

2026 Annual Report

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Oregon State University

WASHINGTON STATE UNIVERSITY

University of Idaho

USDA Agricultural Research Service
U.S. DEPARTMENT OF AGRICULTURE

Table of Contents

PNWHRI Goal 3
PNWHRI Vision 3
PNWHRI Gross Annual Allocation of Funds 3
Stakeholders/Partners 4
List of Collaborators in 2026 4
PNWHRI Objectives 5
Research Accomplishments 6
Objective 1: Biology-Based Theme
1.1) Characterizing weed seed and soil microbiomes under irrigated management within a dryland wheat system 6
1.2) Reference genome for mayweed chamomile identifies genomic signatures of local adaptation and invasiveness 10
1.3) Characterizing suspected mesotrione-resistant palmer amaranth populations 13
1.4) Wild oat herbicide resistance survey 15
1.5) Windgrass, Italian ryegrass, Russian thistle, and common lambsquarters herbicide resistance screening 16
1.6) Herbicide resistance screening and dose-response characterization of Idaho populations 17
1.7) Confirming glyphosate resistance in Idaho waterhemp populations 22
1.8) Confirming glyphosate resistance in Idaho common lambsquarters populations 26
1.9) Effect of wheat canopy on wild oat growth, seed production, and germination ecology 29
1.10) Screening common lambsquarters (*Chenopodium album*) for resistance to imazamox 34
1.11) Modeling lambsquarter (*Chenopodium album*) emergence timing in eastern Washington 38
1.12) Italian ryegrass management at the WSU Cook Agronomy Farm 41
Objective 1: Crop Rotation-Based Theme
1.13) Weed management in dryland wheat-fallow systems 47
Objective 1: Cross-Cutting Theme
1.14) Evaluating a digital phenotyping system for pre-emergence and post-emergence dose-response assays 50
1.15) Demonstrating the cost of managing herbicide-resistant weeds in wheat: pinoxaden-resistant wild oat case study 52
1.16) Efficacy of pre-emergence herbicides for wild oat control as influenced by seed burial depth 57
1.17) Evaluating fluridone for Italian ryegrass and downy brome control in winter wheat 60
1.18) Impact of seed placement depth and preemergence herbicide soil moisture on Italian ryegrass control 63
1.19) Developing a weed emergence decision support tool for the Inland PNW 66
1.20) Development of Agrazer: A retrieval-augmented decision-support platform for agricultural producers 70
Objective 2: Socio-Economic
2.1) Survey data on producer perceptions of weed management and herbicide resistance challenges in the PNW 74
2.2) A community-based herbicide resistance management approach to developing grain sorghum in the PNW 76
Objective 3: Education and Outreach
3.1) Start clean, stay clean in cereal grain cropping systems 78
3.2) Education and outreach summary 79
Publications 81
How to Cite this Report 82

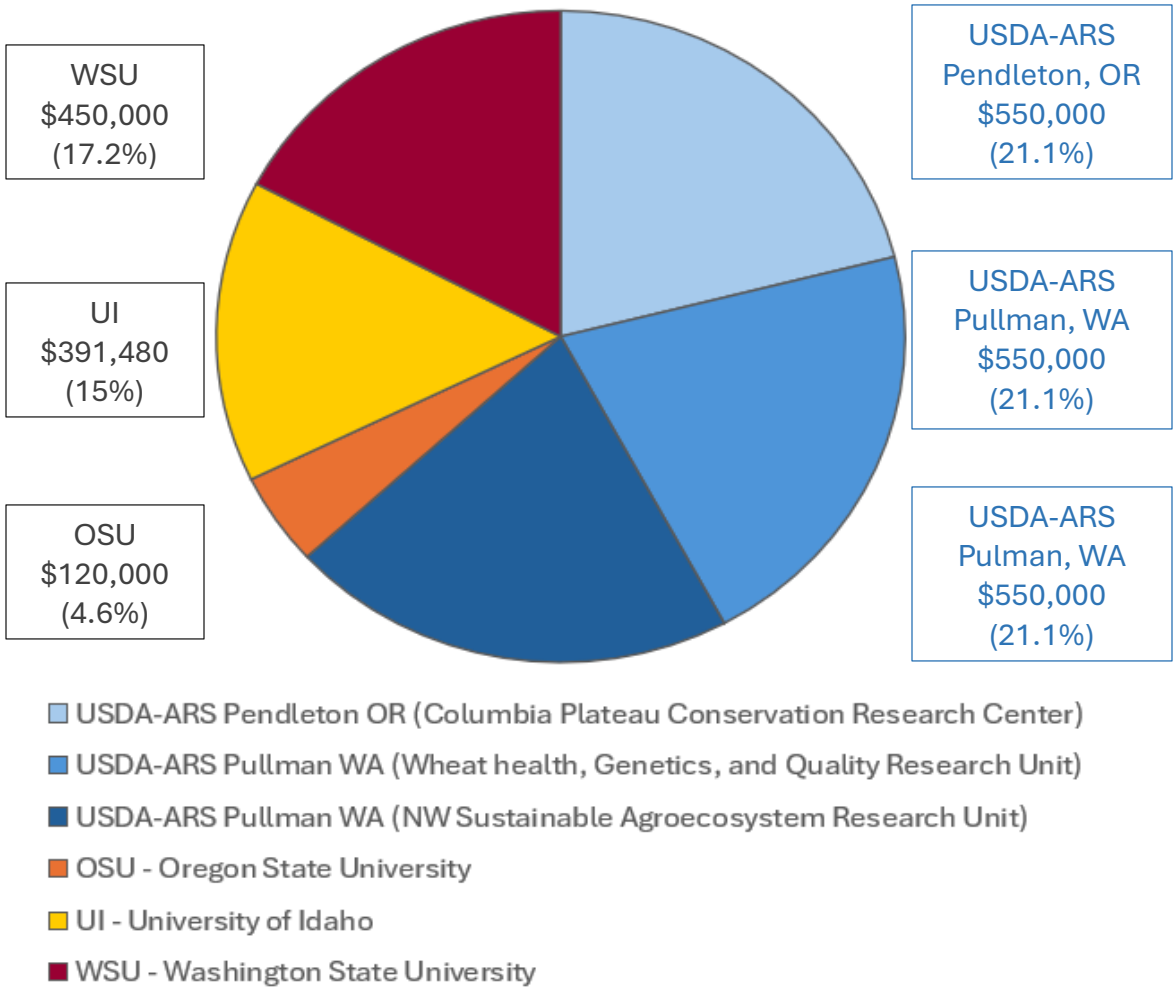
PNWHRI Goal

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.

PNWHRI Vision

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.

PNWHRI Gross Annual Allocation of Funds



Stakeholders/Partners



List of Collaborators in 2026

- USDA-ARS, Pullman, NW Sustainable Agroecosystems Research Unit: Bryan Carlson (Eco-Informaticist), and David Huggins (Research Leader).
- USDA-ARS, Pullman, Wheat health, Genetics, and Quality Research Unit: Olivia Landau (Research Weed Scientist), Kim Garland-Campbell (Research Geneticist), Timothy Paulitz (Research Plant Pathologist), and David Weller (Research Leader; Research Plant Pathologist).
- USDA-ARS, Pendleton, Columbia Plateau Conservation Research Center: Kate Reardon (Microbiologist-Interim Research Leader).
- Oregon State University (OSU): Judit Barroso (Weed Scientist), Pete Berry (Weed Scientist), and Noemi Codina-Pascual (Postdoc).
- University of Idaho (UI): Albert Adjesiwor (Weed Scientist), Joan Campbell (Weed Scientist), Doug Finkelnburg (Cropping Systems Educator), Patrick Hatzenbuehler (Agricultural Economist), and Traci Rauch (Research Associate).
- Washington State University (WSU): Nick Bergmann (Sociologist), Aaron Esser (Extension Agronomist), Christopher Landau (Postdoc), Marija Savic (Research Associate), Jessica Kalin (Research Associate), Franco Sanchez-Izurieta (Scientific Assistant), Raissa Fon Na-ah (Postdoctoral Researcher), Fabio Scarpare (Civil and Environmental Engineering), Shikha Singh (Microbiologist), Surendra Singh (Agronomist – Director of Lind Station), Eduard Steiner (Data Consultant), and P. Weston Maughan (PhD Student).

PNWHRI Objectives

- Objective 1. Develop system adaptive capacity by refining best management practices grounded in the fundamental biology of weed species and integrating diverse management approaches into a real-time, climate-based decision-support system.

  Includes biology-based, crop rotation-based, and Cross-cutting-based themes.

  - Biology theme:
    Evaluate herbicide resistance, weed seedling emergence, seed longevity, timing of viable seed production, and seed retention, among other topics. Target problematic weeds in the PNW, including Italian ryegrass, downy brome, wild oat, common lambsquarters, Russian thistle, and other species identified through stakeholder feedback or changes in weed conditions.

  - Rotational crops theme:
    a) Evaluation of intensification and diversification of PNW cropping systems on weed populations at practical and fundamental levels, utilizing existing and new intermediate- and long-term research trials and novel methods based on emerging phenotypic and genomic resources. *i.e.* Refine best management practices associated with tillage systems (using long-term tillage trials).
    b) Augment existing rotational trials with intensive evaluations of weed populations, emphasizing longitudinal data collection to determine how traditional and novel management tactics influence weed communities over time. Identify gaps in existing short-, intermediate-, and long-term trials and develop targeted experiments to address those gaps.

  - Cross-cutting theme:
    a) Develop innovative and high-throughput or automated pipelines to enhance the efficiency and accuracy of weed data collection.
    b) Incorporate emerging technologies as opportunities arise, including automation for biological data collection, harvest weed seed control, robotics, precision field management, and other technologies.

- Objective 2. Determine the socioeconomic and policy-related opportunities and barriers to adopting integrated weed management systems within traditional and aspirational wheat-based systems to enhance resilience to weeds and climate variability and change.

- Objective 3. Develop an active, engaged extension and outreach program that translates the initiative's fundamental and applied research into actionable knowledge and tools for stakeholders.

Research Accomplishments

Objective 1: Biology-Based Theme

1.1) Title: Characterizing Weed Seed and Soil Microbiomes under Irrigated Management within a Dryland Wheat System

Authors: Olivia Landau, Franco Sanchez-Izurieta, and Cody Willmore

Objective: The objective of this preliminary study was to validate the experimental pipeline for obtaining and analyzing high-quality bacterial and fungal microbiome data from both weed seeds and soil samples within an irrigated dryland wheat cropping system.

Summary: The aims of this research are to characterize the role of weed seed microbiomes as fundamental drivers of weed seedbank ecology under supplemental irrigation within a regional dryland wheat system. The research focuses on characterizing the distinct endophytic and epiphytic microbial communities of target weed seeds alongside native soil microbiomes. Understanding these niches is critical due to the limited exploratory data available for weed seedbanks, particularly for highly problematic species that threaten regional crop stability and long-term economic sustainability of Pacific Northwest (PNW) crops. Key questions addressed include:

- Which microbial species are vertically inherited within developing weed seeds?
- Is there geographical or spatial consistency in the seed endosphere of weed species across different sampling locations?
- How are microbial communities affected by cultural, mechanical, and chemical weed management practices?

Accomplishments: To establish a reproducible, high-throughput collection and processing pipeline, a customized drill bit auger sampler was validated for collecting 10 cm soil core samples on April, May, June, and July for years 2025 and 2026. Random field sampling patterns were evaluated across the Lind, Washington Dryland Research Station experimental plots, which consist of alternating dryland and irrigated spring wheat fields. Samples from irrigated plots consistently yielded a higher abundance of weed seeds and were prioritized for elutriation. Elutriated seeds were morphologically identified and cataloged. Seeds from Russian thistle (*Salsola tragus*), green foxtail (*Setaria viridis*), and prostrate knotweed (*Polygonum aviculare*) represented the most abundant species recovered during each sampling date (Table 1). To distinguish surface epiphytes from internal endophytes, seeds were categorized as non-surface-sterilized (NSS) or surface-sterilized (SS) using bleach and ethanol. Seeds were ruptured and total genomic DNA was extracted and submitted for bacterial and fungal sequencing by the University of Minnesota Genomics Center. The resulting sequences were taxonomically assigned and analyzed to identify the average relative abundance of both bacterial and fungal community compositions between bulk soil and NSS to SS seeds.

Results: The microbial community shows distinct bacterial and fungal assemblages that vary by sample type, indicating weed seeds maintain highly specialized microbiomes independent from the native soil. To establish a broad overview for these preliminary figures, sequence data from the three target weed species were pooled into collective seed profiles. Consequently, the general overview reports the average community compositions across three bulk soil, NSS seed surfaces, and SS seeds. At the phylum level, bacterial communities show a broad compositional range (Figure 1A). The bulk soil consists of a highly diverse background mixture of unclassified species, with seed-associated families and genera appearing only at trace levels (Figure 1B, 1C). In contrast, the NSS seed surface concentrates *Proteobacteria* (Figure 1A), a trend driven by a high abundance of the family *Pseudomonadaceae* (Figure 1B) and genus *Pseudomonas* (Figure 1C). This genus is particularly noteworthy as certain strains of *Pseudomonas* are documented for their ability to actively suppress weed seed germination and root growth. In contrast, the SS seeds have a distinct endosphere where the community shifts to a core of *Actinobacteriota* (Figure 1A), led by families such as *Actinomycetaceae* and *Microbacteriaceae* (Figure 1B, 1C). Members of these groups are noteworthy as *Actinomycetaceae* species produce a broad array of antibiotics which may protect against soil pathogens, while *Microbacteriaceae* produce growth promoting hormones which may give emerging weed seedlings an immediate competitive advantage over surrounding crops.

Conversely, the fungal communities remained consistent across all sample types by a single major phylum, *Ascomycota* (Figure 2A). Despite the shared phylum, the NSS seed surface was distinct with genera like *Chaetomium* (Figure 2C), which is documented as a natural biocontrol agent by producing compounds that suppress plant pathogens and stimulate defense responses. Similarly, the SS seed endosphere maintained a specialized core community like *Fusarium* and *Clarireedia* (Figure 2C). Members of these groups are of interest, as species from both *Fusarium* and *Clarireedia* are known plant pathogens, and the prominent presence may suggest that weed seeds may act as reservoirs.

While these general overviews establish where these microbial communities reside, tracking individual weed species over the growing season demonstrates that these internal microbiomes are highly dynamic and that weed seeds maintain specialized biological environments. To better understand these interactions, longitudinal sampling will continue in subsequent cropping seasons to track multi-year trends and ultimately correlate these unique microbial signatures with regional weed control and field management practices.

Table 1. Seed counts per species from irrigated plots at each sampling date. Shaded cells represent sufficient seed for three biological replicates submission.

Date	*Sa. tragus*	*Se. viridis*	*P. aviculare*	Date	*Se. viridis*	*P. aviculare*
4/28/2025	15	179	30	5/4/2026	141	24
6/9/2025	17	46	54	6/25/2026	94	40
7/11/2025	2	177	14	7/20/2026	99	32

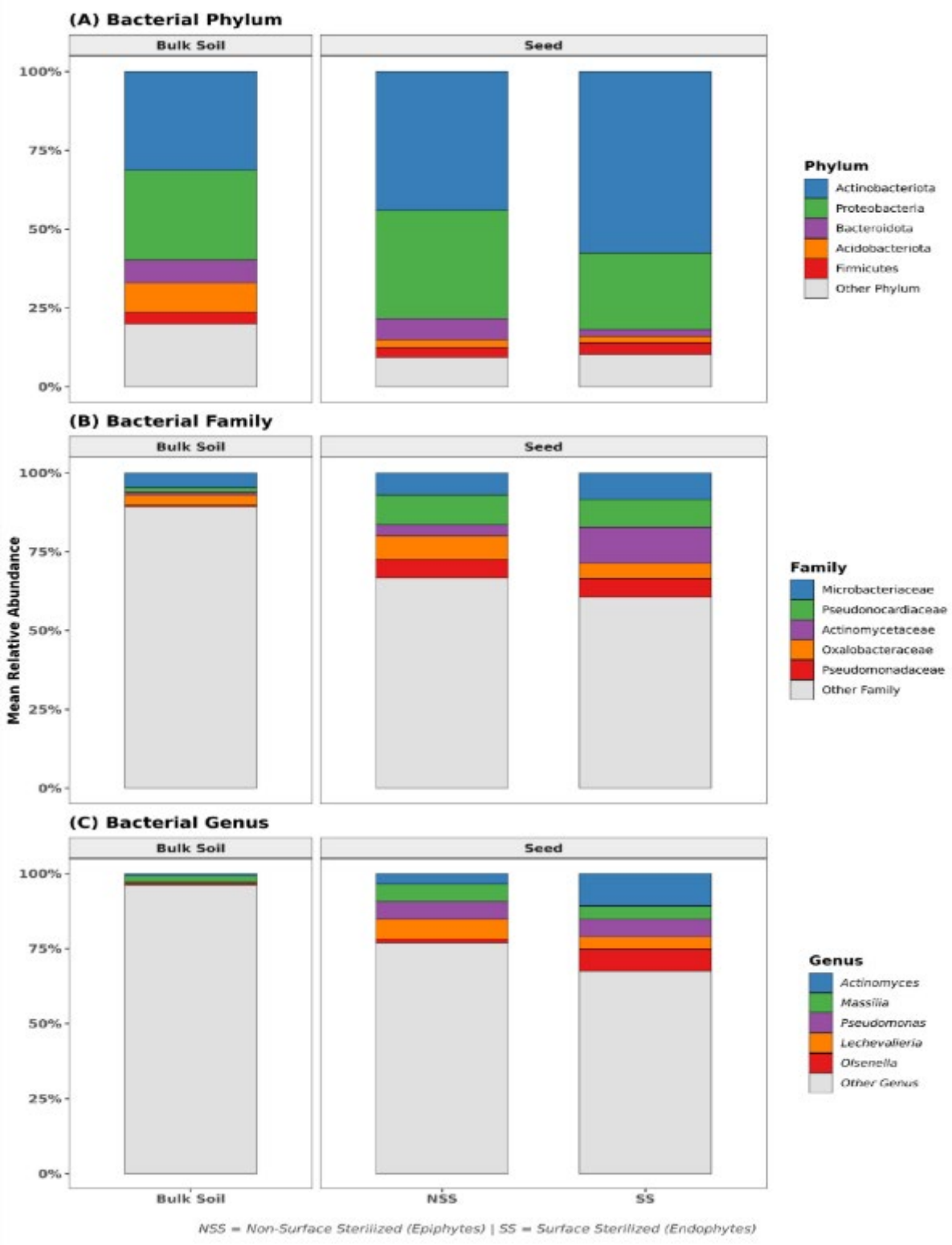


Figure 1: Distribution of bacterial relative abundance across bulk soil, seed surfaces, and internal seed matrices. 100% stacked bar plots show taxonomic composition at the (A) phylum, (B) family, and (C) genus levels. Data compares native bulk soil controls against seed surface epiphytes (NSS) and internal seed endophytes (SS). Minor taxa outside the top five are grouped as "Other."

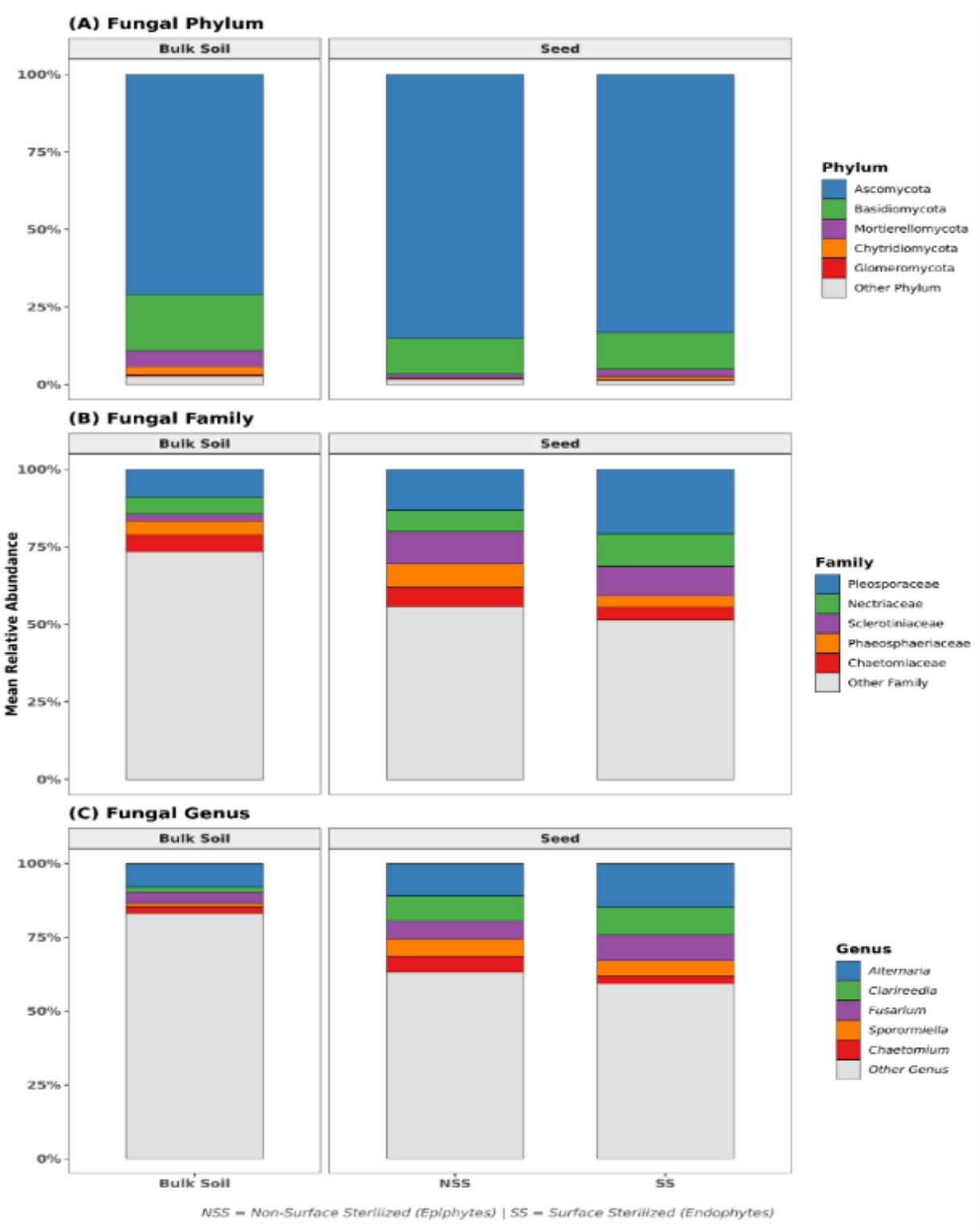


Figure 2: Distribution of fungal relative abundance across bulk soil, seed surfaces, and internal seed matrices. 100% stacked bar plots show taxonomic composition at the (A) phylum, (B) family, and (C) genus levels. Data compares native bulk soil controls against seed surface epiphytes (NSS) and internal seed endophytes (SS). Minor taxa outside the top five are grouped as "Other."

1.2) **Title:** Reference Genome for Mayweed Chamomile (*Anthemis cotula*) Identifies Genomic Signatures of Local Adaptation and Invasiveness

Authors: Olivia Landau and Raissa Na-ah

Objective: Demonstrate the utility of the new mayweed chamomile genome by mapping genotypic data to identify candidate loci associated with adaptive and invasive traits.

Summary: *Anthemis cotula* L. (mayweed chamomile) is a globally invasive annual weed that has become widespread throughout agricultural regions of the Pacific Northwest (PNW). Previous ecological and phenotypic studies demonstrated extensive variation among populations in reproductive traits, growth characteristics, and flowering phenology. Such variation suggests that local adaptation may play an important role in the species' invasion success. However, while phenotypic differentiation has been documented, the genomic basis underlying adaptation and invasiveness remains poorly understood. To address this knowledge gap, we first generated a chromosome-scale, haplotype-resolved reference genome with comprehensive genome annotation. We then used this assembly to assess genome-wide patterns of Tajima's D and nucleotide diversity across populations from the Kashmir Valley, Palouse, and Walla Walla Basin. Genomic regions showing extreme values were identified and subjected to gene ontology enrichment analyses to determine the biological processes potentially associated with selection. Finally, we assessed whether known herbicide target-site mutations overlapped genomic regions exhibiting signatures of selection.

Results: Genome-wide Tajima's D values varied considerably among chromosomes and genomic regions (Figure 3), with both positive and negative deviations from zero observed across the genome. Numerous genomic regions exhibited positive Tajima's D values, indicating an excess of intermediate-frequency alleles relative to neutral expectations. These positive values may reflect the maintenance of genetic variation within populations and can be associated with processes such as balancing selection, population structure, or population contraction. Negative Tajima's D values were also observed across all regional populations, indicating an excess of rare genetic variants in these regions. However, strongly negative windows (Tajima's $D < -2$) consistent with recent directional selection or selective sweeps were relatively uncommon thus, suggesting that selection has not yet driven a single resistant allele to fixation.

To identify biological processes potentially associated with local adaptation, we performed gene ontology enrichment analyses separately for each geographic region using genes located within > 2 Tajima's D outlier window. These analyses revealed several region-specific enrichments, including pathways related to flower development, environmental stress-response processes, cellular and metabolic processes (Figure 4a). Several biological processes were repeatedly enriched among the across the geographic regions, suggesting common targets of selection across the invaded range of *A. cotula*. Regulation of flower development was the only biological process enriched across all three regions, highlighting flowering phenology as a potentially important component of local adaptation. Other processes were shared between specific regions, including ATP metabolic processes between Kashmir Valley and Palouse and response to wounding between Palouse and Kashmir Valley. Within Palouse,

additional enrichment was observed for protein homo-oligomerization and defense response to virus (Figure 4b).

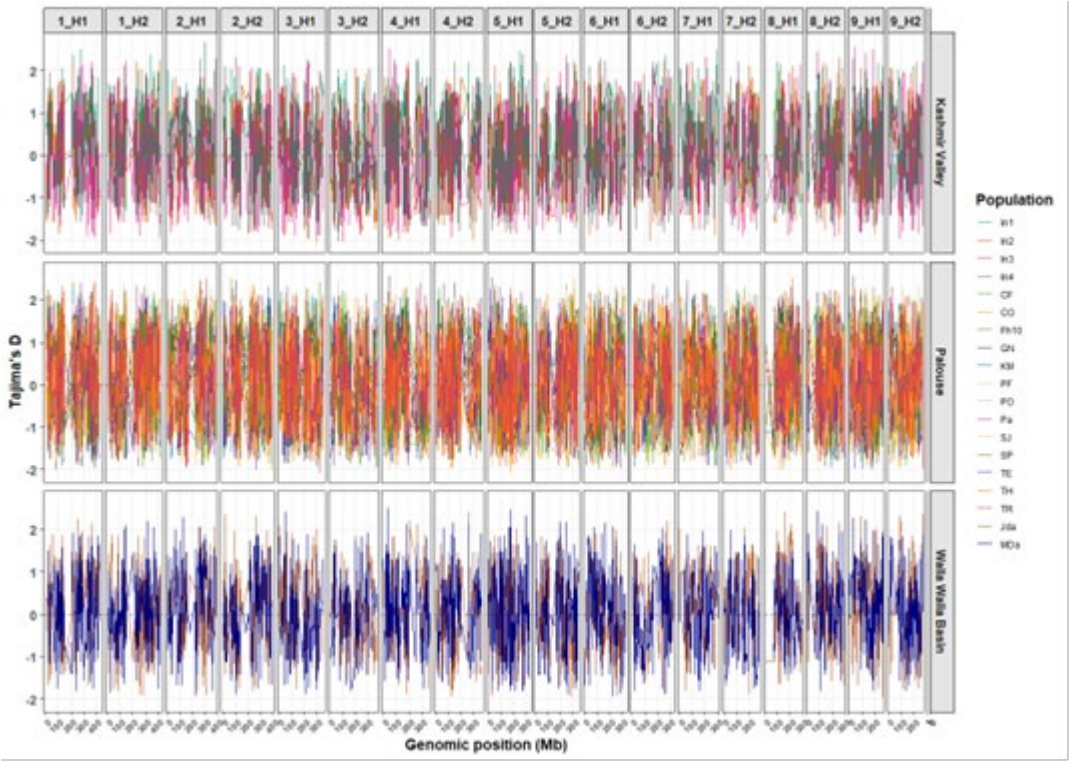


Figure 3. Genome-wide variation in Tajima's D among Kashmir Valley, Palouse, and Walla Walla Basin populations of *Anthemis cotula*. Tajima's D was calculated in 1-Mb genomic windows across chromosomes 1-9. Colored lines represent individual populations within each region and illustrate patterns of genetic diversity and allele frequency distributions across the genome.

The repeated enrichment of regulation of flower development across all three geographic regions was particularly noteworthy. Flowering phenology is a critical life-history trait that affects reproductive success and determines how plants respond to local climatic conditions. The independent detection of flowering-related genes in Kashmir Valley, the Palouse, and the Walla Walla Basin suggests that reproductive timing is a common target of selection throughout the invaded range of *A. cotula*. Previous phenotypic studies reported substantial variation in flowering time among populations, indicating that flowering traits are both variable and potentially adaptive. In highly variable agroecosystems, maintaining different flowering strategies may provide a form of adaptive bet-hedging, whereby some individuals flower earlier and others later, increasing the likelihood of successful reproduction under unpredictable environmental conditions. The recurrent enrichment of flowering-development pathways across all regions therefore suggests that selection on flowering phenology is a major contributor to local adaptation and may be one of the key traits underlying invasion success.

