PACIFIC NORTHWEST HERBICIDE RESISTANCE INITIATIVE

2024 Annual Report

www.pnwhri.org

Oregon State University · University of Idaho · Washington State University · USDA Agricultural Research Service

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Executive Summary

The **2024 Annual Report** for the **Pacific Northwest Herbicide Resistance Initiative (PNWHRI)** highlights significant advancements in tackling the growing issue of herbicide-resistant weeds within the region's cereal-based cropping systems. The initiative, a collaboration between the Agricultural Research Service (ARS), regional universities, and stakeholders, has made important strides in research, stakeholder engagement, and the development of new weed management strategies. Below is a summary focusing on key achievements:

1. Collaborative Efforts and Team Expansion

PNWHRI has maintained regular coordination meetings, fostering a collaborative environment among researchers from ARS and regional universities. These discussions have helped define a clear set of objectives and research priorities. The initiative successfully completed the recruitment of the first of three planned ARS weed science positions, essential for building a cohesive research team. Interviews for the remaining two positions have been conducted, and all three scientists are expected to be in place in the upcoming fiscal year. This expansion is critical for driving forward PNWHRI's mission of developing a regionally coordinated, science-based approach to herbicide resistance management.

2. Coordinated Systems and Regional Assessment

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

3. Research Highlights

Several research projects have yielded promising results in weed control and management:

- **Weed Seedbank Control in Rotational Crops**: A multi-year crop rotation study conducted at the University of Idaho's Kimberly Research Center demonstrated that including alfalfa in crop rotations significantly reduced weed seedbank density, in some cases by as much as 94%. The study compared wheat-alfalfa rotations with wheat-annual crop rotations (corn and dry beans), revealing that alfalfa rotations coupled with preemergence (PRE) and postemergence (POST) herbicide treatments were particularly effective at suppressing weed populations. These findings offer a proactive strategy for managing herbicide-resistant weed populations and improving crop productivity.
- **Herbicide Resistance Surveys**: Comprehensive field surveys were conducted across southern and northern Idaho, Washington, and Oregon to screen for herbicide resistance in key weed species. Results indicate widespread resistance to common herbicides, such as glyphosate, particularly in Palmer amaranth and kochia populations. The surveys also uncovered resistance to multiple herbicide groups in wild oat and downy brome, underscoring the need for integrated weed management (IWM) strategies.
- **Machine Learning in Weed Identification**: A major innovation in PNWHRI's research has been the development of a machine learning tool for the automatic identification and counting of weed seeds. Using a machine learning model, researchers trained the system to accurately

detect and classify seeds from 19 weed species common in the PNW region. This technology significantly accelerates the process of weed seed identification, reducing the time and labor involved in traditional manual methods. It is a crucial tool for both researchers and farmers, enabling faster decision-making in weed management.

- **Development of Novel Weed Control Technologies**: The PNWHRI has also been investigating new technologies for weed seed deactivation. One project evaluated the use of high-intensity infrared (IR) and blue light systems for terminating weed seeds, offering a lower-cost alternative to traditional impact mills. Initial results show that this system effectively controls over 90% of seeds for species like downy brome, rattail fescue, and Italian ryegrass, with potential for significant energy and cost savings.

4. Technological and Genomic Advances

The PNWHRI has invested in advanced equipment and research tools to support its growing capabilities. This includes technology for weed seed extraction, phenotyping platforms, and genetic and genomic research tools. One highlight is the development of a transformation protocol for downy brome, a notoriously troublesome weed in cereal systems. Researchers have successfully initiated tissue culture growth from downy brome embryos, marking a crucial step towards genetic studies of herbicide resistance. These efforts will enable deeper insights into the genetic mechanisms behind resistance, opening the door for novel approaches to weed control, such as gene editing and RNA interference.

5. Farmer Engagement and Co-Innovation

PNWHRI has been actively involving local farmers in the research process through farmer-led co-innovation communities. These communities are exploring diversified farming practices, such as alternative crop rotations and weed seed control methods. One notable project involves testing the viability of grain sorghum as an alternative cash crop in dryland systems, offering new rotational options for farmers in low to intermediate rainfall zones. The first year of field trials has shown promising results, with a second year underway. Another key initiative is the evaluation of harvest weed seed control (HWSC) techniques, particularly the use of impact mills. These devices, mounted on combines, pulverize weed seeds during harvest, reducing the number of viable seeds returned to the field. PNWHRI researchers are collaborating with farmers to assess the effectiveness of these mills in different environments and cropping systems, using aerial imagery, seedbank sampling, and economic analysis to measure their impact.

6. Outreach and Extension

PNWHRI's outreach efforts have been robust, with results shared at various university grower meetings, crop tours, and conferences. The initiative's new website (pnwhri.org) serves as a hub for disseminating research findings and providing resources to farmers, agronomists, and industry stakeholders. In addition, PNWHRI is developing decision support tools that integrate climate, weed biology, and control tactics to help farmers make more informed weed management decisions.

Conclusion

The Pacific Northwest Herbicide Resistance Initiative has made significant strides in advancing weed management practices across the region. Through a combination of cutting-edge research, technological innovation, and strong stakeholder engagement, the initiative is helping farmers address the growing threat of herbicide resistance while promoting sustainable and resilient farming systems.

Project Justification

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

The PNW region includes some of the most productive wheat, small grain, and grain legume production systems in the nation. Nearly 5 million acres of wheat and barley were harvested from Idaho, Oregon, and Washington in 2020. Constituting 12% of U.S. small grain acreage and almost 20% of the total production nationally, the region exports roughly 80% of its production. The wheat, small grain, and legume industries of the region contribute enormously to the economies of the three states and the viability of the region's rural and urban communities.

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

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

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

USDA-ARS and regional land-grant scientists require new funding in addition to that provided by the regional commodity commissions and industry stakeholders, in order to develop new tools and knowledge to address this emerging problem. Our vision for managing herbicide resistance is centered on collaborative, multi-stakeholder region-wide coordinated action integrating multiple situation- and location-specific management practices. This initiative plans a multidisciplinary, multitactic approach that utilizes applied and fundamental agronomic and genetic research, in collaboration with economic and social scientists, resulting in farm practices supported by the NRCS, with the goal of providing farmers with economically viable weed- resilient systems.

Weed management strongly affects the long-term environmental and economic sustainability of PNW farming systems. Investing in improvement of agricultural technology, conservation of soils

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

FOUNDATIONS

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

PARTNERS

Funding for weed science research has historically been provided by grain growers from Idaho, Oregon and Washington. In the present fiscal year, over $300,000 has been committed towards weed research by wheat and barley growers within the three states. However, current funding is insufficient to adequately address the substantial and long-term impacts of weeds on the region's economies and ecosystems.

Emerging partners for the PNWHRI include (1) the USDA LTAR, which includes the Cook Agronomy Farm (CAF) LTAR near Pullman. Regional partners also include multiple state commodity organizations and commissions such as Idaho Wheat Commission, Idaho Barley Commission, Washington Association of Grain Growers, Washington Grain Commission, Oregon Wheat Commission, Oregon Wheat Growers League, USA Dry Pea and Lentil Council and the Far West Agribusiness Association, all in partnership with regional, national, and international crop protection companies. Going forward, federally funded, faculty-led competitive projects would intersect with and support PNWHRI.

Elements And Organizational Structure

- Geographic extent – all of ID, OR, WA and Columbia River Basin Watershed (including the Snake River Plain).
- Collaborative among the partner organizations (land grant universities, ARS) coordinated by the respective University Agricultural Research Center Directors.
- A renewable strategic plan and charter to ensure project adaptability and flexibility.
- Transdisciplinary philosophy and infrastructure that emphasizes farming solutions based on applied and fundamental agricultural research, in collaboration with economic and social sciences.
- Infrastructure that includes:
  - A network of experimental farms and farmer cooperators organized into communities.
  - Long-term experiments and field monitoring efforts, including a network of weather stations.
  - Data storage and management capabilities (provided through the Northwest Knowledge Network and the Long-Term Agroecosystem Research Network associated with the USDA-ARS Northwest Sustainable Agroecosystem Research Unit).
- Core personnel:
  - A coordinated Research, Extension and Outreach Weed Science Team in the three PNW states.
  - Engaged USDA-ARS units with a well-established Long-Term Agroecosystem Research Network and supporting infrastructure, combined with strategic investments in new ARS positions focused on weed ecology and biology.
  - Active group of stakeholders from across the agricultural supply chain to inform and guide research by active participation in the project.

