production systems

Herbicide Resistance Screening in Russian-thistle

Ian Burke and Marija Savic

During fall/winter 2023/24, 80 sites were visited and scouted for Russian-thistle presence. Plants with seeds were collected from approximately 60 sites in central and eastern Washington (**Figure 1**). Plants were collected from fields or areas adjacent to fields (roadsides, field edges, ditches, etc.). The location type (crop, fallow, roadside, natural area, and CRP) was recorded at the time of collection. A total of 20 plants were collected at each site, and each plant was at least 20 feet apart from the previous plant. Additional notes on seed bank collection, other weeds present, and specific site characteristics were recorded at the time of collection.

Plant material was stored under dry and dark conditions until cleaning. During the summer of 2024, seeds were cleaned and extracted from the plants and placed in envelope bags. A small quantity of seeds was tested for germination prior to planting to ensure that there were enough plants for complete screening. Clean seeds were planted in 2-inch cones, and plants were grown to 3-4 inches in height under greenhouse conditions. Herbicide resistance screening consisted of six treatments: nontreated, 2,4-D as 2,4-D LV4 at 24 fl oz/A, bromoxynil as Brox 2EC at 24 fl oz/A, saflufenacil as Sharpen or tiafenacil at 1 and 2 fl oz/A, respectively, metribuzin as OMNI metribuzin at 3 oz/A, and glyphosate as Roundup Powermax at 64 fl oz/A. The collection was divided into three subgroups because of the large number of samples and limited space in the greenhouses.

Herbicides were applied using a single-nozzle spray chamber calibrated to deliver 20 gallons per acre. Photos were taken 21 days after treatment, and the fresh aboveground biomass was recorded.

Overall, Russian thistle in Washington appears susceptible to 2,4-D and bromoxynil at used in-crop rates (**Figures 4 and 5**). Russian thistle is also susceptible to group 14 or PPO herbicides at the recommended rates for fallow. Varying levels of resistance to glyphosate were observed in plants from multiple sites (**Figure 3**).



Future work will involve dose-response studies to confirm resistance at each site where RT survived after glyphosate application.



Figure 1. Visited sites in central and eastern Washington. Each point represents a randomly selected coordinate within 10 km grids.



Figure 2. Nontreated Russian thistle plants at 14 DAT.





Figure 3. Glyphosate treated Russian thistle plants at 14 DAT.



Figure 4. Bromoxynil treated Russian thistle plants at 14 DAT.





Cheatgrass (Bromus tectorum) Resistance to Quizalofop-P Ian Burke and Marija Savic

Cheatgrass seed was collected in 2022, and initial screening was completed. Two lines from the same site near Walla Walla survived quizalofop-P treatment at 12 fl oz/A or 92 g ai/ha. The initial screening was followed by a dose-response experiment to confirm and determine the level of herbicide resistance compared to the susceptible line. Treatments included three biotypes (R1, R2, and S) and nine doses of quizalofop-P ethyl (0, 5.75, 11.5, 23, 46, 92, 184, 368, and 736 g ai/ha). The selected rates correspond to Plants were treated at the beginning of tillering stage using single nozzle spray chamber calibrated to deliver 140 L/ha and cut to approximately one inch height 48 hours after the treatment. Fresh biomass was recorded at 21 DAT. Experiment was repeated twice under greenhouse conditions. Dose response curves were generated in R using the drc package employing a four-parameter log-logistic model (LL.4) to estimate GR₅₀ values.

The dose response experiment was followed with DNA extraction and sequencing to determine if mutation in ACCase gene confers resistance to quizalofop-P. DNA was extracted using CTAB method and the sequence was amplified using PCR with DreamTaqTM master mix. To confirm amplification and the product size, samples were run on 1% agarose gel. The PCR fragments were sent to Elim Biopharmaceuticals (Hayward, CA) and sequenced. Sequences were aligned and analyzed for mutaions in the CT region of ACCase 2 gene using SnapGene tool.

The resistance in two resistant lines was confirmed with dose response experiment in comparison to the sensitive line (**Figure 6**). GR_{50} for resistant biotype R1 was 116.3 g ai/ha and for R2 94.2 g ai/ha with resistance indices of 7 and 5.7 respectively. GR_{50} for sensitive line was 16.7 g ai/ha. Previously reported single nucleotide mutations in the CT domain of plastid ACCase **were not identified** at codon positions Ile1781, Trp1999, Trp2027, Ile2041, Asn2078, Cys2088, and Gly2096.



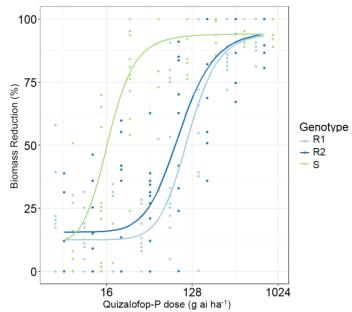


Figure 6. Dose-response curves for three cheatgrass biotypes treated with quizalofop-P 21 DAT. Resistant lines are represented in blue lines.



Figure 7. From left to right: nontreated R1, R2, and S biotype, quizalofop-P treated R1, R2, and S biotype at 92 g ai/ha 21 DAT.



Figure 8. From left to right: nontreated R1, R2, and S biotype, quizalofop-P treated R1, R2, and S biotype at 184 g ai/ha 21 DAT.



Screening for barnyardgrass, common lambsquarters, kochia, redroot pigweed, and wild oat resistance

Albert Adjesiwor

Objective: Characterize the survival of wild oat to herbicides commonly used in PNW cropping systems

Abstract/Summary: About 106 fields were surveyed for kochia, common lambsquarters, redroot pigweed, and barnyardgrass. At least 55% of the kochia and 20% of the common lambsquarters showed reduced sensitivity/resistance to glyphosate. Redroot pigweed was effectively controlled with glyphosate. Dicamba and glufosinate provided very effective control of common lambsquarters, kochia, and redroot pigweed. Wild oat survival to ethalfluralin and fenoxaprop was 68 and 52%, respectively. Survival declined with quizalofop (28%), pinoxaden (26%), and triallate (22%). Very low wild oat survival rates were observed with mesosulfuron (8%), glyphosate and clethodim (4%).

Accomplishments/Results:

Common lambsquarters

Out of the 44 common lambsquarters tested, about 60% survived (control <50%) the 1X rate of glyphosate, and 20% survived the 2X rate of glyphosate (**Figure 9**). Only 5% of the common lambsquarters tested survived the 1X rate of glufosinate and 0% survived the 2X rate. Dicamba provided very effective control of common lambsquarters at both the 1X and 2X rates.

Kochia

About 81% of the kochia tested survived (control <50%) the 1X rate of glyphosate and 55% survived the 2X rate of glyphosate (**Figure 9**). On the contrary, both dicamba and glufosinate provided very effective control of kochia at both the 1X and 2X rates.

Redroot pigweed

Out of the 55 redroot pigweed samples tested, <1% survived (control <50%) at the 1X rate of glyphosate, and there was 0% survival at the 2X rate of glyphosate (**Figure 9**). Both dicamba and glufosinate provided very effective control of redroot pigweed control at both the 1X and 2X rates.



Barnyardgrass

About 40% of the barnyardgrass samples tested survived (control <50%) at the 1X rate of glyphosate, and there was 20% survival at the 2X rate of glyphosate (**Figure 10**). Glufosinate efficacy on barnyardgrass was very variable and this was expected.

Clethodim provided very effective control of barnyardgrass control at both the 1X and 2X rate. This showed that in addition to glyphosate, clethodim will continue to be an additional effective option for controlling barnyardgrass in sugar beet.

Wild oat

There was considerable variability in wild oat response to the 1X rate of the herbicides tested. Wild oat survival to ethalfluralin and fenoxaprop was 68 and 52%, respectively (**Table 1**). Survival declined with quizalofop (28%), pinoxaden (26%), and triallate (22%), showing these herbicides may still provide better control of wild oat but with a significant proportion of wild oat uncontrolled. Very low survival rates were observed with mesosulfuron (8%), glyphosate and clethodim (4%), demonstrating that these herbicides provided the highest levels of wild oat control among the herbicides evaluated. Overall, the levels of wild oat survival to the herbicides tested were concerning and continued monitoring would be essential to track changes in resistance levels.

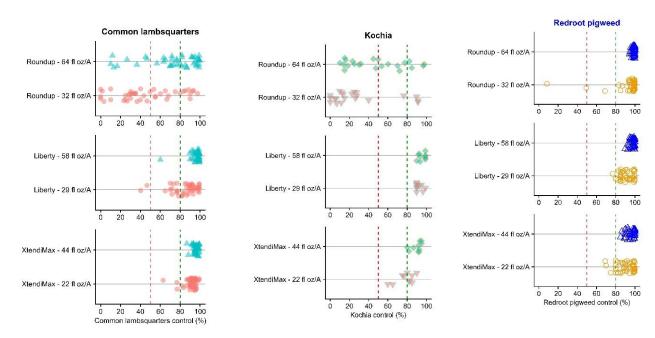


Figure 9. Common lambsquarters, kochia, and redroot pigweed control with 1X and 2X rates of glyphosate (Roundup PowerMax) glufosinate (Liberty) and dicamba (XtendiMax)



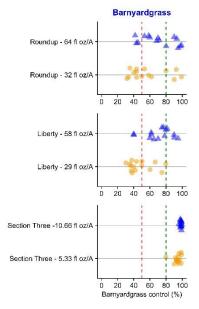


Figure 10. Barnyardgrass control with 1X and 2X rates of glyphosate (Roundup PowerMax) glufosinate (Liberty) and dicamba, and clethodim (Section Three)

Table 1. Summary of wild oat survey results. Numbers in brackets denote the number of viable samples tested.

Farms surveyed		130				
Wild oat survival to	1X rate of sele	ected				
herbicides*						
	ethalfluralin	68%				
	fenoxaprop					
	quizalofop	28%				
	pinoxaden	26%				
	triallate	22%				
	mesosulfuron	8%				
	glyphosate					
	clethodim	4%				



Wild oat and common lambsquarters resistance survey (Idaho wheat Commission partial funded)

Joan Campbell and Traci Rauch

Abstract/Summary: Wild oat was collected from 28 locations in northern Idaho in 2024. Collections were screened to ethalfluralin, clethodim, meosulfuron, quizalofop, pinoxaden, fenoxaprop, quizalofop, triallate, and glyphosate in a greenhouse. No populations were resistant to ethalfluralin and clethodim. Wild oat collection from year two (2024) were resistant to meosulfuron (68%), quizalofop (57%), pinoxaden (36%), fenoxaprop (36%), and triallate (3%). Glyphosate screening is ongoing. Wild oat seed was collected in northern Idaho for the third consecutive year in 2025. Collections will be screened in the greenhouse to the wild oat herbicides listed above. Common lambsquarters seed was collected for the first year to assess herbicide resistance. Collections will continue for three years. Seed will be screened in the greenhouse to broadleaf herbicides used in rotational crops (chickpea, pea, and lentil).



Characterizing Weed Seed and Soil Microbiomes in Irrigated Dryland Wheat Systems

Olivia Landau and Franco Sanchez

Objective

The objective of this preliminary study was to validate the experimental pipeline for obtaining microbiome data from weed seeds and soil in irrigated dryland wheat systems.

Abstract/Summary

This study aims to establish a protocol to characterize the weed seed microbiomes from seedbank samples collected from irrigated dryland wheat systems. In addition to the soil microbiome, both endophytic (internal) and epiphytic (surface-associated) microbial communities of seeds can impact plant growth and establishment.

- Are there microorganisms in the microbiome that are beneficial or antagonistic towards the weed seeds?
- How do microbiomes influence seed decay, dormancy, seedling emergence, and establishment?
- How are microbial communities affected by cultural, mechanical, and chemical weed management practices?
- Which microbial species are vertically inherited within weed seeds?

Accomplishments/Results

To establish an effective sampling and processing pipeline, a customized soil sampler was tested for collecting at a depth of 10 cm (**Figure 11**). The random sampling pattern was evaluated for its efficiency in obtaining sufficient seeds from the Lind Dryland Research Station (**Figure 12**).