None of the genomic windows with Tajima's D values < −2 overlapped known herbicide target-site genes, including *ALS* (acetolactate synthase/AHAS), *HPPD* (4-hydroxyphenylpyruvate dioxygenase), *EPSPS* (5-enolpyruvylshikimate-3-phosphate synthase), *PPO* (protoporphyrinogen oxidase), and *PSII* (photosystem II protein D1). In contrast, several target-site genes were located within windows exhibiting positive Tajima's D values, indicating elevated levels of intermediate-frequency genetic variation at these loci. This pattern provides no evidence of recent strong selective sweeps at the examined target-site genes and may instead indicate the persistence of standing genetic variation at these loci.

These results suggest that *A. cotula* possesses considerable adaptive capacity, with flowering-time genes potentially representing a stronger driver of selection than target-site mutations that endow herbicide-resistance.

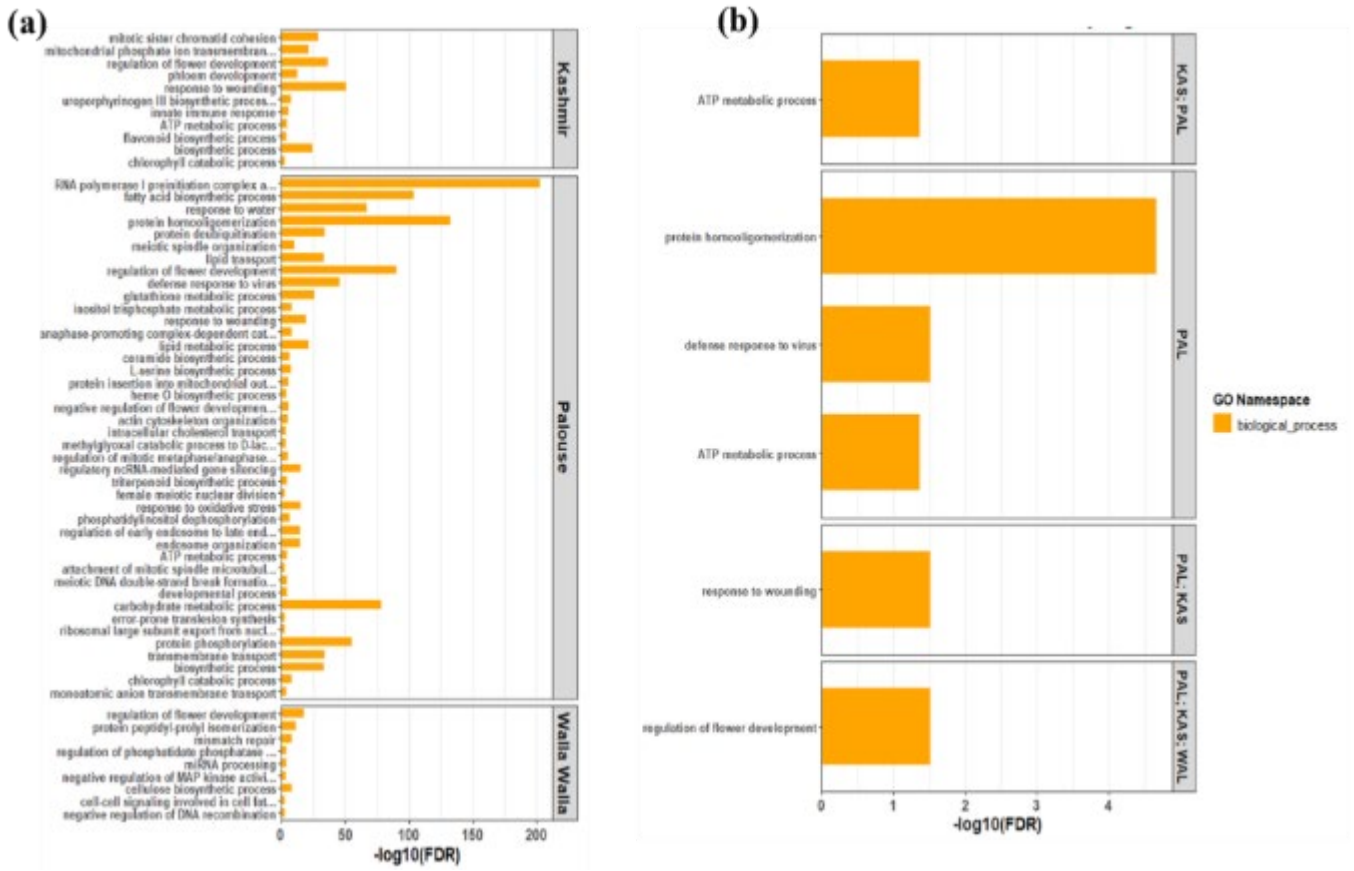


Figure 4. Gene Ontology (GO) enrichment analysis of genes located within Tajima's D outlier windows (> 2) across *Anthemis cotula* populations. (a) Regional GO enrichment analyses showing biological processes enriched within outlier windows in Kashmir Valley, Palouse, and Walla Walla Basin populations. (b) GO enrichment of candidate regions shared across two or more regions, highlighting recurrent biological processes potentially associated with consistent adaptive responses.

1.3) **Title:** Characterizing Suspected Mesotrione-Resistant Palmer Amaranth Populations

Authors: Olivia Landau and Albert Adjesiwor

Objective: Identify mesotrione-resistant palmer amaranth populations by subjecting them to two lethal doses, the field rate and twice the field rate.

Abstract: Palmer amaranth (*Amaranthus palmeri*) is a highly problematic and invasive weed that has spread from its native range of the southwest to most of the continental United States and Canada. The invasion of Palmer amaranth in the Pacific Northwest (PNW) is very recent as it was not discovered until 2022. This species is highly prone to evolving herbicide resistance and thus, any population identified within the PNW is likely resistant to herbicides commonly utilized in small grains and other radiational crops. Four Palmer amaranth populations identified in Idaho and Oregon were characterized for mesotrione resistance. Two of the populations, AMAPA4 and AMAPA5, demonstrated significant biomass accumulation and survival relative to the susceptible population (AMAPA1) at the 1X field rate (105 g ai ha^{-1}).

Results: Among all the populations, AMAPA4 had the highest survivorship and biomass accumulation at 1X and 2X treatments relative to the susceptible population; however, statistical significance was only identified at the 1X rate. The AMAPA5 population displayed intermediate results at the 1X rate, as its biomass and survivorship were not significantly different from either AMAPA4 or AMAPA1. When subjected to the 2X rate, AMAPA5 biomass and survival declined and was not distinguishable from AMAPA1 (Figures 5 and 6). All other populations were not significantly different from AMAPA1 at either rate of mesotrione.

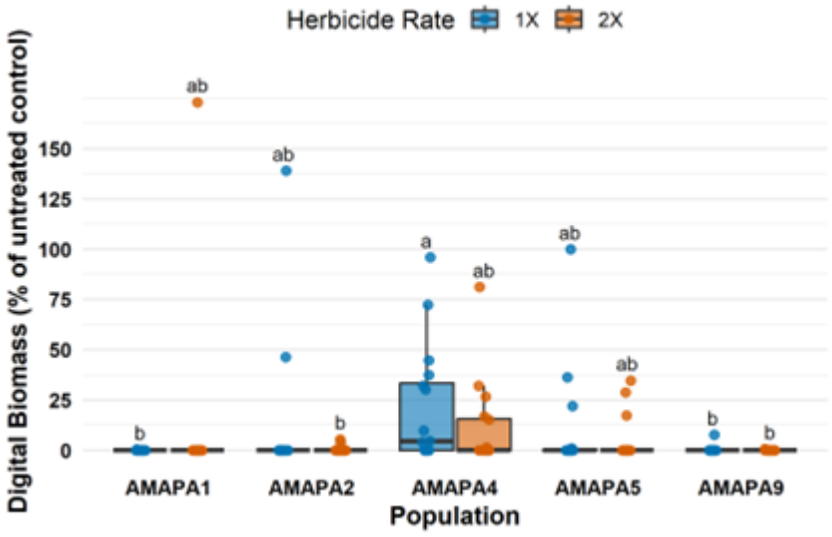


Figure 5. Digital biomass of Palmer amaranth populations at 28 days after treatment. Digital biomass is presented as a percent of untreated control plants (*n*=16). Treatments include 105 g ai ha^{-1} (1X) and 210 g ai ha^{-1} (2X). All treatments included 1% crop oil concentrate and 2.5%

v/v ammonium sulfate. Mean separation was determined with Fisher's LSD (α = 0.01). AMAPA1 is included to serve as standard sensitive population.

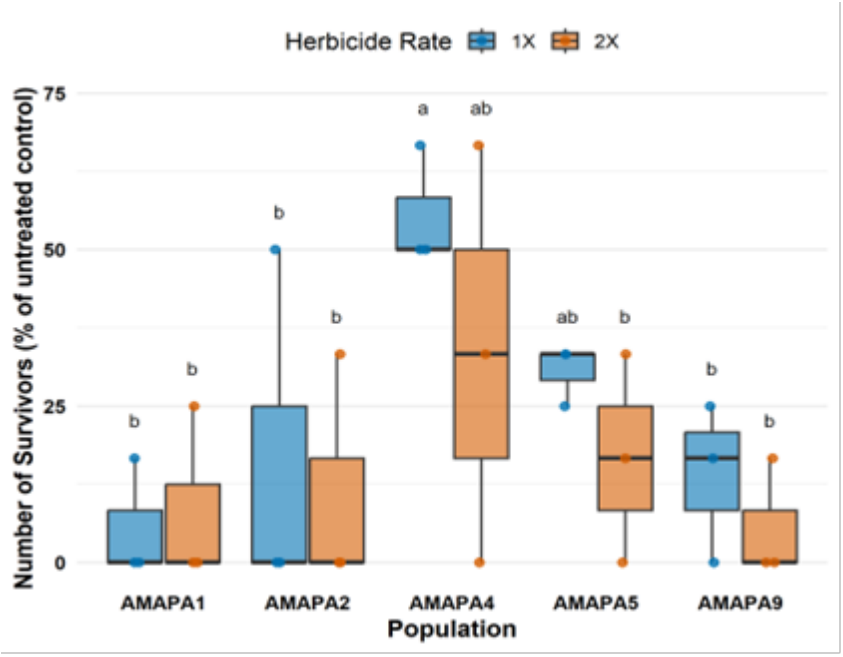


Figure 6. Survival of Palmer amaranth populations at 28 days after treatment. Survival is presented as a percent of untreated control plants across 3 experimental runs (*n*=3). Treatments include 105 g ai ha^{-1} (1X) and 210 g ai ha^{-1} (2X). All treatments included 1% crop oil concentrate and 2.5% v/v ammonium sulfate. Mean separation was determined with Fisher's LSD (α = 0.01). AMAPA1 is included to serve as standard sensitive population.

Additional Group 27 herbicides will be tested on these populations and AMAPA1, AMAPA4, and AMAPA5 will be utilized for future mesotrione dose-response assays to quantify the level of resistance.

1.4) Title: Wild oat herbicide resistance survey (Year 3)

Authors: Traci Rauch and Joan Campbell

Objective: Identify Herbicide-Resistant Wild Oat Populations in Northern Idaho and Eastern Washington.

Summary: Wild oat seed was collected from six fields in northern Idaho and eastern Washington in 2025 and marked with GPS coordinates. Seed was collected by hand and bulked to form a single sample for each location. Seeds from each sample along with a known susceptible biotype were screened in the greenhouse at 2X the labeled rate with herbicides used to control wild oat. Untreated plants were included from each sample. No wild oat population was resistant to ethalfluralin and clethodim. Wild oat collections from year three (2025) were resistant to triallate (1 sample), mesosulfuron (4 samples), pinoxaden (2 samples), fenoxaprop, and quizalofop (3 samples). Glyphosate screening will be completed in winter 2026.



1.5) **Title:** Windgrass, Italian ryegrass, Russian thistle, and Common Lambsquarters Herbicide Resistance Screening

Authors: Traci Rauch and Joan Campbell

Objective: Identify herbicide-resistant weed populations

Summary: Suspected-resistant weed seed samples collected from research plots and submitted by growers, fieldmen, and industry representatives were screened in the greenhouse. The weed seed samples were sprayed with herbicides at twice the labeled rate. Susceptible plants were included to verify spray coverage. Seeds were counted at planting with pre-emergence herbicides and plants counted at emergence with post-emergence herbicides. Untreated plants were included from each sample. Resistance was evaluated on plant survival and vigor compared to the untreated. One interrupted windgrass (*Apera interrupta*) seed sample was screened to six herbicides. The sample was resistant to imazamox, pyroxasulam, and mesosulfuron/thiencarbazone. It was susceptible to pyroxasulfone, pinoxaden, and glyphosate. One Italian ryegrass sample was screened to 12 herbicides. It was resistant to triasulfuron, pyroxsulam, pinoxaden, quizalofop, sethoxydim and mesosulfuron/thiencarbazone. It was susceptible to pyroxasulfone, metolachlor, clethodim, glyphosate, and flufenacet/metribuzin. Five common lambsquarters samples were screened to nine herbicides. Two samples were resistant to imazamox and imazethapyr. All samples were susceptible to pyridate, metribuzin, sulfentrazone, saflufenacil, flumioxazin, glyphosate and pyrasulfotole/bromoxynil. Five Russian thistle seed samples were screened to 10 herbicides. All samples were resistant to prosulfuron and imazethapyr. One sample was resistant to dicamba. A different sample was resistant to glyphosate. All samples were susceptible to bromoxynil, 2,4-D, metribuzin, saflufenacil, sulfentrazone and pyrasulfotole/bromoxynil.

1.6) **Title:** Herbicide Resistance Screening and Dose-Response Characterization of Idaho Populations.

Authors: Sushmita Sharma and Albert Adjesiwor

Objective(s):

1. Evaluate the response of wild oat (*Avena fatua*) populations collected in Idaho to selected herbicides used in small grain production systems.
2. Quantify the level of resistance among selected surviving populations using dose-response analysis.

Abstract: Wild oat (Avena fatua) is one of the most economically damaging grass weeds in Pacific Northwest small grain production, and growers rely heavily on postemergence Group 1 (ACCase) and Group 2 (ALS) herbicides for its control. In 2024 and 2025, 138 wild oat populations were collected and screened against eight postemergence herbicides and two preemergence herbicides. Visual control ratings and plant stand counts were recorded 28 days after spraying (DAS), and survival frequency was calculated for each herbicide. Survival exceeded 55% for fluroxypyr + pyroxsulam (73.9%), quizalofop-p-ethyl (72.7%), mesosulfuron-methyl (59.1%), fenoxaprop-p-ethyl (56.8%), and pinoxaden (55.7%), survival was lower for triallate (14.8%), imazamox (10.2%), and ethalfluralin (9.1%), and no populations survived clethodim or glyphosate. Five populations surviving multiple herbicides were subjected to dose-response analysis at 0.25, 0.5, 1, 2, 4, and 8 times the recommended dose; visual injury and survival counts were recorded 28 DAS, aboveground biomass was collected 28 DAS, and a three-parameter log-logistic model was fit in R 4.5.2 to estimate the doses required for 50 and 90% control (ED_{50} and ED_{90}) and to calculate resistant-to-susceptible (R/S) ratios. At 28 DAS, pinoxaden ED50 estimates for the resistant populations were 114.1 to 226.0 g ai ha^{-1} compared with 14.7 g ai ha^{-1} for a susceptible standard, corresponding to R/S ratios of roughly 8 to 15, whereas imazamox resistance was lower and less uniform (ED_{50} of 38.5 to 173.6 g ai ha^{-1} against 39.3 g ai ha^{-1}). Resistance to quizalofop-p-ethyl was the most severe of the four herbicides characterized, with ED_{50} estimates approximately 25 to 60 times those of the susceptible and 90% control not achieved at any dose, while response to pyroxsulam was more variable. Plants also survived imazamox at 2 and 4 times and pinoxaden at 2 times the recommended rate.

Accomplishments/Results:

Resistance screening of Idaho wild oat populations: Wild oat seed was collected from small grain fields in Idaho, with 50 populations collected in 2024 and an additional 88 in 2025, and screened in the greenhouse against eight postemergence herbicides – Axial XL (pinoxaden), Tacoma (fenoxaprop-p-ethyl), Aggressor (quizalofop-p-ethyl), Section Three (clethodim), Osprey (mesosulfuron-methyl), Roundup PowerMax (glyphosate), OpenSky (fluroxypyr + pyroxsulam), and Beyond Xtra (imazamox) – and two preemergence herbicides, Far-Go (triallate) and Sonalan (ethalfluralin). For each herbicide, populations that were not adequately controlled were classified as survivors and expressed as a percentage of the populations screened (Table 2). Survival was highest for the herbicides most widely used

Table 2. Percentage of Idaho wild oat populations surviving each postemergence and preemergence herbicide in greenhouse screening, based on visual control ratings and plant stand counts 28 days after spraying.

Active ingredient	Trade name	Application timing	Survival frequency (%)
Fluroxypyr + pyroxsulam	OpenSky	Postemergence	73.9
Quizalofop-p-ethyl	Aggressor	Postemergence	72.7
Mesosulfuron-methyl	Osprey	Postemergence	59.1
Fenoxaprop-p-ethyl	Tacoma	Postemergence	56.8
Pinoxaden	Axial XL	Postemergence	55.7
Triallate	Far-Go	Preemergence	14.8
Imazamox	Beyond Xtra	Postemergence	10.2
Ethalfluralin	Sonalan	Preemergence	9.1
Clethodim	Section Three	Postemergence	0.0
Glyphosate	Roundup PowerMax	Postemergence	0.0

against wild oat in small grains: 73.9% of populations survived fluroxypyr + pyroxsulam, 72.7% survived quizalofop-p-ethyl, 59.1% survived mesosulfuron-methyl, 56.8% survived fenoxaprop-p-ethyl, and 55.7% survived pinoxaden. Survival was considerably lower for triallate (14.8%), imazamox (10.2%), and ethalfluralin (9.1%), and no populations survived clethodim or glyphosate. Because more than half of the populations screened survived four ACCase-inhibiting or ALS-inhibiting treatments at the recommended rate, resistance to these two sites of action appears widespread in Idaho wild oat rather than confined to isolated fields.

Dose-response analysis: Five populations that survived multiple herbicides in the greenhouse screening were selected for dose-response analysis. Each was treated at 0.25, 0.5, 1, 2, 4, and 8 times the recommended dose, with four replications per population and five seeds per pot, and herbicides were applied at the three-leaf stage of wild oat using the same spray booth as the screening study. The postemergence herbicides characterized to date were pinoxaden (Axial XL), imazamox (Beyond Xtra), quizalofop-p-ethyl (Aggressor), and pyroxsulam (OpenSky); mesosulfuron-methyl (Osprey) and fenoxaprop-p-ethyl (Tacoma) are scheduled for 2026. Visual injury and survival counts were recorded 28 DAS and aboveground biomass was collected 28 DAS. Resistance to pinoxaden was strong and consistent (Figure 7): ED_{50} estimates for the five populations ranged from 114.1 to 226.0 g ai ha^{-1} compared with 14.7 g ai ha^{-1} for the susceptible standard, corresponding to R/S ratios (resistant ED_{50} divided by susceptible ED_{50}) of roughly 8 to 15, and ED_{90} estimates ranged from 156.6 to 276.4 g ai ha^{-1} compared with 29.2 g ai ha^{-1} for the susceptible standard. Resistance to imazamox was weaker and less uniform (Figure 8): populations 1 and 2 required 173.6 and 153.5 g ai ha^{-1} for 50% control against 39.3 g ai ha^{-1} for the susceptible standard, while populations 4 and 5 (38.5 and 42.5 g ai ha^{-1}) responded much like the susceptible standard. Resistance to quizalofop-p-ethyl was the most severe of the four herbicides characterized (Figure 9): the five populations required approximately 400 to 900 g ai ha^{-1} for 50% control compared with approximately 15 g ai ha^{-1} for the susceptible standard, and the fitted curves for two populations plateaued

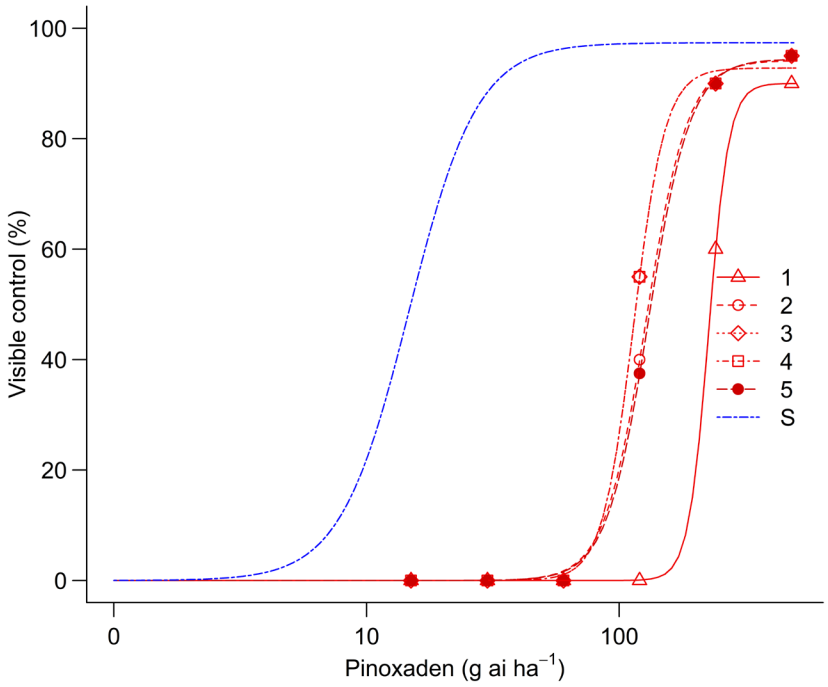


Figure 7. Dose-response of five surviving wild oat populations and a susceptible standard to pinoxaden 28 days after spraying. Curves are labeled 1 to 5 for the surviving populations and S for the susceptible standard.

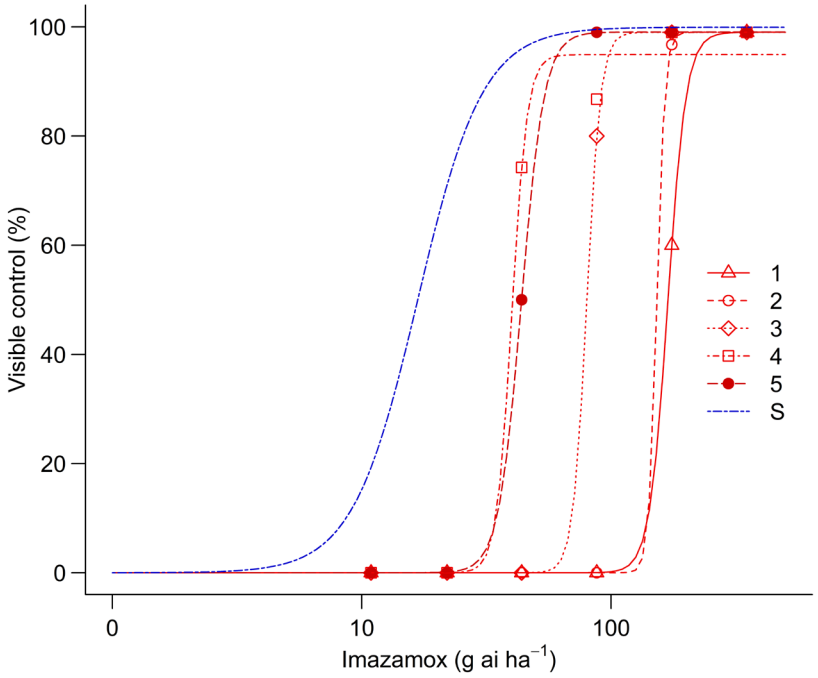


Figure 8. Dose response of five surviving wild oat populations and a susceptible standard to imazamox 28 days after spraying. Curves are labeled 1 to 5 for the surviving populations and S for the susceptible standard.

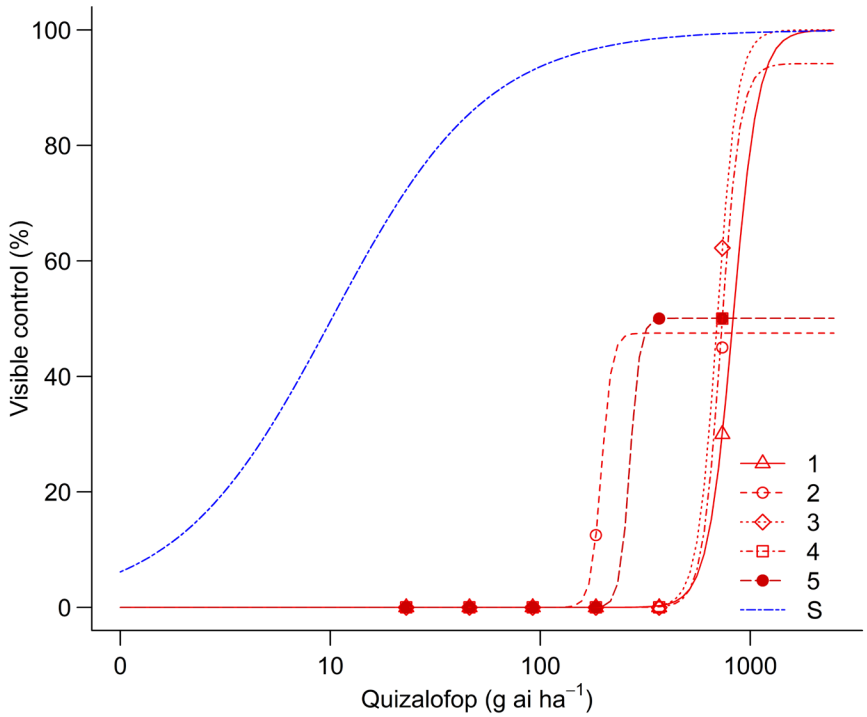


Figure 9. Dose response of five surviving wild oat populations and a susceptible standard to quizalofop-p-ethyl 28 days after spraying. Curves are labeled 1 to 5 for the surviving populations and S for the susceptible standard.

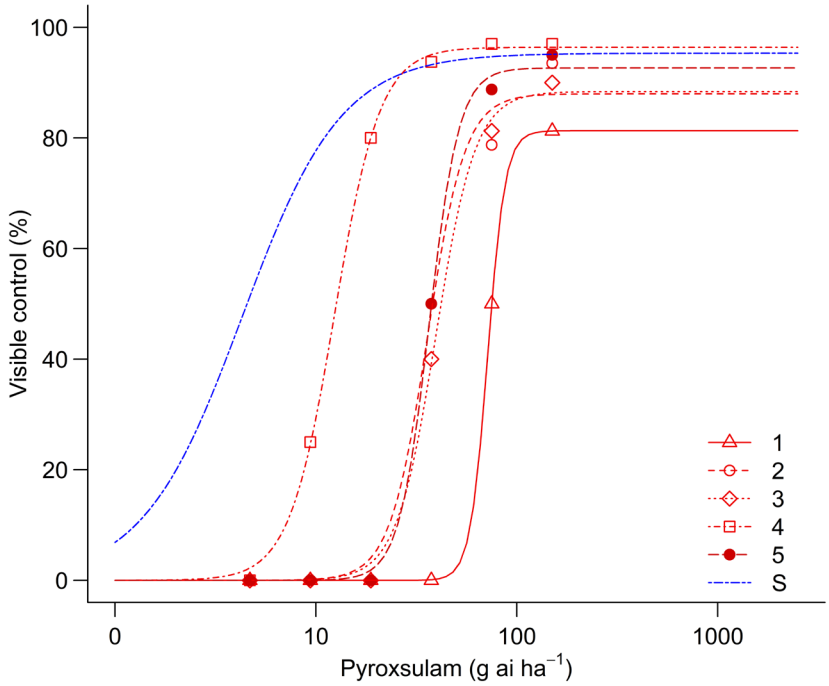


Figure 10. Dose response of five surviving wild oat populations and a susceptible standard to pyroxsulam 28 days after spraying. Curves are labeled 1 to 5 for the surviving populations and S for the susceptible standard.

near 50% visible control, so 90% control was not achieved at any dose tested. Response to pyroxsulam was more variable (Figure 10): four populations required approximately 35 to 75 g ai ha^{-1} for 50% control against approximately 5 g ai ha^{-1} for the susceptible standard, while the remaining population responded much like the susceptible standard. Maximum visible control (d) ranged from approximately 50 to 96% across the four herbicides and five populations, so control remained incomplete even at the highest doses tested. Plants survived imazamox at 2 and 4 times (87.6 and 175.2 g ai ha^{-1}) and pinoxaden at 2 times (120.4 g ai ha^{-1}) the recommended rate (Figure 11), indicating that increasing the field rate of these herbicides is not a viable control strategy for the affected populations.