Key Personnel

Albert Adjesiwor, Assistant Professor and Extension Specialist, Kimberly, ID
Shahbaz Ahmed, Postdoctoral Research Associate, Pullman, WA
Nick Bergman, Postdoctoral Research Associate, Pullman, WA
Sam Agyin-Birikorang, Research Leader and Agronomist, ARS, Pendleton, OR
Judit Barroso, Associate Professor, Pendleton, OR
Pete Berry, Assistant Professor, Corvalis, OR
Jamie Burroughs, Research Associate, Corvalis, OR
Ian Burke, Professor, Pullman, WA
Joan Campbell, Principle Researcher, Moscow, ID
Bryan Carlson, Information Management Specialist, ARS, Pullman, WA
Joaquin Casanova, Research Agricultural Engineer, ARS, Pullman, WA
Douglas Finkelnburg, Area Extension Educator, Lewiston, ID
Garett Heinick, Research Agronomist, ARS, Pullman, WA
David Huggins, Research Soil Scientist, ARS, Pullman, WA
Jessica Kalin, Research Associate, Pullman, WA
Oliva Landau, Research Weed Scientist, ARS, Pullman, WA
Drew Lyon, Professor, Pullman, WA
Peter Weston Maughan, Graduate Research Assistant, Pullman, WA
Raissa Fon Na-ah, Postdoctoral Research Associate, Pullman, WA
Luigi Peracchi, Postdoctoral Research Associate, Pullman, WA
Shikha Singh, Research Assistant Professor, Lind, WA
Timothy Paulitz, Research Plant Pathologist, ARS, Pullman, WA
Catherine Reardon, Research Soil Microbiologist, ARS, Pendleton, OR
Marija Savic, Research Associate, Pullman, WA
David Weller, Research Plant Pathologist, ARS, Pullman, WA

Summary Of Objectives

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

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

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

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

Crop Rotation Based Theme:

a. Evaluation of intensification and diversification of PNW cropping systems on weed populations at the practical and fundamental levels, utilizing existing and new intermediate and long-term research field trials and novel methods based on emerging phenotypic and genomic resources.
   i. Refine best management practices associated with tillage systems (using long-term tillage trials)
b. Augment existing rotational trials with intensive evaluations of weed populations, with a focus on collecting longitudinal data on the effect of discrete traditional and novel management tactics as outlined in the biology-based theme. Identify gaps in existing short-, intermediate-, and long-term trials and work to fill those gaps.

Biology Based Theme

a. Evaluate herbicide resistance, weed seedling emergence (including patterns), seed longevity, seed retention timing of viable seed production based on timing of emergence, or the capacity to extract soil water after harvest if left uncontrolled. The focus is on problematic weeds in the PNW (Italian ryegrass, cheatgrass, wild oat, common lambsquarters, Russian-thistle, or other weeds based on stakeholder feedback or change in condition) and will use PNW collected germplasm. Studies may include:
   i. Occurrence and extent of herbicide resistance in common weeds in the PNW, and an assessment of the genetic, physiological, biochemical and evolutionary factors and mechanisms that facilitated the resistance and persistence of weed seed.
   ii. Determine the relative importance of mutation, migration, selection, and random genetic drift for important traits, including traits that confer resistance, in weed species in wheat cropping systems in the PNW.

iii. Determine the impact of crop management and genetics on weed interference and weed seed production.
iv. Determine minimum, maximum, and optimal temperature requirements for germination under different moisture regimes for use in decision support tools.
v. Response to soil and foliar applied herbicides, at various temperatures.
vi. Response of weed seeds to light quality (red, far-red, and blue light).
vii. Develop a hydrothermal model of weed emergence timing using field and lab data.
viii. Determine how the soil microbiome (fungi and bacteria), microfauna and soil invertebrates affect longevity and survival of seeds in the seed bank.

Cross-Cutting Theme

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

2. Determine the socio-economic and policy-related opportunities and barriers to adopting integrated weed management systems within traditional and aspirational wheat-based systems that impart resilience to weeds (and climate variability and change).

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

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

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

RESEARCH ACHIEVEMENTS

Objective 1: Rotation Based Theme

Inventory of Cropping Systems Trials in the Pacific Northwest for Assessment of Weed Populations

Lead: Garett Heineck
Key Collaborators: Joaquin Casanova, Stewart Wuest, Judit Barroso, Surendra Singh, Shikha Singh, Joan Campbell, Aaron Esser, Dave Huggins,

Project Overview

An inventory of long-term cropping systems trials was created and assessed for their usefulness in assessing weed management inputs in the context of their existing objectives. Cropping systems across locations vary in their experimental designs and treatments but include alternative crop species, novel rotations, and tillage practices. Nine long-term and mid-term field research sites were identified in Eastern WA, NE Oregon, and Northern Idaho (Figure 1). Sites vary greatly in maturity, hectarage, and types of data collection (Table 1). For instance, the Horse Heaven Hills site was established in 2022, while the Pendleton Wheat-Pea location was established in 1963. Although each site has a unique purpose outside of weed science it offers unique perspectives on weed populations across a wide range of traditional and novel agroecosystems.

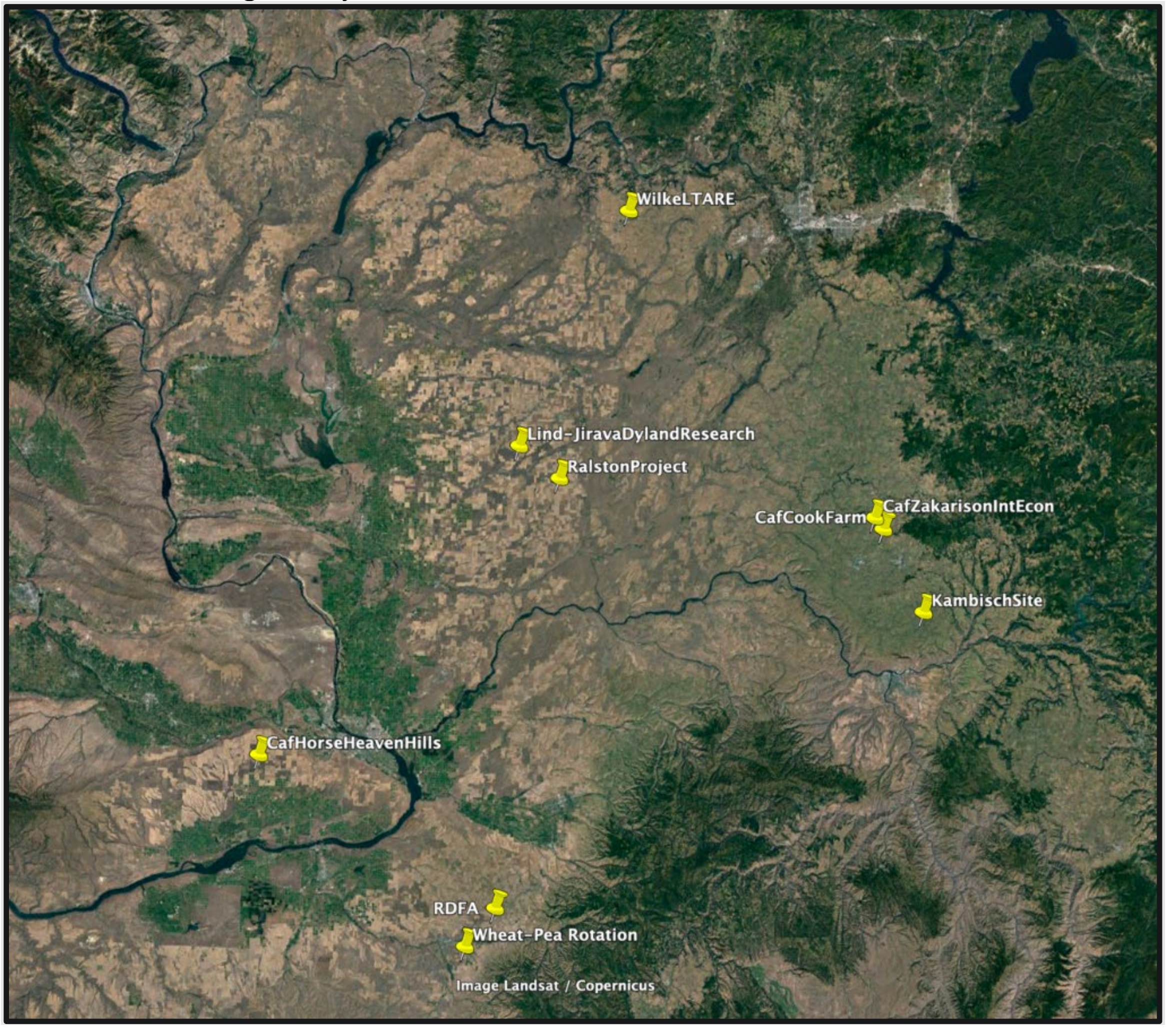


Figure 1. Spatial distribution of field long term cropping systems sites.

Table 1. Site descriptions for each mid- and long-term site in the Crop Rotation Theme.