Seeds were extracted from soil samples with the R-Tech Elutriator-48X machine (**Figure 13**; R-Tech Industries Ltd., Homewood, Canada), followed by seed cleaning with a seed blower to remove additional organic matter. Recovered seeds were identified with an MZ6 Leica microscope (Leica Camera AG, Wetzler, Germany) and cataloged for further analysis. Seed from Russian thistle (*Salsola tragus*), green foxtail (*Setaria viridis*), and prostrate knotweed (*Polygonum aviculare*) were the most abundant among all the sample dates.



For microbiome characterization, DNA extraction was performed with both surface-sterilized and non-sterilized seeds. Additionally, DNA was extracted from bulk soil samples from each of the sampled plots. DNA extraction steps were performed with appropriate kits for soil and plant tissue with a KingFisher Apex (Thermo Fisher Scientific, Waltham, MA,) equipped with a 96 deep-well head (**Figure 14**). Quantification of DNA was performed with a BioTek Synergy HTX multimode microplate reader (BioTek Instruments, Winooski, VT) and BioTek Gen5 software (version 3.08.01). DNA concentrations ranged from 5 to 15 ng μ L, which is sufficient for submission to the University of Minnesota Core facility for microbiome analysis. Once data has been analyzed, we will be able to characterize the microbiome for each species over time. Sampling will also be repeated in future cropping seasons to measure trends over multiple years. These sampling methods will also be applied to other experiments that aim to address the questions mentioned in the abstract.



Figure 11. Dr. Olivia Landau collecting soil samples using the customized soil sampler. The sampler was designed by Dr. Stuart Wuest (USDA-ARS, Pendleton, OR). In summary, the sampler is a drill bit auger covered by a metal sheath. The metal sheath has an opening that allows the collected soil to be funneled into a bag as the researcher is sampling through the field. The diameter of the auger is 1.0"



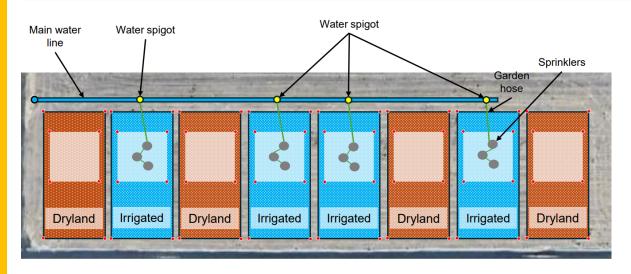


Figure 12. Schematic of the experimental plots, illustrating alternating dryland and irrigated wheat fields. The irrigation system layout is shown, with irrigated plots yielding sufficient seeds for analysis compared to dryland plots. Samples from irrigated plots were prioritized for elutriation and further processing. Photo Credit: Cody Willmore

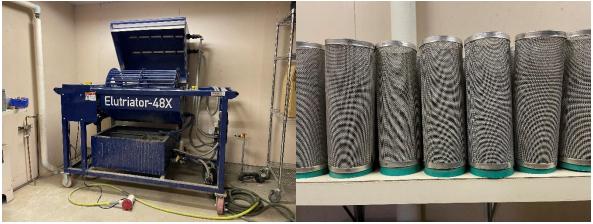


Figure 13. The R-Tech Elutriator-48X machine, used for soil sample processing. Metal mesh cylinders are filled with soil for elutriation to separate weed seeds from finer soil particles.



Figure 14. The Thermo Scientific KingFisher Apex, a high-throughput extraction system capable of processing 96 samples simultaneously. This instrument supports DNA, RNA, and protein extraction, with specialized kits for plant tissue and soil samples for microbiome analysis.



Developing Reference Genomes for Pacific Northwest Weeds

Olivia Landau and Raissa Na-ah

Objectives:

- 1. Develop reference genomes for weed species of the Pacific Northwest (PNW).
- 2. Utilize these genomes for genomic and transcriptomic analysis.

Abstract/Summary: To improve the understanding of the genetics behind any trait in a weed species, genomic and transcriptomic studies are necessary, but these studies require a reference genome. Historically, crops and model species have been the primary focus for reference genome development. Plant genomes are a challenge compared to animal and microbial species due to their comparatively large size and high amounts of repetitive sequences. The addition of polyploidy and high genetic diversity can also complicate reference genome assembly. As sequencing technologies have improved and become more affordable, there has been more interest in the reference genome development for weed species. Mayweed chamomile (Anthemis cotula; Figure 15) was selected for reference genome development. This weed can be very difficult to control in small grain crops due to limited effective chemical options, which is compounded by the fact that may weed chamomile can produce approximately 5,000 to 17,000 seeds that can remain viable for over 10 years. This project included the following collaborators: Dr. Ian Burke (Washington State University), Dr. P. Jeff Maughn (Brigham Young University), and P. Weston Maughn (Washington State University).

Accomplishments/Results:

We present a high-quality, complete telomere-to-telomere chromosome-scale de novo genome assembly of *A. cotula*. Flow cytometry estimated the genome size at ~4.1 Gb per 1C, with somatic chromosome counts of 2n = 2x = 18. *K-mer* analyses using PacBio HiFi reads indicated a haploid genome size of 3.3-3.5 Gb and a relatively high heterozygosity (1.32-1.98%). Combining PacBio SMRT sequencing (141.9 Gb, $40.5\times$ coverage), ONT PromethION ultra-long reads (56.5 Gb, $16.14\times$ coverage), and Hi-C paired-end reads (136 Gb, $38.9\times$ coverage), we generated two phased chromosomescale assemblies totaling 6.35 Gb, with haplotypes 1 and 2 contributing 3.07 Gb and 3.06 Gb, respectively, arranged into nine pairs of pseudo-chromosomes (**Table 2**). The assemblies exhibited high contiguity (1.50: 1.59), and accurate repeat resolution (1.59), high completeness (1.59), and accurate repeat resolution (1.59), resolved at chromosome termini, indicating superior assembly quality compared to other Asteraceae species.



Gene annotation identified 121,177 genes in the diploid assembly, with functional annotation assigned across major protein databases. Repetitive sequences accounted for ~73% of the genome, predominantly LTR retrotransposons (Gypsy: 28.46%, Copia: 14.56%), with smaller contributions from DNA transposons and long interspersed elements. The chloroplast and mitochondrial genomes were also assembled, yielding 149.2 kb and 238.7 kb sequences, respectively, with high collinearity to the reference genome of *Tanacetum vulgare*.

This high-quality reference genome enables downstream genomic analyses, including genome-wide association studies (GWAS) and quantitative trait locus (QTL) mapping. Phenotypic data, including plant height, biomass, and other growth traits, were collected across 19 populations, providing quantitative variation for association with genomic variation. Candidate genes underlying these traits are expected to include hormone biosynthesis and signaling pathways, cell wall biosynthesis and elongation genes, photosynthesis and carbon partitioning genes, and stress-response regulators. This resource lays the foundation for understanding the genetic basis of growth traits in *A. cotula*, and identified genes could be targets of future weed control strategies, such as gene drive and RNA interference.



Figure 15. Pictures of flowering mayweed chamomile (Anthemis cotula). Photo Credit: USDA-NRCS PLANTS Database



Table 2. Quality assessment metrics for the Anthemis cotula genome

	Primary Diploid ^a	Haplotype 1	Haplotype 2			
Genome Assembly						
Total length (bp)	6,351,453,630	3,066,547,061	3,064,349,806			
GC content (%)	36.1	36.1	36.1			
Gene Annotation						
Number of gene models	121,177	59,894	59,817			
Genic space (%)	4.3	4.4	4.4			
Number of CDS	134,889	66,614	66,657			
Number of exon	514,640	253,465	255,467			
Number of intron	379,751	186,851	188,810			
Total gene length (bp)	273,329,338	135,077,063	135,228,716			
Total CDS length (bp)	145,940,353	72,129,055	72,046,308			
Genome Assembly Quality and Completeness						
BUSCO ^b - Genome	C:99.5% [S:2.0%, D:97.5%]	C:97.9% [S:88.8%, D:9.1%]	C:98.0% [S:88.0%, D:10.0%]			
BUSCO ^b - Transcript	C:99.2% [S:1.2%, D:98.0%]	C:97.0% [S:75.5%, D:21.5%]	C:97.3% [S:74.7%, D:22.7%]			
BUSCO ^b - Protein	C:99.3% [S:1.3%, D:98.0%]	C:97.1% [S:75.5%, D:21.6%]	C:97.3% [S:74.5%, D:22.9%]			
LTR Assembly Index	28.4	28.4	28.4			
Merqury - Genome QV	61.2	64.3	64.4			
Merqury - Completeness (%)	98.7	65.6	65.8			

^aPrimary diploid includes haplotype 1, haplotype 2, and unplaced scaffolds.



bBUSCO scores generated with the *viridiplantae_odb10* (n = 1,644) gene dataset.

Optimizing tissue culture for Italian ryegrass, Russian thistle, and common lambsquarters for gene editing

Olivia Landau and Franco Sanchez-Izurieta

Objectives:

- 1. Establish reproducible tissue culture protocols for three weed species (Italian ryegrass, Russian thistle, and common lambsquarters) to enable transformation.
- 2. Develop CRISPR-Cas9 constructs targeting herbicide resistance genes (e.g., acetolactate synthase (ALS)) as a proof-of-concept for functional gene studies.

Abstract/Summary:

One of the challenges within plant biology is determining which gene(s) control traits of interest. Identifying candidate genes can be achieved through genomic and transcriptomic experiments, but these genes require further characterization. One approach is to create knock-out mutations in the gene of interest through genome editing and examine the change in the phenotype of interest. However, for genome editing to be applied to any species there must first be a reliable tissue culture and regeneration protocol established. While model species, like Arabidopsis, have wellestablished protocols for editing genes of interest, and they offer valuable basic understanding of gene function, genome structure, and gene regulation can vary widely in a given weed species from this model species. Thus, direct investigation with the weed species allows for examination of gene function within the context of the genomes structure and regulation mechanisms. This project focuses on three problematic weeds in Pacific Northwest wheat systems: Italian ryegrass (Lolium perenne ssp. multiflorum), Russian thistle (Salsola tragus), and common lambsquarters (Chenopodium album). We aim to develop tissue culture using optimized phytohormone matrices for callus induction and regeneration. Once tissue culture protocols are established, a transformation protocol with CRISPR-Cas9 genome editing will be determined. Eventually, these successful protocols will be implemented for functional studies of traits of interest, such as herbicide resistance, seed dormancy, seed longevity, or stem and seed abscission. When we identify the genetic controls behind a trait, then there is the potential to create herbicide resistance detection assays or create novel weed control methods.

Accomplishments/Results:

A tissue culture protocol was developed for Russian thistle, common lambsquarters, and Italian ryegrass. For Russian thistle and lambsquarters, basal media was first optimized to reduce browning through the addition of activated charcoal and Polyvinylpolypyrrolidone (PVPP). Subsequently, callus formation was successfully achieved from hypocotyl and leaf explants using auxin/cytokinin gradients (**Figure 16** a–



h), where it was determined that stem explants yielded the highest callus formation for Russian thistle, while both leaf and stem explants were effective for lambsquarters. This was followed by the induction of shoot regeneration in both species (**Figure 17**).

The current observed regeneration rates for Russian thistle and common lambsquarters, however, remain too low to reliably proceed with testing this gene delivery system. While alternative explant sources such as apical meristems or immature embryos could be explored to improve efficiency, scaling up with these more laborious methods presents a significant practical challenge for subsequent transformation work. Given that the success of tissue culture is also genotype dependent, other populations of Russian thistle and common lambsquarters can also be tested for tissue culture suitability.

To enable future genome editing once regeneration is optimized for common lambsquarters and Russian thistle, a Golden Gate-compatible plasmid was designed to target the ALS gene as a proof-of-concept to confer herbicide resistance through the induction of an indel mutation, and the efficacy of the designed sgRNA was validated via in vitro cleavage assays.

For Italian ryegrass, a working protocol for sterilizing and dehusking seeds was first established to initiate calli from mature embryos (**Figure 18**), followed by the use of a media matrix to identify optimal phytohormone concentrations. Regeneration has been achieved (**Figure 19**), though this requires further validation with a higher number of explants.