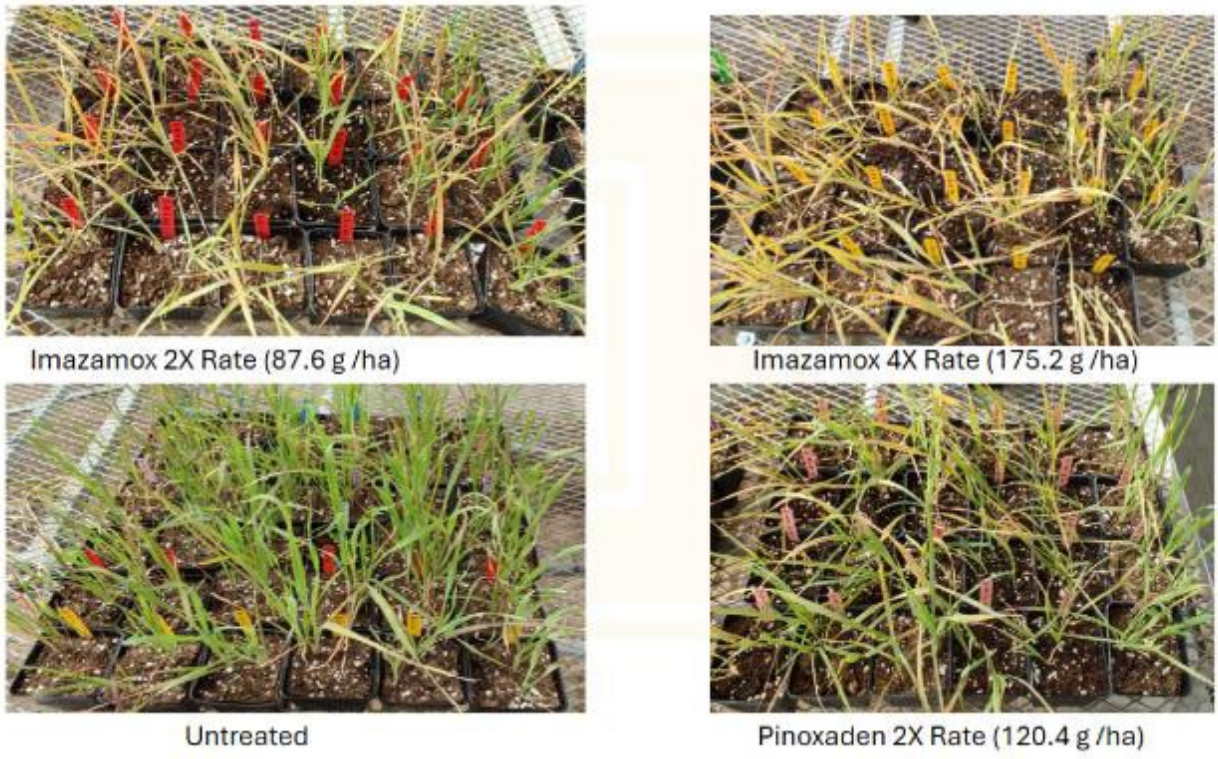


Figure 11. Wild oat treated with imazamox at 2 times (87.6 g ai ha^{-1}) and 4 times (175.2 g ai ha^{-1}) the recommended rate and pinoxaden at 2 times (120.4 g ai ha^{-1}) the recommended rate, compared with a nontreated check.

1.7) **Title:** Confirming Glyphosate Resistance in Idaho Waterhemp Populations Through Dose-Response Bioassays and *EPSPS* Gene Duplication Analysis

Authors: Laura Rodriguez, Albert Adjesiwor, and Olivia Landau

Objective(s):

1. Confirm glyphosate resistance in waterhemp (*Amaranthus tuberculatus*) populations from southern Idaho using whole-plant dose-response bioassays.
2. Determine EPSPS gene copy number and target-site sequence variation as potential mechanisms contributing to glyphosate resistance.

Abstract: Waterhemp (*Amaranthus tuberculatus*) is a troublesome weed in U.S. cropping systems, and its recent detection in southern Idaho sugar beet fields has raised concerns about the spread of herbicide-resistant populations into the PNW. Five waterhemp populations that survived field-rate glyphosate applications in southern Idaho (AMATU1 to AMATU5) were evaluated in whole-plant dose-response bioassays and compared with a known-susceptible population (Sus) from Ohio. *EPSPS* gene copy number relative to the *CPS* reference gene was quantified by qPCR, and a portion of the *EPSPS* gene spanning codon 106 was sequenced. All five resistant populations exhibited 5- to 19-fold higher GR_{50} values than the susceptible population and contained greater *EPSPS* copy numbers (5.4–9.7 copies versus 1.8 copies). Target-site sequencing identified a Pro106Ser (P106S) substitution in one composite sample each from populations AMATU3 and AMATU5. These results confirm glyphosate resistance in southern Idaho waterhemp involving multiple target-site mechanisms, including *EPSPS* gene amplification and P106S, and suggest that relatively low *EPSPS* copy numbers combined with P106S may only partially explain the observed resistance levels, pointing to a possible role for additional non-target-site mechanisms.

Results:

Glyphosate dose-response: Whole-plant dose-response bioassays confirmed glyphosate resistance in all five waterhemp populations collected from southern Idaho sugar beet fields (Figures 12 and 13). Based on visible control ratings at 21 days after treatment, resistant populations required 5- to 19-fold more glyphosate than the susceptible population to achieve 50% control (GR_{50}; Table 3), with AMATU2 and AMATU3 showing the greatest resistance (19- and 18-fold, respectively) and AMATU4 the least (5-fold). GR_{90} values followed a similar pattern, ranging from about 4,745 to 69,249 g ae ha^{-1} among resistant populations compared with 4,620 g ae ha^{-1} for the susceptible population. Biomass reduction data showed a comparable trend, with resistant populations requiring substantially more glyphosate than the susceptible population to achieve equivalent reductions in aboveground biomass. The magnitude of resistance observed in these Idaho populations falls within the range previously reported for glyphosate-resistant waterhemp in the Midwestern and Northeastern United States.

EPSPS gene copy number: Quantitative PCR analysis of *EPSPS* gene copy number relative to the *CPS* reference gene showed that all five glyphosate-resistant populations contained greater *EPSPS* copy numbers than the susceptible population, ranging from 5.4 to 9.7 copies compared with 1.8 copies in the susceptible population (Figure 14). Copy numbers were

broadly consistent with values previously reported for glyphosate-resistant waterhemp populations from the Midwest, though considerably lower than the large-scale *EPSPS* amplification reported in glyphosate-resistant Palmer amaranth, where resistant populations can carry dozens to more than 100 *EPSPS* copies.

Target-site (EPSPS) sequencing: Sequencing of a highly conserved portion of the *EPSPS* gene spanning codon 106 identified a cytosine-to-thymine substitution (CCA to TCA) in one composite sample each from populations AMATU3 and AMATU5, resulting in a Pro106Ser (P106S) amino acid substitution. All composite samples from the susceptible population and from populations AMATU1, AMATU2, and AMATU4 carried the wild-type cytosine allele at this position. The P106S mutation is a well-documented target-site mechanism of glyphosate resistance in waterhemp and has previously been reported in resistant populations from Illinois, Kentucky, and Mississippi. Its detection here, together with *EPSPS* gene amplification across all five resistant populations, indicates that surviving Idaho plants are genetically resistant rather than simple field escapes, and that multiple target-site mechanisms are already present in populations established in the region.

The presence of relatively low *EPSPS* copy numbers alongside P106S in only a subset of populations suggests that these target-site mechanisms may only partially explain the observed resistance levels, and that non-target-site mechanisms (such as reduced glyphosate translocation or metabolism) may also be contributing. Whether glyphosate-resistant waterhemp arose from local selection pressure or was introduced via contaminated seed, feed, or equipment from previously resistant U.S. regions remains an open question, though the presence of identical resistance mechanisms in a non-native species within a short timeframe raises concern about introduction from elsewhere.

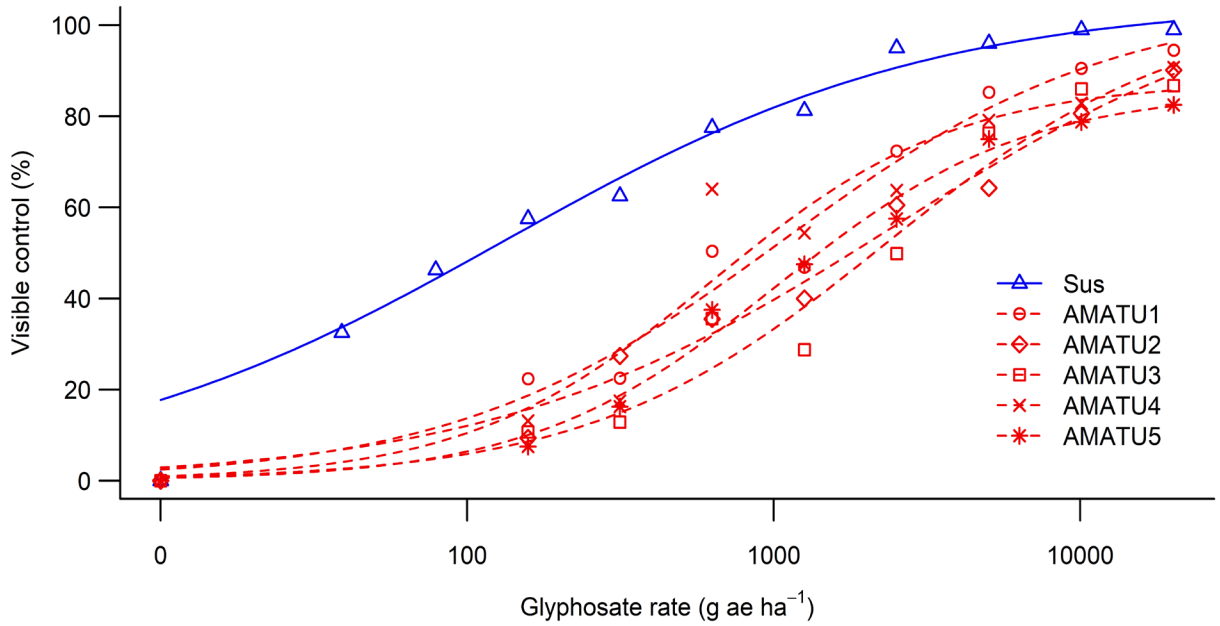


Figure 12. Dose-response curves of visible control for five suspected glyphosate-resistant waterhemp populations from Idaho (AMATU1–AMATU5) and a susceptible population from Ohio (Sus) at 21 days after treatment with glyphosate.

Table 3. Nonlinear regression parameter estimates (GR_{50}, GR_{90}) and resistance ratios (R/S) based on visible control of a glyphosate-susceptible (Sus) and five glyphosate-resistant (AMATU1–AMATU5) waterhemp populations at 21 days after treatment with glyphosate.

Population	GR_{50} (g ae ha^{-1} ± SE)	GR_{90} (g ae ha^{-1} ± SE)	R/S ratio
Sus	132 (58)	4,620 (6,431)	—
AMATU1	1,068 (387)	16,530 (15,021)	8
AMATU2	2,465 (2,088)	69,249 (120,135)	19
AMATU3	2,338 (968)	27,337 (25,227)	18
AMATU4	628 (168)	4,745 (3,582)	5
AMATU5	1,023 (389)	7,808 (7,245)	8

R/S = resistance ratio, calculated as the GR_{50} of each resistant population divided by the GR_{50} of the susceptible population.



Figure 13. Visible control of A) the glyphosate-susceptible waterhemp population and B) a representative glyphosate-resistant waterhemp population (AMATU3) at 21 days after treatment with glyphosate at rates ranging from 0X to 16X (left to right).

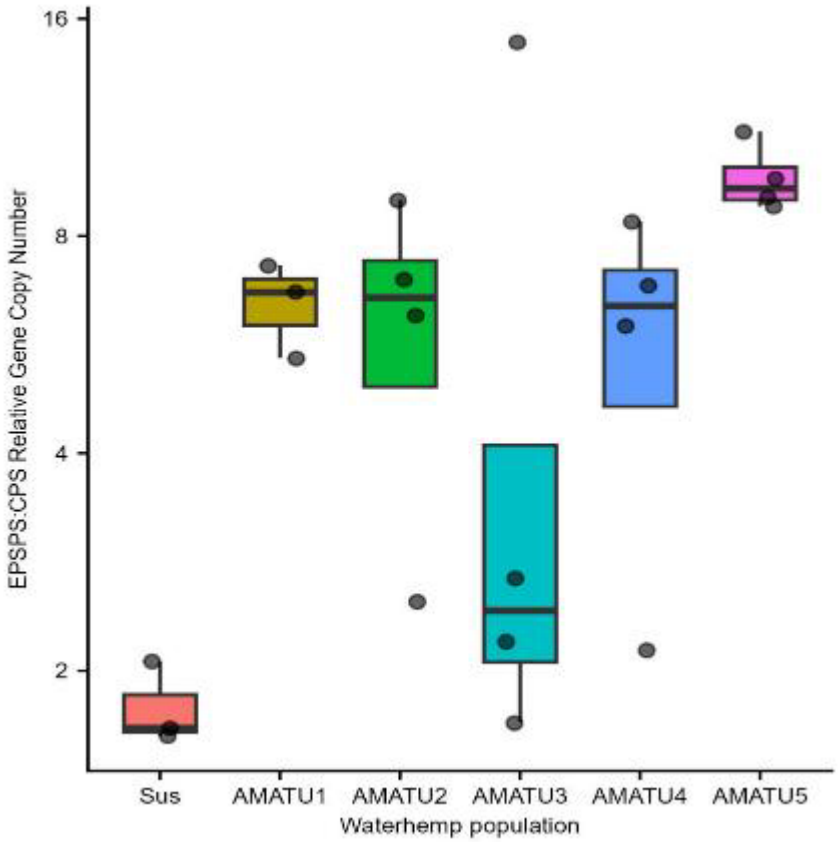


Figure 14. *EPSPS* gene copy numbers (relative to the *CPS* reference gene) of five suspected glyphosate-resistant waterhemp populations from Idaho (AMATU1–AMATU5) and a susceptible population from Ohio (Sus). All resistant populations survived the 4X glyphosate rate (5,040 g ae ha^{-1}).

1.8) **Title:** Confirming Glyphosate Resistance in Idaho Common Lambsquarters Populations Through Whole-Plant Dose-Response Bioassays

Authors: Albert Adjesiwor

Objective(s):

1. Screen common lambsquarters populations collected from southern Idaho for survival following 1X and 2X field rates of glyphosate.
2. Characterize glyphosate resistance in surviving common lambsquarters populations using whole-plant dose-response bioassays.

Abstract: Common lambsquarters (*Chenopodium album*) is among the most common broadleaf weeds in Idaho cropping systems, and growers have reported escapes following glyphosate applications at labeled field rates. To determine whether these escapes reflect heritable resistance rather than application or environmental factors, 44 common lambsquarters populations collected from southern Idaho were screened in the greenhouse against the 1X (1,260 g ae ha^{-1}) and 2X (2,520 g ae ha^{-1}) field rates of glyphosate (Roundup PowerMax), with visible control rated on a 0 to 100% scale. About 60% of the populations survived the 1X rate (control below 50%) and 20% survived the 2X rate. Four populations that survived the field rate were then evaluated in whole-plant dose-response bioassays alongside a known-susceptible check, using glyphosate rates spanning 0X to 16X of the field rate, and visible control was assessed 28 days after treatment. Dose-response curves for all four suspected resistant populations were displaced to the right of the susceptible check, indicating that more glyphosate was required to achieve equivalent control, with one population (population 4) requiring roughly three times the rate needed by the susceptible population to reach 50% control. These results indicate that glyphosate resistance is present in southern Idaho common lambsquarters populations and is widespread enough across the sampled populations to affect glyphosate-based weed management in the region.

Results:

Glyphosate screening of field-collected populations: Common lambsquarters plants that survived field applications of glyphosate were collected from southern Idaho fields (Figure 15), and 44 populations were screened in the greenhouse against the 1X (1,260 g ae ha^{-1}) and 2X (2,520 g ae ha^{-1}) field rates of glyphosate (Roundup PowerMax). About 60% of the populations survived the 1X rate, defined as visible control below 50%, and 20% survived the 2X rate (Figure 16). Control at the 1X rate was spread across the full 0 to 100% range, with many populations falling below the 50% threshold, whereas control at the 2X rate was concentrated between 60 and 100%, so doubling the rate improved control substantially but did not eliminate survivors.

Glyphosate dose-response: Four populations that survived the field rate of glyphosate were evaluated in whole-plant dose-response bioassays and compared with a known-susceptible check (Figure 17). Plants were treated with glyphosate rates spanning 0X to 16X of the field rate, and visible control was rated 28 days after treatment. Dose-response curves for all four suspected resistant populations (populations 4, 6, 17, and 75) were displaced to the right of the susceptible check. The susceptible population reached 50% visible control near 600 g ae



Figure 15. Common lambsquarters plants that survived a field application of glyphosate (1,260 g ae ha^{-1}) in southern Idaho.

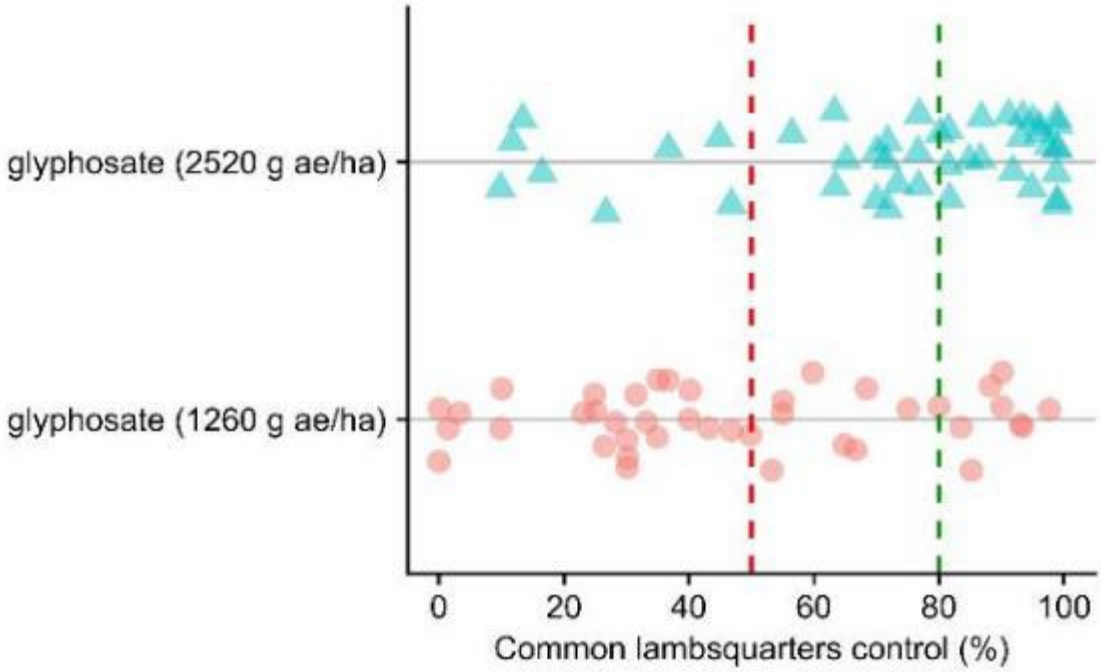


Figure 16. Visible control of 44 common lambsquarters populations from southern Idaho following the 1X (1,260 g ae ha^{-1}) and 2X (2,520 g ae ha^{-1}) rates of glyphosate (Roundup PowerMax). Each symbol is one population; the dashed lines mark the 50% and 80% control thresholds.

ha^{-1} and was completely controlled at or below the 1X field rate, whereas the four suspected resistant populations required roughly 900 to 1,700 g ae ha^{-1} for 50% control and were not fully controlled until rates well above the field rate. Population 4 was the least sensitive, requiring approximately three times the glyphosate needed by the susceptible population to reach 50% control, while populations 6, 17, and 75 were intermediate.

This is the first confirmation of glyphosate resistance in common lambsquarters in Idaho. The remaining work includes investigating resistance mechanisms, including EPSPS gene copy number and target-site sequence variations.

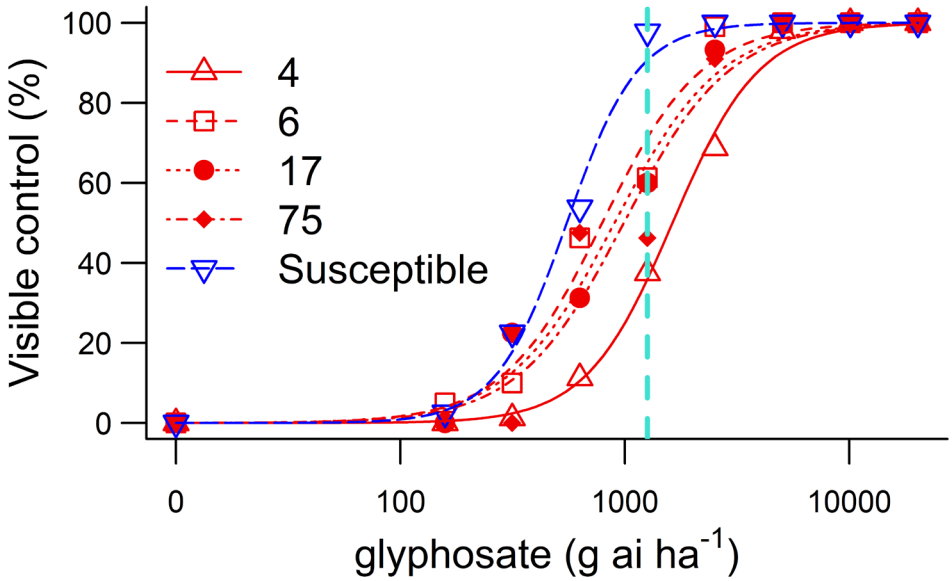


Figure 17. Dose-response of visible control for four suspected glyphosate-resistant common lambsquarters populations from southern Idaho (populations 4, 6, 17, and 75) and a susceptible check, rated 28 days after treatment. The vertical dashed line marks the 1X field rate (1,260 g ae ha^{-1}).

1.9) **Title:** Effect of Wheat Canopy on Wild Oat Growth, Seed Production, and Germination Ecology

Authors: Sushmita Sharma and Albert Adjesiwor

Objective(s):

1. Determine how crop canopy and shading influence wild oat growth and seed production.
2. Assess the effect of crop canopy on seed dormancy and germination potential of harvested seeds.

Abstract: Wild oat (*Avena fatua*) is one of the most competitive annual grass weeds of Pacific Northwest small grain production, and the seed returned to the soil each season determines the size of subsequent infestations. Seed that matures inside a crop canopy develops under shade and under altered temperature and humidity, which may change how dormant it is and when it germinates. A field experiment at Kimberly, Idaho, in 2025 compared wild oat growing within a wheat canopy with wild oat growing without a canopy, and tillers per plant, seeds per plant, and seed weight per plant were recorded. Seed harvested from each canopy treatment was tested for germination after harvest and again after six months of dry storage. Temperature response was evaluated at 10 constant temperatures from 0 to 40 C. Germination moisture requirement response was compared at seven osmotic potentials (0, -0.2, -0.4, -0.6, -0.8, -1.0, and -1.2 MPa) at a constant 21 C, using polyethylene glycol 8000. Germination was recorded daily for 28 days and cumulative germination was described with a three-parameter Weibull type 1 model. Freshly harvested seed was strongly dormant: germination did not exceed about 7% at any temperature, no seed germinated at 6.3 C or above 30.2 C, and under water stress germination reached about 35% at 0 MPa but ceased below -0.4 MPa. After dry storage, dormancy was largely released; germination peaked at about 80% at 20.3 C, was between about 47 and 80% from 13.6 to 26.7 C depending on temperature and canopy treatment and was measurable at 6.3 C and at osmotic potentials down to -1.2 MPa. Seed that matured without a canopy germinated more than canopy seed under most conditions, particularly at cool temperatures and under water stress, although in stored seed the pattern reversed between 20.3 and 26.7 C. These results indicate that maturation within a wheat canopy increases wild oat seed dormancy and that after-ripening in dry storage widens both the temperature and the moisture range over which the seed will germinate.

Results:

Field experiment and seed collection: The field experiment was conducted at Kimberly, Idaho, in 2025 and compared two conditions: wild oat growing within a wheat canopy and wild oat growing in the open without a canopy (Figure 18). Tillers per plant, seeds per plant, and seed weight per plant were recorded in each condition, and seed produced under each condition was retained for the germination studies. Seed from the two canopy treatments was then compared in two germination experiments, one varying temperature and one varying water potential, so that any difference in dormancy attributable to the maturation environment could be detected. Germination was tested on freshly harvested seed and again

on seed held in dry storage for six months, allowing the effect of after-ripening to be separated from the effect of the maturation environment.

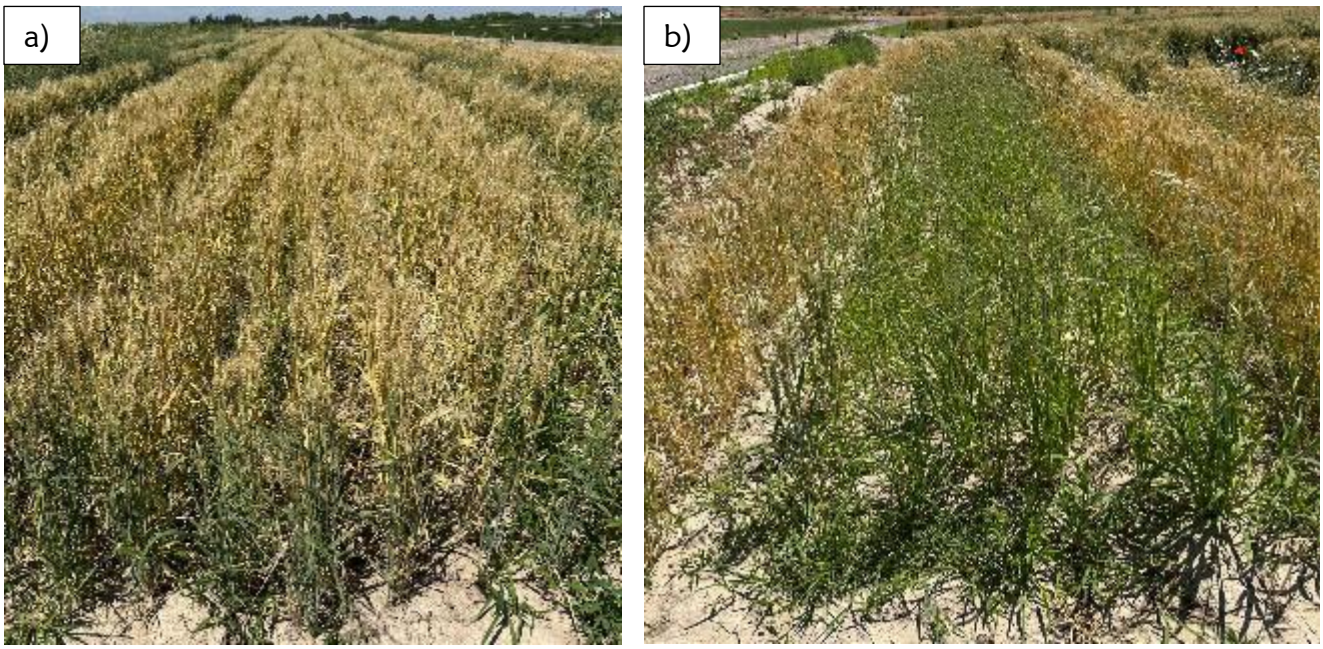


Figure 18. Field experiment at Kimberly, Idaho, in 2025, showing wild oat growing within a wheat canopy (a) and in the open without a canopy (b). Seed produced under each condition was used in germination studies.

Germination response to temperature: Freshly harvested seed was strongly dormant (Figure 19). Germination did not exceed about 7% at any temperature tested, no seed germinated at the coldest temperature (6.3 C) or above 30.2 C, and cumulative germination rose only gradually over the 28-day test rather than reaching a plateau within the first week. Within that narrow window, seed that matured without a canopy germinated more than canopy seed at 10.1, 13.6, and 17.1 C, the two treatments were nearly equal at 20.3 and 23.5 C, and canopy seed was slightly higher at 26.7 C. After dry storage, dormancy was largely released and the temperature range over which the seed germinated widened substantially (Figure 20). Final germination peaked near 20.3 C at about 80% (canopy) and 75% (no canopy), was between about 47 and 70% at the other temperatures from 13.6 to 26.7 C, declined to about 22 to 35% at 30.2 C, and fell to 5% or less at 33.3 and 36.3 C. Stored seed also germinated at 6.3 C (about 13% in both treatments), a temperature at which freshly harvested seed did not germinate at all. The canopy effect shifted with temperature: no-canopy seed germinated more at 10.1 and 13.6 C, the two treatments were equivalent at 17.1 C, canopy seed germinated more from 20.3 to 26.7 C, and no-canopy seed was again higher at 30.2 C.

Germination response to water potential: Water stress limited germination in both seed lots, but the limiting potential differed sharply between fresh and stored seed. Freshly harvested seed germinated to about 35% (no canopy) and 19% (canopy) in the absence of stress, to about 20% and 7% at -0.2 MPa, and to about 7% and 1% at -0.4 MPa, with no germination

at potentials below -0.4 MPa (Figure 21). Stored seed germinated across the entire range tested (Figure 22), reaching about 80% (no canopy) and 52% (canopy) at 0 MPa and declining progressively to about 7% (no canopy) and 1% (canopy) at -1.2 MPa. At nearly every osmotic potential and in both seed lots, seed that matured without a canopy germinated more than canopy seed, and the difference between the two was widest under the least stressful conditions.

These results indicate that wild oat seed maturing inside a wheat canopy is more dormant than seed maturing in the open, and that after-ripening in dry storage releases much of that dormancy, widening both the temperature range and the water potential range over which germination occurs. The practical implication is that canopy-matured seed is likely to germinate later and over a longer period, and across a wider range of soil conditions once dormancy is lost, which complicates the timing of both preemergence and postemergence control.