Site Name	Location	Established	Primary Objective
Pendleton Wheat-Pea Rotation	Pendleton, OR	1963	Determine the impact of tillage and lime on soil OM, wheat, add pea performance
Jirava-Lind Cropping System Study	Ritzville, WA	1998	Determine the impact of traditional and novel crop rotations on yield and profitability
Cook Research Farm	Pullman, WA	1998	Paired watershed study that spatially maps crop performance and soil health
Kambitsch Farm Tillage Strips	Genesee, ID	1998	Determine the impact of tillage on crop yield and weed composition
Zakarison Integrated Economic Assessment	Pullman, WA	2012	Measure the impact of convention no-till and organic cropping systems on soil health and economics
Wilke Farm Rotational Experiment	Davenport, WA	1998	Measure the economic performance of 2- 3- and 4-year crop rotations
RDFA Cover Crops	Pendleton, OR	2023	Measure the impact of cover cropping in a traditional wheat-fallow system
Ralston Project	Ralston, WA	2000	Determine the feasibility of continuous no-till, spring cereals, and alternative crops
Horse Heaven Hills Alternative Cropping Systems	Horse Heaven Hills, WA	2022	Measure the performance and water use of re-cropping alternative crops, perennial grains and cover crops in a wheat-fallow system

Research Approach

Each site has one or more principal investigators responsible for the maintenance of their site and the collection of data germane to the general purpose of the experimental location. Through regular meetings with the PNW Herbicide Resistance leaders, there has been consensus on how weed populations will be quantified and mapped at each site.

Methodology

Each site will be sampled yearly to determine weed seed numbers and identify weed species. Sampling will be typically accomplished in the fall at the beginning of the water year, but before the germination of winter annual weeds. A unified sampling method has been devised, which uses a custom soil sampling auger and the use of a GIS geofenced sampling scheme. The soil sampling auger will sample weed seed in the top two inches (Figure 2). Weed seeds will be isolated from soil samples using an elutriator and a deep learning model trained to identify weed seed species.

Figure 2. Weed seed bank sampling apparatus that will be used at each site.

Weed Density Assessment Via Visual Collection and Proximal Sensing

Emerged weed counts will be taken yearly at each site. These data will not only serve to inform weed incidence and distribution but will also serve to feed data into models for automated quantification of weeds through image analysis. Proximal images will be collected using a simple RGB DSL camera mounted on a monopod. Once taken, images will be uploaded to ArcGIS with a geo-referenced tag.

Weed Density Assessment Via Remote Sensing

Joaquin Casanova

Some sites cover acreage that is difficult to quantify using traditional means. For example, the Cook Agronomy Farm is 150 acres. Therefore, drones will be used to collect image data across many acres of experimental ground to map weeds. The approach combines ground truth images and UAV images to build a deep-learning model that can identify weeds. The model will be built off of georeferenced counts on the ground and image data collected using the drone (Figure 2). The preliminary model produced promising results when applied to quantifying downy brome in a winter wheat field (Figure 3).

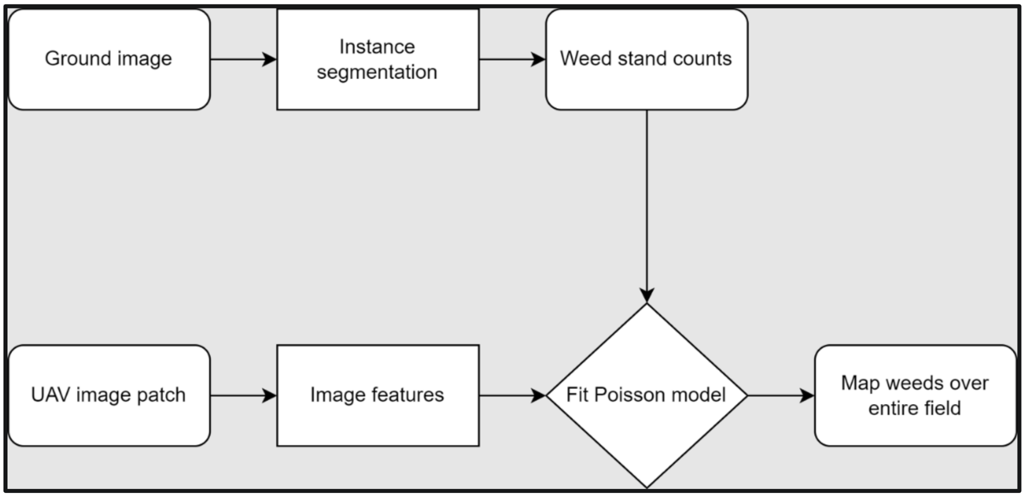


Figure 3. Model developmental pipeline for remote weed identification.

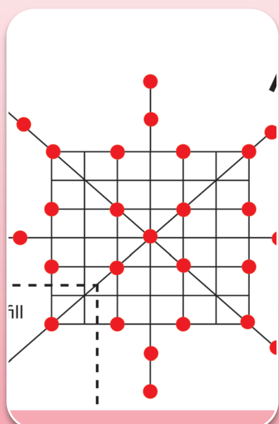
Figure 4. Downy brome identified in a winter wheat field at one of five locations measured.

PNWHRI Weed Seedbank Sampling Approach

General Considerations

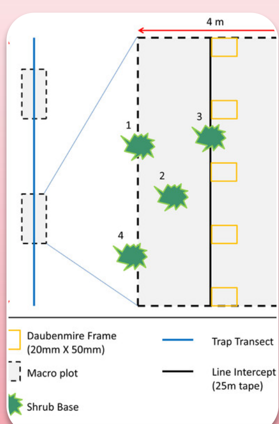
- Collect at the same density and using the same methods as used in for assessments of fertility.
- Collected from the surface of the soil to the depth of tillage or planter, and then below the depth of the tillage or planter implement ~8 cm. If no-till, sample to 10 cm.
- Use a standard soil sampling core and take a composite sample at the twice the frequency as the soil fertility sample (for example, 3 profile cores, composited by depth for fertility would mean 6 shallow seedbank samples, composited together).
- Consider collecting a GPS coordinate for each sample, if there are multiple samples per plot, and estimate the area the sample was collected from. Consider assessing aboveground vegetation through biomass, percent cover, structure from motion, or proximal sensing.

Assessment by Grid



- Grid larger plots into smaller subplots (for example, 15'x30').
- Collect composite samples from each subplot - a minimum of 6 and ideally 10 individual subsamples per composite sample, collected randomly from within the subplot.
- Collected from the surface of the soil to the depth of tillage or planter, and then below the depth of the tillage or planter implement ~8 cm. If no-till, sample to 10 cm.
- Consider assessing aboveground vegetation through biomass, percent cover, structure from motion, or proximal sensing.

Assessment by Transect



- Use a point transect method to identify areas to collect seedbank samples across the long axis of a plot. Each intercept point (spaced some arbitrary distance and based on the total length of the plot and a power calculation) would be a subplot and could range in size from 1 m^2 to 9 m^2.
- Collect composite samples from each subplot - a minimum of 6 and ideally 10 individual samples per composite sample, collected randomly from within the subplot. If no-till, sample to 10 cm.
- Collected from the surface of the soil to the depth of tillage or planter, and then below the depth of the tillage or planter implement ~8 cm.
- Consider assessing aboveground vegetation through biomass, percent cover, structure from motion, or proximal sensing.

Weed Seedbank Control in Rotational Crops as a Proactive Herbicide Resistance Management Strategy

Albert Adjesiwor
Funded by IWC and partly supported with PNWHRI funds

Herbicide-resistant weed populations are evolving rapidly and threatening the sustainability of crop production in Idaho. A 4-year crop rotation study was initiated in 2021 at the University of Idaho Kimberly Research and Extension Center to evaluate weed control and seedbank dynamics in wheat-alfalfa vs wheat-annual crop (corn and dry bean) rotations. There were three herbicide treatments: untreated, postemergence (POST) only, and preemergence (PRE) + POST. It was observed that weed seedbank density was reduced from 8,737 to as low as 470 seeds per 10 square ft in some treatments. Weed seedbank density tended to be higher in the untreated checks and there was a trend of preemergence (PRE) + postemergence (POST) treatments slightly reducing weed seedbank density compared to POST-only treatment. Including alfalfa in the crop rotation significantly reduced weed seedbank density, irrespective of the herbicide treatment. On the contrary, dry bean in the rotation significantly increased weed seedbank density. Weed density within the crops during the growing season was influenced by the crop type and herbicide treatment. Both POST-only and PRE + POST treatments reduced weed density compared to the untreated and the PRE + POST treatments reduced weed density in each crop compared to the POST-only treatment. Weed control treatments did not affect alfalfa yield. However, herbicide application (POST only and PRE + POST) improved corn and dry bean yield. The combination of fewer weeds and greater crop yield in the PRE + POST treatments holds promise for reducing weed seedbank and potentially improving crop productivity and economics.