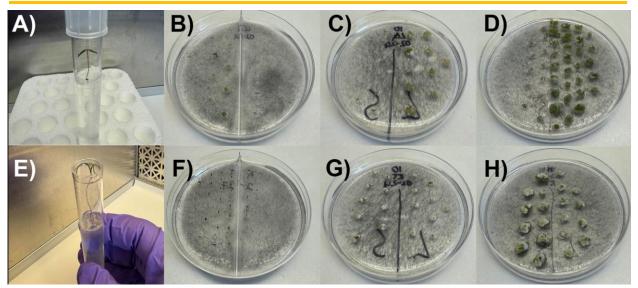


Figure 16. Callus induction in lambsquarters (A–D) and Russian thistle (E–H). Photo credit: Dr. Luigi Peracchi.

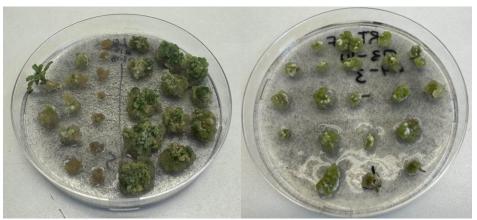


Figure 17. Shoot regeneration in lambsquarters (left) and Russian thistle (right). Photo credit: Dr. Luigi Peracchi.



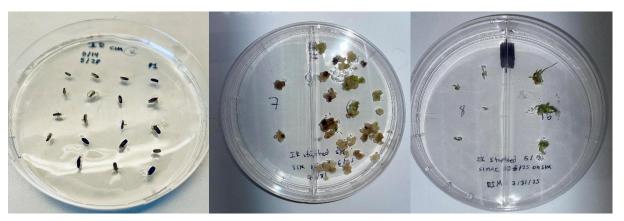


Figure 18. Italian ryegrass tissue culture pipeline. The left panel shows mature embryos poststerilization, the center panel illustrates formed calli on shoot induction media and the right panel shows regenerated shoots transferred to root induction media. Photo credit: Franco Sanchez.



Figure 19. Three Italian ryegrass plants regenerated from the tissue culture pipeline that were highlighted in Figure 18.



Establishing a Tissue Culture—Based Transformation System for Downy Brome (Bromus tectorum): A Gateway to Molecular Weed Biology

Shahbaz Ahmed and Ian C. Burke

Bringing weeds into the molecular biology laboratory has the potential to transform our understanding of weed biology, herbicide resistance, and their adaptation to biotic and abiotic stresses (Wong et al., 2022). Developing robust tissue culture and transformation protocols for weedy species would open new avenues for dissecting the genetic mechanisms underlying invasiveness and resistance. Insights gained from these resilient plants could also be harnessed to identify genes and pathways that improve crop resilience and inform innovative weed management strategies.

After more than year of work, we have finally established the first tissue culture—based, Agrobacterium-mediated transformation pipeline for downy brome (Bromus tectorum), an invasive grass with major agronomic impacts but no prior reproducible genetic toolkit. We optimized callus induction from mature and immature embryos and demonstrated stable transgene expression (GFP) in calli and in leaves of fully regenerated plants. GFP signals were documented by fluorescence stereomicroscopy, and transgene integration was confirmed by PCR amplification of GFP and hygromycin loci (Figures 20 & 21). Together, these results show that downy brome is amenable to transformation and regeneration under defined conditions, providing a practical entry point for molecular studies of weed biology and herbicide resistance.

This transformation system opens the door for a wide range of future applications and by establishing a reproducible pathway for genetic modification in downy brome, this work sets the stage for researchers to bring weedy species into molecular biology labs, where they can be studied with the same precision as crops and model plants. The paper describing this study will soon be sent for publication.



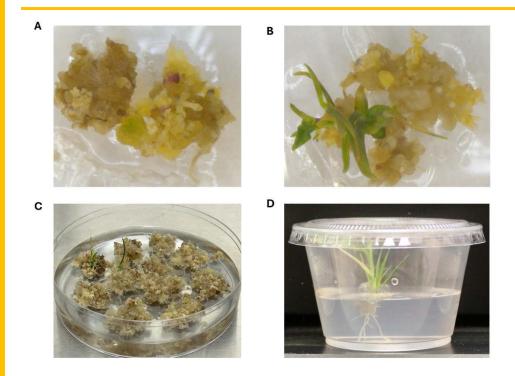


Figure 20. The successful regeneration of transgenic downy brome from callus induction to rooting

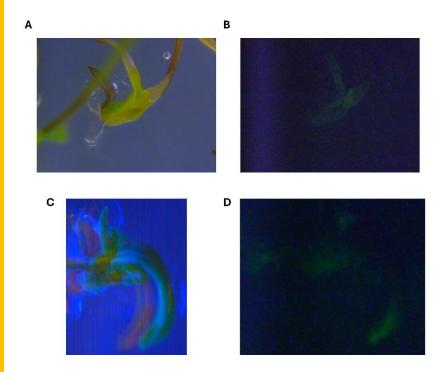


Figure 21. GFP fluorescence observed in transgenic shoots under a GFP filter



Structural Genome Variation as a Driver of Adaptive Glyphosate Resistance in Downy Brome

Ahmed, Shahbaz. Marija Savic, Pragya Asthana, and Ian C. Burke

Herbicide resistance in weeds represents one of the clearest examples of rapid adaptation and evolution in response to strong human selection. We are investigating this process in downy brome (*Bromus tectorum*), a major agricultural weed that has recently evolved resistance to glyphosate. Understanding the genetic basis of this adaptation is critical both for basic evolutionary biology and for developing sustainable weed management strategies.

In this project, we focused on resistant downy brome biotypes that were identified and confirmed under greenhouse conditions. We first sequenced the EPSPS gene, the target of glyphosate, to test for known resistance-causing point mutations. Our analyses revealed no target-site mutations in resistant plants. We then used qPCR-based copy number analysis, which demonstrated that resistant lines carry substantially elevated EPSPS copy number compared to sensitive controls (**Figure 22**).

To further investigate the genomic architecture of this amplification, we performed whole-genome sequencing (WGS) of resistant lines. When aligned to the published reference genome (assembled from a sensitive biotype), the resistant reads showed breakdown of alignments across the EPSPS region, suggesting major structural rearrangements. A de novo assembly of the resistant genome recovered a 37 kb contig carrying EPSPS, which showed multiple complex alignments against the reference. These results indicate that glyphosate resistance in downy brome is mediated by copy number amplification through structural rearrangements, likely involving repetitive elements (**Figure 23**).

Together, this work provides a framework for understanding the molecular basis of glyphosate resistance in *B. tectorum* and establishes the foundation for deeper investigations into the role of structural variation in weed adaptation.



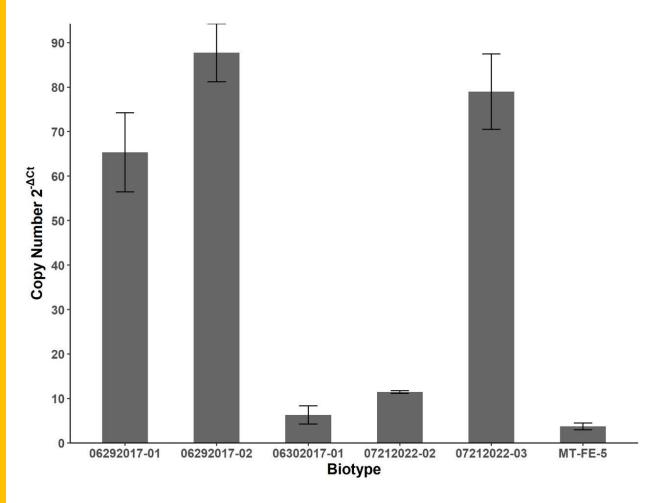


Figure 22. EPSPS copy number in susceptible (06302017-01 and MT-FE-5) and resistant (06272017-02, 07212022-02, 07212022-03, 06292017-01) downy brome biotypes relative to ALS copy number.



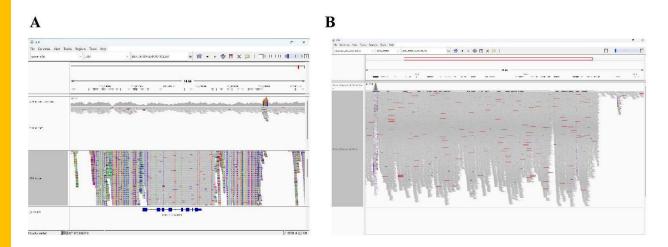


Figure 23. A. Increased read coverage in resistant line S5 compared to susceptible line S3 from whole-genome sequencing alignments indicates higher EPSPS copy number in resistant plants. In panel A, the break in read alignments when mapping to the susceptible reference genome highlights structural variation and the presence of sequences not represented in the reference. By contrast, the continuous alignment in panel B of reads against the de novo—assembled resistant genome demonstrates that resistant lines have acquired and incorporated new sequence into the EPSPS locus.



Germination temperature and moisture requirements of herbicide-resistant downy brome

Victor Ribeiro and Albert Adjesiwor

Objective:

Evaluate the germination temperature requirements of herbicide-resistant downy brome from Oregon

Abstract/Summary:

Knowledge of weed emergence timing and patterns is critical in developing integrated weed management strategies. In the Pacific Northwest, downy brome (*Bromus tectorum*) is one of the most widespread and problematic grassy weeds in small grain production systems. Laboratory experiments were conducted in 2025 to assess germination temperature requirements of acetyl-CoA carboxylase (ACCase), acetolactate synthase (ALS), and ALS + photosystem II (PSII) herbicide-resistant downy brome collected from Oregon. At the cold (5 C) and warm temperatures (36 C), ALS and ACCase resistant downy brome had slower germination and relatively low cumulative germination over 28-day period compared to the susceptible or multiple resistant downy brome (ALS + PSII). The ALS + PSII resistant downy brome has the highest cumulative germination at the warmest temperature (36 C).

Accomplishments/Results:

At cold temperatures, ALS and ACCase resistant downy brome had slower germination and relatively low cumulative germination over 28-day period compared to the susceptible or multiple resistant downy brome (ALS + PSII) (Figure 24). At 22 C, germination speed and cumulative germination were similar among the susceptible and resistant populations. At the highest temperature (36 C), the ALS + PSII resistant downy brome has the highest cumulative germination, followed by the susceptible population. The ALS and ACCase resistant downy brome had slower germination and low cumulative germination at 36 C.



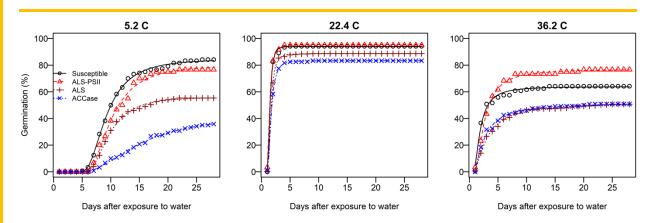


Figure 24. Germination of acetyl-CoA carboxylase (ACCase), acetolactate synthase (ALS), and ALS + photosystem II (PSII) herbicide-resistant downy brome collected from Oregon at different temperatures (5.2 C/41 F, 22.4 C/72 F, and 36.2 C/97 F).



Germination moisture requirements of Italian ryegrass, downy brome and wheat

Chandra Montgomery, Albert Adjesiwor, Joan Campbell

Objective:

Evaluate the germination requirements of Italian ryegrass vs spring wheat and downy brome vs winter wheat

Abstract/Summary:

Laboratory studies were initiated in 2024 at the University of Idaho Research and Extension Center to determine the germination moisture requirements of Italian ryegrass (*Lolium multiflorum*) vs spring wheat (*Triticum aestivum*), and downy brome vs winter wheat collected from the Pacific Northwest. Polyethylene glycol (PEG 8000) was used to obtain 10 different osmotic potentials (0 [wet soil] to -2 MPa [dry soil]). At osmotic potentials of 0 to -0.2 MPa, germination was 80 to 100% for both Italian ryegrass and spring wheat. Italian ryegrass germination was at least 1.5x greater than spring wheat at osmotic potentials of -0.4 to -0.8 MPa. There was minimal to no germination of both Italian ryegrass and spring wheat at osmotic potentials less than -1.0 MPa. Winter wheat germination was similar or greater than downy brome at 0 to -0.2 MPa osmotic potentials. When osmotic potentials reduced to -0.8 to -1.0, winter wheat germination was significantly greater than downy brome.