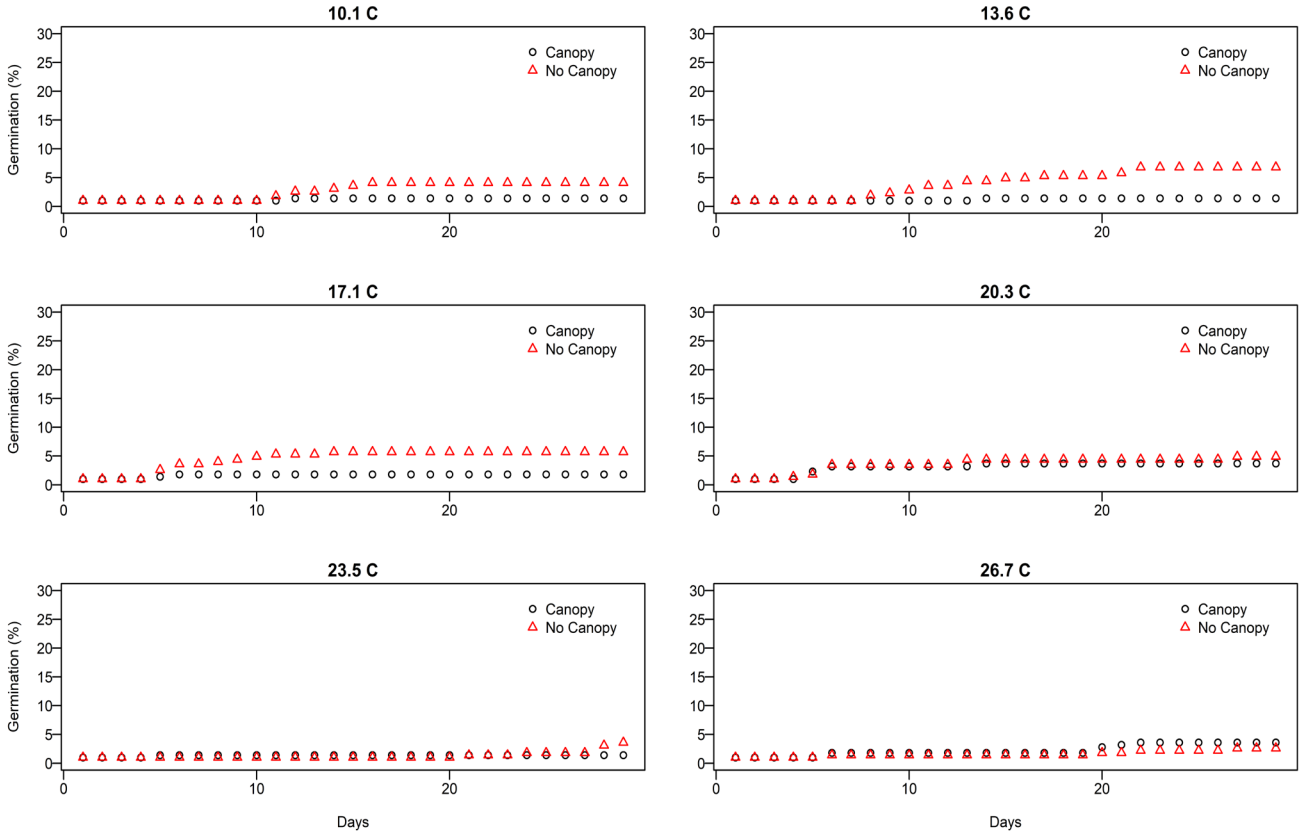


Figure 19. Cumulative germination of freshly harvested wild oat seed from the canopy and no-canopy field treatments, recorded daily for 28 days at six constant temperatures. No germination occurred at 6.3 C or above 30.2 C.

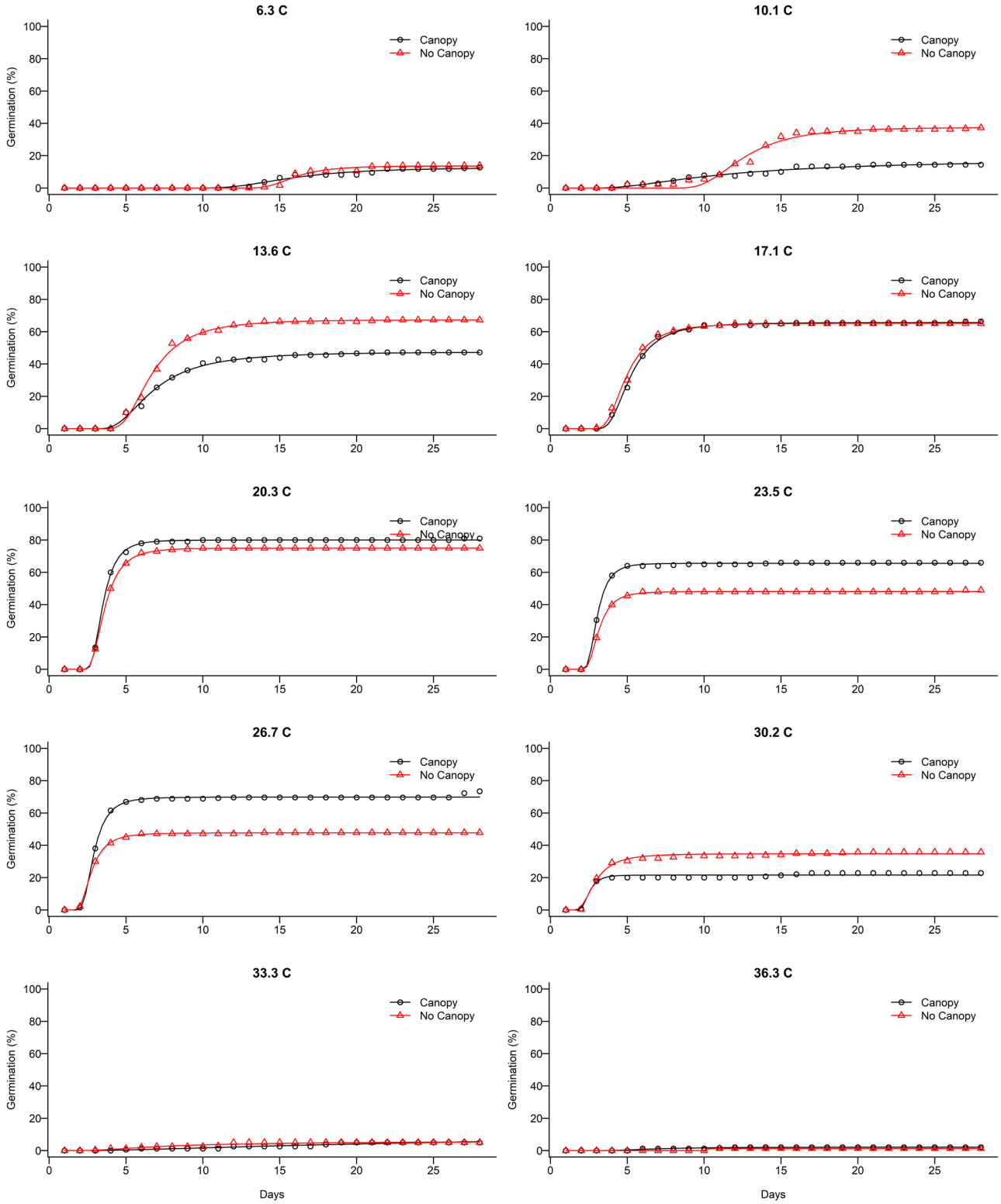


Figure 20. Cumulative germination of stored wild oat seed (6 months of dry storage) from the canopy and no-canopy field treatments, recorded daily for 28 days at 10 constant temperatures from 6.3 to 36.3 C.

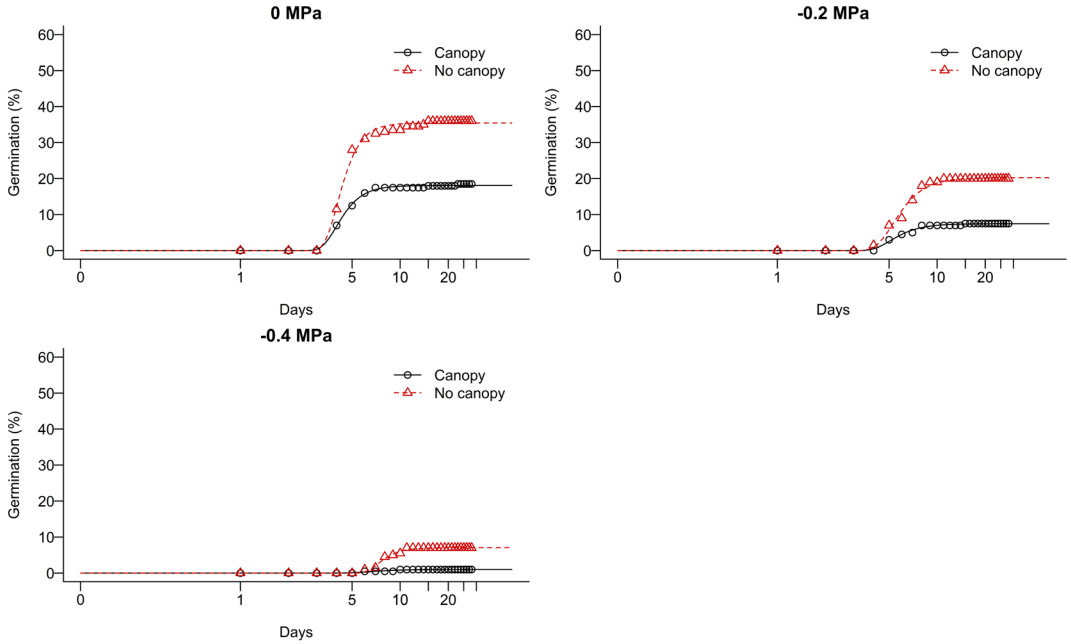


Figure 21. Cumulative germination of freshly harvested wild oat seed from the canopy and no-canopy field treatments at osmotic potentials of 0, -0.2, and -0.4 MPa at a constant 21 C. No germination occurred below -0.4 MPa.

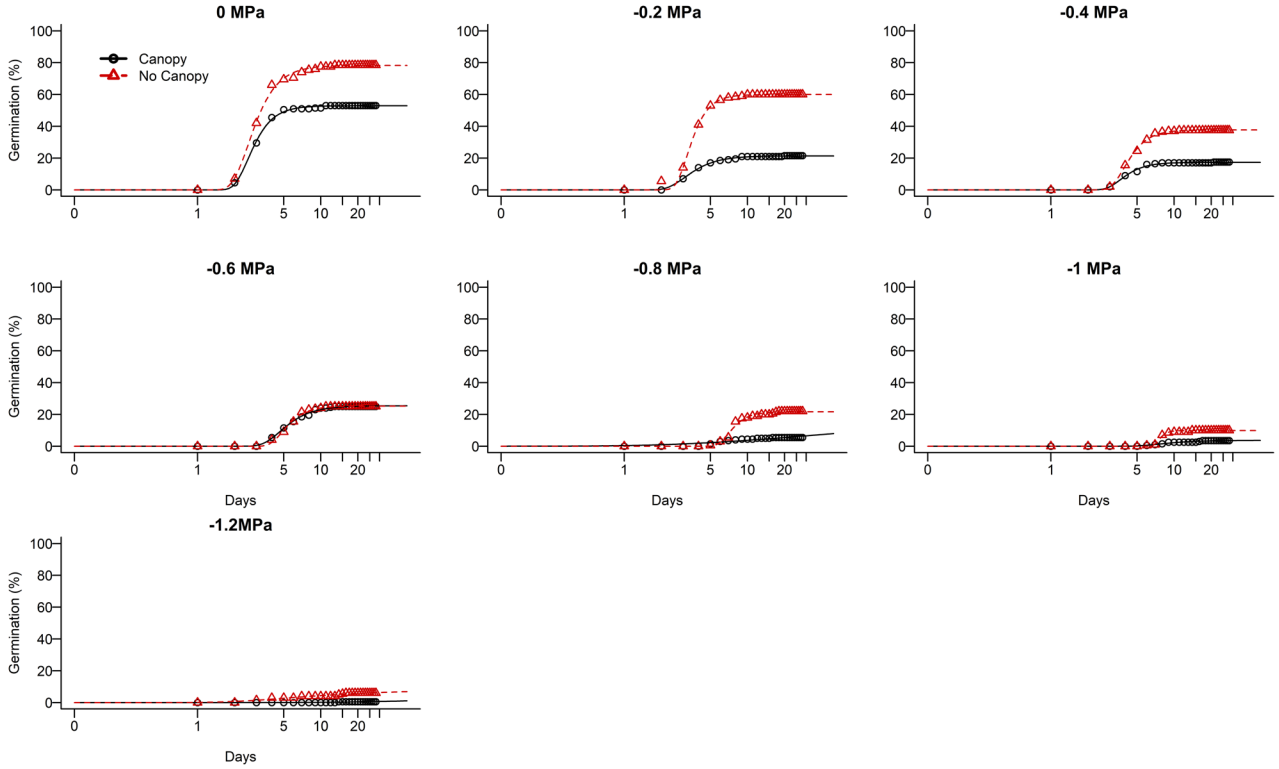


Figure 22. Cumulative germination of stored wild oat seed (6 months of dry storage) from the canopy and no-canopy field treatments at osmotic potentials of 0 to -1.2 MPa at a constant 21 C.

1.10) **Title:** Screening Common Lambsquarters (*Chenopodium Album*) for Resistance to Imazamox

Authors: Albert Adjesiwor and Olivia Landau

Objective(s):

1. Determine the level of resistance to imazamox in suspected-resistant common lambsquarters populations relative to a known-susceptible population.
2. Sequence the acetolactate synthase (ALS) homoeologs to identify target-site mutation(s) associated with imazamox resistance.

Abstract: Imazamox is an acetolactate synthase (ALS)-inhibiting herbicide that is an important tool for broadleaf and grass weed control in Clearfield small grain production systems in the Pacific Northwest. Dose-response experiments were conducted on four suspected imazamox-resistant common lambsquarters populations (D-1B1, D-1B2, GA7-1, and GA7-2) and a known-susceptible population. All four suspected resistant populations required substantially more imazamox to achieve 50% control than the susceptible population (10.8 g ai ha^{-1}), with resistance levels ranging from about 3-fold (GA7-1, 35.2 g ai ha^{-1}) to 67-fold (D-1B1, 724.7 g ai ha^{-1}). Sequencing of the three ALS homoeologs (on the chromosomes corresponding to 5B, 5C, and 5D) identified a single target-site mutation, Ala-122-Thr, consistent with mutations previously reported in Chinese common lambsquarters populations. No other target-site mutations were detected. The number of homoeologs carrying the Ala-122-Thr mutation varied among individuals, ranging from a single mutated copy to all three copies being mutated in the same plant, and this variation appears to partially track the degree of resistance observed among populations.

Results:

Dose-response to imazamox: Whole-plant dose-response assays were conducted with the susceptible, D-1B1, D-1B2, GA7-1, and GA7-2 common lambsquarters populations treated with a range of imazamox rates (at 0, 22, 44, 88, 175, and 350 g ha^{-1}). All four suspect populations survived rates that killed essentially all of the susceptible plants (Figure 23 & 24). Based on the fitted dose-response models, the susceptible population required only 10.8 g ai ha^{-1} of imazamox for 50% control, whereas the resistant populations required 3- to 67-fold more herbicide to achieve the same level of control (Table 4). D-1B1 had by far the highest level of resistance, with an estimated 724.7 g ai ha^{-1} needed for 50% control and an ED_{90} of 8,819 g ai ha^{-1}—well above field use rates. GA7-2 and D-1B2 were intermediate (73.5–74.0 g ai ha^{-1} for 50% control), and GA7-1 had the lowest level of resistance among the suspect populations (35.2 g ai ha^{-1}). ED_{90} values could not be reliably estimated for D-1B2, GA7-1, and GA7-2 because control did not reach 90% even at the highest rate tested.

ALS gene sequencing: Common lambsquarters is an allohexaploid species, and the ALS gene is present as three homoeologous copies located on the chromosomes corresponding to 5B, 5C, and 5D. All three homoeologs were sequenced from individual plants representing the susceptible check and the D-1B1, D-1B2, GA7-1, and GA7-2 populations. No target-site mutations were detected in any homoeolog of the susceptible plants. Across the resistant

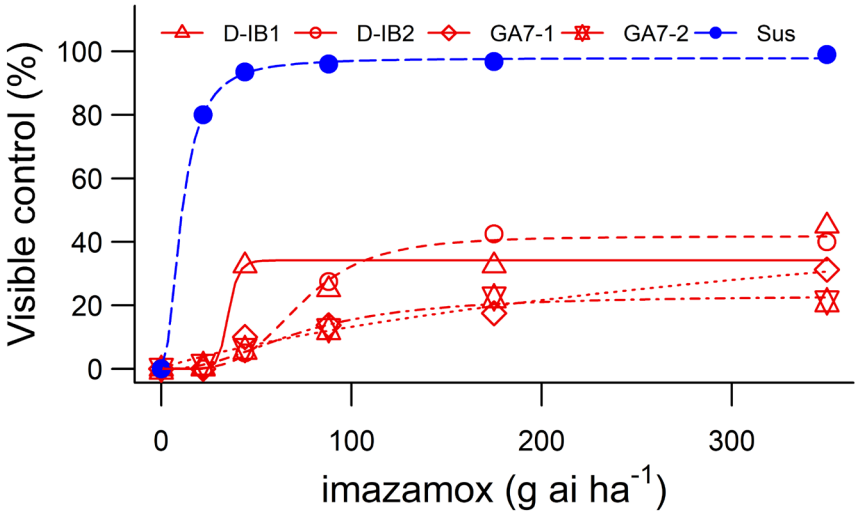


Figure 23. Visible control (%) of susceptible, D-1B1, D-1B2, GA7-1, and GA7-2 common lambsquarters populations two weeks after treatment with increasing rates of imazamox.

Table 4. Imazamox rates required for 50 and 90% control of susceptible and suspected-resistant common lambsquarters populations, based on fitted dose-response models.

CLQ population	Imazamox rate (g ai ha^{-1}) to provide 50% control	Imazamox rate (g ai ha^{-1}) to provide 90% control
Susceptible	10.8	30.6
D-1B1	724.7	8,819
D-1B2	73.5	NA*
GA7-1	35.2	NA*
GA7-2	74.0	NA*

**NA: model estimate not available or not accurate because control did not reach 90% at the highest rate tested.*



Figure 24. Common lambsquarters populations 2 weeks after treatment with imazamox at 0, 22, 44, 88, 175, and 350 g ha^{-1} (right to left within each panel). The susceptible population was killed at all but the lowest rates, while D-1B1, D-1B2, GA7-1, and GA7-2 plants survived across the rate range, though injury was visibly greater in GA7-1.

populations, the Ala-122-Thr (GCA to ACA) substitution was the only mutation identified among the eight ALS resistance-conferring codons, which is consistent with the mutation reported in imazamox/ALS-resistant common lambsquarters populations from China.

The Ala-122-Thr mutation was not present on all three homoeologs in every plant (Table 5). Three samples (GA7-1-18, GA7-2-17, and D-1B1-17) carried the mutation on only the 5C homoeolog. One sample (D-1B1-18) carried the mutation on the 5B and 5D homoeologs but not 5C. The remaining samples carried the mutation on all three homoeologs.

Comparing the average number of mutated ALS homoeologs per plant with the dose-response results (Table 6) shows a pattern consistent with a gene-dosage effect for D-1B2 versus GA7-1: all three D-1B2 plants sequenced carried the mutation on all three homoeologs (mean = 3.0), and this population also had the higher ED_{50} (73.5 g ai ha^{-1}). GA7-1 plants were more variable (0, 1, and 3 mutated homoeologs; mean = 1.3), and this population had the lowest ED_{50} (35.2 g ai ha^{-1}) of the four resistant populations. GA7-2 fell in between on both measures (mean = 2.3 mutated homoeologs; ED_{50} = 74.0 g ai ha^{-1}).

D-1B1 does not fit this pattern as cleanly. Its plants averaged 2.0 mutated homoeologs per plant, similar to or lower than GA7-2 and D-1B2, yet D-1B1 was by far the most resistant population (ED_{50} = 724.7 g ai ha^{-1}; ED_{90} = 8,819.5 g ai ha^{-1})—roughly an order of magnitude more resistant than any other population tested. This suggests that homoeolog copy number for the Ala-122-Thr mutation is not the sole driver of the resistance phenotype in D-1B1, and that additional factors are likely contributing, such as enhanced herbicide metabolism (non-target-site resistance), differences in expression or zygosity of the mutant alleles, or the small number of individuals genotyped relative to the larger population used in the dose-response assay. Follow-up work will include genotyping additional individuals from each population, and, where feasible, pairing genotype with individual-plant dose-response phenotype, to better resolve the relationship between homoeolog mutation load and the level of imazamox resistance, and to evaluate whether non-target-site mechanisms are contributing to resistance in D-1B1.

Table 5. Number of replicate plants (of 3 sequenced per population) carrying the Ala-122-Thr ALS mutation on each of the three common lambsquarters homoeologs (5B, 5C, 5D), summed across replicates within each population.

Common lambsquarters population	5B (of 3)	5C (of 3)	5D (of 3)	Total homoeologs mutated (of 9)
Susceptible	0	0	0	0
GA7-1	1	2	1	4
GA7-2	2	3	2	7
D-1B1	2	2	2	6
D-1B2	3	3	3	9

Table 6. Mean number of mutated ALS homoeologs (of 3) per common lambsquarters population compared with the imazamox rate estimated for 50% control.

Common lambsquarters population	Mean no. of mutated ALS homoeologs (of 3)	Imazamox rate (g ai ha^{-1}) for 50% control
Susceptible	0	10.8
GA7-1	1.3	35.2
GA7-2	2.3	74.0
D-1B1	2.0	724.7
D-1B2	3.0	73.5

1.11) Title: Modeling Lambsquarter (*Chenopodium Album*) Emergence Timing in Eastern Washington

Authors: P. Weston Maughan

Objective: Field studies were initiated in the winters of 2024 and 2025 at two eastern Washington farms (Palouse Conservation Field Station and Wilke Farm) with the objectives of 1) characterize lambsquarters emergence in wheat-fallow using hydrothermal time, 2) model the relationship between hydrothermal time and emergence, and 3) evaluate whether hydrothermal time models transferred across environments with the same geographical region.

Summary: Common lambsquarters (*Chenopodium album*) is an important summer annual weed in dryland wheat production, and improved prediction of emergence timing could help optimize the timing of weed management. This study evaluated whether hydrothermal time could be used to characterize and predict lambsquarters emergence across environments within the inland PNW wheat region. Four wheat-fallow studies were conducted at the Palouse Conservation Field Station near Pullman, WA, and Wilke Farm near Davenport, WA, during 2025 and 2026. Glyphosate (1135 g ai ha^{-1}) was applied to plots at staggered 30-day intervals in the winter and 14-day intervals during the spring and summer to reset emergence and define successive emergence periods. Soil temperature and moisture were used to calculate cumulative hydrothermal time, and cumulative lambsquarters emergence was modeled using three-parameter log-logistic, Weibull, and Gompertz models. Model transferability was evaluated using leave-one-location-year-out cross-validation.

Accomplishments/Results: Cumulative lambsquarters emergence and accumulated hydrothermal time were monitored across the study environments (Figure 25). The location-year datasets were used to evaluate three sigmoidal models: the three-parameter log-logistic, Weibull, and Gompertz models (Table 7). Leave-one-location-year-out cross-validation was used to evaluate model predictions in withheld environments. All three models demonstrated

Table 7. Three-parameter model formulas

Model	Formula
Logistic	$f(x) = \frac{d}{1 + \exp[\, b(\ln(x) - \ln(e))}$
Weibull	$f(x) = d\ \exp[-\exp\{b(\ln(x) - \ln(e))\}]$
Gompertz	$f(x) = d\ \exp[-\exp\{b(x - e)\}]$

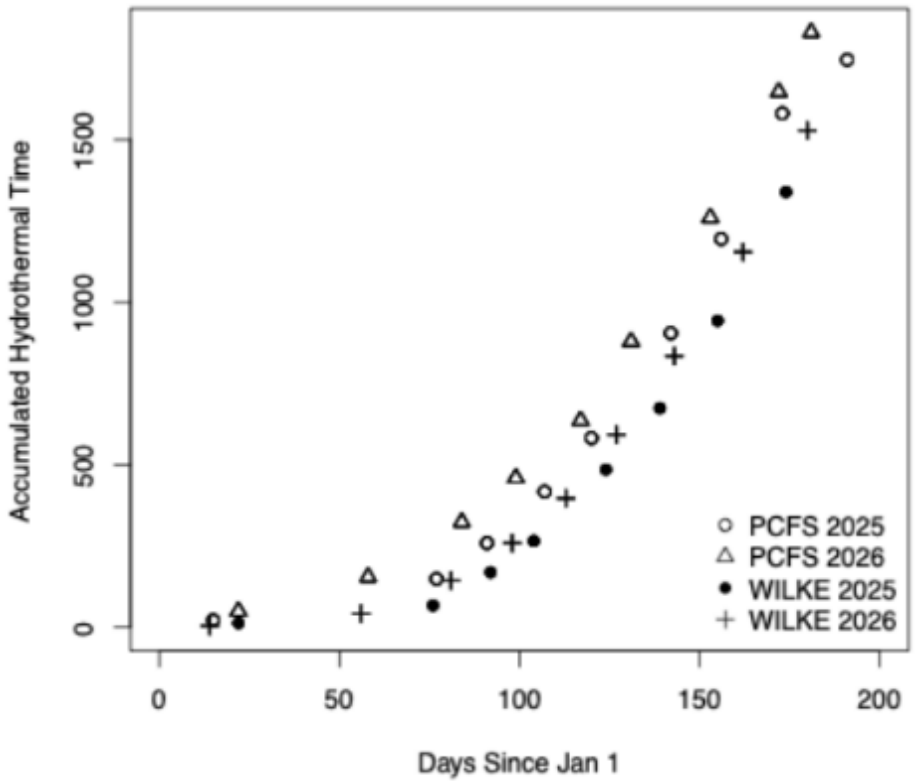


Figure 25. Hydrothermal time accumulation over four lambsquarter emergence studies using soil temperature and moisture potential at 5 cm depth.

similar predictive performance (Table 8). Overall RMSE ranged from 0.176 to 0.185, MAE ranged from 0.073 to 0.078, and predictive R^2 ranged from 0.843 to 0.858. The Gompertz model had an RMSE of 0.176, MAE of 0.073, and predictive R^2 of 0.858, while the log-logistic and Weibull models produced similar values.

Table 8. Cross-validated predictive performance of lambsquarters (*Chenopodium album*) emergence models across location-year environments.

Model	RMSE	MAE	Predictive R^2
Logistic	0.18	0.07	0.85
Weibull	0.19	0.08	0.84
Gompertz	0.18	0.07	0.86

Model-derived thermal-time thresholds differed more substantially at the lower and upper portions of the emergence curve than at the midpoint (Table 9). T10 ranged from 66.9 to 89.4 thermal-time units, T50 ranged from 169.9 to 176.8 thermal-time units, and T90 ranged from 349.3 to 466.1 thermal-time units. The relatively narrow range in T50 indicates that the three models estimated similar hydrothermal-time requirements for 50% cumulative emergence. The wider ranges in T10 and T90 reflect differences in the shape and asymmetry of the fitted emergence curves.

Overall, the three model forms provided similar predictions of cumulative lambsquarters emergence across the evaluated location-year environments. The consistency of T50 estimates and cross-validation performance indicates that the relationship between hydrothermal time and emergence was relatively stable among the environments included in the analysis. These results indicate that hydrothermal time can provide a useful basis for characterizing and predicting lambsquarters emergence timing across the environments evaluated. Additional weed species have been characterized and will be modeled soon using a similar methodology.

Table 9. Estimated model parameters and accumulated hydrothermal time corresponding to 10%, 50%, and 90% cumulative lambsquarters emergence.

Model	Parameters			Predicated Cumulative Emergence					
				T10		T50		T90	
	b	c	d	Est	SE	Est	SE	Est	SE
				Accumulated Hydrothermal Time					
Logistic	-2.62	1.02	173.60	75.08	10.41	173.60	9.36	401.41	48.97
Weibull	-1.90	1.03	139.64	89.37	12.57	169.93	9.62	466.07	89.43
Gompertz	-0.01	1.00	143.26	66.92	787.20	176.81	1570.22	349.25	8000.17

1.12) Title: Italian Ryegrass Management at the WSU Cook Agronomy Farm

Authors: David Huggins

Objective(s):

- Explore crop sequence diversification impact on Italian Ryegrass management.
- Identify future crop sequence and associated weed management research priorities.

Summary: A three-year crop sequence was imposed on the 92-ac WSU Cook Agronomy Farm to help manage Italian ryegrass. Austrian winter pea with pronamide herbicide, followed by Roundup-Ready spring canola, followed by metribuzin tolerant winter wheat (cv. Rydyryck) proved to be effective on managing Italian ryegrass. Herbicide damage in the winter wheat, however, may have occurred due to metribuzin on upland, more degraded soils, identifying a future research priority. Future research may consider: (1) assessment of pronamide use in grain legumes; (2) use of a three-year crop sequence of winter wheat-winter pea-spring canola to manage Italian ryegrass; (3) development of herbicide tolerant crops (e.g. wheat, grain legumes, canola); (4) potential within-field herbicide damage in tolerant crops; (5) weed seedbank spatial and temporal dynamics at the WSU Cook Agronomy Farm.

Results:

Background Information: During harvest years 2019 through 2021, the effectiveness of managing Italian ryegrass at the WSU Cook Agronomy Farm started to completely fail due to an interesting sequence of circumstances. These began with the winter wheat crop of 2019, where herbicide program effectiveness was poor, and Italian ryegrass started to explode in the following spring wheat crop (2020). Here, the extensive rains in the spring of 2020 following spring wheat establishment resulted in continued emergence of Italian ryegrass in crop, visibly impacting yield and producing viable seed by harvest. Noting the aggressive return of Italian ryegrass, we followed the spring wheat with Roundup-Ready spring canola with the expectation that this would aid management of the Italian ryegrass. Unfortunately, in 2021 we experienced a rather dry spring, so, despite our use of Round-Up prior to seeding and in crop, we suspect that the seedbank still had considerable Italian ryegrass following harvest. We attributed this to Italian ryegrass that did not germinate and emerge due to the dry spring soil conditions that resulted in seed persisting in a dormant, yet viable condition as we moved into planting winter wheat that subsequent fall. The Italian ryegrass exploded in the winter wheat of the next year (harvest year 2022), seriously impacting yield in some of the typically most productive, low-lying, portions of the field (Figure 26).