Background: Herbicide-resistant weed populations are evolving rapidly and threatening the sustainability of crop production. In a bid to manage the current threat of herbicide-resistant weeds, weed scientists continue to recommend crop rotations that include competitive crops like wheat and alfalfa. This research project seeks to answer the following questions: (1) what happens to the weed seeds in the soil when wheat is planted in rotation with alfalfa? (2) is it better to rotate wheat with alfalfa or other annual crops to manage troublesome weed seeds in the soil?

Objectives: The objectives of this study were to:
1. Compare weed seedbank densities in wheat-alfalfa and wheat-corn/dry bean rotations
2. Evaluate residual herbicide programs for effective weed seedbank management within wheat-alfalfa rotations
3. Assess the economic impact of using herbicide mixtures and crop rotations for proactive herbicide resistance management

Accomplishments
2023 field trial and weed seedbank density:
The soil samples collected from fall 2021 were thawed in spring 2022 for exhaustive germination in the greenhouse to estimate weed seedbank density. Seed density was counted weekly throughout the summer until there was no weed emergence. It was observed that weed seedbank density ranged from 470 to 8,737 seeds per 10 square ft (Figure 4). Weed seedbank density tended to be higher in the untreated checks and there was a trend of preemergence (PRE) + postemergence (POST) treatments slightly reducing weed seedbank density (Figure 1). Including alfalfa in the crop rotation significantly reduced weed seedbank density, irrespective of the herbicide treatment. On the contrary, dry bean in the rotation significantly increased weed seedbank density (Figure 4).

Weed density within the crops during the growing season was influenced by the type of crop as well as the herbicide treatment (Figure 5). Both POST only and PRE + POST treatments reduced weed density compared to the untreated. In addition, PRE + POST treatments reduced weed density in each crop compared to the POST-only treatment. This has implications for the number of weeds that will go to seed at the end of the growing season.

Weed control treatments had minimal effect on alfalfa yield (Figure 6). However, herbicide application (POST only and PRE + POST) improved dry bean and wheat yield. The combination of fewer weeds and greater crop yield in the PRE + POST treatments holds promise for reducing weed seedbank and potentially improving crop productivity and economics.

Projections: This study will be continued in 2024 and results will be made available to the Idaho Wheat Commission and Idaho wheat growers. Results from this study will be presented at the 2024 Weed Tour at Kimberly and the 2023 and 2024 Western Society of Weed Science Conference.

Outreach: This study was showcased at the 2023 Weed Tour at Kimberly.

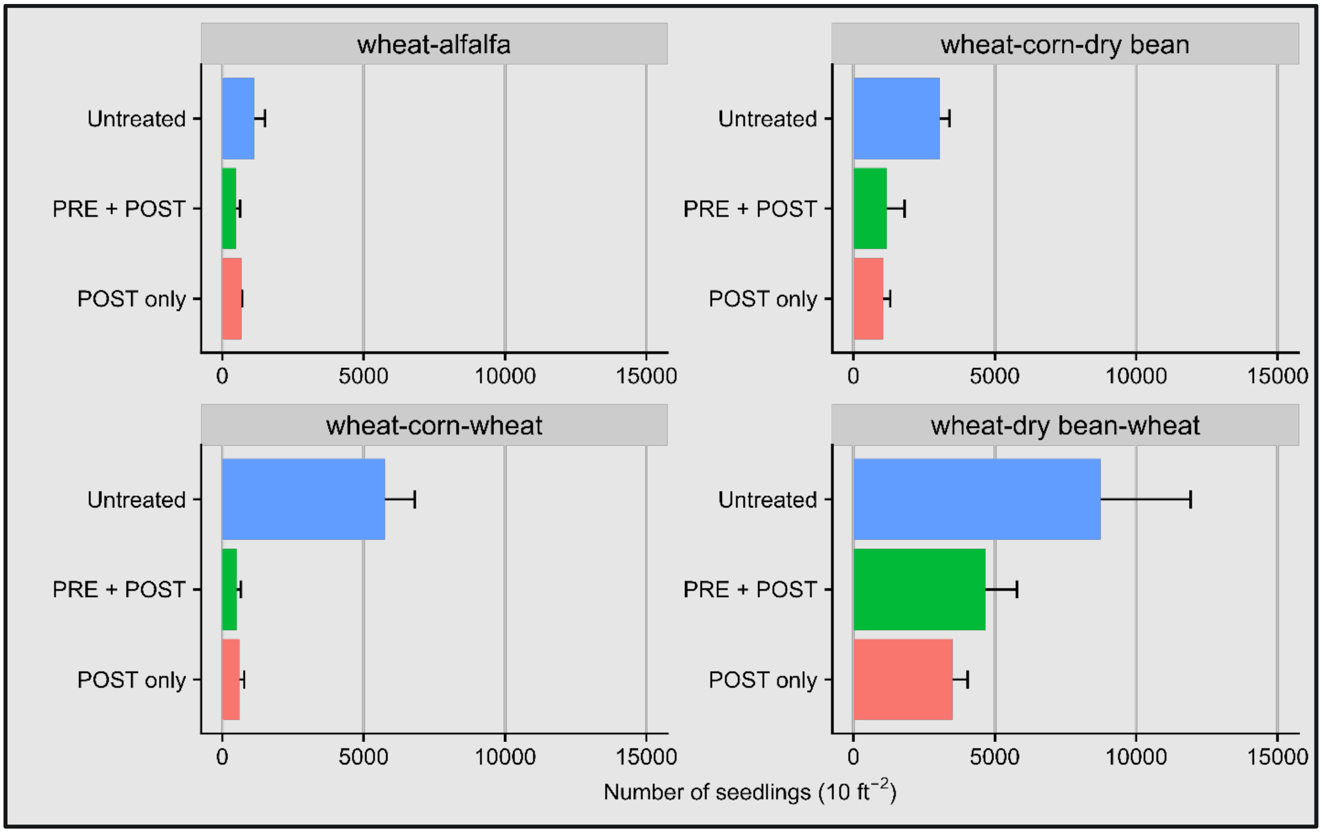


Figure 5. Effect of postemergence (POST) and preemergence (PRE) + POST herbicide treatments on weed density in spring wheat rotations. Soils collected from fall 2022 at Kimberly, Idaho.

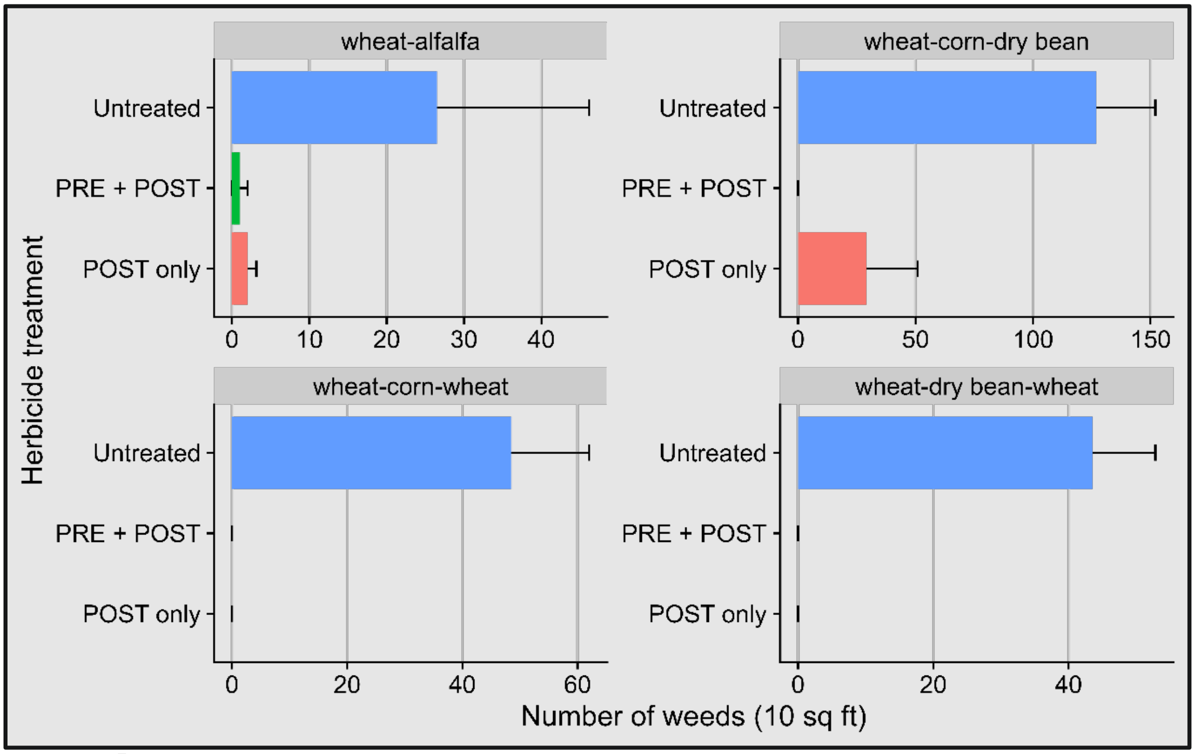


Figure 6. Effect of postemergence (POST) and preemergence (PRE) + POST herbicide treatments on weed density in spring wheat rotations in 2023 at Kimberly, Idaho.