Accomplishments/Results:

Under wetter soil moisture conditions (osmotic potentials of 0 to -0.2 MPa), germination was 80 to 100% for both Italian ryegrass and spring wheat (**Figure 25**). Italian ryegrass germination was at least 1.5x greater than spring wheat at slightly dry conditions (osmotic potentials of -0.4 to -0.8 MPa). There was minimal to no germination of both Italian ryegrass and spring wheat at osmotic potentials less than -1.0 MPa.

In the winter wheat vs downy brome experiments, winter wheat germination was similar or greater than downy brome under wetter conditions (0 to -0.2 MPa) (**Figure 26**). Under moderately dry conditions (osmotic potentials of -0.8 to -1.0), winter wheat germination was significantly greater than downy brome collected from the PNW.



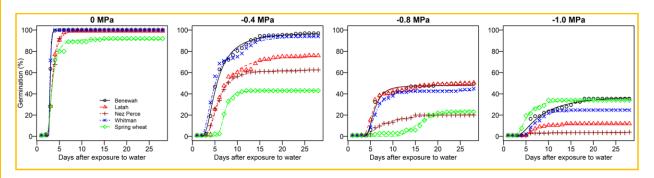


Figure 25. Germination of spring wheat and Italian ryegrass collected multiple counties in Idaho and Washington at different osmotic moisture potentials.

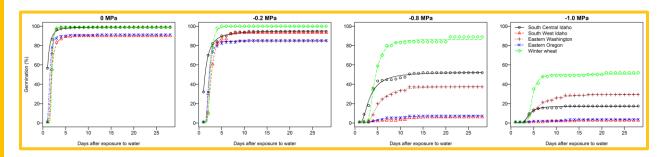


Figure 26. Germination of winter wheat and downy brome collected from the Pacific Northwest at different osmotic moisture potentials.



Objective #1: Crop Rotation Based Theme

Weed Management in Dryland Wheat-Fallow Systems.

Judit Barroso, Nicole Durfee, Stewart Wuest, Vhuthu Ndou.

Objective: Refining best management practices associated with integrated chemical and mechanical weed control systems

Abstract/Summary: Herbicide-resistant weeds are a threat to agricultural productivity nationwide with significant consequences to no-till crop systems. As the pace at which weeds develop resistance surpasses that for the discovery of novel herbicides, new technologies and practices are necessary for effective weed management and conservation of current herbicide chemistries. Chemical control with integrated weed management strategies is a potential option to maintain long-term sustainability in the wheat cropping systems; however, information on best integrated weed management practices is lacking for predominant dryland regions of eastern Oregon and the inland Pacific Northwest (PNW). This research will evaluate the efficacy and sustainability of different weed management practices applied during the fallow year of the common winter wheat-fallow rotation. The study will determine whether occasional tillage can reduce herbicide-resistant weeds without the negative outcomes associated with tillage (increased soil erosion, water runoff, soil compaction, etc.). The study will be conducted at two sites in Oregon (Pendleton and Moro) under intermediate and low annual precipitation. The main plots will be used to study the effect of weed management in fall and/or spring and the subplots will be used to study the effect of two different weed managements in late summer, chemical (with herbicides) vs. mechanical (with an undercutter pass that is considered minimum tillage). Weeds will be evaluated in the fallow and crop phases. In the crop phase, weeds will be controlled chemically and uniformly among the different plots. In addition, soil water content, water infiltration and soil compaction will be evaluated per subplot each year in spring and fall.

Accomplishments/Results: Similar to what was reported in the first season, analysis from the second season (harvest 2024) indicated that the two different weed control practices conducted in June or early July (sweep vs. spray) are impacting the results much more than the different weed control treatments in fall and spring (**Table 3**).

In season 2024, two of the trials were in crop (one in Pendleton and the one in Moro) and one was in fallow (one in Pendleton). Both trials in crop showed results similar to the previous year, but the trial in Pendleton presented some peculiarities that will be explained later. In Moro, we observed greater crop cover (better crop establishment) and weed cover in the subplots that had a sweep operation in summer 2023 (**Figures 27a & 27b**). Even though more weeds germinated in the area with the sweep pass, the weed



infestation was controlled after our spring evaluation and those subplots had significantly greater yields than the subplots with a spray (herbicide) application in July 2023 (**Figure 27c**). As observed in 2023, the subplots that had a sweep in the previous fallow, in addition to having greater yield, also stored more water (**Figure 27d**). The different treatments conducted in fall and spring of the fallow year (**Table 3**) did not show significant differences for all the studied variables (**Figure 27**).

In the crop trial in Pendleton this year, Block 1 with replications 1 and 2 performed differently than Block 2 with replications 3 and 4. When we started this trial in fall 2022, Block 2 had a uniform weed infestation, while Block 1 had markedly lower infestation in the subplots assigned to be sprayed in summer. The analysis from this year indicated replications were significantly different and we analyzed Block 1 independently from Block 2. Regarding crop cover, Block 2 did not show significant differences among fall and/or spring treatments, or between subplots (with different summer treatments), but Block 1 showed marginally significant (p = 0.086) greater crop cover in the subplots with a sweep pass the previous fallow. The weed cover results followed the crop cover, while no differences were found in Block 2 between subplots or treatments, a greater weed cover was found in the subplots with sweep in Block 1 (Figure 28a). Similarly, the yield did not show differences between treatments and subplots in Block 2, but it was higher in the subplots with chemical control (spray) in late summer in the fallow year (Figure 28b), probably because that area had fewer weeds. This year, the predominant weed in this trial was jointed goatgrass (Aegilops cylindrica) that we could not control in-crop (there are no herbicides to control this weed in traditional wheat varieties), so it is probable that the weed competition from germination to harvest caused the yield loss. The gravimetric water content in the soil profile was greater in the subplots with the sweep pass than with the spray pass. This difference in water storage was more pronounced in Block 1 than in Block 2 probably because of the lower yield in those subplots (Figures 28c & 28b) in addition to the sweep effect observed in 2023 and this year. It would be very important to see how this trial evolves once the weeds are being controlled in the entire trial area equally for one more year.

The infiltration analysis conducted in spring 2024 in both crop trials (Pendleton and Moro) showed no significant differences between the six treatments or sweep *versus* spray. The soil compaction data collected in the two trials in Pendleton in spring 2024 (one trial was fallow and the other had crop) indicated again that the most important effect was caused by the subplots (different summer weed control in fallow) and not among the fall and/or spring weed control treatments in fallow. The subplots with the sweep pass showed less soil compaction than the subplots with the spray pass.



Overall, the work performed in 2024 (the second year where we could see the effect on the crop year) suggests that the sweep operation in the late summer to control broadleaf weeds in fallow might be a sustainable practice for combating herbicide-resistant weeds. More years of data are necessary to confirm these results.

Note: A summary of results from these trials in 2023 can be found online in the Weeders of the West blog: https://smallgrains.wsu.edu/weeders-of-the-west/2024/09/12/undercutter/

Table 3. Weed control treatments conducted in fall (≈ November), spring (≈ April - May), and summer (≈ late June - early July) in replicated plots established at Pendleton, Oregon and Moro, Oregon in 2022, 2023 and 2024.

Treatment	Fall treatment to main plots	Spring treatment to main plots	Summer treatment to subplots
1	-	Herbicide	1a. Herbicide 1b. Undercutter
2	Herbicide	Herbicide	2a. Herbicide 2b. Undercutter
3	Herbicide	Turbo-Max*	3a. Herbicide 3b. Undercutter
4	-	Herbicide + Turbo-Max	4a. Herbicide 4b. Undercutter
5	-	Turbo-Max	5a. Herbicide 5b. Undercutter
6	Turbo-Max	Turbo-Max	6a. Herbicide 6b. Undercutter

^{*}Turbo-Max is a vertical tillage implement with 20" turbo blades spaced 7.5" apart (https://www.greatplainsag.com/en/products/418/turbo-max%C2%AE)



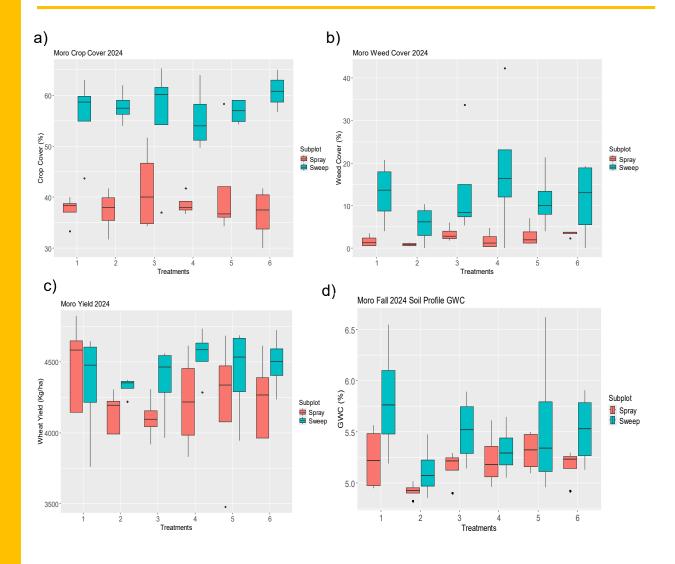


Figure 27. Percentage crop cover (a), percentage weed cover (b), wheat yield in kg/ha (c), and gravimetric water content (GWC) in the soil profile in percentage (d) in the Moro trial in 2024.



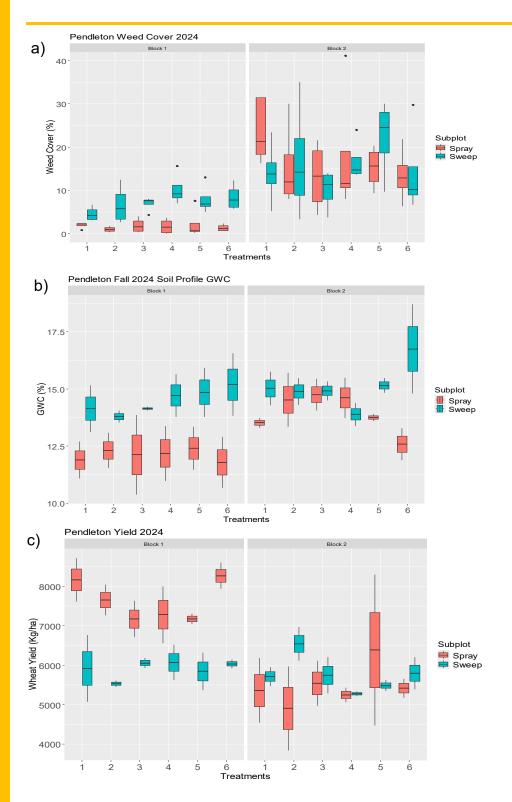


Figure 28. Percentage weed cover (a), wheat yield in kg/ha (b), and gravimetric water content (GWC) in the soil profile in percentage (c) in the Pendleton trial in crop (winter wheat) in 2024, according to replications 1&2 (Block 1) and replications 3&4 (Block 2).



Weed response to acid soil versus lime amended soil (Idaho Wheat Commission partial funded)

Joan Campbell and Traci Rauch

Objective: Monitor soil weed seed and weed control among twelve crop rotations and pH adjusted soil

Abstract/Summary:

An experiment was placed near Moscow and Genesee, Idaho to measure weed seed bank and weed control among twelve crop rotations and pH adjusted soil. Lime was applied to half the experiment, incorporated with a field cultivator, and wheat was planted to the entire experiment in April 2024. The fields were farmed as direct seed for several years and will be direct seed for the duration of the experiment. The twelve rotations will be winter wheat, winter wheat, rotational crops and winter wheat, spring wheat, rotational crops. Chickpea, mustard, and glyphosate resistant canola are rotational crops. The rotational crops were planted in spring 2025. Weeds were counted in chickpea plots only since canola and mustard were weed-free. Crops were harvested at maturity. Soil will be sampled in the fall of 2025 to measure weed seed bank.

Accomplishments/Results: Wheat yield in 2024 was not different among soil pH. This was 3 months after placing lime which is not enough time to see pH changes, generally. Soil pH and available aluminum were measured in spring 2025 (**Table 4**). Soil pH was higher in near the surface likely due to shallow lime incorporation. Variability in edaphic parameters are likely due to uneven incorporation. This is expected to be more uniform over time. Weed populations were higher and crop yield was lower in non-limed soil at both locations. However, only wild oat was statistically different (**Tables 5 & 6**).