Moving forward, we knew that a different strategy would be required to effectively manage the Italian ryegrass. After consulting weed management expertise, we came up with the start of a new plan that used crop diversification and crop sequence to allow for the use of different herbicide options (Table 10).

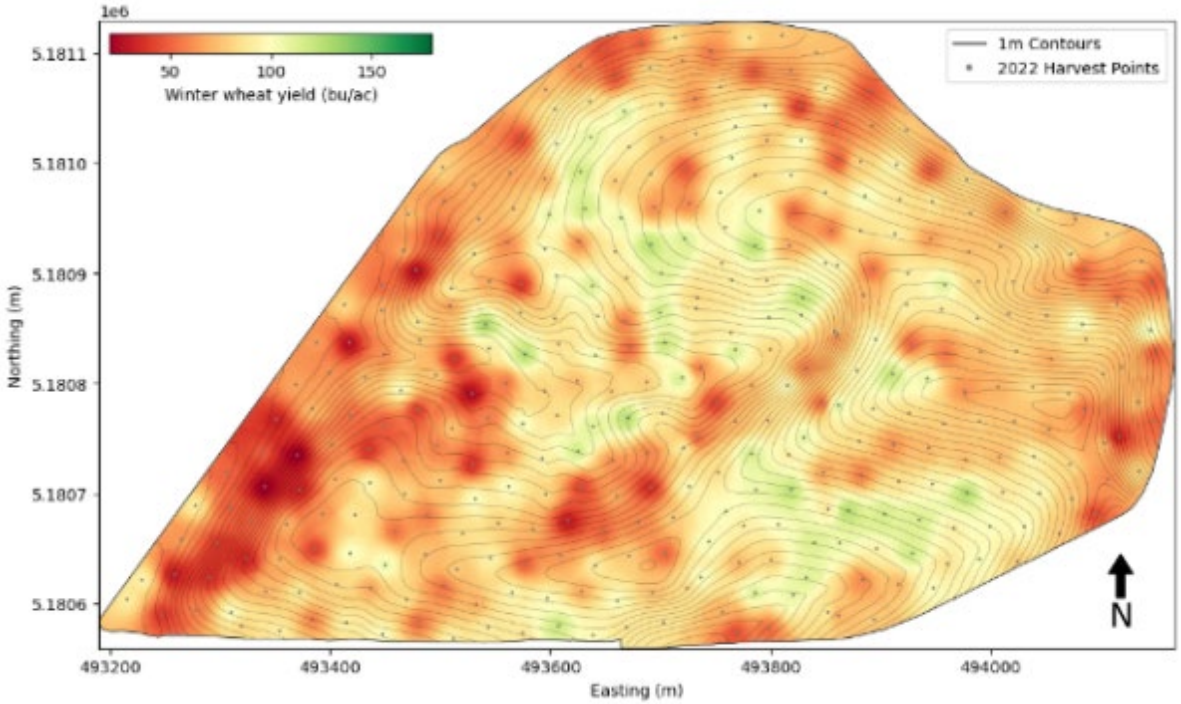


Figure 26. Winter wheat (Tandem) yield (2022 harvest year) at the Cook Agronomy Farm (92-ac, continuous no-till field). Yield ranged from 19 to 128 averaging 78 bu/ac (about 20 in annual precipitation).

Table 10. Herbicide program used from fall of 2021 through spring 2025 at the WSU Cook Agronomy Farm.

Harvest Year	Crop	Date	Herbicide	Rate
2022	Tandem Winter Wheat	10/1/2021	D-638	16 oz/ac
2022	Tandem Winter Wheat	10/1/2021	Sharpen	2 oz/ac
2022	Tandem Winter Wheat	10/4/2021	RT3	32 oz/ac
2022	Tandem Winter Wheat	10/4/2021	Zidua	2 oz/ac
2022	Tandem Winter Wheat	4/24/2022	Dimetric	3 oz/ac
2022	Tandem Winter Wheat	5/20/2022	Brox-M Ultra	16 oz/ac
2022	Tandem Winter Wheat	5/20/2022	Osprey Xtra	4.5 oz/ac
2023	Granger Winter Pea	10/13/2022	RT3	24 oz/ac
2023	Granger Winter Pea	11/15/2022	Pronamide 3.3 SC	56 oz/ac
2023	Granger Winter Pea	5/17/2023	Metribuzin75	4 oz/ac
2024	CP9978TF Spring Canola RR	4/1/2024	RT3	32 oz/ac
2024	CP9978TF Spring Canola RR	5/24/2024	Roundup Power Max	40 oz/ac
2024	CP9978TF Spring Canola RR	5/24/2024	Dimetric Ext	10 oz/ac
2025	Rydyryck Winter Wheat	9/30/2024	RT3	24 oz/ac
2025	Rydyryck Winter Wheat	9/30/2024	Sharpen	1 oz/ac
2025	Rydyryck Winter Wheat	10/11/2024	Anthem Flex	4.5 oz/ac
2025	Rydyryck Winter Wheat	4/14/2025	Dimetric	8 oz/ac

Diversification with Winter Pea: Considering the new release of green and yellow varieties of winter pea, along with the availability of different herbicide options with winter pea, we no-till fall-seeded Granger Austrian winter pea following winter wheat, as seed for edible types was not available. Notable was the effectiveness of fall-applied Pronamide 3.3 (a.i. pronamide) on fall-emerged Italian ryegrass as well as volunteer winter wheat that extended into the following spring of 2023. Although the winter peas looked less than stellar coming out of the winter, they still yielded 2500 lbs/ac on average (Figure 27), and the Italian ryegrass was dramatically reduced.

Diversification with Spring Canola: Considering the 12-month plant back to winter wheat following a Pronamide 3.3 application as used in the winter pea, we then planted Roundup-Ready spring canola providing time for the pronamide to dissipate and relied on the effectiveness of Roundup Power Max (a.i. glyphosate) and Dimetric (a.i. metribuzin) for managing Italian ryegrass. Again, Italian ryegrass pressure in the spring canola was very curtailed and the canola yield averaged 1421 lbs/ac (Figure 28).

Diversification with Herbicide Tolerant Winter Wheat: Following spring canola we were able to obtain Rydyryck winter wheat seed prior to its release from the WSU winter wheat breeding program. Rydyryck winter wheat has tolerance to metribuzin and our intent was to now shift our mode of herbicide action to include spring applied Dimetric in 2025 (Table 10). Again, throughout the 2025 crop year, management of Italian ryegrass looked very effective as we spring applied 8 oz/ac of Metribuzin 75 (Figures 29 and 30). Rydyryck winter wheat yield for the Cook Agronomy Farm averaged 93 bu/ac (Figure 29).

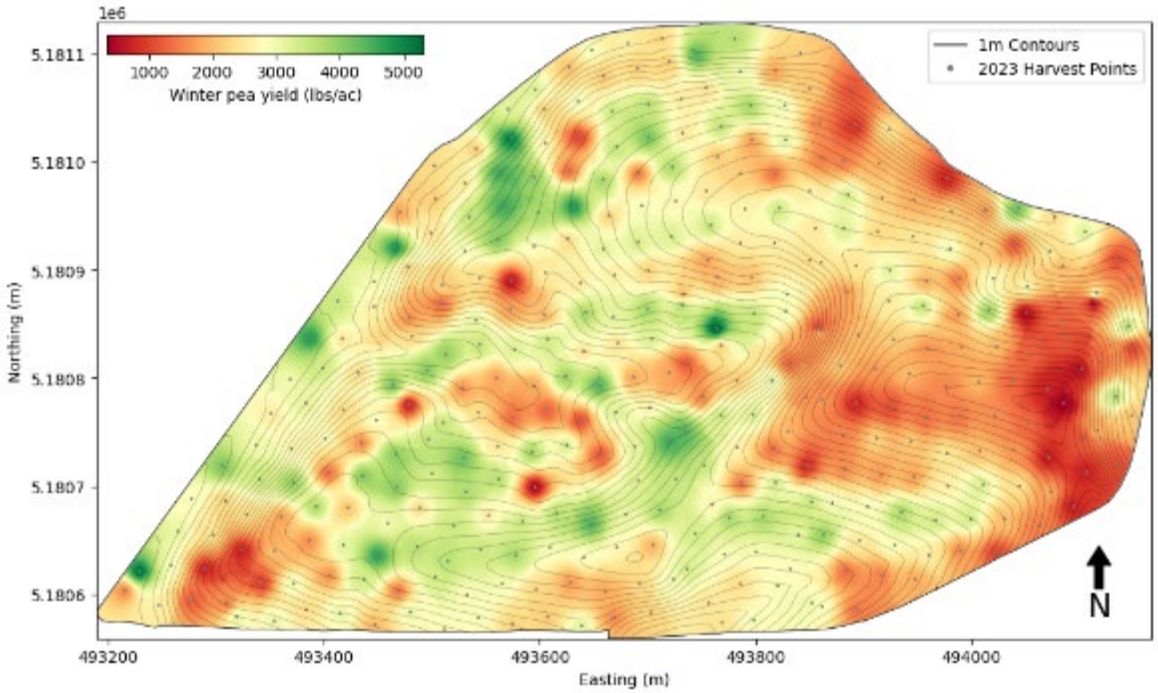


Figure 27. Austrian winter pea (cv. Granger) yield (2023 harvest year) at the Cook Agronomy Farm (92-ac, continuous no-till field). Yield ranged from 349 to 5317, averaging 2530 lbs/ac (18.4 in annual precipitation).

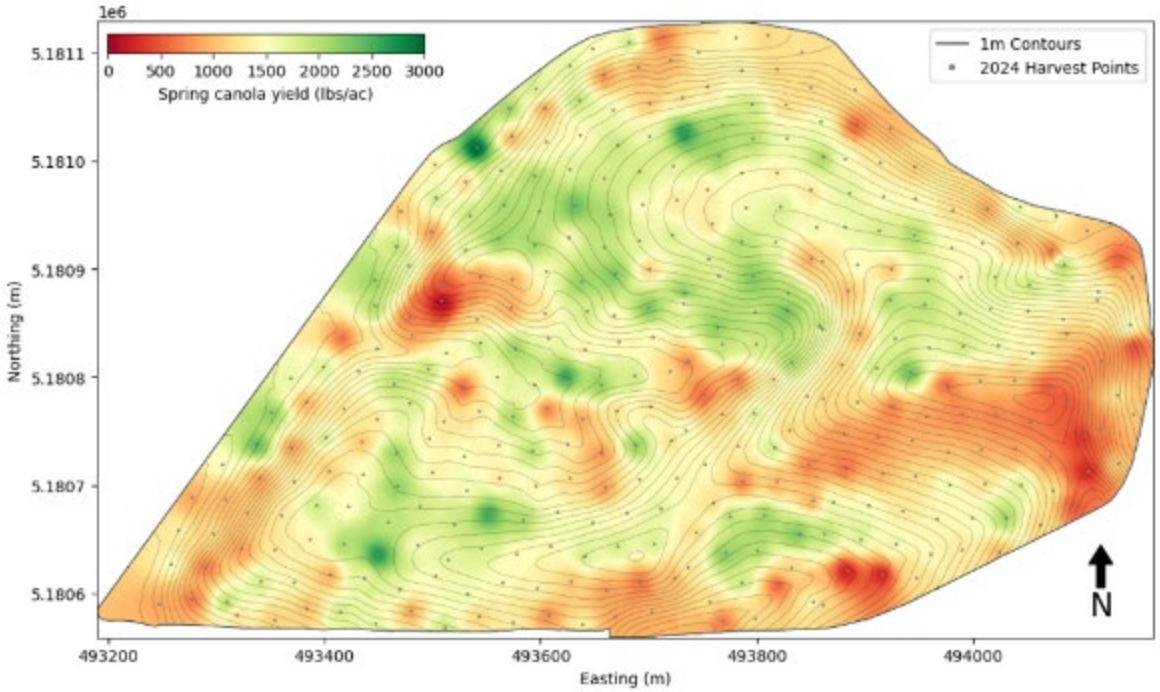


Figure 28. Roundup-Ready spring canola yield (2024 harvest year) at the Cook Agronomy Farm (92-ac, continuous no-till field). Yield ranged from 72 to 2991 averaging 1421 lbs/ac (17.3 in annual precipitation).

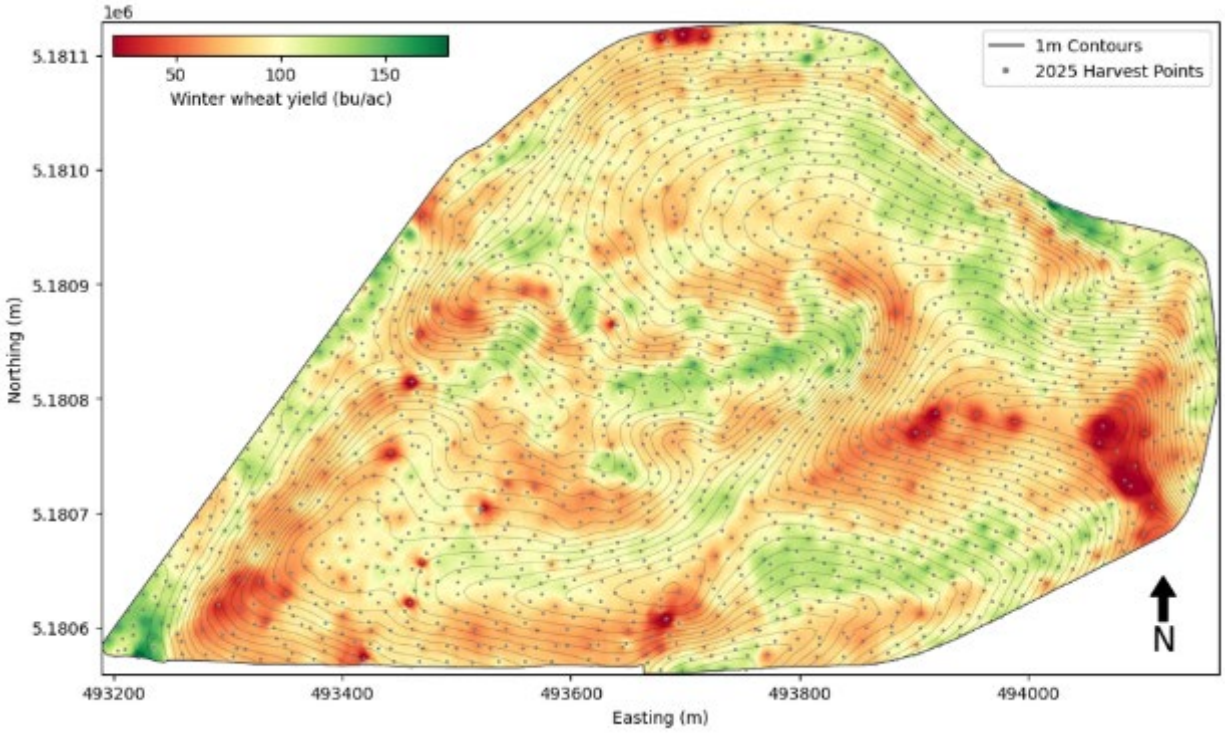


Figure 29. Rydyryck winter wheat yield (2025 harvest year) at the Cook Agronomy Farm. Yield ranged from 7 to 207 averaging 93 bu/ac (21 in annual precipitation).



Figure 30. Rydyryck Winter Wheat (picture on left) as compared to adjacent field of winter wheat (not Rydyryck) (picture on right). Tremendous difference in Italian ryegrass pressure due to lack of crop rotation and herbicide options.

Yield differences between the 2022 (Figure 26) and 2025 (Figure 29) winter wheat crop were both positive and negative on a field basis, though the overall difference was a 15 bu/ac increase (Figure 31). Notably, winter wheat yields were substantially increased in the higher producing, low-lying portions of the field where Italian ryegrass primarily occurred in 2022, but yields were significantly decreased in upland summit and eroded portions of the field where herbicide damage may have occurred.

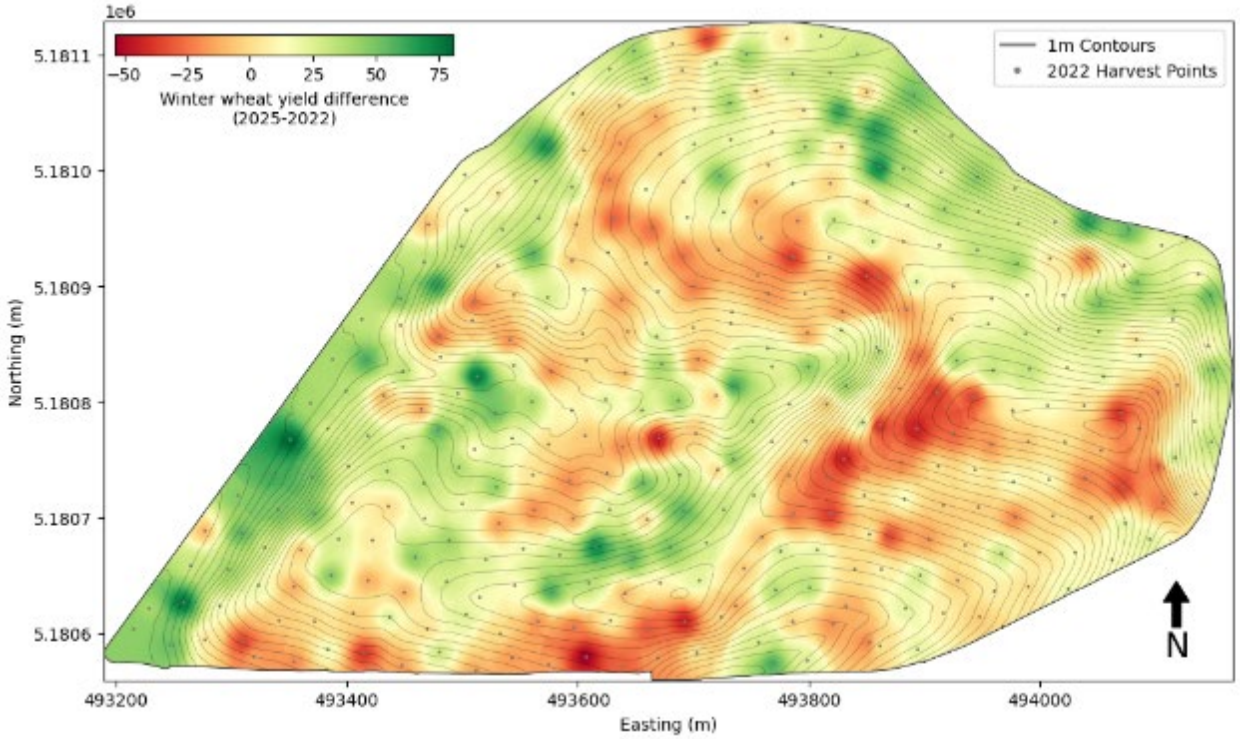


Figure 31. The 2025 (Figure 29) minus the 2022 (Figure 26) winter wheat yield at the Cook Agronomy Farm (92-ac, continuous no-till field). Yield differences were both positive and negative ranging from - 54 to +81 and averaged + 15 bu/ac. Note interesting relationship of yield differences with field topography.

Conclusions and Future Research Considerations: Crop diversification using winter pea and spring canola as well as integration of herbicide tolerant winter wheat provided options for effectively managing Italian ryegrass. Future research may consider: (1) assessment of pronamide use in grain legumes; (2) three year crop sequence of winter wheat-winter pea-spring canola to manage Italian ryegrass; (3) development of herbicide tolerant crops (e.g. wheat, grain legumes, canola); (4) potential within-field herbicide damage in tolerant crops; (5) weed seedbank spatial and temporal dynamics at the WSU Cook Agronomy Farm.

Objective 1: Rotational Crops Based Theme

1.13) Title: Weed Management in Dryland Wheat-Fallow Systems

Authors: Judit Barroso, Nicole Durfee, Noemi Codina-Pascual, and Vhuthu Ndou

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

Summary: Herbicide-resistant weeds threaten the sustainability of dryland wheat systems, particularly where reliance on herbicide is high, as in no-till cropping systems. Integrating chemical control with other weed management strategies is a potential option to maintain long-term sustainability. However, information on effective integrated weed management (IWM) practices is limited for dryland wheat cropping systems in eastern Oregon and the inland PNW. This research will evaluate IWM practices applied during the fallow phase of the winter wheat-fallow rotation to identify effective alternatives for managing herbicide-resistant weeds while minimizing the negative impacts of tillage. The study will be conducted at two sites in Oregon, Pendleton and Moro, representing intermediate and low annual precipitation environments. Main plots will evaluate weed management applied in fall and/or spring, while subplots will compare two late-summer managements approaches: herbicides (chemical) and undercutter tillage (mechanical). Weeds will be evaluated during both the fallow and crop phase, with weeds in the crop phase controlled uniformly with herbicides across treatments. Soil water content, infiltration, and compaction will also be measured to evaluate the agronomic and soil-related consequences of each management strategy.

Results: Similar to what we showed in previous seasons, results from the 2025 growing season indicated that the two different weed control practices conducted in June (sweep vs. spray) are impacting the results much more than the different weed control treatments in fall and spring (Table 11).

Table 11. Weed control treatments conducted in fall (≈ November), spring (≈ April), and early summer (≈ June) in replicated plots established at Pendleton and Moro, Oregon in 2022, 2023, 2024 and 2025.

Treatment ID	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 machine with 20" turbo blades spaced 7.5" apart

Regarding weed infestations, results in 2025 were similar to those observed in previous seasons (Figure 32a and 32b). During the crop phase, weed infestations were lower in subplots where weeds had been chemically controlled in June of the preceding fallow year (Figure 32b) than in subplots where weeds had been mechanically controlled, except for treatments 4 and 5, for which weed infestations did not differ between the two management approaches.

Crop yield followed patterns similar to those observed for weed pressure and in previous years (Figure 32c and 32d). Early-summer weed control practices during the fallow phase significantly affected yield, with higher yields observed in subplots where weeds had been controlled mechanically than in those where weeds had been controlled with herbicide (Figure 32d).

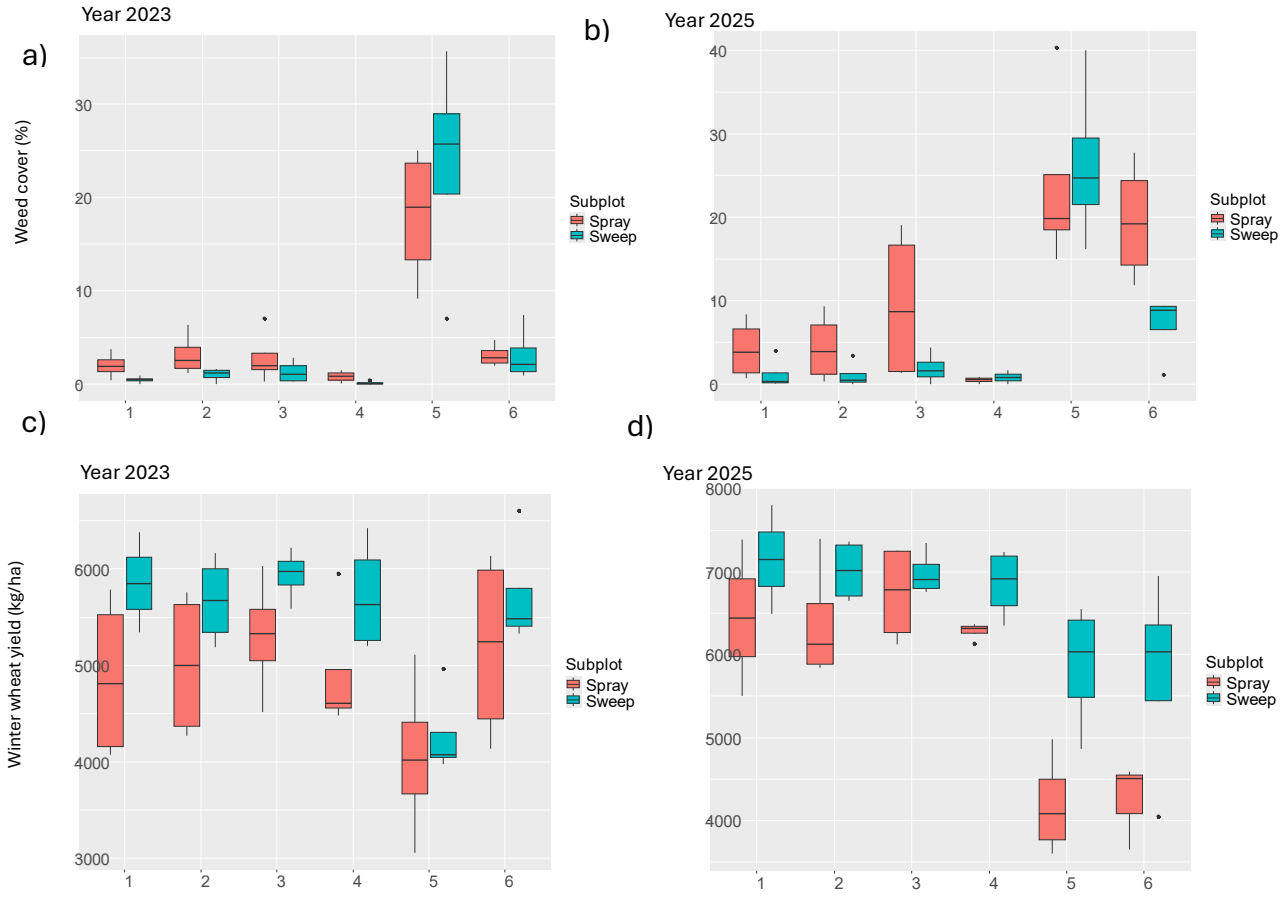


Figure 32. Weed cover (%) (a, b) and crop yield (kg ha^{-1}) (c, d) by fallow treatment (X-axis) and subplot (chemical control, orange; mechanical control, blue) during the winter wheat phase in Pendleton, OR. Weed cover was assessed in April 2023 (a) and April 2025 (b), and crop yield was measured at harvest in July 2023 (c) and July 2025 (d). The solid black line within each box represents the median. Fallow treatments are described in Table 11.

Contrary to observations in 2023 and 2024 observations, the soil sampling conducted in September 2025, following crop harvest, did not show greater soil water storage in the subplots that had received sweep tillage during the preceding fallow year (Figure 33b). This year, substantial rainfall occurred early in September (23.3 mm, 153% above normal), and we believe the September soil sampling results may have been influenced by these precipitation events. Higher water storage in the subplots managed with herbicides in the previous fallow observed this year might reflect the faster water infiltration in these subplots compared with those under mechanical control in the previous year. However, no statistically significant differences in infiltration among spring fallow treatments were detected.

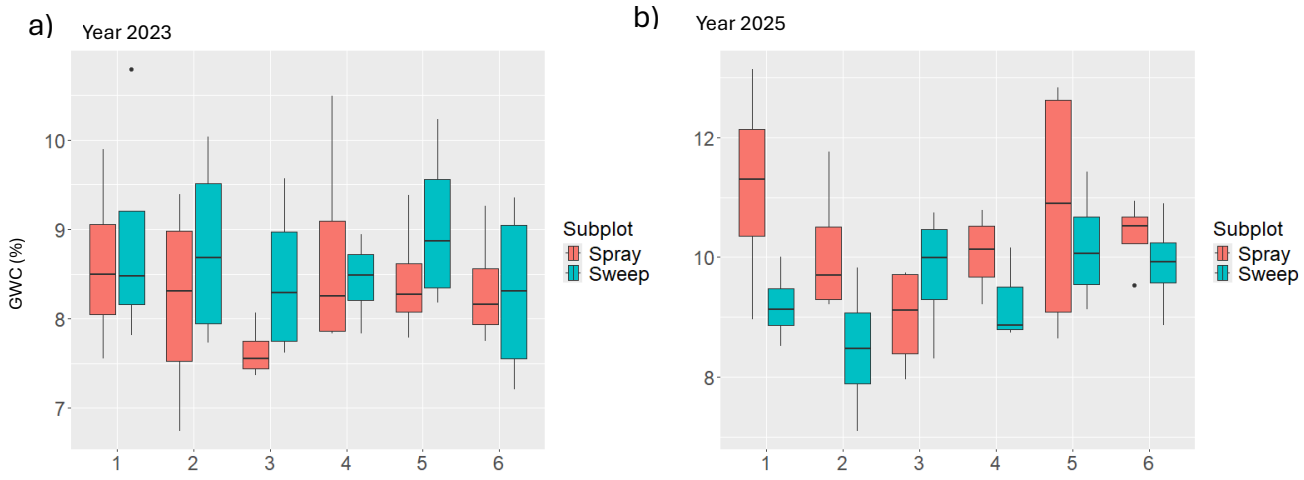


Figure 33. Gravimetric water content (GWC, %) in the soil profile (0-120 cm) by fallow treatment (X-axis) and subplot (chemical control in orange; mechanical control in blue) at Adams, OR. Measurements were taken in September 2023 (a) and September 2025 (b) following crop harvest. The solid black line within each box represents the median. Fallow treatments are described in Table 11.

Overall, the work conducted under Objective 1 in 2025—the third year in which treatment effects on the crop year could be evaluated—suggests that the use of a sweep operation in early summer to control weeds during fallow may represent a sustainable strategy for managing herbicide-resistant weeds. However, because contrasting results in soil water storage were observed this year, additional years of data will be necessary to better understand the variability and consistency of these responses.