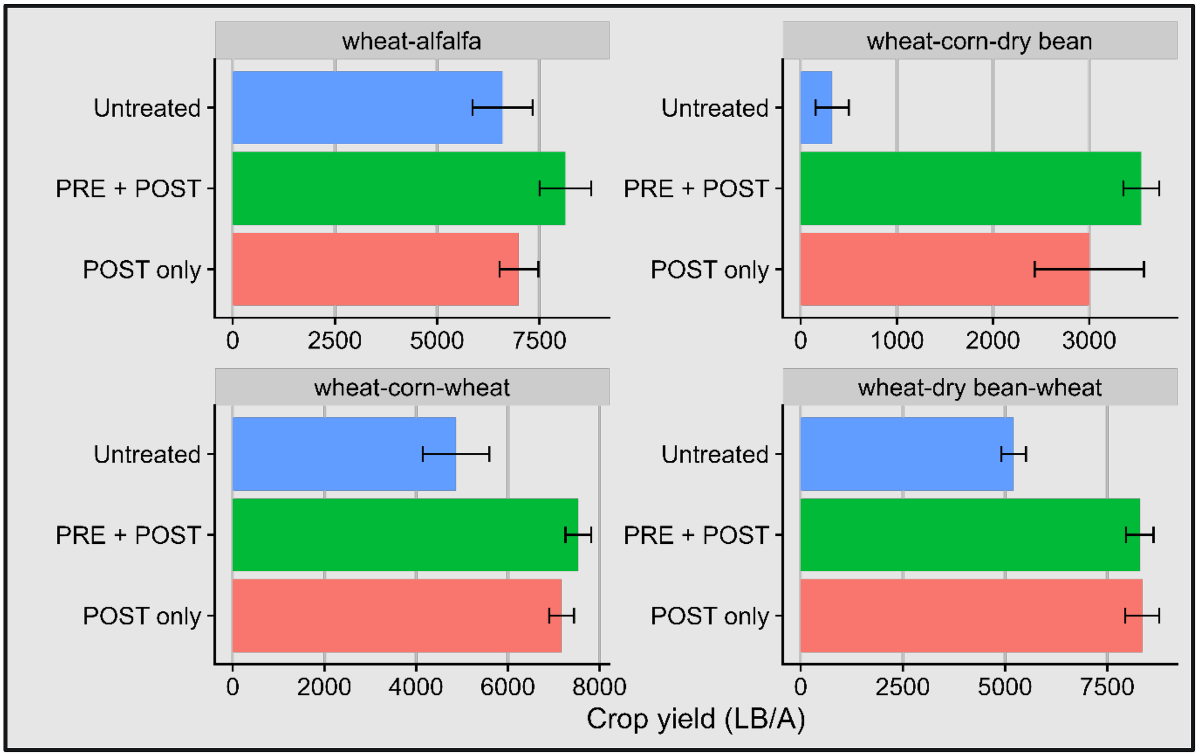


Figure 7. Effect of postemergence (POST) and preemergence (PRE) + POST herbicide treatments on crop yield in spring wheat rotations in 2023 at Kimberly, Idaho.

Wilke Farm Report: Monitoring Weed Populations in Dryland Wheat Systems at the Long-Term Agroecological Research and Extension (LTARE) Site

Haly Neely and Shikha Singh

A long-term agroecological research and extension (LTARE) site was established at the Washington State University's Wilke Research and Extension Farm near Davenport, WA in the intermediate rainfall zone (13-16" of annual precipitation) of eastern WA. In this region, winter wheat-fallow is the major crop rotation, however, there have been efforts to intensify these rotation systems for short- and long-term environmental and economic benefits to the growers. There have been numerous studies in dryland regions investigating the effects of tillage and crop rotations on soil properties, crop productivity and weed populations, but very limited information is available on incorporating livestock. The overall goal of this site is to evaluate the feasibility of incorporating multifunction crops and livestock grazing in dryland wheat systems. In collaboration with the Herbicide Resistance Initiative, we are also monitoring the effects of incorporating multifunction crops and livestock grazing on weed populations.

Objective: To assess the impacts of management practices on weed populations in dryland wheat systems.

Accomplishments: The Dryland LTARE at the Wilke Research and Extension Farm completed its first year in June 2024. Significant activities include establishing and grazing the "multifunction (cover) crop" treatment, maintaining the trial overall, hosting two growers focused events at the site, and reaching out to advisory panel members. The multifunction crops including proso millet, Horizon Spring forage peas, forage barley, blackoil sunflowers, and purple top turnip were seeded in June 2023. Prior to seeding the multifunction crops, we collected soil samples for weed seed banks. The samples were transferred to the weed science lab in Pullman on ice and are pending analysis. The plots seeded with multifunction crops were mob grazed using nine steers in September 2023. After grazing for a week, the plots were seeded with winter wheat. We hosted the Washington State University's Center for Sustaining Agriculture and Natural Resources summer advisory committee meeting and the Washington Soil Health Initiative's SoilCon at this LTARE site.

Future work: We plan to analyze the soil samples for weed seed banks from 2023 and start analyzing the data. We are going to bring in the steers this year again to mob graze the winter wheat stubbles. The second round of soil sampling will be conducted in year 3 of this project to assess the effects of these management strategies on weed seed banks.

Objective 1: Biology Based Theme

Herbicide Resistance Surveys

Field surveys were conducted in the summer and fall of 2022 and 2023 across the PNW region for herbicide resistance screening.

Research Objectives:

1. Characterize herbicide resistance in weeds to herbicides commonly used in PNW cropping systems.
2. Create a map of herbicide-resistant weed species within the PNW.

Southern Idaho
Albert Adjesiwor
In southern Idaho, seeds from common lambsquarters, kochia, redroot pigweed, barnyardgrass, and wild oat were collected. In addition, tissue and seed samples were collected from kochia, Palmer amaranth, and waterhemp for resistance screening. Out of 40 sites analyzed for glyphosate resistance in kochia, 18 sites representing 45% were resistant to glyphosate. About half of the sites with resistant kochia had 5 or more gene copy numbers, which means they were high to very highly resistant to glyphosate. In the first round of greenhouse herbicide resistance bioassay, about 50% of common lambsquarters and barnyardgrass survived field use rate of glyphosate (Roundup PoweMax), while less than 5% of redroot pigweed survived glyphosate. No resistance to glufosinate or dicamba was observed in the kochia, common lambsquarters, and redroot pigweed populations. Out of the 23 Palmer amaranth tissue samples collected, 17, representing 70% were identified to have elevated gene copy numbers, which was indicative of glyphosate resistance. All waterhemp samples were resistant to glyphosate (Figure 2).

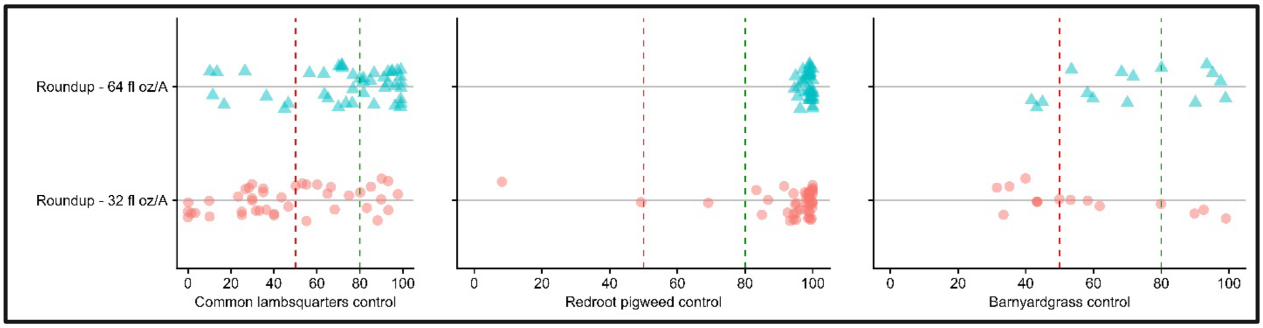


Figure 8. Glyphosate-resistance screening results for common lambsquarters, redroot pigweed, and barnyardgrass seed samples collected from multiple counties in southern Idaho in 2023.