Table 4. Soil pH and available aluminum at Moscow and Genesee, Idaho.

Location	Soil depth	Soil acidity (mean)	Available aluminum (max)
	inch	рН	ppm
Moscow	0 to 2	4.6 to 6.4 (5.6)	34 (88)
	2 to 4	4.7 to 5.8 (5.1)	38 (101)
Genesee	0 to 2	5.5 to 7.0 (6.3)	<1 (<1)
	2 to 4	5.3 to 6.1 (5.6)	2(2.5)



Table 5. Weed populations in chickpea for pH amended soil in 2025 at Moscow and Genesee, Idaho.

Soil	Moscow, Idaho		Genesee, Idaho		
treatment	Wild oat	All weeds	Common lambsquarters All weed		
	plants/plot				
Limed	5	49	11 4		
Not limed	10	59	18 60		

Table 6. Crop yield for pH amended soil in 2025 at Moscow and Genesee, Idaho.

Soil	Moscow			Genese		
treatment	Canola Mustard Chickpea Canola Mustard Chickpe				Chickpea	
	lb/acre			lb/acre		
Limed	1371	1150	2222	1486	1857	1811
Not limed	1249	1044	1991	1391	1816	1646



Objective #1: Cross-Cutting Theme

Impact of seed placement depth on preemergence herbicide efficacy

Chandra Montgomery and Albert Adjesiwor

Objective:

Quantify the impact of tillage (seed burial depth) on Italian ryegrass control with preemergence herbicides

Abstract/Summary:

Tillage (seed burial depth) may impact the efficacy of preemergence herbicides by allowing weed seeds to germinate before herbicides are available for uptake. To better understand how seed placement depth affects the efficacy of preemergence herbicides, greenhouse studies were conducted in 2025 determine how Italian ryegrass seed placement at different depths affects the efficacy of Zidua (pyroxasulfone) and Treflan (trifluralin). Zidua was more effective at controlling Italian ryegrass when seeds were in the top 2 inches of the soil. Treflan efficacy was variable when Italian ryegrass seeds were placed on the soil surface, but optimum efficacy was obtained when seeds were buried at 0.25 inches deep. Treflan efficacy was reduced when Italian ryegrass seeds were placed deeper than 0.25 inches, with efficacy dropping to about 25% at 2 inches.

Accomplishments/Results:

When Italian ryegrass seeds were placed were in the top 2 inches of the soil, pyroxasulfone was more effective at controlling Italian ryegrass than trifluralin (**Figure 29**). Also, pyroxasulfone efficacy was very consistent in the top 2 inches of the soil. Trifluralin efficacy was variable when Italian ryegrass seeds were placed on the soil surface (0 inch), but optimum efficacy was obtained when seeds were buried at 0.25 inches deep. trifluralin efficacy was reduced when Italian ryegrass seeds were placed deeper than 0.25 inches, with efficacy dropping to about 25% at 2 inches. At 4 inches, there was no Italian ryegrass emergence, even in the nontreated checks (**Figures 29 & 30**).



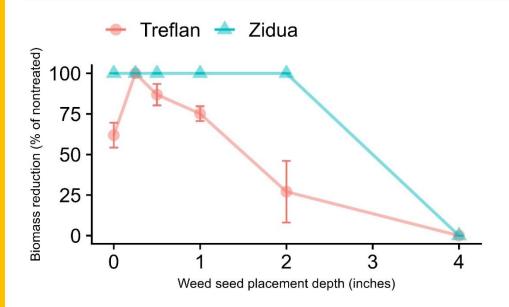


Figure 29. Zidua (pyroxasulfone) and Treflan (trifluralin) efficacy as influenced by Italian ryegrass seed placement depth in field soil.



Figure 30.
Experimental
setup to assess
Zidua
(pyroxasulfone)
and Treflan
(trifluralin) efficacy
as influenced by
Italian ryegrass
seed placement
depth in field soil.



Using a Digital Phenotyping System for Pre-emergence Dose-response Assays

Olivia Landau

Objective:

- 1. Compare manual measurements of fresh-biomass (FB) and plant height (PH True) to the morphological and spectral parameters collected by the Phenospex TraitFinder through Pearson correlation analysis.
- **2.** Determine the utility of the Phenospex Traitfinder parameters for dose-response (DR) assays by generating DR curves and growth reduction 50 (GR₅₀) estimates from the data and comparing results to FB data.

Abstract/Summary:

Herbicide DR assays are a quantitative approach for measuring herbicide sensitivity that requires biomass from plants subjected to a spectrum of herbicide doses to estimate GR₅₀ values. These GR₅₀ values are compared among herbicide-resistant and sensitive plant populations. The Phenospex TraitFinder is a digital phenotyping system that collects data for 13 morphological and 7 spectral parameters. This equipment should eliminate the need for manual collection of biomass by collecting digital biomass (DB). However, comparisons of digitally and manually collected data for DR assays have not been performed. Thus, this study sought to compare digitally and manually collected data and assess the utility of all 20 Phenospex TraitFinder parameters in DR assays. To address these objectives, pre-emergence DR assays using fomesafen and atrazine were implemented with a sensitive population of *Chenopodium album* L. (common lambsquarters). At 21 days after treatment, plants were scanned with the Phenospex TraitFinder and manual measurements for FB and PH were collected.

Accomplishments/Results:

In both experiments, morphological parameters displayed strong positive correlations ($r \ge 0.70$, P < 0.05) with each other and the manual measurements (**Figure 31**). Some of the highest positive correlations (r = 0.97, P < 0.05) occurred between digitally collected data (DB, PH Mean, and PH Max) and their equivalent manual measurements (FB and PH True; **Figure 31**). Among the Phenospex TraitFinder parameters, only morphological parameters generated highly similar DR curves and GR₅₀ estimates relative to FB data, including 3D Leaf Area, DB, Convex Hull Area, Projected Leaf Area, and Voxel Volume Total (**Figure 32** and **Table 7**). Results indicate that multiple metrics could be employed for DR assays in lieu of using FB. Implementing some form of digital phenotyping to avoid manual measurements allows researchers to decrease turnaround time and labor to complete any phenotyping research and share relevant findings. Furthermore, when



herbicide-resistant plants are identified, they can be preserved for phenotyping at later growth stages, tissue collection, and to produce progeny for future genomic experiments. Whether the same trends for morphological parameters will be observed for *C. album* DR assays utilizing other herbicides with different modes of action warrants further exploration. Examining other dicots and grass species will also be necessary in the future.

Figures and Tables:

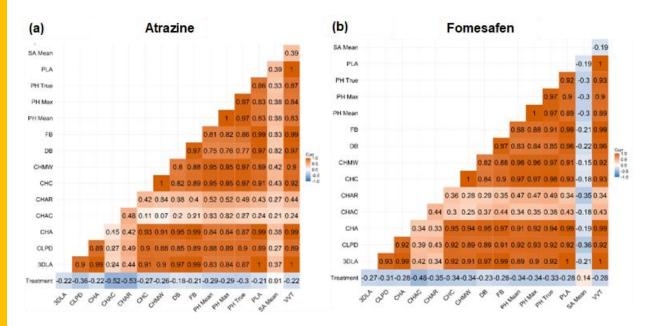


Figure 31. Pearson correlation coefficients between the specified herbicide treatment, manual measurements, and morphological parameters. Results for the atrazine experiment are displayed in (a) and results for the fomesafen experiment are displayed in (b). Treatment represents increasing doses of the specified herbicide. An "X" in the background of the cell indicates P > 0.05. A lack of an "X" in the background of the cell indicates P < 0.05. Abbreviations: 3DLA, 3D leaf area; CHA, convex hull area; CHAC, convex hull area coverage; CHAR, convex hull aspect ratio; CHC, convex hull circumference; CHMW, convex hull max width; CLPD, canopy light penetration depth; DB, digital biomass; FB, fresh biomass; PH Max, plant height max; PH Mean, plant height mean; PH True, plant height true; PLA, projected leaf area; SA Mean, surface area mean; VVT, voxel volume total.



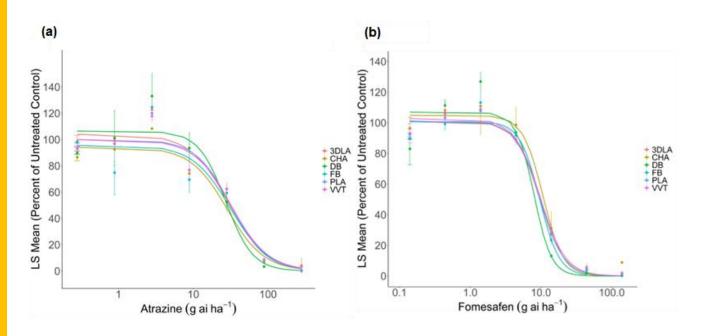


Figure 32. Atrazine (a) and Fomesafen (b) dose-response curves generated from morphological parameters. Only curves similar to the fresh biomass (FB) data are highlighted in these graphs. Doses for atrazine ranged from 0.28 to 280 g ai ha-1 and doses for fomesafen ranged from 0.14 to 140 g ai ha-1. All doses were spaced by a factor of 3.16. Each circle represents the Least-Square (LS) mean expressed as a percentage of the untreated control. Error bars depict the standard error of the mean. Abbreviations: 3DLA, 3D leaf area; CHA, convex hull area; DB, digital biomass; FB, fresh biomass; PLA, projected leaf area; VVT, voxel volume total.



Table 7. Summary of growth reduction (GR50) estimates for morphological parameters that are similar to fresh biomass (FB) data. Abbreviations: 3DLA, 3D leaf area; CHA, convex hull area; DB, digital biomass; FB, fresh biomass; PLA, projected leaf area; VVT, voxel volume total; SE, standard error of the mean. P-value indicates whether the given GR50 estimate significantly differs from the FB GR50 estimate.

Atrazine					
Parameter	GR ₅₀ Estimate (SE) g ai ha ⁻¹	<i>P</i> -value			
3DLA	29.57 (±8.76)	0.8887			
CHA	28.36 (±8.58)	0.8085			
DB	27.05 (±5.58)	0.6713			
FB	31.36 (±9.75)	NA			
PLA	31.74 (±9.04)	0.9770			
VVT	31.96 (±9.37)	0.9643			
	Fomesafen				
Parameter GR ₅₀ Estimate (SE) P-value g ai ha ⁻¹					
3DLA	9.55 (±2.16)	0.9977			
CHA	10.65 (±2.21)	0.7423			
DB	7.93 (±1.83)	0.5291			
FB	9.56 (±2.19)	NA			
PLA	9.64 (±2.15)	0.9785			
VVT	9.75 (±2.14)	0.9516			



Wild oat interference in wheat affected by acid soils (Idaho wheat Commission partial funded)

Joan Campbell

Objectives: Assess competition between wild oat and an aluminum tolerant and susceptible wheat variety, and assess plant response in the greenhouse to two soil acidity levels.

Abstract/Summary:

Effects of soil pH on weeds growing with crops are being assessed near Moscow, Idaho. A field with soil pH of 4.3 was amended with 2 tons/acre calcium carbonate (lime) in 2017 in randomized strips. The experiment was placed across the strips of lime/no lime. The experiment is a 2 by 2 by 2 factorial with two varieties, two levels of soil pH, and wild oat vs no wild oat. Plots are 5 by 36 ft. Wild oat was planted in half the plots. The experiment has four replicates and is duplicated in time. Net CL (aluminum susceptible) and Seahawk (aluminum tolerant) are the spring wheat varieties. Wild oat population is measured, and light penetration through the canopy is measured for 4 weeks. Wheat grain yield is assessed at harvest. In 2022, wild oat population was 10 and 5 panicles per ft-row comparing no lime to lime and 9 and 5 panicles per ft-row comparing Seahawk to Net CL. Grain yield was similar among lime and no lime Seahawk and limed Net CL, at 2604, 2608, and 2695 lb/acre, respectively. Grain yield was 557 lb/acre for Net CL non-limed. In 2023, wild oat populations were 5 and 7 plants per ft-row with lime and non-lime, respectively. Wild oat populations were 4 and 8 plants per ft-row with Seahawk and Net CL, respectively. In 2023, there was no variety by lime interaction. Seahawk and Net CL averaged 1658 and 840 lb/acre, respectively. Wheat grain yield was 1928 and 570 lb/acre for limed and no lime, respectively. Plant growth was assessed in the greenhouse with the same field soil. Common lambsquarters and spring pea plants grew taller in lime soil compared to non-limed. Downy brome and wild oat grew taller in non-limed soil compared to limed soil.