Objective 1: Cross-Cutting Theme

1.14) Title: Evaluating a Digital Phenotyping System for Pre-emergence and Post-emergence Dose-response Assays

Authors: Olivia Landau

Objective: Continuing the previously established framework of comparing dose-response (DR) curves and growth reduction 50 (GR_{50}) estimates derived from manual biomass measurements to the digital morphological metrics collected by the Phenospex TraitFinder to determine which metrics are viable for future DR assays.

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 GR_{50} values. The Phenospex TraitFinder offers a non-destructive alternative for data collection but has limited validation in herbicide DR assays. Previous experimentation with pre-emergence applications of fomesafen and atrazine on *Chenopodium album* L. (common lambsquarters) determined several suitable parameters that could generate GR_{50} estimates are reflective of fresh biomass (FB) data: 3D Leaf Area, Digital Biomass, Convex Hull Area, Projected Leaf Area, and Voxel Volume Total. Continued experimentation with other pre-emergence herbicides, mesotrione and clomazone, further demonstrates this trend. Additional experimentation with a post-emergence herbicide, imazamox, along with resistant and sensitive downy brome (*Bromus tectorum*) populations further establishes the trend while also demonstrating that these parameters also reflect the results from dry weight (DW; Table 12) and the calculated resistance ratios will lead to the same conclusion of resistance being present (Table 13).

Results: Results of the mesotrione and clomazone further establish the trend of 3D Leaf Area, Digital Biomass, Convex Hull Area, Projected Leaf Area, and Voxel Volume Total producing the GR_{50} estimates that are not statistically different from FB results (Figure 34).

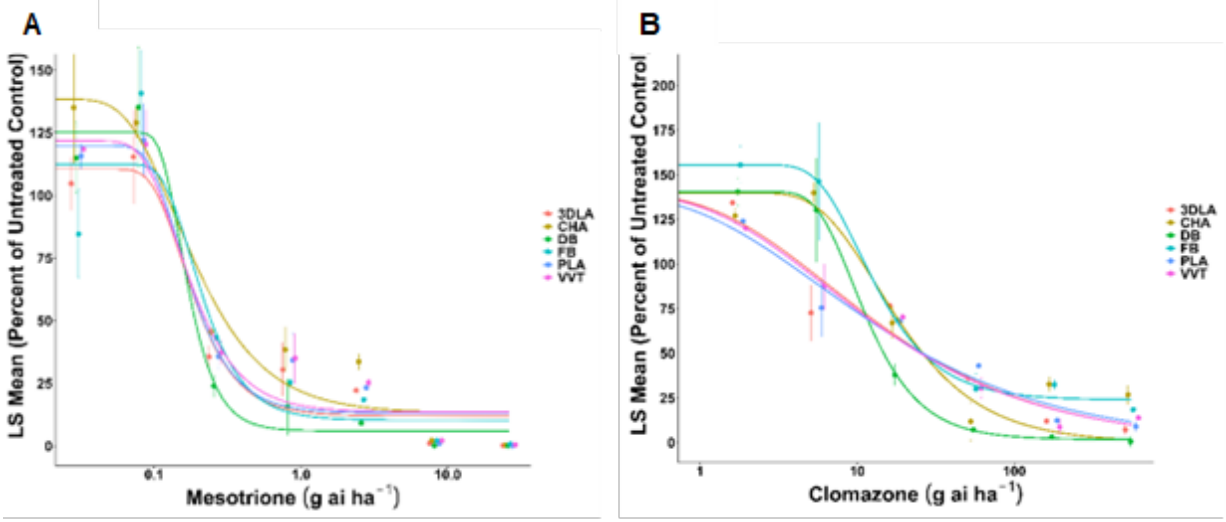


Figure 34. Mesotrione (a) and clomazone (b) dose-response curves performed on common lambsquarters. Only curves that generated GR_{50} estimates that reflect the fresh biomass (FB) data are highlighted in these graphs. Doses for mesotrione ranged from 0.03 to 26.27 g ai ha^{-1} and doses for clomazone ranged from 1.77 to 559.55 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 12. Summary of growth reduction (GR_{50}) estimates for morphological parameters that reflect results of dry weight and fresh weight. Notes: These estimates were derived from imazamox dose-response assays performed with resistant and sensitive downy brome populations. Abbreviations: 3DLA, 3D leaf area; CHA, convex hull area; DB, digital biomass; DW, dry weight; FW, fresh weight; PLA, projected leaf area; VVT, voxel volume total; SE, standard error of the mean. P-value indicates whether the given GR_{50} estimate significantly differs from the DW GR_{50} estimate.

Resistant		
Parameter	GR_{50} Estimate (g ai ha^{-1}; SE)	*P*-value
3DLA	25.44 (±10.14)	0.8059
CHA	27.58 (±13.65)	0.7835
DB	29.96 (±7.20)	0.5584
DW	16.43 (±22.76)	NA
FW	23.13 (±19.26)	0.8578
PLA	22.81 (±9.54)	0.7886
VVT	24.37 (±9.68)	0.7375
Sensitive		
Parameter	GR_{50} Estimate (g ai ha^{-1}; SE)	*P*-value
3DLA	3.08 (±0.61)	0.2731
CHA	4.92 (±3.87)	0.4801
DB	4.74 (±5.71)	0.2975
DW	2.08 (±0.46)	NA
FW	2.06 (±0.41)	0.9725
PLA	3.19 (±0.69)	0.0832
VVT	3.24 (±0.69)	0.0693

Table 13. Summary of resistance ratios for morphological parameters that reflect results of dry weight and fresh weight. Notes: These estimates were derived from imazamox dose response assays performed with resistant and sensitive downy brome populations. Abbreviations: 3DLA, 3D leaf area; CHA, convex hull area; DB, digital biomass; DW, dry weight; FW, fresh weight; PLA, projected leaf area; VVT, voxel volume total; SE, standard error of the mean.

Resistance Ratio	
Parameter	GR_{50} Estimate (g ai ha^{-1}; SE)
3DLA	8.27 (±3.68)
CHA	5.60 (±5.21)
DB	6.32 (±7.76)
DW	7.89 (±11.06)
FW	11.22 (±9.61)
PLA	7.15 (±3.36)
VVT	7.52 (±3.39)

The imazamox experiment is the first attempt in conducting this type of research with a post-emergence herbicide application in a grass species using both resistant and sensitive populations (Tables 12 and 13). This type of experimentation allows for determination of whether the digital metrics will result in the same conclusion in determining whether a resistant is resistant. Examining other species, especially those with resistant and sensitive populations, and other herbicides will continue to determine if there is variation in the reliability of these parameters.

1.15) Title: Demonstrating the Cost of Managing Herbicide-Resistant Weeds in Wheat: Pinoxaden-Resistant Wild Oat Case Study

Authors: Albert Adjesiwor, Sushmita Sharma, Joan Campbell, Patrick Hatzenbuehler, and Traci Rauch

Objective(s):

1. Evaluate alternative herbicide programs for controlling wild oat populations resistant to pinoxaden in spring wheat.
2. Quantify the direct costs of alternative herbicide programs relative to standard programs.
3. Assess crop injury, weed interference, and yield loss associated with each herbicide program.
4. Compare the economic performance of proactive herbicide management strategies to demonstrate the cost of resistance to Pacific Northwest wheat growers.

Abstract: Resistance to pinoxaden (Group 1, ACCase inhibitors) in wild oat (*Avena fatua*) has eroded the effectiveness of postemergence programs for spring wheat growers, raising both weed control risk and production cost. This study evaluates the herbicide programs a grower could turn to after confirming pinoxaden resistance, and pairs efficacy and yield data with program cost so the economic consequence of resistance can be quantified. The trial was established at Kimberly and Moscow, Idaho in the 2025/2026 cropping season. Sixteen treatments were included: an untreated weedy check, a pinoxaden-treated weed-free check, and fourteen alternative programs spanning fall and spring soil-residual applications (triallate, pyroxasulfone, and tank mixes, applied surface or mechanically incorporated), preemergence and delayed preemergence applications (pyroxasulfone alone or with pendimethalin or carfentrazone-ethyl), and postemergence alternatives (imazamox, pyroxsulam plus fluroxypyr, thiencarbazone-methyl plus fluroxypyr, and mesosulfuron-methyl). The trials were established where wild oat is susceptible so that a weed-free check could be included for the economic analysis. Wild oat density, visual control ratings, survivor counts at heading, crop injury, and grain yield were recorded. Wild oat density was highly variable across the study site, ranging from zero to about 58 plants m^{-2}, so treatment means should be read alongside the spread between replications. Yield loss increased with wild oat density (Figure 35), but density explained less than half of the variation in plot-level yield loss ($r^2 = 0.48$, $P < 0.001$). Postemergence programs gave the highest visible wild oat control (94 to 97%), while soil-applied programs ranged from 64 to 88%. Spring wheat yield loss due to uncontrolled wild oat was up to 54.7% in the nontreated check in the worst-affected replication and 17.5% on average. Visible control alone did not predict spring wheat yield. Herbicide, adjuvant, application, and mechanical incorporation costs are being compiled at current regional retail prices to calculate net return, break-even yield, and risk indicators for each program.

Results:

Wild oat control: Visible wild oat control differed markedly between soil-applied and postemergence programs (Table 11). All five postemergence programs provided 94 to 97%

wild oat control: imazamox and thiencarbazone-methyl plus fluroxypyr at 97%, pyroxsulam plus fluroxypyr at 96%, delayed preemergence pyroxasulfone followed by postemergence imazamox at 95%, and mesosulfuron-methyl at 94%. Pinoxaden, applied to the susceptible population (as the weed-free check), also provided 97%, confirming that the programs above matched the standard that resistance removes from a grower's options. Soil-applied programs were less consistent, ranging from 64 to 88%. The strongest was fall-applied triallate tank-mixed with pyroxasulfone and mechanically incorporated (88%), followed by fall-applied triallate alone (81%), fall-applied pyroxasulfone (80%), and delayed preemergence pyroxasulfone (80%). The weakest was delayed preemergence pyroxasulfone plus pendimethalin (64%).

Yield loss: Spring wheat yield loss due to uncontrolled wild oat was up to 54.7% in the nontreated check in the worst-affected replication and 17.5% on average. This sets the scale of the potential yield loss when pinoxaden programs fail to control resistant wild oat (Table 14). The gap between those two values reflects how variable wild oat density was across the site. Postemergence programs generally provided good wild oat control with minimal yield loss, with average losses of 0.7% for imazamox, 1.9% for thiencarbazone-methyl plus fluroxypyr, 3.5% for mesosulfuron-methyl, and 4.9% for pyroxsulam plus fluroxypyr. Among the soil-applied programs, fall-applied pyroxasulfone (2.4%) and preemergence pyroxasulfone plus carfentrazone-ethyl (3.5%) protected yield best, fall-applied triallate alone lost 7.3%, and spring preplant incorporated triallate lost 16.5% on average, nearly as much as leaving the field untreated.

Visible control did not predict yield protection: Visible wild oat control and wild oat density were not good predictors for spring wheat yield loss. The highly variable wild oat density across the site is a major contributor (Figure 35): across all plots, yield loss rose by about 0.69 percentage points for each additional wild oat plant per square meter, a highly significant relationship ($P < 0.001$) that nonetheless explained less than half of the variation in yield loss ($r^2 = 0.48$). Plots at similar densities often differed widely, with several plots below 10 plants m^{-2} losing 27 to 42% of yield while some plots above 40 plants m^{-2} lost 20% or less.

Cost analysis and next steps: Direct program costs are being compiled from current regional retail prices for herbicides, adjuvants, and application (custom rate or estimated per-pass cost), including the added pass required by the sequential and incorporated programs. Plot-level yields will be combined with a standardized spring wheat price to calculate gross revenue and net return per acre, break-even yield, and risk indicators capturing yield variability and control consistency, with the pinoxaden weed-free check as the no-resistance benchmark and the untreated check as the no-control reference. Because wild oat density varied so much across the site, those risk indicators carry particular weight. The comparison of interest is the cost of a proactive program adopted before resistance is confirmed against the cost of the reactive alternatives a grower is left with afterward.

Table 14. Visible wild oat control and spring wheat yield loss for herbicide programs evaluated at Kimberly, Idaho. Yield loss is expressed relative to the pinoxaden-treated weed-free check; Max. yield loss is the largest loss recorded in any single replication and mean yield loss is the average across the four replications.

Herbicide program (g ai/ha)	Application timing[1]	Control (%)	Max. yield loss (%)	Mean yield loss (%)
Nontreated (weedy check)	None	0	54.7	17.5
triallate (1401)	Fall	81	9.1	7.3
triallate (1401) + pyroxasulfone (146)	Fall, mechanically incorporated	88	0	0
pyroxasulfone (146)	Fall	80	6.9	2.4
pyroxasulfone (146)	Fall, mechanically incorporated	74	30.6	8.6
pyroxasulfone (146) + pendimethalin (1331)	Fall *fb* delayed preemergence	73	41.2	12.4
triallate (1401)	Spring preplant, mechanically incorporated	75	41.9	16.5
pyroxasulfone + carfentrazone-ethyl (128)	Preemergence	78	13.7	3.5
pyroxasulfone (119)	Delayed preemergence	80	32.5	11.1
pyroxasulfone (119) + pendimethalin (1331)	Delayed preemergence	64	19.9	10.3
imazamox (44)	Postemergence	97	2.9	0.7
pyroxasulfone (119) fb imazamox (44)	Delayed preemergence *fb* postemergence	95	0	0
pyroxsulam + fluroxypyr (148)	Postemergence	96	19.4	4.9
thiencarbazone-methyl + fluroxypyr (122)	Postemergence	97	7.6	1.9
mesosulfuron-methyl (15)	Postemergence	94	7.3	3.5
pinoxaden (60), weed-free check	Postemergence	97	-	-

[1]*fb*, followed by. preemergence (immediately after planting); delayed preemergence (about 80% crop emergence); and postemergence (about the three-leaf stage). Mesosulfuron-methyl is not labeled for spring wheat and was included as a research comparison only.

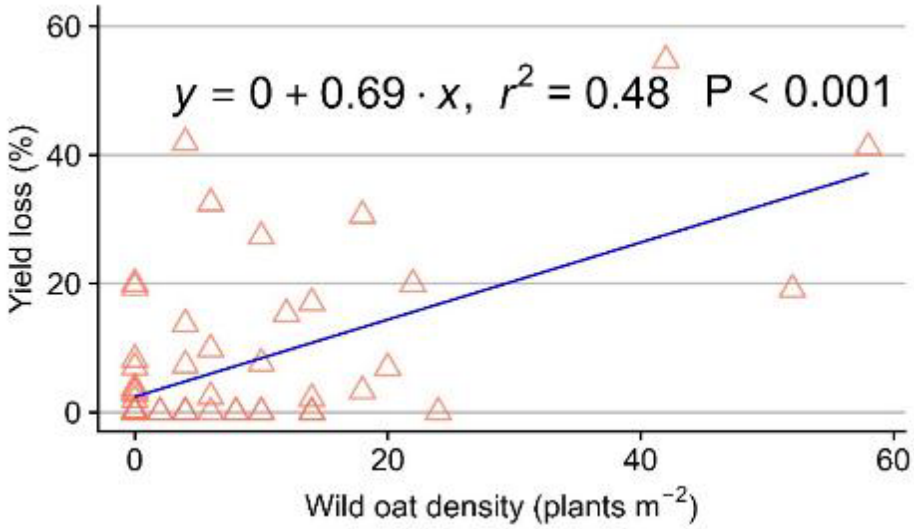


Figure 35. Relationship between wild oat density and spring wheat yield loss across all plots at Kimberly, Idaho. Each symbol is an individual plot; the fitted line is y = 0.69x (r^2 = 0.48, P < 0.001).

1.16) **Title:** Efficacy of Preemergence Herbicides for Wild Oat Control as Influenced by Seed Burial Depth

Authors: Sushmita Sharma and Albert Adjesiwor

Objective: Determine the efficacy of pre-emergence herbicides as influenced by wild oat seed burial depth.

Abstract: Wild oat (*Avena fatua*) is a persistent annual grassy weed in PNW small grain production, and soil-applied herbicides remain an important part of wild oat management. The performance of a soil-applied herbicide depends on contact between the germinating weed seed and the treated soil layer, so the depth at which wild oat seed is positioned in the soil profile may determine how much control a preemergence herbicide provides. A greenhouse study evaluated two preemergence herbicides, triallate (Far-Go) at 560 g ai ha^{-1} and ethalfluralin (Sonalan) at 1120 g ai ha^{-1}, applied to wild oat seed placed at six burial depths: 0, 0.64, 1.27, 2.54, 5.08, and 10.16 cm. Triallate reduced wild oat biomass by about 93 to 99% from the soil surface through 5.08 cm and by about 57% when seed was buried at 10.16 cm. Ethalfluralin was consistently weaker and declined more steadily with depth, from about 75% at the soil surface to about 65% at 0.64 and 1.27 cm, 58% at 2.54 cm, and only about 23 to 27% at 5.08 and 10.16 cm. Variability among replications also increased with burial depth, particularly for ethalfluralin at the two deepest placements and for triallate at 10.16 cm. These results indicate that triallate maintained activity across a much wider range of seed burial depths than ethalfluralin, and that deeply buried wild oat seed can escape control by either herbicide.

Results:

Wild oat biomass reduction across seed burial depths: Percentage reduction in wild oat biomass relative to the nontreated control depended on both the herbicide applied and the depth at which the seed was placed (Figure 36). Triallate at 560 g ai ha^{-1} was highly effective across most of the depth range, reducing biomass by about 93% at the soil surface, 94% at 0.64 cm, 98% at 1.27 cm, 99% at 2.54 cm, and 94% at 5.08 cm, with little practical difference among these depths. Control fell sharply only at the deepest placement, to about 57% at 10.16 cm. Ethalfluralin at 1120 g ai ha^{-1} was consistently less effective and declined more gradually across the shallow depths: biomass reduction was about 75% at the soil surface, 65 to 66% at 0.64 and 1.27 cm, and 58% at 2.54 cm, before dropping to about 23 to 27% at 5.08 and 10.16 cm. The two herbicides therefore differed most in the middle of the depth range, where triallate remained near complete control and ethalfluralin had already lost roughly a third to half of its activity. Variability among replications increased with burial depth for both herbicides (Figure 36).

Figure 37 presents the same biomass reduction values positioned against the soil profile, which shows the contrast directly: triallate held 93 to 99% reduction from the surface through 5.08 cm and dropped to 57% at 10.16 cm, whereas ethalfluralin declined from 75% at the surface through 65% and 58% at intermediate depths to 23 to 27% for the two deepest placements. The visual difference between treatments was also clear in the greenhouse, where nontreated

and ethalfluralin-treated pots carried substantial wild oat growth while triallate-treated pots carried very few surviving plants (Figure 38).

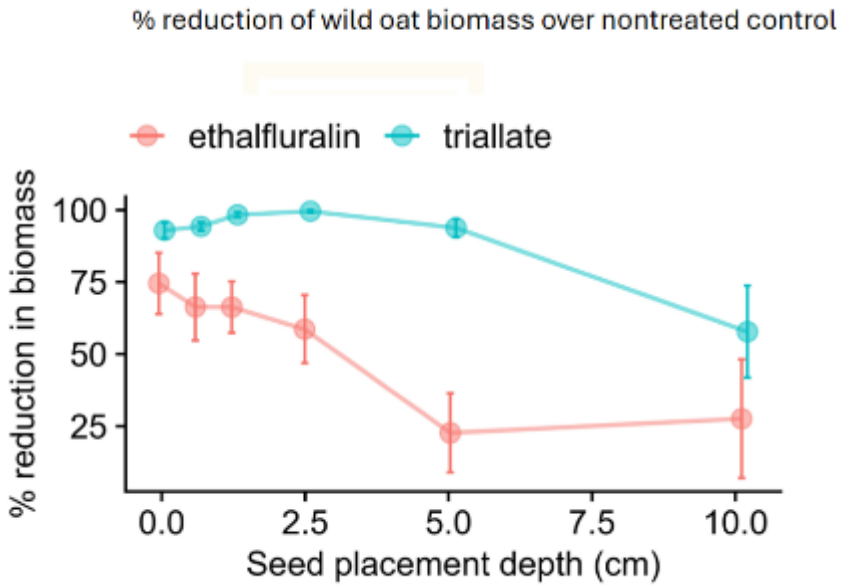


Figure 36. Percentage reduction in wild oat biomass relative to the nontreated control 28 days after spraying, for triallate (560 g ai ha^{-1}) and ethalfluralin (1120 g ai ha^{-1}) applied to wild oat seed placed at six burial depths. Error bars indicate variability among replications.

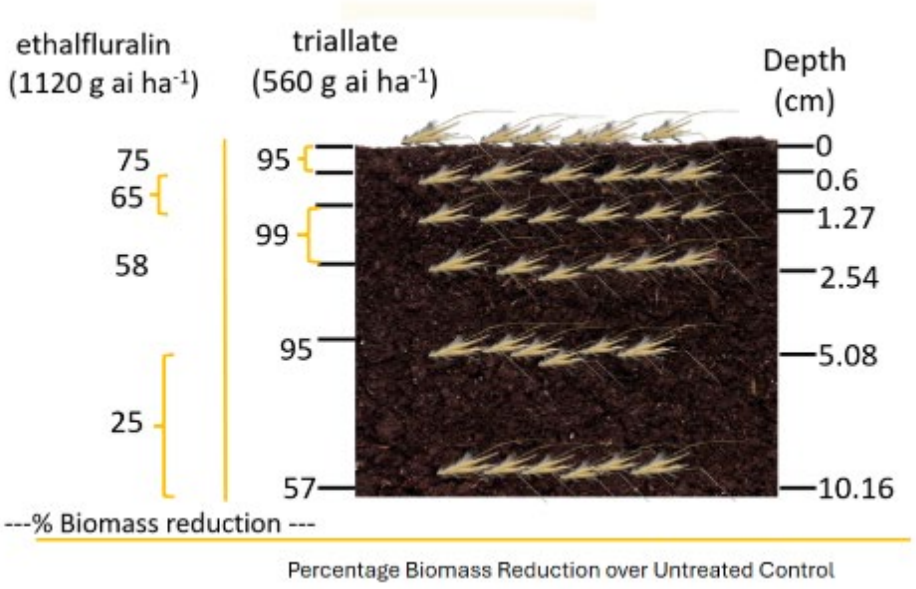


Figure 37. Percentage biomass reduction relative to the nontreated control shown against the soil profile, with values for ethalfluralin (1120 g ai ha^{-1}) and triallate (560 g ai ha^{-1}) at each wild oat seed burial depth from 0 to 10.16 cm.

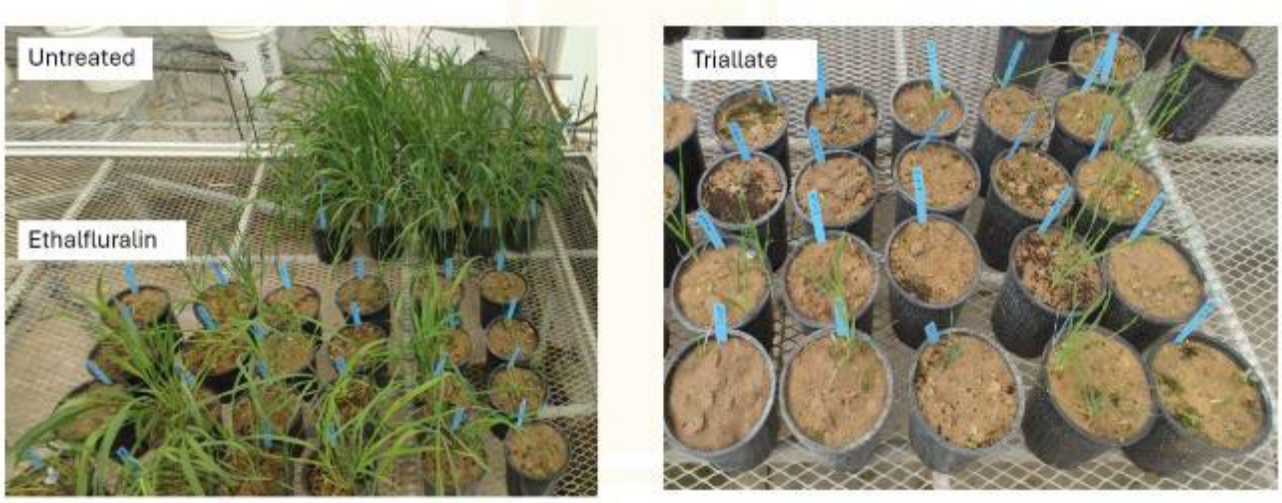


Figure 38. Greenhouse pots 28 days after spraying, showing wild oat growth in the nontreated and ethalfluralin treatments (left) compared with the triallate treatment (right).

These results indicate that the depth at which wild oat seed sits in the soil profile is a major determinant of preemergence herbicide performance. Triallate maintained near-complete biomass reduction through 5.08 cm, while ethalfluralin activity was largely confined to seed germinating at or near the soil surface. Both herbicides lost substantial activity at 10.16 cm, consistent with seedlings emerging from below the treated soil layer and escaping exposure.

1.17) Title: Evaluating Fluridone for Italian Ryegrass and Downy Brome Control in Winter Wheat

Authors: Albert Adjesiwor

Objective(s):

1. Evaluate the efficacy of fluridone (Group 12), alone and tank-mixed with flumioxazin, for preemergence control of Italian ryegrass and downy brome.
2. Assess winter wheat crop safety following preemergence applications of fluridone.

Abstract: Herbicide options for controlling Italian ryegrass (*Lolium multiflorum*) and downy brome (*Bromus tectorum*) in PNW production systems continue to narrow as resistance to Group 1 (ACCase), Group 2 (ALS), and increasingly Group 9 (glyphosate) herbicides becomes more widespread. Fluridone (Group 12, a phytoene desaturase inhibitor) is a new site of action with no prior history of use in PNW small grains. In 2026, a greenhouse study at the University of Idaho Kimberly Research and Extension Center evaluated Brake On! (fluridone) applied preemergence at 220, 330, and 440 g ai/ha, alone and tank-mixed with Chateau EZ (flumioxazin) at 61 g ai/ha, alongside flumioxazin alone and Zidua SC (pyroxasulfone) at 91 g ai/ha. Fluridone at 330–440 g ai/ha and both fluridone + flumioxazin tank mixes provided Italian ryegrass control statistically similar to pyroxasulfone, the best current soil-applied standard. Downy brome control by fluridone alone was weaker (about 50–65%) and reached levels similar to pyroxasulfone only when tank-mixed with flumioxazin (about 85%). However, winter wheat injury was substantial at every fluridone rate tested (about 50–95%), indicating that crop safety, not efficacy, is the main obstacle to using fluridone in wheat. Fluridone is not currently registered for use in wheat; the Brake On! label covers perennial crops (tree fruit, tree nuts, citrus, berries, and forages) in Idaho, Oregon, and Washington, and all results reported here are research data rather than a use recommendation.

Results:

Italian ryegrass control: Italian ryegrass control was the most promising result of the study (Figure 39). Fluridone at 330 and 440 g ai/ha and both fluridone + flumioxazin tank mixes (220 + 61 and 440 + 61 g ai/ha) gave essentially complete control, statistically similar to pyroxasulfone. Control dropped to about 80% and became noticeably more variable at the lowest fluridone rate tested (220 g ai/ha). Flumioxazin applied alone at 61 g ai/ha did not provide meaningful Italian ryegrass control.

Downy brome control: Downy brome was more difficult to control than Italian ryegrass (Figure 40). Fluridone alone provided only about 50–65% control and increasing the rate from 220 to 440 g ai/ha did not meaningfully improve control. Adding flumioxazin to fluridone increased downy brome control to roughly 85%, statistically similar to pyroxasulfone, which remained the strongest treatment overall at about 95%. These results suggest that if fluridone has a fit for downy brome management, it is likely as a tank-mix partner rather than as a stand-alone treatment.

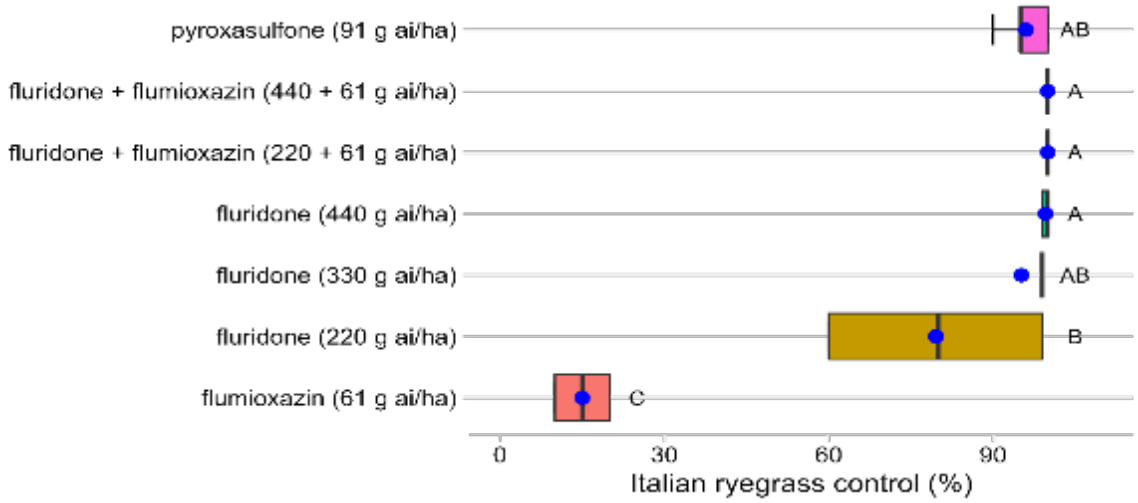


Figure 39. Italian ryegrass control four weeks after preemergence applications of Brake On! (fluridone) alone or tank-mixed with Chateau EZ (flumioxazin), compared with Chateau EZ and Zidua SC (pyroxasulfone) applied alone. Treatments with the same letter are not significantly different.