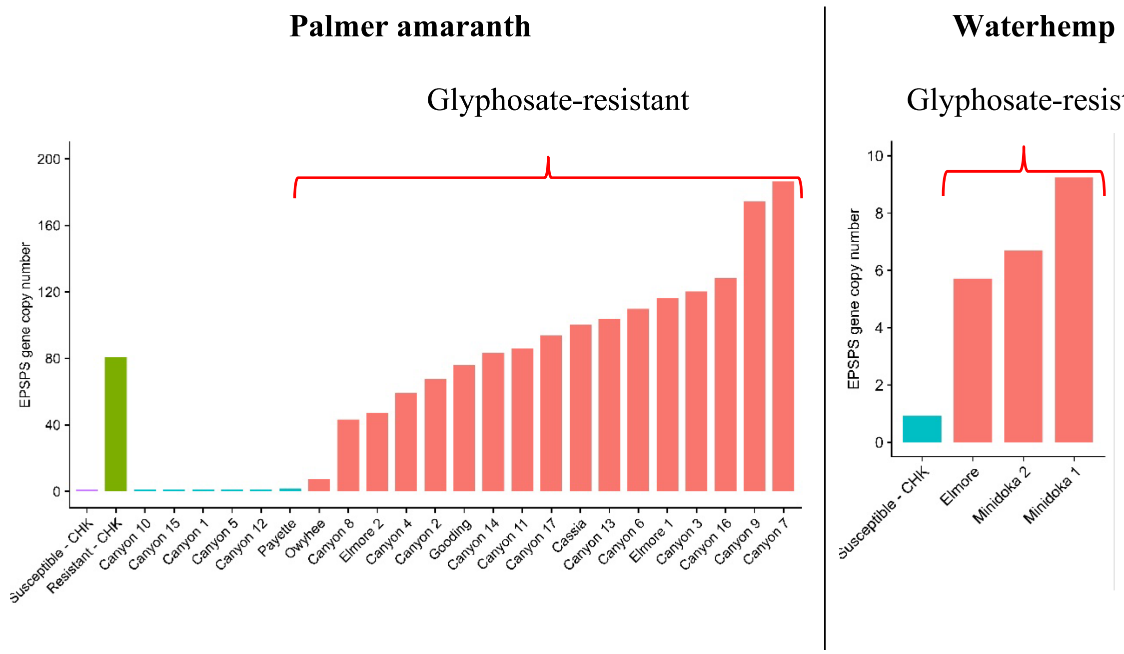


Figure 9. Glyphosate-resistance screening results for Palmer amaranth and waterhemp tissue samples collected from multiple counties in southern Idaho in 2023.

In the wild oat, there were populations, that survived group 1 herbicides [clodinafop (Discover), fenoxaprop (Tacoma), pinoxaden (Axial XL)], and some group 2 herbicides (Goldsky, Opensky, and Powerflex HL). Additional wild oat was collected in the summer of 2024 and seeds are currently being cleaned for resistance screening to other common herbicides used in small grain cropping systems.

Northern Idaho
Joan Campbell

Wild oat was collected from fifty locations across Lewis, Idaho, Latah, Nez Perce, Kootenai, Boundary, and Benewah counties. Collections were screened to triallate, ethalfluralin, pinoxaden, glyphosate, clethodim, mesosulfuron, fenoxaprop, and quizalofop in a greenhouse. No populations were resistant to triallate or ethalfluralin. Identifying wild oat changes in herbicide resistance overtime aids growers in understanding how their weed control management practices, including tillage, crop, and herbicide rotation, have altered the makeup of the population.

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 preemergence herbicides and plants counted at emergence with postemergence herbicides. Untreated plants were included from each sample. Resistance was evaluated on plant survival and vigor compared to the untreated. Four downy brome seed samples were screened to 6 herbicides. One sample was resistant to PowerFlex and one sample was resistant to Beyond. Four samples were susceptible to Zidua, clethodim, Aggressor, and glyphosate. One Italian ryegrass sample was screened to 12 herbicides. It was resistant to Amber, Osprey Xtra, PowerFlex, clethodim, Assure II, and Poast. It was susceptible to Zidua, Outlook, Dual Magnum, Axiom, Axial XL and glyphosate. One interrupted windgrass sample was screened to 7 herbicides. It was resistant to PowerFlex, Everest and Beyond. It was susceptible to Zidua, Aggressor, clethodim and glyphosate. A jointed goatgrass sample was susceptible to Beyond, Aggressor, clethodim and glyphosate. Screening weed seed samples enables growers to combat herbicide resistance by adjusting their weed control approach so that it includes rotating chemicals, changing crop rotations, and implementing other cultural practices.

Washington
Marija Savic and Ian Burke
In 2023 downy brome collection of 2400 genotypes from 80 randomly selected field and natural sites (Figure 1) were initially screened for resistance to main herbicide groups (1, 2, 5, and 9). These herbicides are typically used by growers in Washington, most frequently group 2 herbicides (Figure 2). Initial screening was completed in winter of 2023 on all genotypes plus two selected sensitive genotypes from Washinton and Montana that have never been exposed to herbicides. Untreated plants were grown to produce seed for future research.
In addition, herbicide resistance screening is done on samples received by growers and industry representatives across the state. However, focusing only on submitted samples may result in bias or overestimation of a resistance issue in the region. Samples are tested to the same herbicide groups to determine if there is a cross or multiple resistance and offer additional herbicides to growers to rotate in their systems. Each submitter receives a report after the screening summarizing results with photos attached.

Initial screening results indicate widespread group 2 resistance, particularly resistance to pyroxulam and imazamox herbicide (Figure 2). Group 2 herbicides are frequently used by grain growers as they can control grassy weeds without injuring wheat. After the introduction of Coaxum wheat, which is tolerant to quizalofop, growers started relying more on this herbicide that would typically heavily injure wheat. However, this adds a selection pressure on grassy weeds resulting in resistance development. Resistant biotypes were detected during the initial screening in genotypes found near Walla Walla where CoAXium wheat is more common (Figure 3). Initial screening also revealed multiple resistance at a single site in southern Washington. Average downy brome biomass at this site was always higher than sensitive control for each herbicide tested with high survival rate after glyphosate treatment (Figure 4).
Survey results are presented, discussed at field tours and conferences, and published in Weed Control Reports. Additionally, survey results will be published in scientific journals.
During the fall/winter of 2023, Russian thistle seed was collected from the same sites as downy brome to assess its resistance across dryland Washington. In the fall/winter of 2024, Russian thistle will be initially screened to herbicides used by growers for its control (group 9, 14, 5, 6, and 4).

The initial screening for all the species collected will be followed by dose-response experiments, genotyping by sequencing, and RNAseq to determine genes and metabolic pathways conferring resistance to herbicide/s and herbicide group/s. The same protocol will be performed on each species after the initial screening. In summer and fall of 2024 mayweed chamomile and Italian ryegrass collection will begin and continue until as many sites as possible are visited.