Table 8. Wild oat panicles are affected by variety and soil pH.

		Wild oat panicles		
Variety	Limed	2022	2023	
		Number per m row		
Net CL	No	42	32	
Net CL	Yes	15	14	
Seahawk	No	18	10	
Seahawk	Yes	13	16	

Table 9. Wheat yield is affected by wild oat.

	Wheat yield		
Wild oat	2022	2023	
	kg	/ha	
No	2220 a	1290 a	
Yes	2012 b	1208 a	

Table 10 Wheat yield is affected by soil pH and variety.

		Wheat yield		
Variety	Limed	2022	2023	
		kg/ha		
Net CL	No	557 a	139 a	
Net CL	Yes	2695 b	1540 c	
Seahawk	No	2608 b	1001 b	
Seahawk	Yes	2604 b	2315 d	



Table 11. Effect of limed soil on plant height 4 and 8 weeks after emergence

		Plant height				
	Lime	No lime	Lim	ie	No lime	
Species	4 w	4 weeks		8 weeks		
			cm			
com. lambsquarters (1)	4.2	3.3^{1}		11	8 ²	
com. lambsquarters (2)	4.6	3.2^{1}		9	6	
prickly lettuce **	3.4	0.9^{1}		6	4 ²	
Italian ryegrass	13.0	11.5		18	22	
ventenata	4.6	3.0		7	6	
interrupted windgrass	4.7	4.8		8	7	
rattail fescue	10.0	10.7		9	11	
downy brome	8.9	10.2		14	17¹	
wild oat	18.6	18.8		37	50 ²	
'Kamiak' wheat	17.6	16.2		22	25	
'Voodoo' wheat	18.7	16.6		30	30	
pea	6.1	5.6		13	8 ²	



¹ Statistically different P < 0.01 ² Statistically different P < 0.05

Effect of tillage on weed soil seed bank and weed control (Idaho wheat Commission partial funded)

Joan Campbell and Traci Rauch

Objective: Monitor soil weed seed bank and weed control among no tillage versus chisel plow/field cultivation.

Abstract/Summary: Tillage plots were established two decades ago near Genesee, Idaho. The plots are 60 by 260 ft with five replications. Treatments are direct seed (notilled) or chisel plow followed by field cultivation. Soil samples were taken across each plot at 30 ft increments along a line transect. Weeds were counted in crop along the same transect line. In 2025, the weed population was 3 and 4 plants/sq ft for no-tilled and tilled treatments, respectively. Chickpea plant population was 22 and 21 plants/sq ft for no-tilled and tilled treatments, respectively. Chickpea seed yield was 1554 and **1**430 lb/a for no-tilled plots and tilled, respectively.



Sorgoleone extract from sorghum for potential weed control (Idaho wheat Commission partial funded)

Joan Campbell

Objective: Screen weed and crop seeds for potential control and tolerance to sorgoleone.

Abstract/Summary: Crop and weed seeds were screened to sorgoleone sorghum extract on agar plates. The sorgoleone dose ranged from 0.025 to 0.3 ppm. Germination and seedling growth of all crops and weed seeds screened so far were reduced to increasing amounts of sorgoleone.

Accomplishments/Results: Italian ryegrass, kochia, Russan thistle, and downy brome, germination and seedling growth were inhibited with increasing doses of sorgoleone. Results of weed species tested are all similar to Russian thistle (Figures 32, 33 & 34). Although canola and wheat varieties tested to date have not shown high amount of tolerance to sorgoleone, this product has potential for non-selective weed control.

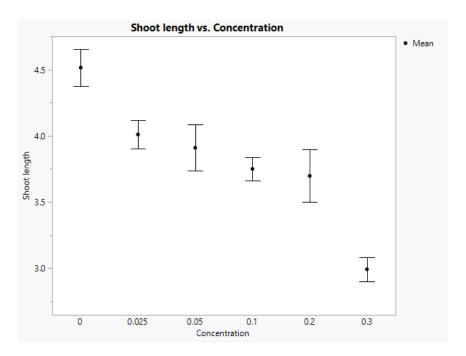


Figure 32. Russian thistle shoot length during germination affected by sorgoleone. Bars are at the 95% confidence level.



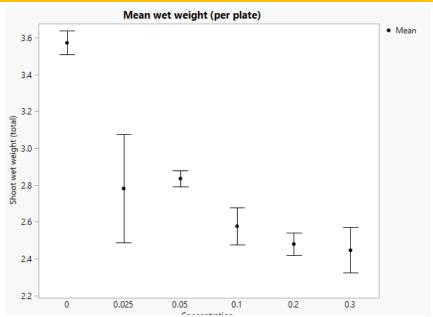


Figure 33. Russian thistle biomass during germination affected by sorgoleone. Bars are at the 95% confidence level.



Figure 34. Russian thistle exposed to 0, 0.25, 0.05, 0.1, 0.2, and 0.3 ppm sorgoleone.



Infrared and high intensity blue light for crop seed stimulation and weed seed nonviability (Idaho wheat Commission partial funded)

Joan Campbell

Objective: Stimulate crop seed viability and decrease weed seed viability with infrared and blue light exposure.

Abstract/Summary: High levels of infrared (IR) and blue light exposure can render weed seeds nonviable. At lower IR levels, crop seed/seedling vigor can be increased. Adding a high level exposure of IR and blue light can be used on combines to destroy weeds seeds that are ejected from the combine. At lower level of IR and high level of blue light, exposed crop seeds can be more vigorous. This will allow higher competition of crops with weeds. Soybean has been shown to have increased viability. This research is looking at wheat, pulse crops, and canola to determine increased competitive ability with weeds.

Accomplishments/Results: Research is ongoing to determine the optimum exposure of blue LED and infrared combinations to increase viability of wheat, canola, and pulse crops. Combinations include five exposure times and four levels of IR intensity.



Light exposure to canola plants for increased yield (Idaho wheat Commission partial funded)

Joan Campbell and Traci Rauch

Objective: Determine canola yield after exposure to high intensity light

Abstract/Summary: Plants exposed briefly to high light intensity have been shown to have increases in branches and seeds. Canola was planted in a field near Moscow, Idaho. Two hundred plants from 3 leaf to 7 leaf stages were exposed for 5 or 10 seconds of high light intensity. Seed yield is being measured compared to 100 non-treated plants.

Accomplishments/Results: One third of the plants have been harvested. Yield is not different from the non treated plants so far.



Objective #2: Socio-economic

Weed Management Perspectives among Pacific Northwest Agricultural Producers

Pat Hatzenbuehler, Doug Finkelnburg, and Nick Bergmann

Abstract/Summary:

A survey designed to determine PNW producer perspectives on weed prevalence, weed management practices, and herbicide resistance was developed in the fall 2024. The electronic Qualtrics version of the survey was disseminated via email through partnerships with the ID, OR, and WA grain commissions from November 2024 through March 2025. The survey responses were assessed for validity and completeness in the following months, and 81 were determined as valid and mostly complete. These included 38 responses from ID, 10 from OR, and 33 from WA. The data were further organized and analyzed by a University of Idaho Applied Economics MS student in the summer 2025. Initial results show that out of 9 listed challenges facing PNW producers, "herbicide resistance" was ranked as 3rd most threatening, with only "high equipment costs" (ranked 2nd) and "low commodity prices" (ranked 1st) ranked higher (**Figure 35**). Additionally, there were more counties for which producers stated there are more problematic weed species on their operations today compared to 10 years ago than those that stated there were fewer problematic weed species.

Accomplishments/Results:

An abstract for a symposium at the Western Society of Weed Science Annual Meeting in March 2026 that includes discussion of the PNW weed management perspectives survey was approved in August 2025. In addition, more results and insights will be disseminated at several extension and research presentations in the fall 2025 through summer 2026.



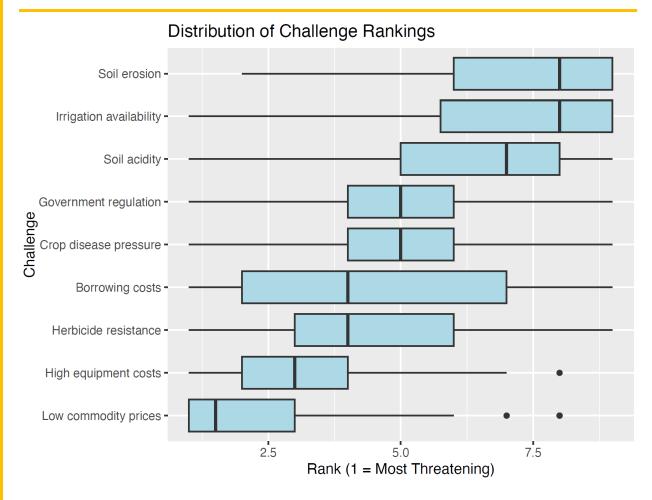


Figure 35. Distribution of Rankings of Challenges to PNW Producer Operations from Most to Least Threatening. Note: 72 total responses.



Community-Based Management of Herbicide Resistance

Nick Bergmann, Ian Burke, Garett Heineck, Joaquin Casanova

Abstract/Summary: Community-based approaches to herbicide resistance management have historically centered on common pool resource theory and cooperative weed management. We have applied an alternative framework – coproduction of knowledge – to create high functioning community-engaged research projects focused on solving farmer-driven research questions and priorities through coinnovation. As a well-established method used to conduct participatory research, coproduction of knowledge reworks the fundamental relationship between scientific experts and resource users. Specifically, the experiential knowledge of agriculture producers is elevated to that of weed and plant scientists and as a result traditional social power dynamics embedded within the knowledge creation are reworked. We facilitated three farmer-centered community working groups across the PNW grounded in a co-production of knowledge framework. The goal of these groups was to brainstorm and create innovative, place-based approaches to herbicide resistance management. Ultimately, these three groups developed into two distinct community-engaged research projects: 1) Cropping Systems Diversification and 2) Harvest Weed Seed Control.

Accomplishments/Results:

Cropping Systems Diversification

The farmer-centered herbicide resistance management working group we facilitate in North-Central Washington is a highly functioning community-engaged research project focused on co-innovating solutions to herbicide resistance that are both place-based and scalable across dryland PNW cropping systems (**Figure 36**). This group of farmers, scientists, agronomists, grain handlers and marketers, conservation professionals, and other community members initially spent eighteen months working together to co-innovate different ideas for herbicide resistance management solutions. The group eventually settled on cropping systems diversification as the primary focus and is currently carrying out three-year field-scale research experiments involving grain sorghum. Results from the first- and second-year show promise (**Figure 37**).

Our group ultimately settled on growing grain sorghum at the field-scale for several key reasons. First, many farmers in the group have grown mixtures of cover crops that contain warm season grasses that have performed well in North Central Washington. Farmers saw potential for different species of millets and sorghums to be adapted to a cash crop and integrated into their rotations. Second, the taller height of grain sorghum when compared with proso millet was an attractive option to many farmers in the area because of the significant presence of rocks and rock piles within their fields. Third,



grain sorghum is more robust and flexible market opportunities than proso millet. Fourth, improving crop rotations is a key component of successful Integrated Weed Management (IWM). Fifth, grain sorghum offers herbicide options previously unavailable to the wheat-based cropping of the PNW. Farmers insisted on prioritizing the value of growing grain sorghum (themselves) at the field scale. This challenged researchers to create innovative methods for collecting meaningful data across many field sites.

Our community-based approach has enabled a level of co-innovation between farmers and researchers that may transform the region's ability to successfully adapt to the growing spread and intensification of herbicide resistant weed populations. Grain sorghum appears to be a viable alternative cash crop for certain fields of North-Central Washington. We are also expanding grain sorghum research plots to other areas of the PNW beyond North-Central Washington to evaluate crop viability. This includes southeast Washington, Horse Heaven Hills, and the Pullman area. Initial results suggest that existing early maturing hybrid varieties are better adapted to certain regions and fields. However, potential for further improving grain sorghum's integration within PNW dryland cropping systems appears possible through breeding, agronomic, infrastructural, and market development research efforts. In summary, finding potential workable solutions such as grain sorghum would not have been possible without a coproduction of knowledge approach to herbicide resistance management elevating farmer experiential knowledge with that of scientific expertise. Consequently, this social science component of PNWHRI is merging both community-engaged and transdisciplinary research in novel ways to improve herbicide resistance management.