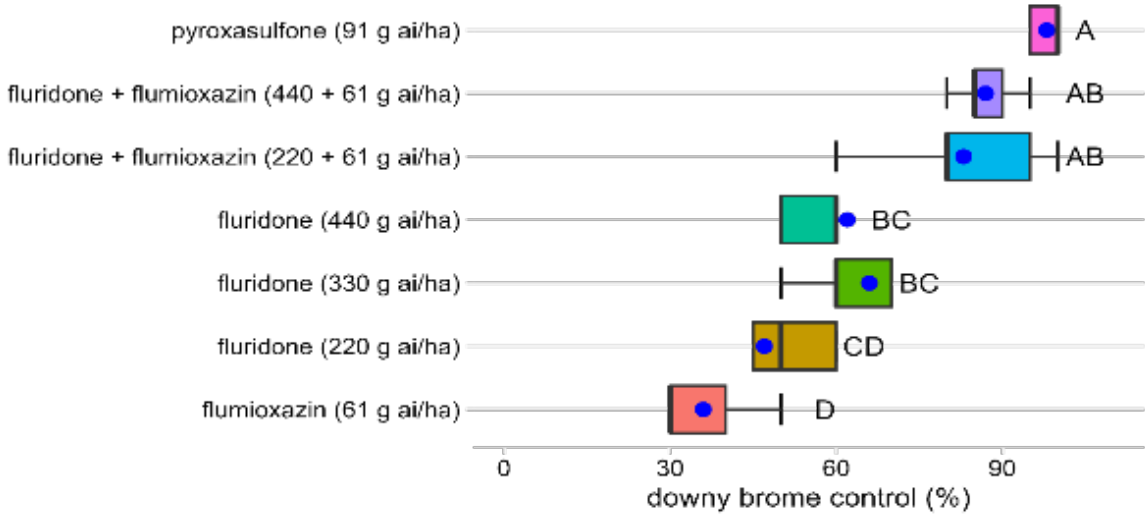


Figure 40. Downy brome control four weeks after pre-emergence applications of Brake On! (fluridone) alone or tank-mixed with Chateau EZ (flumioxazin), compared with Chateau EZ and Zidua SC (pyroxasulfone) applied alone. Treatments with the same letter are not significantly different.

Winter wheat injury: Winter wheat injury was substantial across the fluridone rate range (Figure 41), with injury of about 50% at 220 g ai/ha, 70% at 330 g ai/ha, and 85–95% at 440 g ai/ha and in both tank-mix treatments. Symptoms followed the classic fluridone bleaching pattern, in which carotenoid biosynthesis is inhibited, chlorophyll is degraded by light, and seedlings emerge white before dying (Figure 42). Notably, the fluridone rates needed for the strongest Italian ryegrass control were the same rates that caused the greatest

injury to winter wheat, indicating that the current hurdle to using fluridone in wheat is crop selectivity rather than herbicide efficacy.

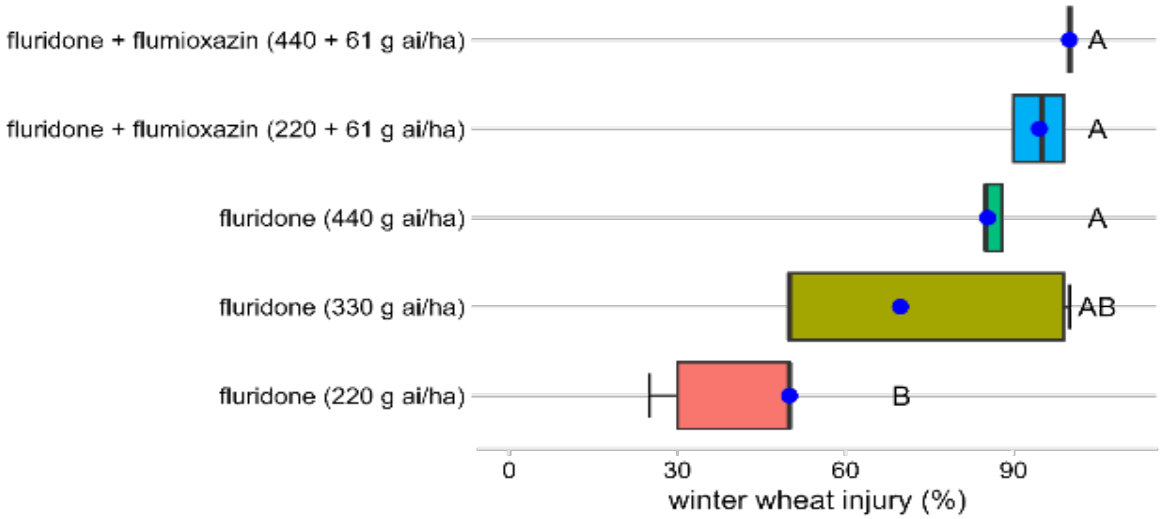


Figure 41. Winter wheat injury four weeks after preemergence applications of Brake On! (fluridone) alone or tank-mixed with Chateau EZ (flumioxazin). Treatments with the same letter are not significantly different.

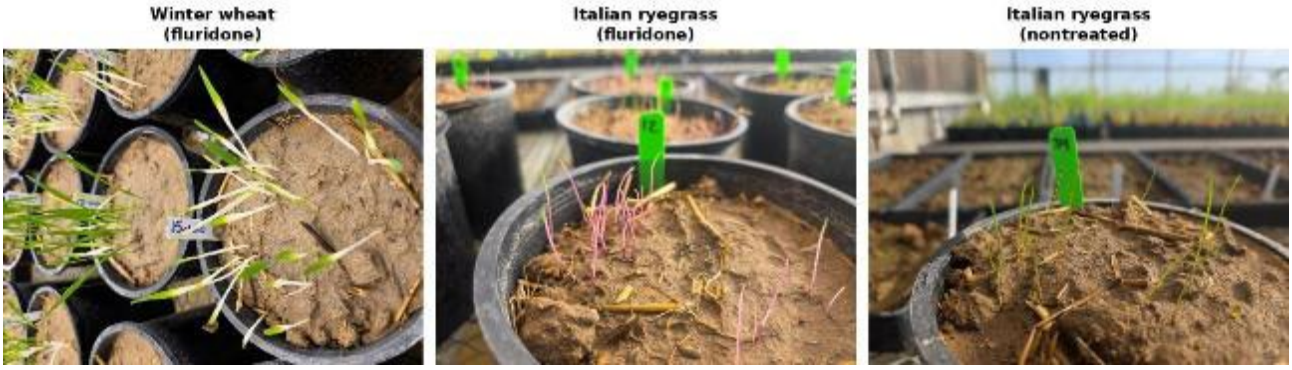


Figure 42. Winter wheat (left) and Italian ryegrass (center) treated with fluridone compared with nontreated Italian ryegrass (right), showing the characteristic fluridone bleaching symptom.

Because this was a greenhouse study, root growth was confined and there was no dilution into a deeper soil profile, so wheat injury observed here likely represents a worst-case scenario; field performance under real soil and precipitation conditions, and with different seed placement depths, may differ. Fluridone is also a Group 12 herbicide, and its label already limits use to no more than two consecutive years on the same field, so a new site of action would need to be managed carefully even if crop safety is resolved. Planned next steps include field evaluation of fluridone for grass weed control in winter wheat, testing whether deeper wheat seed placement or reduced rates can preserve Italian ryegrass control while improving crop safety, and evaluating fluridone safety in pulse crops (fluridone is currently labeled for forage legumes such as alfalfa, beans, and clovers).

1.18) **Title:** Impact of Seed Placement Depth and Preemergence Herbicide Activation Moisture Requirements on Italian Ryegrass Control

Authors: Chandra Montgomery and Albert Adjesiwor

Objective(s):

1. Determine whether Italian ryegrass seed placement depth affects the efficacy of preemergence herbicides (pyroxasulfone and trifluralin).
2. Determine the minimum amount of soil moisture, and the effect of activation timing, needed to activate preemergence herbicides for Italian ryegrass control.

Abstract: Italian ryegrass (*Lolium multiflorum*) remains one of the most troublesome weeds in PNW small grain production, and growers rely heavily on soil-applied herbicides whose performance depends on where weed seeds sit in the soil profile and on how much moisture is available to activate the herbicide. Two greenhouse studies were conducted at the University of Idaho in 2025 to quantify these factors for Italian ryegrass. The seed placement depth study used a 3 by 6 factorial design with four replications (June to August 2025): pyroxasulfone (Zidua SC) at 53 g ai/ha, trifluralin (Treflan HFP) at 755 g ai/ha, and a nontreated control, combined with six seed placement depths of 0, 0.64, 1.27, 2.54, 5.08, and 10.16 cm (0 to 4 inches). The herbicide activation study used a 3 by 3 by 8 factorial design with four replications (July to September 2025): the same three herbicide treatments, three watering timings (0, 3, and 6 days after treatment), and eight soil moisture levels (0, 5, 10, 20, 40, 60, 80, and 100% of field capacity, where 100% field capacity equaled 238 mL). Italian ryegrass density and biomass were recorded four weeks after treatment, and again two weeks after uniform watering resumed in the activation study. Herbicide efficacy declined as seed placement depth increased, and the decline was steepest for trifluralin, which was also highly variable when seed was left on the soil surface; no Italian ryegrass germinated from the 10.16 cm depth. Pyroxasulfone provided more consistent control than trifluralin across depths, consistent with its longer persistence in the soil profile. In the activation study, pyroxasulfone again outperformed trifluralin, and watering timing had little to no effect on pyroxasulfone efficacy. Pyroxasulfone biomass reduction increased sharply above 20% of field capacity, indicating a moisture threshold for activation, whereas trifluralin remained below about 75% at all moisture levels. Together, these results indicate that shallow weed seed placement and adequate activating moisture both favor preemergence herbicide performance.

Results:

Italian ryegrass density and biomass across seed placement depths: Preemergence herbicide performance depended strongly on where Italian ryegrass seed was positioned in the soil profile (Figure 1). Trifluralin was highly variable when seed was left on the soil surface, reflecting its higher water solubility and susceptibility to volatilization when it is not incorporated. Pyroxasulfone maintained essentially complete density and biomass reduction from the soil surface through 5.08 cm, whereas trifluralin declined progressively with depth, to roughly 60 to 75% density reduction and about 25% biomass reduction at 5.08 cm. This pattern is consistent with pyroxasulfone's low water solubility and longer persistence in the

treated soil layer, which allows it to remain available as germination is delayed. No Italian ryegrass emerged from the deepest placement (10.16 cm) in any treatment, so no reduction relative to the nontreated control could be measured at that depth. Differences between the two herbicides were significant at 0, 2.54, and 5.08 cm and not significant at 0.64 and 1.27 cm (alpha = 0.05; Figure 43).

Soil moisture during herbicide activation: Soil moisture was tracked throughout the activation study with TEROS 21 (water potential) and TEROS 12 (volumetric water content) sensors so that the applied field capacity treatments could be verified rather than assumed (Figure 44). The three-way analysis of variance showed no significant interaction among watering timing, herbicide treatment, and moisture amount, so the three-way interaction was removed from the model and herbicide treatments were compared at each moisture level.

Italian ryegrass response to activation moisture and timing: Pyroxasulfone provided better Italian ryegrass control than trifluralin across the moisture levels tested, both in emergence recorded two weeks after uniform watering resumed (Figure 45) and in biomass reduction relative to the nontreated control (Figure 46). Watering timing had little to no effect on pyroxasulfone efficacy, indicating that a delay of up to six days between application and the first activating moisture event did not compromise its performance. Trifluralin was the more moisture-sensitive of the two herbicides. Biomass reduction by pyroxasulfone rose sharply from about 40% at 20% of field capacity to more than 90% at 40% of field capacity and above, whereas trifluralin never exceeded about 75%; differences between the two herbicides were significant at 0% and at 40% of field capacity and above, and not significant from 5 to 20% of field capacity (alpha = 0.05; Figure 46).

Overall, the two studies indicate that both weed seed placement depth and activating moisture shape preemergence herbicide performance, and that pyroxasulfone is the more robust option when either factor is less than ideal.

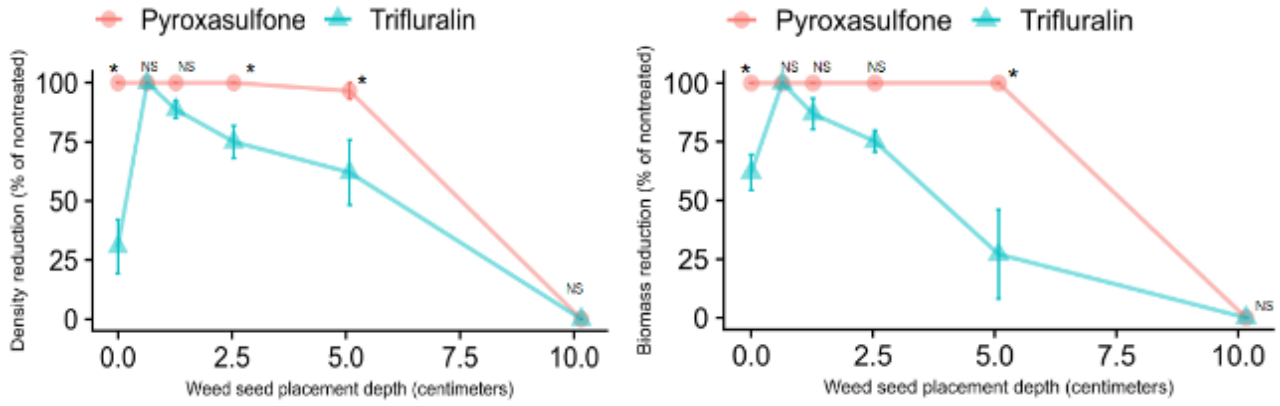


Figure 43. Italian ryegrass density reduction (left) and biomass reduction (right), expressed as a percentage of the nontreated control, four weeks after preemergence applications of Zidua SC (pyroxasulfone) at 53 g ai/ha and Treflan HFP (trifluralin) at 755 g ai/ha at six seed placement depths (0 to 10.16 cm). Error bars indicate standard error of the mean; NS, not significant; * significant at 0.05.

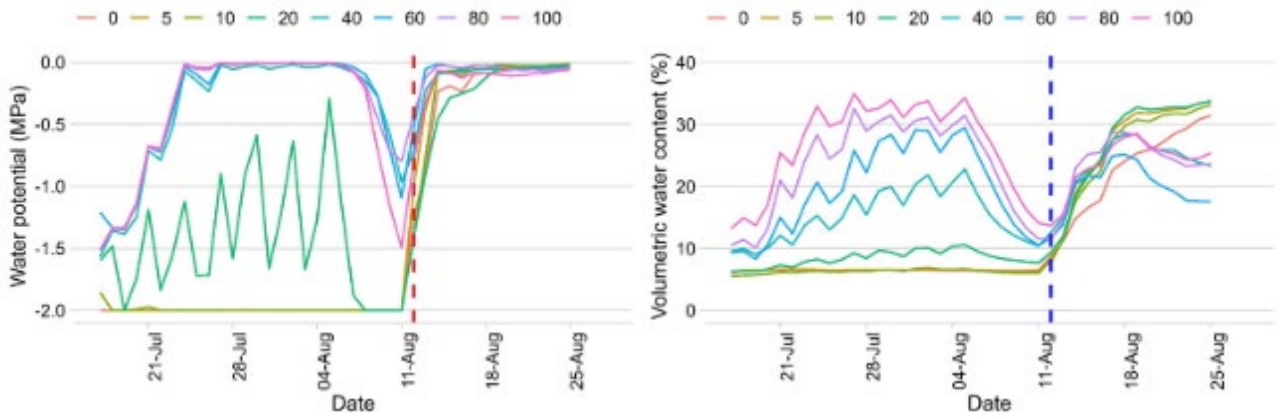


Figure 44. Soil water potential (TEROS 21) and volumetric water content (TEROS 12) measured across the eight field capacity treatments (0 to 100% of field capacity; 100% field capacity = 238 mL) during the herbicide activation study. The vertical dashed line in each panel indicates when uniform watering was initiated after herbicide application.

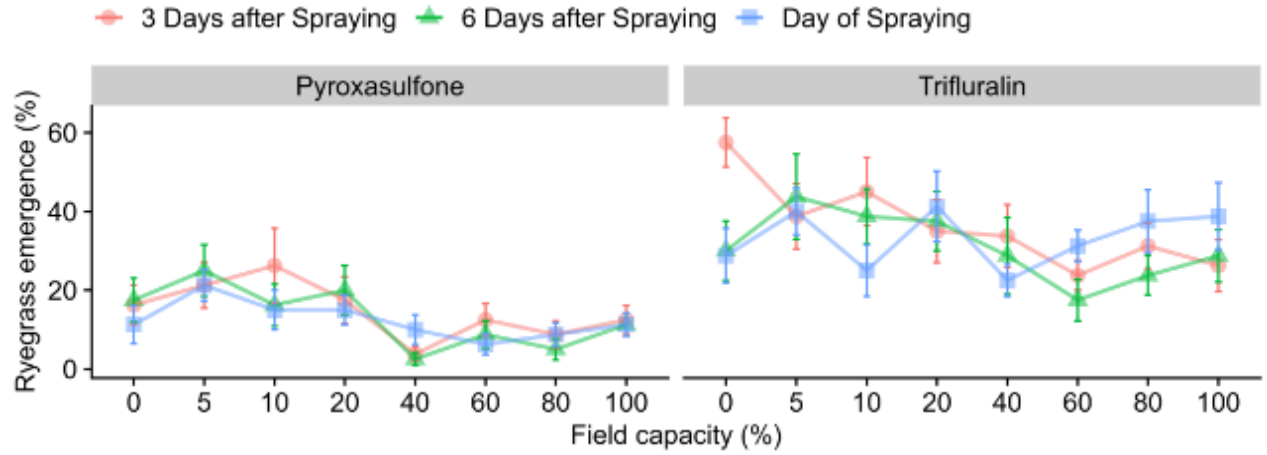


Figure 45. Italian ryegrass emergence two weeks after uniform watering resumed, expressed as a percentage, for pyroxasulfone and trifluralin across soil moisture levels (percent of field capacity) and three watering timings (day of application, 3 days after, and 6 days after treatment). Error bars indicate standard error of the mean.

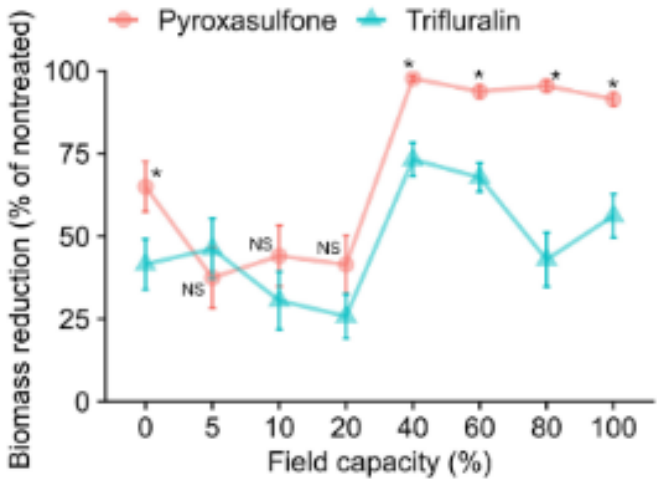


Figure 46. Italian ryegrass biomass reduction, expressed as a percentage of the nontreated control, for pyroxasulfone and trifluralin at each soil moisture level (percent of field capacity). Error bars indicate standard error of the mean; NS, not significant; * significant at 0.05.

1.19) **Title:** Developing a Weed Emergence Decision Support Tool for the Inland Pacific Northwest

Authors: Fabio Vale Scarpare, Albert Adjesiwor, Christopher Landau, Joan Campbell, Traci Rauch, and David Huggins

Objective(s):

- Evaluate whether field-based weed emergence observations, soil temperature, and soil water potential can support a predictive weed emergence tool for the inland Pacific Northwest.
- Determine whether thermal time (growing degree-days, GDD) and hydrothermal time (HTT) characterize seasonal emergence patterns of major weed species under contrasting crop and soil-management conditions.
- Establish a quantitative basis for estimating onset and peak weed emergence as key outputs of a future decision support tool.
- Identify methodological and experimental limitations to address during model calibration and testing across additional locations, years, weed populations, and management systems.

Abstract: Two field experiments were conducted in spring 2026 at Pullman, Washington, and Kimberly, Idaho. Weed species composition differed between sites, and redroot pigweed (*Amaranthus hybridus*) was the only species abundant enough at both locations to support a direct cross-site comparison; it was therefore selected as the focal species. Daily soil temperature and soil water potential were recorded at 5 cm depth in wheat and fallow treatments. Cumulative growing degree-days (GDD, base 9 °C) and moisture-gated hydrothermal time (HTT, base −500 kPa) were accumulated from March 26 at Kimberly and May 19 at Pullman through the final emergence counts on July 17 and August 14, respectively, and three-parameter Weibull models were fit to cumulative emergence against each index. GDD described emergence as well as or better than HTT at both sites, providing proof-of-concept that environmentally driven emergence models can support a regional weed emergence prediction tool.

Results:

Analytical framework: Cumulative growing degree-days (GDD) and moisture-gated hydrothermal time (HTT) were accumulated daily from daily soil temperature and soil water potential at 5 cm depth, and related to cumulative emergence with a three-parameter Weibull model:

$$GDD_{\mathrm{cum,n}} = \sum_{\mathrm{d}=1}^{n} GDD_d = \sum_{\mathrm{d}=1}^{n} \max(T_{\mathrm{mean}} - T_{\mathrm{base}}, 0)$$

$$HTT_{\mathrm{cum,n}} = \sum_{\mathrm{d}=1}^{n} \max(T_{\mathrm{mean}} - T_{\mathrm{base}}, 0) \times I(\psi_{\mathrm{mean}} > \psi_{\mathrm{base}})$$

$$E(x) = k\left[1 - \exp\left(-\left(\frac{x}{b}\right)^{c}\right)\right]$$

where T_{mean} is mean daily soil temperature (°C), T_{base} is the base temperature (9 °C; Werle et al., 2014; Wiese & Binning, 1987), ψ_{mean} is mean daily soil water potential (kPa), $\psi_{base} = -500$ kPa (Werle et al., 2014), and I(·) equals 1 when the moisture condition is met and 0 otherwise. *E(x)* is cumulative emergence (%), x is cumulative GDD or HTT (°C d), k is the upper asymptote, b is the scale parameter, and c is the shape parameter. Fitted curves were used to estimate E_{10}, E_{50}, and E_{90}, the accumulated GDD or HTT required to reach 10%, 50%, and 90% of maximum emergence.

Emergence response to thermal and hydrothermal time: Across the 2026 trials, cumulative GDD described redroot pigweed emergence as well as or better than HTT (Figures 47 and 48). Adding soil water potential through the moisture-gated HTT formulation did not improve model performance, indicating that soil moisture was largely non-limiting during the main emergence period, that the assumed base water potential did not represent the species' moisture threshold, or that water-potential readings were affected by high variability among replicates. GDD is therefore a practical first-generation predictor of emergence, with soil moisture warranting further evaluation under drier conditions.

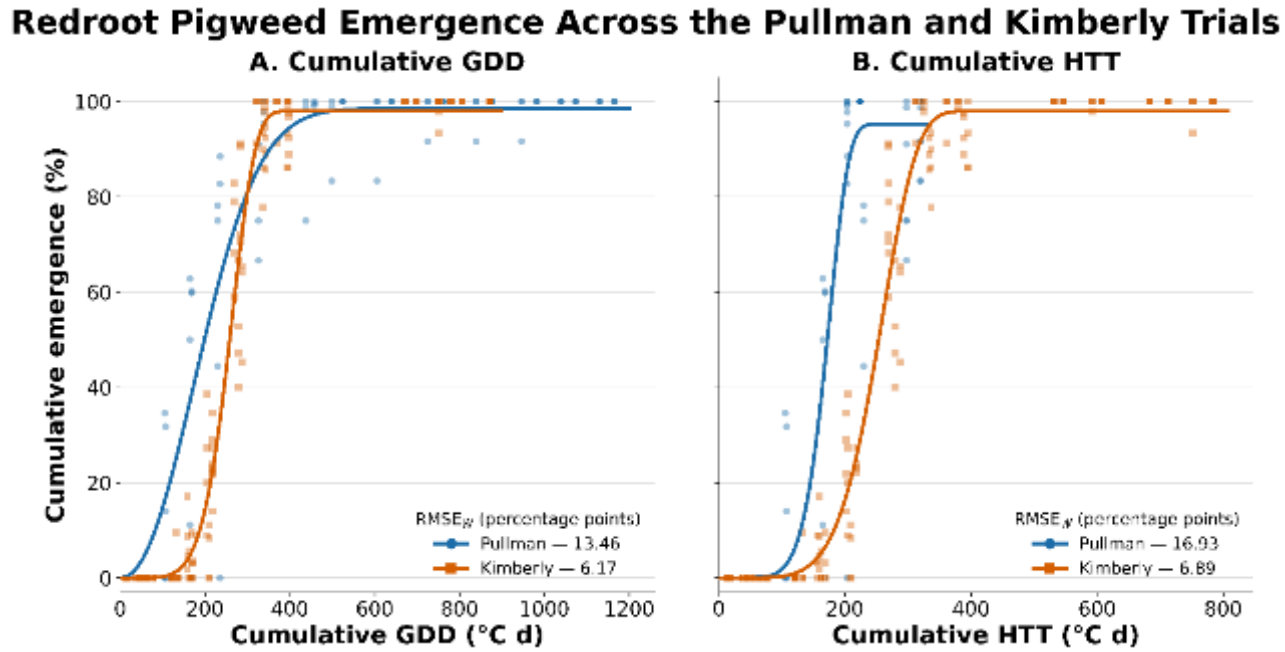


Figure 47. Observed cumulative redroot pigweed emergence in the Pullman and Kimberly trials as a function of cumulative growing degree-days (GDD; A) and moisture-gated thermal time (HTT; B). Symbols distinguish trial sites, and lines represent Weibull fits to treatment means. Weibull-model RMSE ($RMSE_W$) is reported in percentage points.

Site and management effects: Fitted Weibull curves separated more between the Pullman and Kimberly experiments than among crop and tillage treatments within a site (Figure 47). Site-level environmental conditions, population differences, and other unmeasured local factors appear to have influenced emergence timing more strongly than the imposed management contrasts.

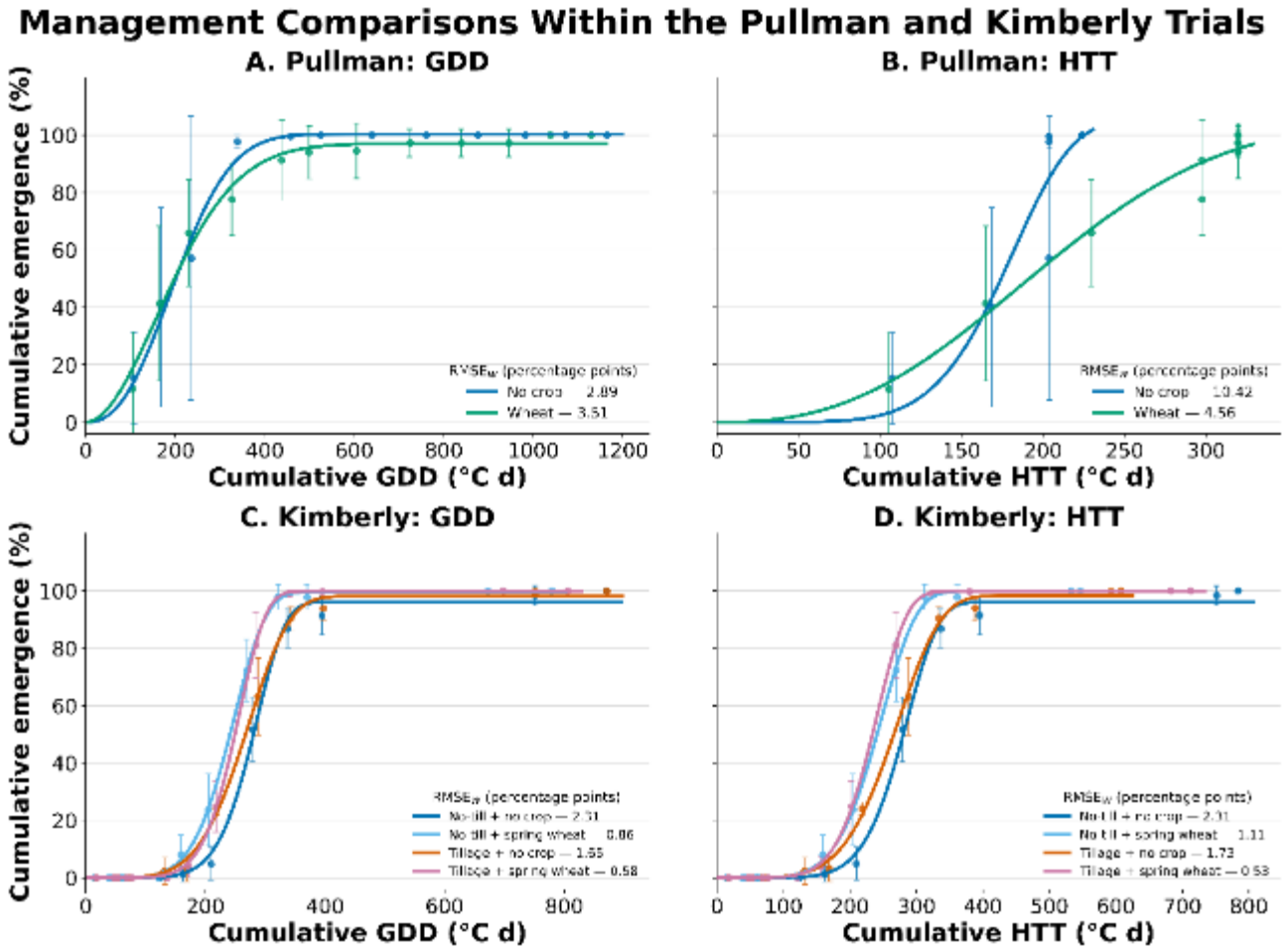


Figure 48. Observed cumulative redroot pigweed emergence in the Pullman and Kimberly trials as a function of cumulative growing degree-days (GDD; A and C) and moisture-gated thermal time (HTT; B and D). Points show mean cumulative emergence, and error bars show ±1 SD among plots; lines represent Weibull fits to treatment means. Weibull-model RMSE ($RMSE_W$) is reported in percentage points. Pullman panels (A and B) compare fallow *vs.* wheat, whereas Kimberly panels (C and D) compare the four crop-by-tillage combinations.