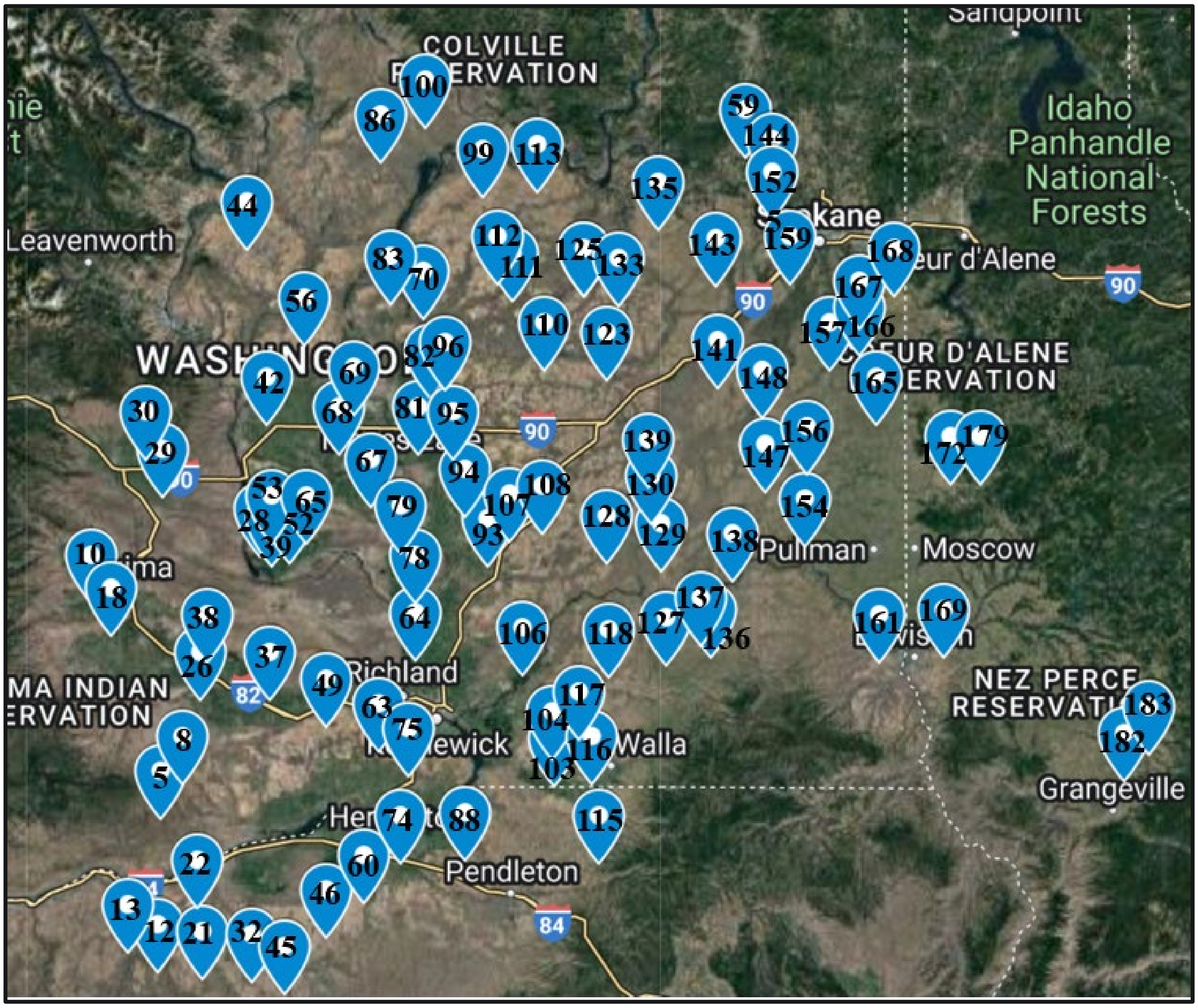


Figure 10. Sampling sites for weed collection in central and eastern Washington.

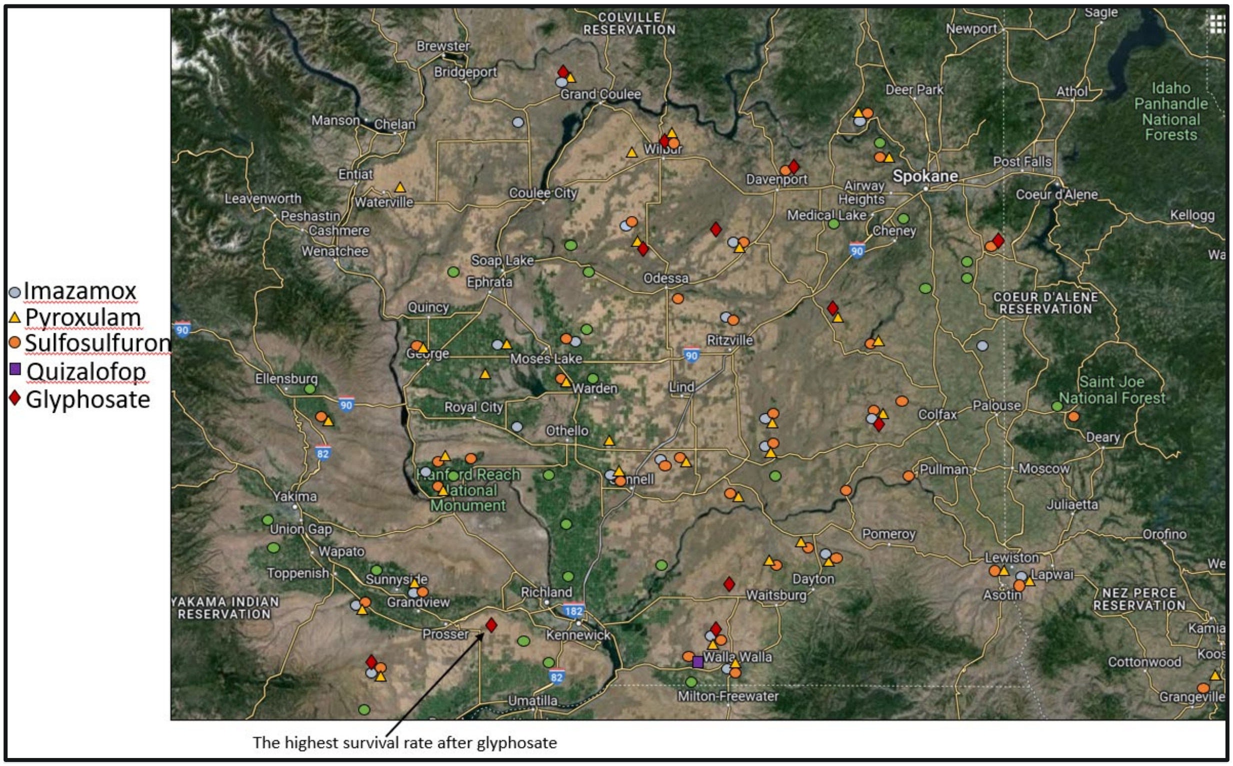


Figure 11. Sampling sites for weed collection and resistance distribution pattern for downy brome after the initial screening. Sites were randomly selected in a 10 km grid.

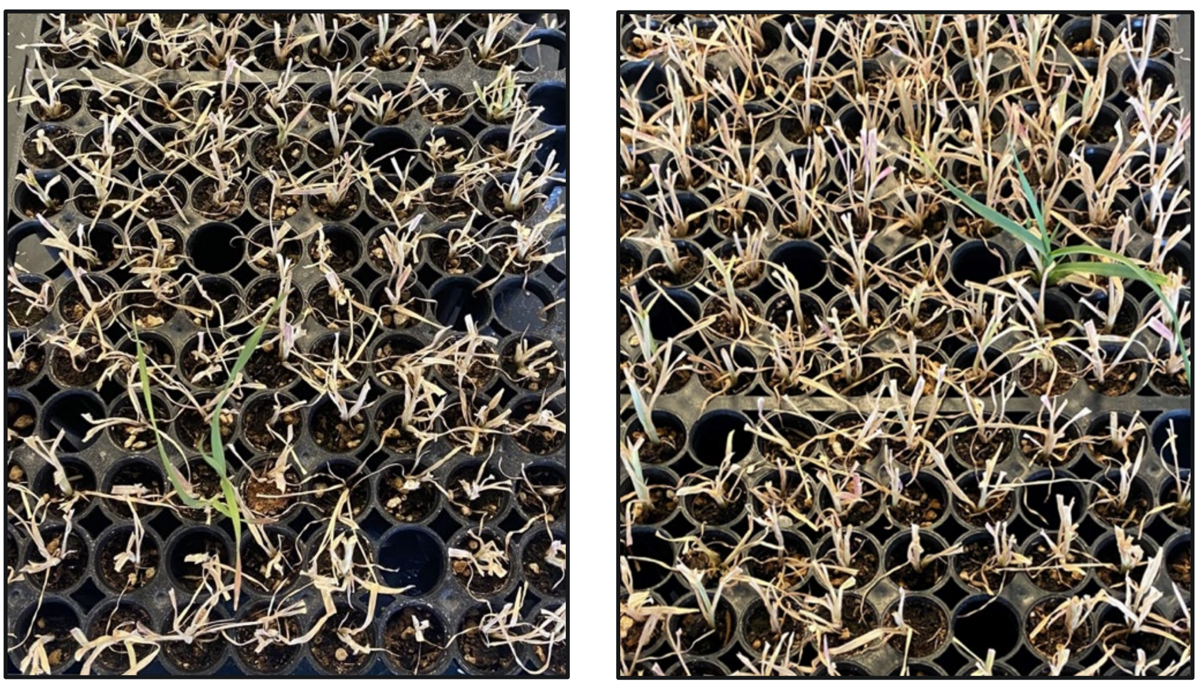


Figure 12. Two plants collected from the same site near Walla Walla 21 days after quizalofop treatment.