Harvest Weed Seed Control

The PNW has the highest adoption of impact mills for harvest weed seed control of any region in the United States (**Figure 38**). Harvest weed seed control refers to a variety of harvesting practices that minimize the spread and maximize the neutralization of weed seed viability. Impact mills represent one approach to harvest weed seed control. Specifically, they are a mechanical device that is mounted on the back of a combine. After the grain is threshed, the chaff runs through the impact mill and pulverizes remaining weed seeds. Despite early adoption by producers across the region, there is little existing research about the efficacy of these machines for weed management in the PNW. This is problematic because impact mills cost a significant amount of money to buy and install ~\$80,000 and have additional operational and maintenance costs.

Farmers in eastern Washington and northern Idaho (Palouse and Camas Prairie) reached out to members of the PNWHRI expressing their desire to partner for a coordinated, on-farm evaluation of their impact mills. To develop a set of innovative research questions and methods, we coordinated and facilitated meetings in the Winters of 2023-2024 and 2024-2025 with producers from four local farms to coproduce a research agenda. At these meetings, researchers and farmers collaboratively



developed an on-farm research approach focused on understanding the efficacy of impact mills for weed control as well as an analysis of their economic benefits and costs.

Consequently, we are currently conducting a two-year pilot study across the four farms and in close collaboration with the farmers to understand the effect of impact mills on weed patches using aerial and proximal imagery (**Figures 39** and **40**) and seedbank sampling (**Figure 41**). Dr. Casanova recently led the publication of select results from Year 1 of the pilot study in an article entitled "A comparison for protocols for high-throughput weeds mapping" in the academic journal *Smart Agricultural Technology*. Dr. Casanova and Dr. Bergmann also appeared on an episode of the Wheat Beat Podcast with Dr. Drew Lyon to discuss the project. Our team also submitted a grant to the 2025 Western SARE Research and Education Program. Although our expanded research proposal was reviewed favorably, it was ultimately not funded. We are currently in the process of putting together a revised research proposal to submit to a different grant program. Our goal is secure additional funding to continue and expand on-farm weed patch mapping and seedbank sampling, while also layering on additional economic, social, and extension components to the project.



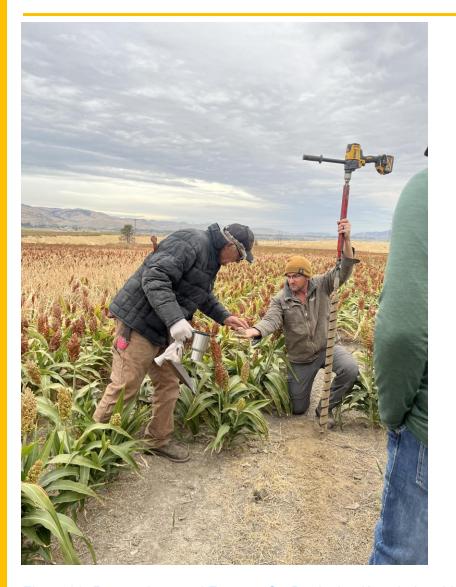


Figure 36. Researchers and Farmers Co-Producing Knowledge. Mature Grain Sorghum. October 2024. Okanogan County, WA.



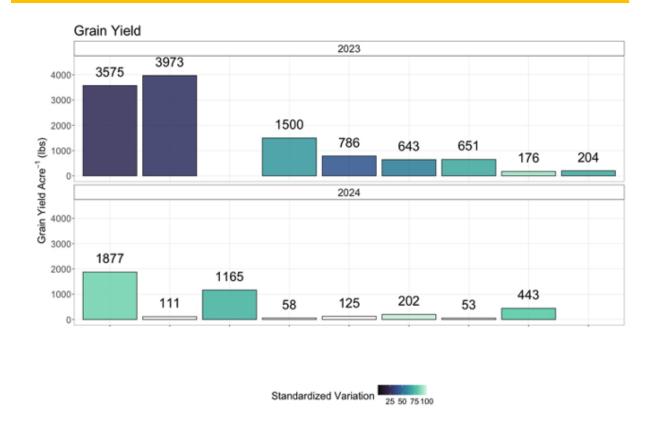


Figure 37. 2023 and 2024 Grain Sorghum Yield Results from Field-Scale Experiments.





Figure 38. A Seed Terminator unit mounted on a combine for harvest weed seed control. July 2023. Whitman County, WA.





Figure 39. Fixed wing drone used to collect aerial imagery in order to track the spatial dynamics of weed populations. April 2025. Whitman County, WA.



0.97 0 0.48 0 0.97 0 0 0 3.38 0.48 8.7 3.86 1.93 UhlornWeedsVisited CatchweedBedstraw/m2 0.000000 0 0.97 0 0 0.97 0.97 0 0.48 0 0.000001 - 0.483092 0.483093 - 0.966184 0.966185 - 1.932367 • 1.932368 - 2.415459 0 0.48 0 0.97 3.86 1.45 0 0.97 2.42 2.42 1.93 0 0 2.415460 - 3.864734 3.864735 - 4.830918 4.830919 - 8.695652 8.695653 - 22.222222 22.22223 - 146.859903 3.86 0 22.22 0 0 1.45 0 0 4.35 0 0 0.97 4.83 0 2.42 0 0.48 0 0 0.48 0 0 0 0 0.48 0 0 0.48 0 CatchweedBedstrawAltum/ Value

Figure 40. Mapping Catchweed Bedstraw using aerial and proximal imagery.



DruffelWeeds



Figure 41. Seedbank sampling grid and resulting weed seed counts for each sampling point location.



Objective #3: Education and Outreach

Development of a geospatial database for mapping herbicide resistant weeds in the Pacific Northwest dryland wheat production and surrounding areas

Pete Berry, Albert Adjesiwor, Judit Barroso, Joan Campbell, Doug Finkelnburg, Olivia Landau, Drew Lyon, Victor Ribeiro, Ian Burke

Objectives:

- Develop a geodatabase of weed distribution and total production of wheat across the Pacific Northwest over time to monitor and map herbicide resistant weed populations.
- 2) Create a grower focused educational tool to help in resistant weed management.

Abstract/Summary:

The Pacific Northwest Herbicide Resistance Initiative (PNWHRI) has developed a regional mapping tool to document and track herbicide resistance across the Pacific Northwest (PNW). Data from weed surveys and herbicide screenings conducted by Oregon State University, Washington State University, the University of Idaho, and USDA-ARS were compiled into a comprehensive database and published through the PNWHRI.org website using the ESRI Experience Builder platform. The interactive tool currently maps over 400 resistant weed populations at the county level, classified by species, active ingredient, WSSA herbicide group, including cross- and multiple-site resistance. Designed as a dynamic and expandable resource, the database is regularly updated as new surveys are completed. An additional feature, the Palmer Watch heat map, tracks confirmed populations of *Amaranthus palmeri*, an invasive and highly competitive weed of growing concern. Together, these tools provide an accessible, upto-date platform for researchers, growers, and industry to monitor resistance, support integrated management strategies, and respond proactively to emerging weed threats in the PNW.

Accomplishments/Results:

A central challenge faced by collaborators within the Pacific Northwest Herbicide Resistance Initiative (PNWHRI) has been documenting and understanding the distribution of herbicide resistance across the diverse cropping systems of the Pacific Northwest (PNW). To address this need, researchers from Oregon State University, Washington State University, the University of Idaho, and USDA-ARS compiled their previous weed surveys and herbicide screening results into a comprehensive regional database. This collective effort allowed for the classification of individual resistant populations by state, county, weed species, and the specific Weed Science Society of



America (WSSA) herbicide group numbers and active ingredients to which resistance was confirmed.

To make the data accessible and actionable for growers, industry, and scientists, the information was published using the Environmental Systems Research Institute (ESRI) Experience Builder platform and is publicly available through the PNWHRI website (PNWHRI.org). The interactive mapping tool currently documents over 400 unique resistant populations across the region. Each population is linked to its county-level location and annotated with herbicide resistance details, enabling users to visualize both the geographic spread and the complexity of resistance across multiple sites of action. This tool provides a user-friendly interface for stakeholders to quickly identify resistance issues in their area and tailor management decisions accordingly.

Importantly, the database is designed to be dynamic and expandable. As new weed surveys and herbicide screening trials are conducted, additional records will be incorporated into the system, ensuring that the map reflects the most up-to-date status of resistance in the region. This 'living' resource will play a critical role in monitoring the evolution of herbicide resistance, supporting research on resistance management, and guiding growers in implementing integrated weed management strategies to slow the spread of resistant populations across the PNW.

Another component of the PNWHRI.org mapping tool focuses on tracking the spread of Palmer amaranth (*Amaranthus palmeri*), an invasive and highly competitive weed of growing concern in the Pacific Northwest. To visualize its presence, a heat map was developed that highlights the locations where *Palmer amaranth* populations have been confirmed. This spatial layer provides a clear picture of areas where infestations have occurred and allows stakeholders to monitor patterns of introduction and spread over time. As new detections are made through ongoing surveys and field monitoring, the heat map will be updated, ensuring that the tool remains a timely and reliable resource. By integrating *Palmer amaranth* data alongside herbicide resistance information for other species, the PNWHRI mapping tool serves as an early warning system, supporting proactive management strategies and helping researchers, growers, and industry partners respond quickly to emerging weed threats across the PNW.

Through the PNWHRI platform, USDA CropScape data have been integrated to map the distribution of major small grain crops across the Pacific Northwest, including winter wheat, spring wheat, fallow, triticale, and barley. These maps provide both county- and regional-level perspectives on cropping patterns, illustrating the total acreage devoted to each crop and highlighting zones of concentrated production. By visualizing the extent of cereal-based systems across the landscape, the maps offer valuable insights into the scale and diversity of small grain production within the PNW. This information can be



used to better understand regional land-use trends, support resource planning, and guide research and extension efforts that align with the dominant cropping systems. Because the maps are built from annually updated CropScape datasets, they also serve as a dynamic tool for monitoring changes in acreage and crop distribution over time, providing a consistent framework for evaluating the role of cereals in the agricultural economy of the region.



Figure 42. Home page of the PNWHRI herbicide resistance mapping tool. The interactive interface, hosted through the ESRI Experience Builder platform, allows users to explore documented cases of herbicide resistance across the Pacific Northwest. The homepage provides navigation to additional features, including the Palmer amaranth heat map and resources for resistance management.



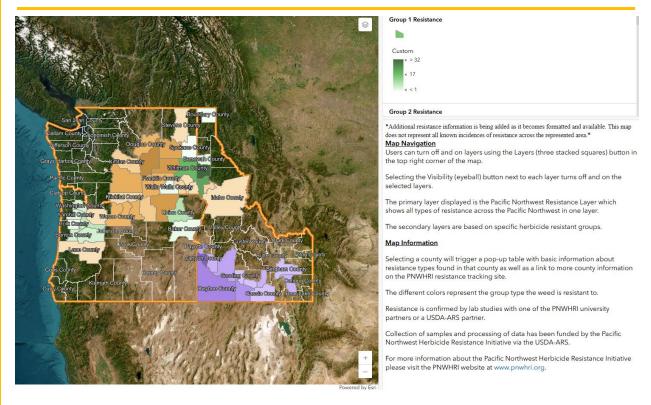


Figure 43. Resistant populations are displayed at the county level, with a filtering option by herbicide WSSA group numbers.



Figure 44. Example of county-level data from the PNWHRI herbicide resistance mapping tool. Each county is linked to detailed records of documented resistant weed populations, including species identity, the active ingredient(s) tested, and the corresponding Weed Science Society of America (WSSA) herbicide group numbers. The dataset also identifies whether resistance is specific to a single herbicide or if cross-resistance and multiple site-of-action resistance have been confirmed. This county-level resolution allows users to assess both the geographic distribution and the complexity of resistance within individual production regions.