Next steps: A regional Weibull model calibrated across multiple locations and years should be compared with models that allow site-specific parameter adjustments, using additional site-years under contrasting temperature and soil-moisture conditions. Future monitoring should begin before the expected onset of emergence and continue at roughly 3-day intervals during active emergence, extending to weekly or biweekly once cumulative emergence approaches the plateau.

1.20) **Title:** Development of Agrazer: A Retrieval-Augmented Decision-Support Platform for Agricultural Producers

Authors: Eduard Steiner, Bryan Carlson, David Huggins, and Christopher Landau

Objective(s):

1. Develop and deploy Agrazer, a transparent, public-facing retrieval-augmented decision-support platform providing evidence-based information for agricultural producers and professionals regarding weed-related topics
2. Enable direct source verification and guided reading by allowing users to review original reference materials and conduct focused conversations.
3. Streamline document ingestion and knowledge-base management using custom tools.
4. Develop analytical tools, such as cluster analysis, to examine knowledge-base coverage and identify research or extension gaps.

Summary: Agricultural producers have access to extensive collections of university extension publications, scientific literature, research reports, and other educational resources that can inform farm-management decisions. However, locating relevant information and synthesizing it for a producer's specific and immediate needs can be difficult and time-consuming. Large language models (LLMs) can help users interpret these resources, but general-purpose models may provide inaccurate information, lack sufficient domain knowledge, or fail to clearly identify the evidence supporting their responses.

During the past year, the project transitioned from fine-tuning an individual language model to developing Agrazer, a retrieval-augmented generation (RAG) platform for agricultural decision support. Rather than relying on information learned during model training, Agrazer retrieves relevant information directly from a curated collection of agricultural resources when answering a question. Its hybrid retrieval system combines semantic similarity with lexical keyword matching, merging, and ranking search results from both methods to produce a unified set of relevant sources.

The objective was to develop a transparent, public-facing application that allows producers and agricultural professionals to ask questions, receive evidence-based answers, and directly examine the source materials used to generate those answers. The resulting application is publicly available at https://agrazer.cafltar.org/.

Accomplishments: Agrazer was developed and deployed as a public-facing agricultural question-and-answer application (Figure 49). Users can submit questions and receive generated answers accompanied by a list of the supporting sources retrieved by the system. Each source can be opened directly, allowing users to view the original PDF or webpage and verify the information provided. Agrazer also supports guided reading, enabling users to continue a focused conversation about an individual source.

The platform uses hybrid retrieval that combines semantic and lexical scoring. These independently ranked results are combined through rank fusion, improving the system's

ability to retrieve both conceptually relevant passages and resources containing important domain-specific terminology.

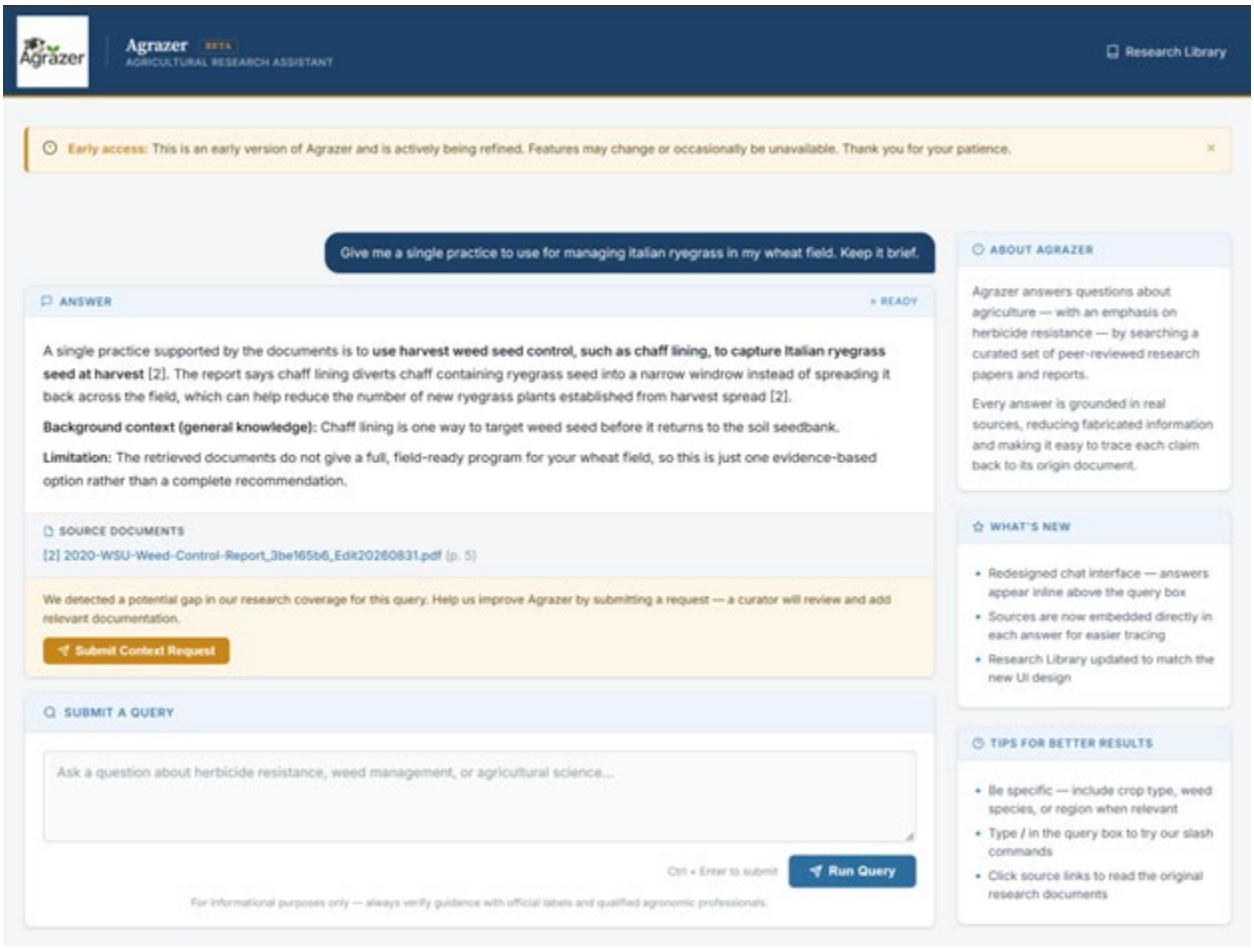


Figure 49. Agrazer's public-facing interface for asking agricultural questions and receiving source-grounded answers.

In April 2026, a preliminary version of the platform was deployed online. Built on cloud infrastructure, the platform incorporates multi-tiered security protocols and safety constraints. The application underwent continuous refinement over the past year based on feedback from expert reviews and end-user testing.

An accompanying application, "Agrazer Feeder", was developed to streamline the processing and ingestion of new resources into the Agrazer knowledge base (Figure 50). This provides a more efficient and repeatable process for expanding and maintaining the platform's collection of agricultural information.

An early-stage cluster-analysis tool was also developed to examine the topics represented within the collected resources (Figure 51). With further development and validation, this tool may help researchers explore the composition of the knowledge base and identify subject areas that are underrepresented in existing research or Extension materials.

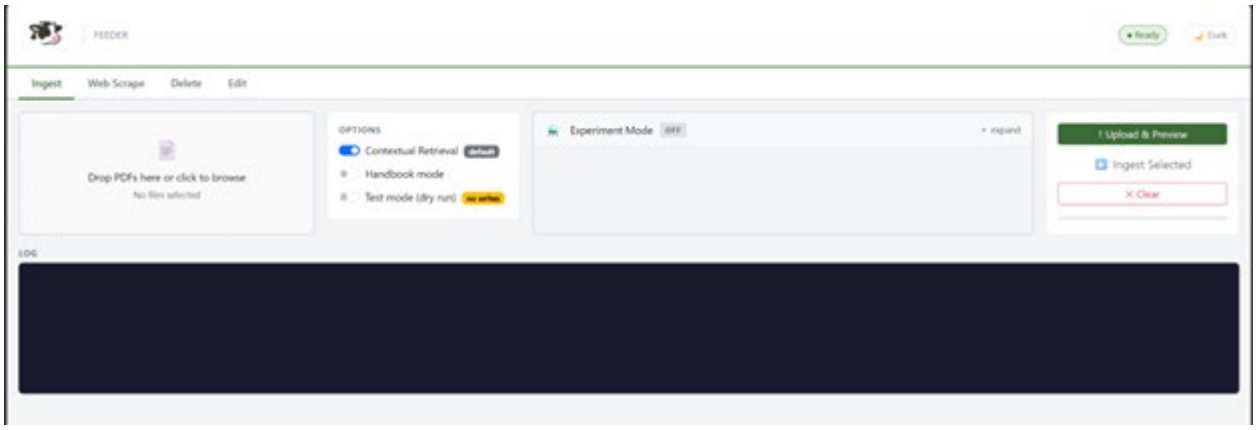


Figure 50. Agrazer Feeder interface for streamlined ingestion and management of source documents in the Agrazer knowledge base.



Figure 51. Agrazer's cluster-analysis application for exploring topics within the knowledge base and identifying potential research gaps.

Collaboration with WSU was expanded through an Electrical Engineering and Computer Science Senior Design project. Participating students are contributing to experiments involving agentic AI orchestration and tool integration. This collaboration provides students with experience working on an applied agricultural AI system while supporting research into potential future capabilities for Agrazer.

Future Efforts: Future work will focus on expanding the number and diversity of resources available through Agrazer, improving retrieval and answer-quality evaluation, further

developing tools for streamlined ingestion and knowledge-base analysis, and open sourcing the code. A "co-production" campaign is planned to engage producers for feedback and evaluation using a pre-defined rubric and other emerging standards for evaluation of RAG-based systems. The project will also explore the feasibility of scaling Agrazer into a federated RAG system. Under this model, participating agricultural research regions or organizations could maintain control of their own resources and local knowledge bases while making relevant information accessible through a central Agrazer interface. This approach could allow Agrazer to connect distributed agricultural knowledge across regions without requiring all information to be managed within a single centralized database.

Agentic orchestration and tool-integration approaches will be evaluated as potential methods for coordinating searches across these distributed systems. Continued collaboration with Washington State University students will support this experimentation while helping establish a pipeline for student involvement in agricultural artificial intelligence research and development.

Objective 2: Socio-Economic

2.1) Title: Expanded Analysis of Survey Data on Producer Perceptions of Weed Management and Herbicide Resistance Challenges in the Pacific Northwest.

Authors: Nick Bergmann, Sabin Bhattarai (UI graduate student), Doug Finkelnburg, Patrick Hatzenbuehler, and Pawan Pyakurel (UI graduate student).

Objective: Implement additional analysis of a survey dataset composed of producer responses to questions pertaining to changes in weed challenges, producer adjustments in weed management practices, and the extent of herbicide resistance and report the analysis findings in a research publication.

Summary: The social science team collaborated on the implementation of an online Qualtrics-based producer survey focused on weed management and herbicide resistance challenges in the fall 2024 through winter 2025. These data were cleaned and organized by a University of Idaho (UI) graduate student, Sabin Bhattarai, in the summer of 2025. Initial feedback on the dataset composition and preliminary analysis was obtained during the 2025 PNWHRI Annual Meeting, and the dataset was further cleaned based on the feedback obtained to exclude responses from areas in the PNW without substantial grain production.

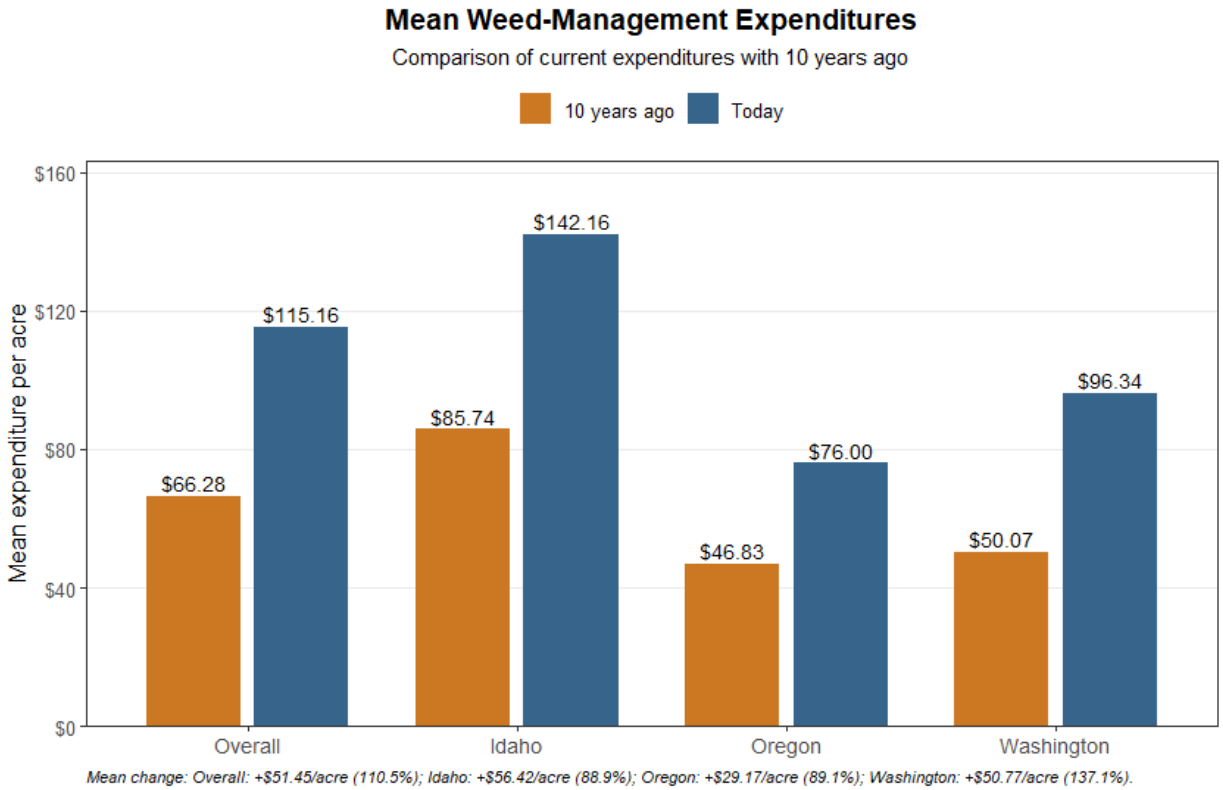


Figure 52. Comparison of weed management expenditures over the past decade for the full sample and across states.

The finalized dataset, with 78 submissions that had valid and mostly complete responses, was further analyzed by another UI graduate student, Pawan Pyakurel, during the summer of 2026 and prepared into a draft report that will be published as a UI Extension Research Bulletin publication after peer review.

Accomplishments: A complete report that encompassed in-depth analysis of the finalized dataset with producer responses to weed management and herbicide resistance challenges was drafted in the summer 2026. Additionally, a proposal for the report to be published as a UI Extension Research Bulletin was drafted, submitted, and approved for preparation. Submission of the manuscript for peer review is anticipated during fall 2026.

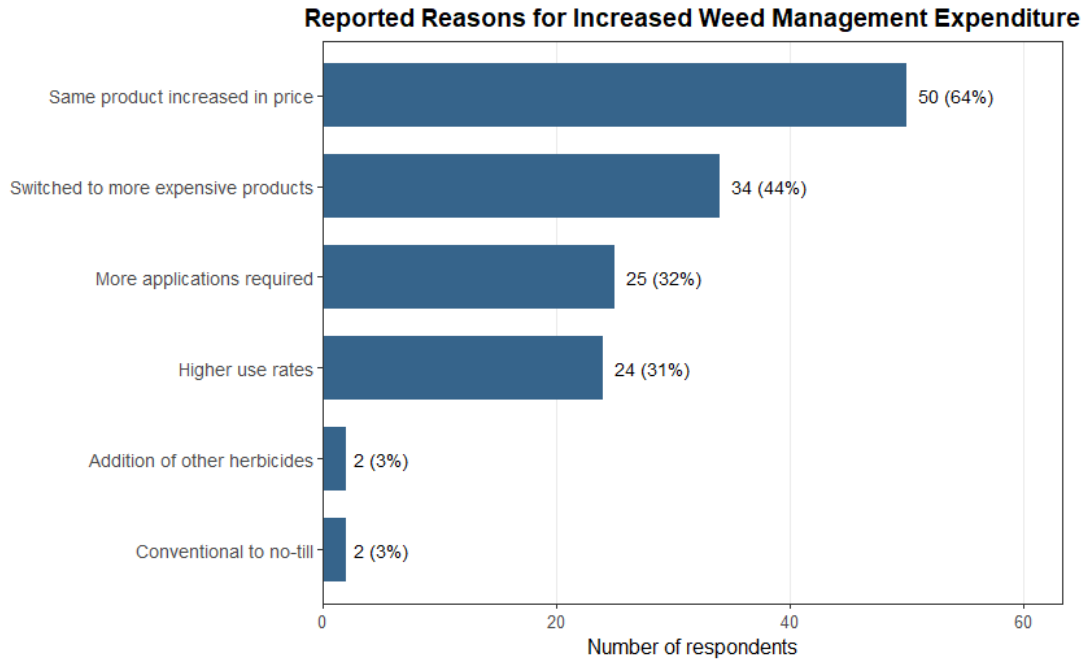


Figure 53. Ranking of the reported reasons for increased weed management expenditures.

2.2) Title: A Community-Based Herbicide Resistance Management Approach to Developing Grain Sorghum in the Pacific Northwest

Authors: Nick Bergmann, Doug Finkelnburg, Rachel Weime, Morgan Menaker, Jesse Ford, Sarah Peery, Steven Lee, Jennifer MacMillan, and Ryan Higginbotham

Objective(s):

1. Analyze the efficacy of a co-production of knowledge approach to facilitate community-based herbicide resistance management.
2. Evaluate the potential of grain sorghum as a viable alternative crop in the Pacific Northwest to improve herbicide resistance management.

Summary: Herbicide resistance is a spatial phenomenon that moves across the landscape. Because herbicide resistance is a resource management problem that crosses political and property boundaries, many scholars and practitioners argue that a collaborative or community-based approach to herbicide resistance may offer positive management results. This project evaluates a co-production of knowledge approach to herbicide resistance management centered on a producer-focused community working group established in North Central Washington. For approximately five years, this working group has met with the goal of co-innovating new management strategies to adapt to the growing threat of herbicide resistance. This group has focused its energy of developing tools to improve cropping systems diversification including researching the social and agronomic potential of adapting grain sorghum to dryland cropping systems across the Pacific Northwest. Using four primary data collection methods: reoccurring focus groups, agronomic field trial data, germplasm selection, and autoethnography, we are creating a unique data set that will be used to evaluate both objectives.

Accomplishments/Results: The 2025 growing season focused on both field scale farmer trials of grain sorghum as well as small plot variety trials and germplasm selection. 2025 results were mixed with some grain sorghum sites performing well. In particular, the variety trial site near Dayton, WA showed promising results (Figure 54 and Table 15). Partnering with agronomist David Wichman and grain sorghum breeder Melinda Yerka, we also grew and performed initial selection on germplasm developed in Montana, Nevada, and California to develop better adapted grain sorghum varieties to the Pacific Northwest. The 2026 growing season includes expanded germplasm selection, small plot and field scale variety trials, and a row spacing and seeding rate trial. Harvest for the trials will occur in October. During the winter, we also held two focus group meetings with the North Central Washington working group focused on herbicide resistance management and cropping systems diversity. We now have five years of focus group data related to the project that is currently undergoing analysis. We presented ongoing results from the project at the Palouse Conservation District's Alternative Cropping Symposium in February 2026. Two manuscripts from the project are currently in preparation.

Table 15. Grain Sorghum Yield Data from 2025 Variety Trial near Dayton, WA

Variety	Harvest Date	Yield (lbs/acre)	Yield (bu/acre)
V2 (G1156 - Richardson)	10.10.25	8769.89	**156.61**
V11 (5B29 Channel - Bayer)	10.10.25	7917.26	**141.38**
V7 (251 – Sorghum Partners)	10.10.25	7016.97	**125.30**
V5 (SP 43M80 – Sorghum Partners)	10.10.25	6386.76	**114.05**
V10 (DKS28-05 Dekalb - Bayer)	10.10.25	6365.58	**113.67**
V8 (SP 29A27 DT2 – Sorghum Partners)	10.10.25	6084.90	**108.66**
V3 (G1053 - Richardson)	10.10.25	5359.37	**95.70**
V1 (LGS 5002 - Legend Seeds)	10.10.25	4718.58	**84.26**
V12 (5C42 Channel - Bayer)	10.10.25	4469.68	**79.82**
V4 (G2 - Richardson)	10.10.25	3537.61	**63.17**
V9 (SP 28C17 DT2 – Sorghum Partners)	10.10.25	2579.07	**46.05**
V6 (SP 31A15 – Sorghum Partners)	10.10.25	1763.51	**31.49**



Figure 54. Mature Grain Sorghum from 2025 Variety Trial near Dayton, WA.

Objective 3: Education and Outreach

3.1) Title: Start Clean, Stay Clean in Cereal Grain Cropping Systems

Author: Aaron Esser, WSU Regional Extension Agronomist

Objective: Herbicide-resistant weeds remain a major concern for farmers in the dryland cropping region of eastern Washington, including winter wheat–summer fallow systems, and continue to be a major focus of my Extension outreach program.

Summary: I hosted or participated in 11 educational events focused on tools and strategies for managing herbicide resistance, reaching an estimated 760 participants. In addition, I provided individualized weed management support through more than 150 direct communications with farmers and crop consultants. These activities demonstrate the integration of my research and Extension programs to provide farmers with timely, research-based strategies for improving weed control and managing herbicide resistance.

Accomplishments: One-on-one communication with farmers and crop consultants is an important component of my program, and this year I responded to more than 150 direct calls and text messages related to weed control in dryland cropping systems.

I organized two grower meetings in the Lincoln-Adams Extension Area that attracted 190 participants. A major focus of these meetings was sharing research results on the use of fall-applied residual herbicides to improve weed control during summer fallow. Adoption of this practice began last fall and is expected to continue increasing this season.

I also organized a field day attended by 115 participants. Multiple educational stops addressed weed management, including research results on the new herbicide active ingredient Rapidicil® (epyrifenacil), developed by Valent; weed-seed germination growing-degree-day models to improve the timing of control; and the use of crop rotation as a tool for enhancing long-term weed management.

I was invited to speak at eight events this year focused on tools and strategies for managing herbicide resistance. My presentation, "Start Clean, Stay Clean: Pre's in Cereal Grain Cropping Systems," was delivered at five educational events and reached an estimated 360 farmers and crop consultants. Three additional presentations conducted across the region reached another 95 participants, including farmers, crop consultants, and Extension educators.

My weed management research program remains focused on incorporating residual herbicides into crop rotations and utilizing technology to improve weed control. In collaboration with Valent, I evaluated the new herbicide active ingredient Rapidicil® (epyrifenacil) and its potential fit within eastern Washington cropping systems. This work is intended to enhance and diversify weed management programs, with particular emphasis on reducing reliance on glyphosate and addressing glyphosate-resistant weeds.

3.2) Title: Education and Outreach Summary

Author: Doug Finkelnburg, Area Cropping Systems Educator, UI

Objective: Support an active, engaged Extension and outreach program centered on the fundamental and applied work of the Pacific Northwest Herbicide Resistance Initiative (PNWHRI).

Accomplishments: During the past year, PNWHRI-generated information was shared through university and industry grower meetings, crop tours, pesticide applicator recertification clinics, online and print publications, and the 2026 Western Society of Weed Science (WSWS) Annual Meeting. These activities reached local, regional, and national audiences—including producers, agricultural consultants, industry representatives, students, researchers, and policymakers.

Online outreach included the following *Weeders of the West* blog articles:

- "Beyond Perception: Putting Numbers to the Story on Grass Weed Emergence" by Dr. Judit Barroso
- "Grass Weed Emergence in Fall 2025" by Dr. Judit Barroso
- "Optimizing the Use of Green-on-Brown Precision Sprayers" by Dr. Judit Barroso;
- "Wild Oat Resistance Screening and Updates" by Dr. Albert Adjesiwor; and
- "It's Getting Exciting Again!" by Dr. Drew Lyon.

Additional outreach included the University of Idaho Extension *AgTalk Tuesday* presentation, "What's Up with Herbicide-Resistant Weeds?" by UI Extension Weed Scientist Dr. Albert Adjesiwor. Print outreach included "Grower Perceptions of Herbicide-Resistant Weeds and Management Cost Considerations," by Drs. Patrick Hatzenbuehler and Albert Adjesiwor, published in *Potato Grower Magazine*.

PNWHRI was also featured at the 2026 WSWS Annual Meeting in Tucson, Arizona with a symposium, titled "Transdisciplinary Collaborative Research Panel Discussion," that included Dr. Pete Berry, Dr. Nick Bergmann, Dr. Patrick Hatzenbuehler, and Doug Finkelnburg. Dr. Judit Barroso also presented "Integrating Tillage into No-Till Systems to Mitigate Herbicide Resistance." Collectively, PNWHRI outreach activities reached 1,105 people through in-person programming and at least 9,000 through print materials during the reporting period.

Biweekly meetings of PNWHRI Extension and Outreach team members were held throughout the year to maintain project coordination, cohesion, and momentum. These meetings provided regular opportunities to exchange information, coordinate activities, and strengthen collaboration among participating institutions and disciplines.

Several improvements were also made to PNWHRI.org. The Herbicide Resistance Tracker, Palmer Watch, and Wheat Acreage Data map layers were maintained and updated. Current university publications addressing weed management in the PNW were added to the website's Resources page, and a searchable database of studies authored by PNWHRI members was maintained.

During the past year, PNWHRI.org recorded 2,551 active users. Interestingly, most were in China (866) and Singapore (865) followed by the United States (727), Iran (37), Germany (36), Brazil (10), and Russia (10). When considering engaged US-based sessions by city; Pullman, WA (122), Moscow, ID (99), Seattle, WA (35), Corvallis, OR (34), Colfax, WA (21), East Lansing, MI (12), Portland, OR (10), Boise, ID (9) and Des Moines, IA (9) led the list.

A producer survey was to document how weed-control challenges have changed for producers in Idaho, Oregon, and Washington was analyzed and summarized. Results from the 2024–2025 survey were widely shared at producer events, and a scholarly manuscript based on the findings has been submitted for publication as a University of Idaho Technical Bulletin.

Looking ahead, the Education and Outreach team will continue refining the Herbicide Resistance Tracker, Palmer Watch, and Wheat Acreage Data maps. A robust producer survey on herbicide resistance and factors that influence its management will be deployed over the winter of 2026-2027. The team will continue to highlight PNWHRI supported projects, findings and webtools at upcoming meetings, conferences, field days and crop tours as well as online and in print.

Publications

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Barroso J, Durfee N, Oreja FH, Ndou V, Codina-Pascual N, & Wuest SB. (2026). Sustainable Strategies to Mitigate Herbicide Resistance in No-Till Wheat Cropping Systems. *Proceedings of the Spanish Society of Weed Science Biannual Meeting*. Madrid, Spain. October 2026.

Codina-Pascual N, Ndou V, Oreja FH, Gourlie JA, & Barroso J. (2026). Seed Retention Dynamics of Downy Brome (*Bromus tectorum* L.) at Winter and Spring Wheat Harvest in the Pacific Northwest. 2026. *Proceedings of the 79th WSWS Annual Meeting*. Tucson, AR. March 2, 2026. Abstract.

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Ndou V, Oreja FH, Gourlie JA, & Barroso J. (2026). Effect of Germination Time on Downy Brome Seed Production and Seed Viability in Spring Wheat. *Proceedings of the 79th WSWS Annual Meeting*. Tucson, AR. March 2, 2026. Abstract.

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Sharma SK, Montgomery C, Rauch T, Campbell J, & Adjesiwor AT. (2026). Herbicide Resistance Screening of Wild Oat (*Avena fatua* L.) Collected from Small Grain

Production System. *Proceedings of the 79th WSWS Annual Meeting*. Tucson, AZ. March 2-5, 2026. Abstract.

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Rodriguez L, Felix J, Alder C, Liu R, Landau O, & Adjesiwor A. (2026). Efficacy of Selected Herbicides for Control of Palmer Amaranth (*Amaranthus palmeri*) and Waterhemp (*Amaranthus tuberculatus*). *Proceedings of the 79th WSWS Annual Meeting*. Abstract.

How to Cite this Report

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Individual project reports: Author(s). (2026). Title of project report. In: *Pacific Northwest Herbicide Resistance Initiative (PNWHRI) 2026 Annual Report* (pp. xx–xx). Pacific Northwest Herbicide Resistance Initiative. https://www.pnwhri.org