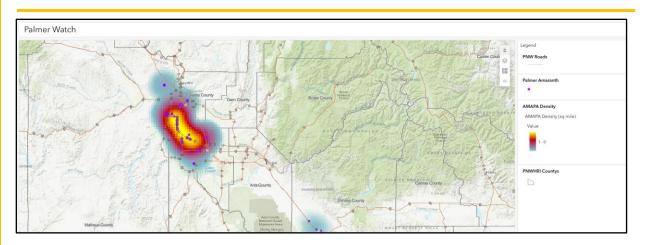


Figure 45. Palmer Watch tool from the PNWHRI mapping interface. The tool displays a heat map highlighting the highest documented populations of Palmer amaranth (Amaranthus palmeri) as well as additional confirmed locations across the Pacific Northwest. By visualizing areas of greatest infestation alongside new detections, the tool enables stakeholders to track the movement of this invasive and herbicide-resistant weed through the region. Continuous updates from surveys and grower reports ensure the map functions as an early warning system, supporting rapid response and long-term management planning.

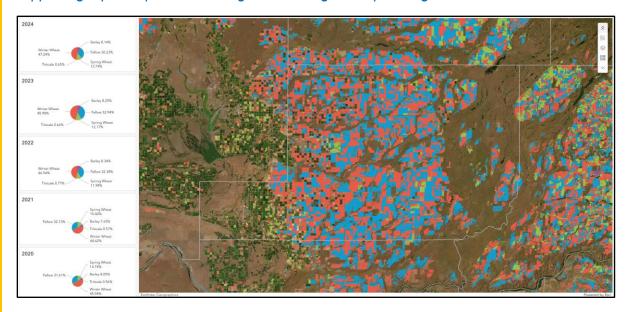


Figure 46. Total acreage of cereal crops in the Pacific Northwest mapped using USDA CropScape data. The map displays the spatial distribution of winter wheat, spring wheat, barley, and triticale, along with fallow acres, across counties in the region. This layer provides a comprehensive overview of the extent and concentration of cereal crop production, highlighting areas of highest acreage.



Fine-tuning a large language model for use as a farmer decision support tool: a case study

Bryan Carlson, Eduard Steiner, David Huggins

Abstract/Summary:

Producers have access to vast amounts of information, (e.g. University Extension publications, scientific literature, and research reports) that can inform their farm management decisions. However, this information can be difficult for producers to access and potentially overwhelming to synthesize for their specific and immediate needs. While large language models (LLMs) can aid in understanding large amounts of information, they often provide poor insights into domain-specific areas. Model fine-turning provides a method to enhance the accuracy and robustness of general LLMs, tailoring them for specific areas of expertise. We set out to create a prototype of a data and model pipeline to fine-tune a general LLM on agronomic educational resources, with an emphasis on publications relating to herbicide resistance. The objective was to investigate the challenges associated with creating a public-facing chat interface to act as a decision aid for producers in the dryland region of the inland Pacific Northwest.

Accomplishments/Results:

A data and model pipeline was developed (**Figure 47**) and implemented that led to a LLM that is fine-tuned in the domain of herbicide resistance. A resource identification and extraction script found and verified 236 PDFs from the Herbicide Resistance section of the WSU Small Grains website. The PDFs were used to generate 1426 instruction/response pairs that were used to fine-tune the open source general LLM LLaMa 3-8B. The resultant model shows a mean logit of 1.77, an indication that the fine-tuned model has changed from the base.

Future efforts will focus on gathering more resources, better redundancy and filtering logic, a potential retrieval-augmented generation (RAG) system to reduce model error, and an interface to access resources used in the training and those provided as citations in the answers.



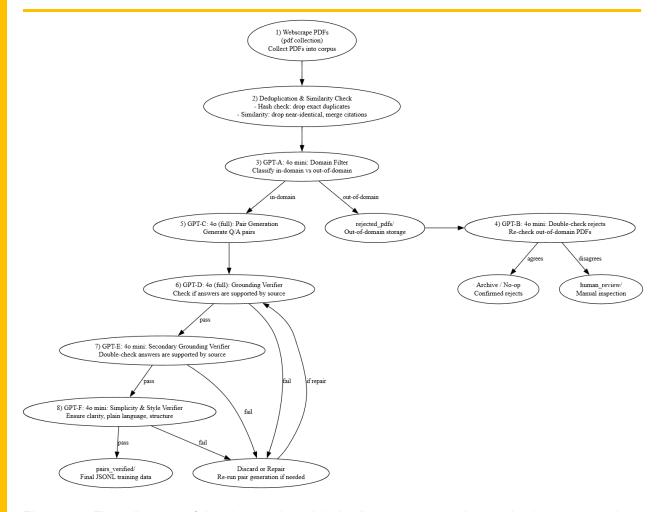


Figure 47. Flow diagram of the data and model pipeline to generate instruction/response pairs for training a generative model.



Outreach Activities for Integrated Weed Control in Cereal Grain Systems

Aaron Esser

Objectives:

- 1. Provide hands-on outreach activities to help growers with knowledge and demonstration to incorporating multiple integrated approaches to managing herbicide resistant weeds in cereal grain systems
- 2. Outreach is focused on university research, large scale multi-year on-farm trials, and show-and-tell demonstrations at the WSU Wilke Research and Extension Farm near Davenport, WA.

Abstract/Summary:

Weeds and herbicide resistant weeds are the single greatest barrier farmers in the dryland cereal grain cropping region of the Inland Pacific Northwest face in today's agriculture and is a large threat to conservation tillage moving forward. I have dedicated a large portion of my time to providing and facilitating research and outreach to this significant challenge farmers face. In my region, downy brome resistant to Group 2 and Group 9 herbicides is the biggest issue; however, my program is focused on the larger problem across eastern Washington. My efforts include using the WSU Wilke Research and Extension Farm and large-scale research to 'show-and tell' farms how they can economically use a long-term cropping plan to get multiple effective herbicides onto the ground, and how to use targeted tillage to enhance winter annual weed control for an integrated approach. My program is also looking at biological (Battalion Pro) weed control for enhanced long-term control in a series of large-scale demonstrations across the dryland wheat producing region of Adams County. This barrier farmers face will truly take a combination of chemical, physical and potentially biological methods to maintain economically viable winter wheat production.

Accomplishments/Results:

Outreach methods consist of a combination of field days and local, statewide, and regional grower meeting event presentations focused on many aspects of integrated weed control for cereal grain cropping systems. Presentations are different as new information is made available and often have some kind of hands-on involvement. Dice and showing a numbers game regarding seed production and herbicide resistance has been key. Over the course of the last 2-years, I have participated in 38 educational events with an estimated 2,440 participants talking about integrated weed control for cereal grain cropping systems (**Table 12**). Growers have been integrating soil residual herbicides into their rotations and will continue in subsequent years.



Table 12. Summary of events and participants attending outreach on integrated weed control for cereal grain systems.

Year	Events	Participants
2023	12	880
2024	19	1,100
2025	7	460
Total	38	2,440



Education and Outreach Summary

Doug Finkelnburg

The Education and Outreach objective seeks to develop an active and engaged extension and outreach program built around fundamental and applied aspects of the Initiative. During the past year, PNWHRI-sourced information was shared at University and Industry Growers Meetings, Crop Tours, Pesticide Applicator Recertification Clinics, the Western Society of Weed Science 2025 Meeting, online (Weeders of the West, Ag-Talk Tuesday) and in-print (Ag-Proud Idaho). The most recent PNWHRI themed Weeders of the West post was picked up for wider distribution on Morning Ag Clips, an online news outlet with national distribution. A PNWHRI led project on "Warm Season Grasses and Herbicide Resistance Management" was given a general session at the 2025 Pacific Northwest Direct Seeders Cropping Systems Conference (Figure 48) and PNWHRI updates were provided to the Idaho Grain Producers Association Leadership at the Tri-State Grain Growers Convention.



Figure 48. PNWHRI Human Geographer, Dr. Nicolas Bergmann, WSU, leads a general session panel discussion at the 2025 Pacific Northwest Direct Seeders Cropping Systems Conference.

To maintain project cohesion and momentum, bi-weekly meetings with PNWHRI Extension & Outreach members have been held. These regular meetings serve as valuable communication and networking opportunities for members. Specific accomplishments include the addition of the "Herbicide Resistance Tracker", "Palmer Watch" and "Wheat Acreage Data" map layers to the PNWHRI.ORG website. Short



educational videos on <u>Cropping Systems Trials in the Pacific Northwest for Assessment of Weed Populations</u> and <u>Use of a Machine Learning Object Detection Tool to Identify and Count Weed Seeds</u> were produced and added to the website. Current university publications on PNW weed management were added to a "<u>Resources</u>" page on the website and a searchable database of <u>PNWHRI member authored studies</u> was created. Lastly, a producer survey on how weed control challenges have shifted for producers in Idaho, Oregon and Washington was created and distributed.

The PNWHRI.ORG website is gaining traction. In the past year, the website has had active users (850) mostly based in the United States (762), followed by Canada (13), China (12), Germany (11), Taiwan (8), Australia (6) and Poland (6). While active users visited all pages on the website the landing page had the most use (618), followed by "Resources" (253) and "Contacts" (140).

Looking forward, more efforts will be made to further refine the *Herbicide Resistance Tracker*, *Palmer Watch* and the *Wheat Acreage Data maps* on the website. Efforts are underway to create a farmer or field agronomist focused herbicide resistance submission system to further track incidences of the development and spread of herbicide resistant weed populations. The results of the 2024-2025 producer survey on changes to weed control challenges will be shared at multiple producer events and an academic publication is in progress. Finally, an academic symposium has been organized for the 2026 Western Society of Weed Science Annual Meeting titled "*The Pacific Northwest Herbicide Resistance Initiative: An Invitation to Collaborate*" to facilitate regional and national collaboration in addressing herbicide resistance issues.



Publications

- Adjesiwor A, Felix J, Alder C, Landau O, Liu R, and Hutchinson P. (2025). Palmer amaranth and Waterhemp in the Pacific Northwest: current distribution and herbicide resistance status. *Proceedings of the 65th Annual Meeting of the Weed Science Society of America*. Paper.
- Ahmed S, Savic M, Landau O, and Burke I. (2025). EPSPS gene amplification in glyphosate-resistant cheatgrass (*Bromus tectorum*) from Washington.

 *Proceedings of the 65th Annual Meeting of the Western Society of Weed Science. Poster.
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- Barroso J and Wuest SW. Fallow residue management. Abstract included in the proceedings of the 2025 Cropping Systems Conference. Three Rivers Convention Center, Kennewick, WA. January 7-8, 2025.
- Berry P, Adjesiwor A, Barroso J, Campbell J, Finkelnburg D, Landau O, Lyon D, Ribeiro V, and Burke I. (2025). Mapping herbicide-resistant weed populations across the Pacific Northwest: a collaborative approach. *Proceedings of the 78th Annual Meeting of the Western Society of Weed Science*. Paper.
- Casanova JJ, Bergmann NT, Kalin JER, Heineck GC, Burke IC. (2025). A comparison of protocols for high-throughput weeds mapping. Smart Agricultural Technology. 12: 101076. https://doi.org/10.1016/j.atech.2025.101076.
- Finkelnburg D, Berry P, Adjesiwor A, Barroso J, Campbell J, Landau O, Lyon D, Ribeiro V, and Burke I. (2025). Breaking the cycle: educating for effective herbicide resistance management. *Proceedings of the 78th Annual Meeting of the Western Society of Weed Science*. Paper.
- Landau OA, Borges, JL, Na-ah RF, Peracchi L, and Sanchez-Izurieta, F. (2025).

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- Rauch, T. and J. Campbell. (2025). Pre-emergence Herbicide Resistant Italian Ryegrass Survey in Northern Idaho and Eastern Washington. *Abstract included in the proceedings of the 2025 Cropping Systems Conference. Three Rivers Convention Center, Kennewick, WA. January 7-8, 2025.* Poster
- Rauch, JM Campbell and A. Adjesiwoir. 2025. Herbicide Resistant Wild Oat (*Avena fatua*) Survey in northern Idaho and eastern Washington. *Proceedings of the 78th Annual Meeting of the Western Society of Weed Science*. Poster.
- Rodriguez L, Felix J, Alder C, Hutchinson P, Liu R, Landau O, and Adjesiwor A. (2025). Palmer amaranth in the Pacific Northwest: glyphosate resistance confirmation and response to selected herbicides. *Proceedings of the 78th Annual Meeting of the Western Society of Weed Science*. Poster.