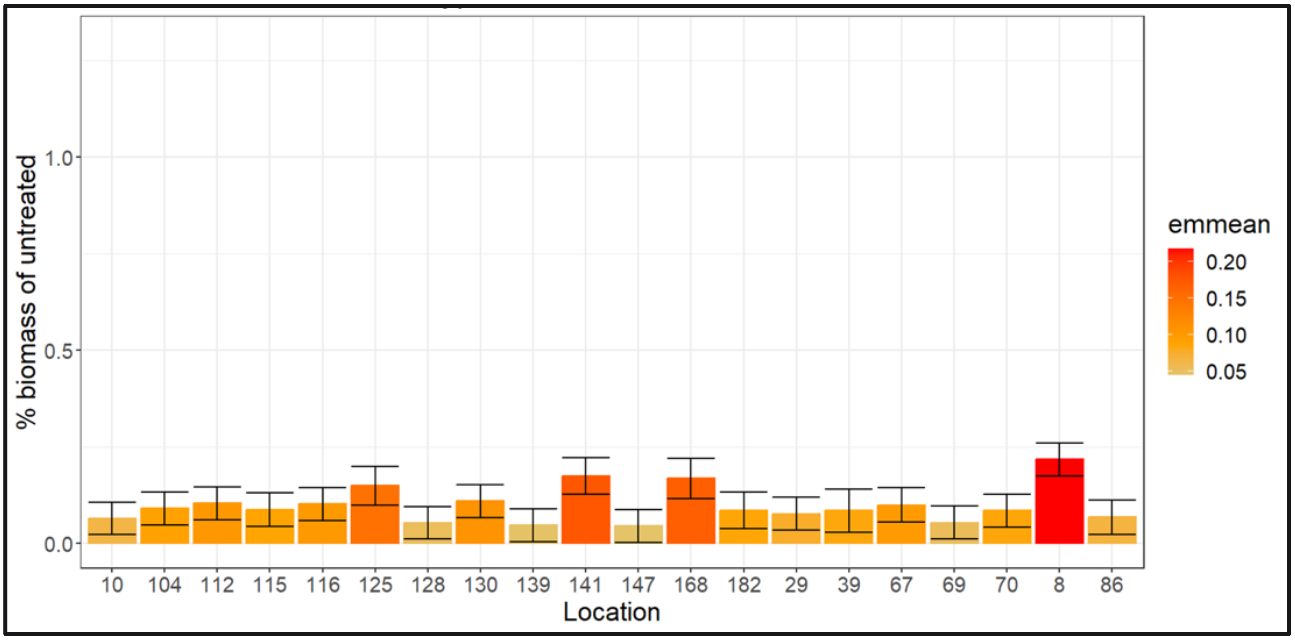


Figure 13. The average biomass for all plants collected from 20 sites 21 days after glyphosate treatment represented relative to sensitive genotypes from Montana and Washington.

Germination Ecology of Weeds and Minimum Amount of Moisture for Preemergence Herbicide Activation

Albert Adjesiwor

Laboratory and field studies were initiated in 2023 at the University of Idaho Research and Extension Center to 1) determine the germination temperature and moisture requirements of Italian ryegrass and spring wheat, 2) assess the germination temperature and moisture requirements of cheatgrass and winter wheat, and 3) quantify the minimum amount of moisture for preemergence herbicide activation for the control of kochia and Italian ryegrass. All weed biotypes and wheat cultivars were obtained from Idaho, Washington, and Oregon. For the germination temperature and moisture requirement, weed biotypes and wheat cultivars are being grown on a thermogradient table with 10 varying temperatures between 41 F and 97 F. Polyethylene glycol (PEG 8000) will be used to obtain different water potentials to determine the minimal amount of moisture needed for germination. Differences in germination rates between the Italian ryegrass and spring wheat have already been observed with most populations having 50% germination at 41 F while the spring wheat had < 5% germination. The germination study will be continued until 2026 at a minimum and the field trial will be repeated in 2024 and 2025. This will provide valuable information for ecological and effective weed management in small grain production systems.

Background: The changing climate is impacting weed ecology and growth patterns as well as the timely availability of moisture to activate preemergence herbicides in dryland production systems. General understandings of temperature and moisture requirements have been documented for different weed species, however, there is evidence that production practices and environmental factors affect weed species response to temperature and moisture.

Objectives: The objectives of this study were to:

1. determine the germination temperature and moisture requirements of Italian ryegrass and spring wheat,
2. assess the germination temperature and moisture requirements of cheatgrass and winter wheat, and
3. quantify the minimum amount of moisture for preemergence herbicide activation for the control of kochia and Italian ryegrass.

Results/Accomplishments

Germination temperature requirements of Italian ryegrass and spring wheat:
At temperatures of 66 F and above there were minimal differences in germination temperature requirement of the Italian ryegrass populations than the two spring wheat cultivars. At 54 F, germination exceeded 60% in most of the Italian ryegrass populations, while spring wheat germination was 40% or less. Italian ryegrass and spring wheat have already been observed with most populations having 50% germination at 41 F while the spring wheat had < 5% germination. (Figure 4).

Minimum amount of moisture for preemergence herbicide activation
Due to an extremely dry soil profile and high soil temperatures, not even the highest irrigation amount (1 inch of water) was enough to successfully incorporate any of the herbicides (Figure 5). Beginning at 3 weeks after herbicide application, research plots were uniformly overhead irrigated weekly with 1 inch of water at each irrigation event for 4 weeks to evaluate how delayed incorporation influenced preemergence herbicide efficacy. Italian ryegrass control from metribuzin, pyroxasulfone, and s-metolachlor was less than what would have been expected following timely incorporation (Table 1). Delayed incorporation did not appear to have reduced pendimethalin efficacy on Italian ryegrass (Table 1). Pendimethalin provided greater Italian ryegrass control compared to the other herbicides

(Table 1). Kochia control from metribuzin, pendimethalin, and pyroxasulfone was similar to what would have been expected following timely incorporation. Delayed incorporation of s-metolachlor reduced efficacy on kochia and this was statistically similar to the nontreated check (Table 1).
Projections: This study will be continued in 2024 and results will be made available to the Idaho Wheat Commission and Idaho wheat growers. Results from this study will be presented at the 2024 Weed Tour at Kimberly and the 2025 Western Society of Weed Science Conference.
Outreach: Parts of the results were presented at the 2024 WSWS Annual Meeting.

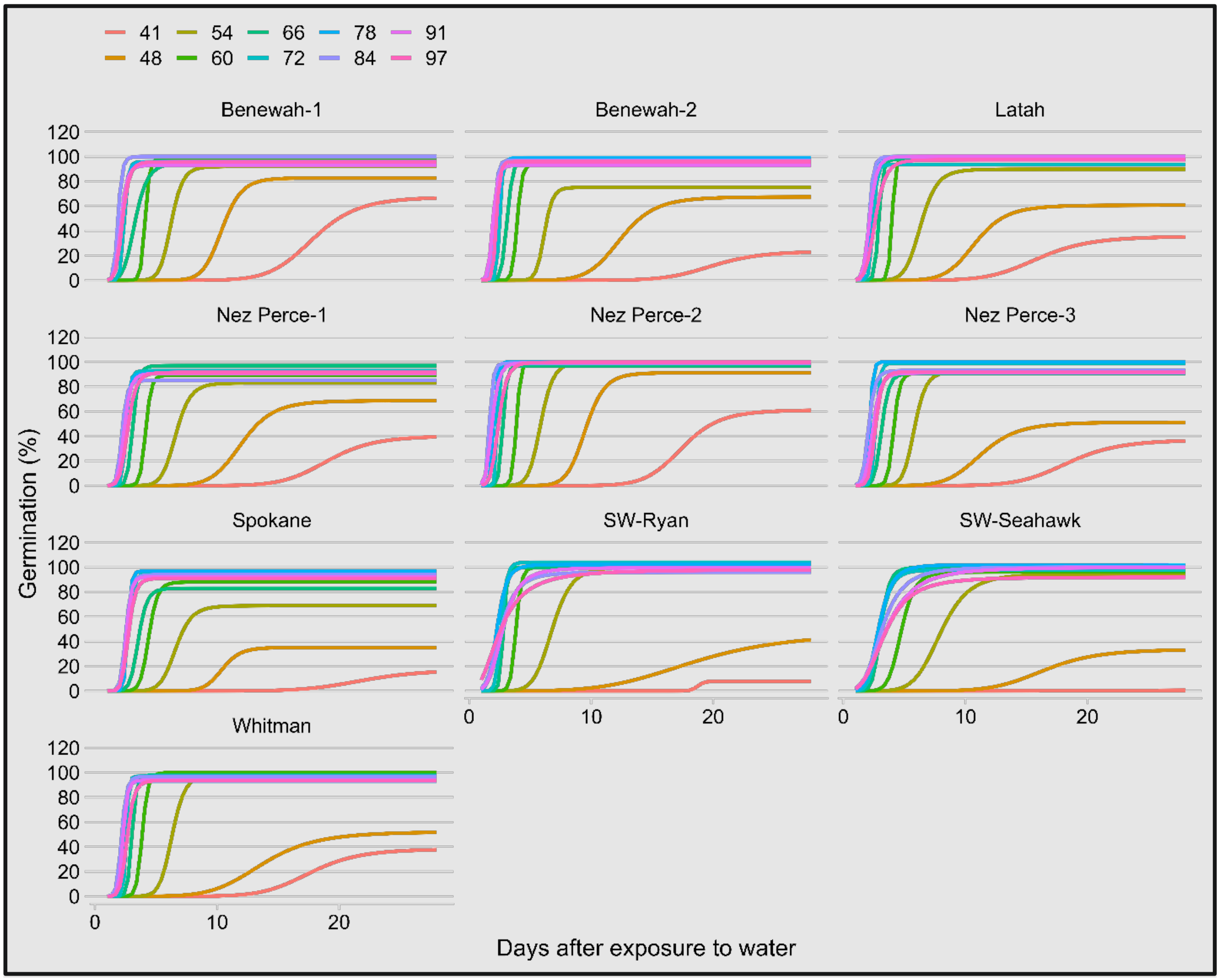


Figure 14. Germination temperature requirement of Italian ryegrass compared to spring wheat.

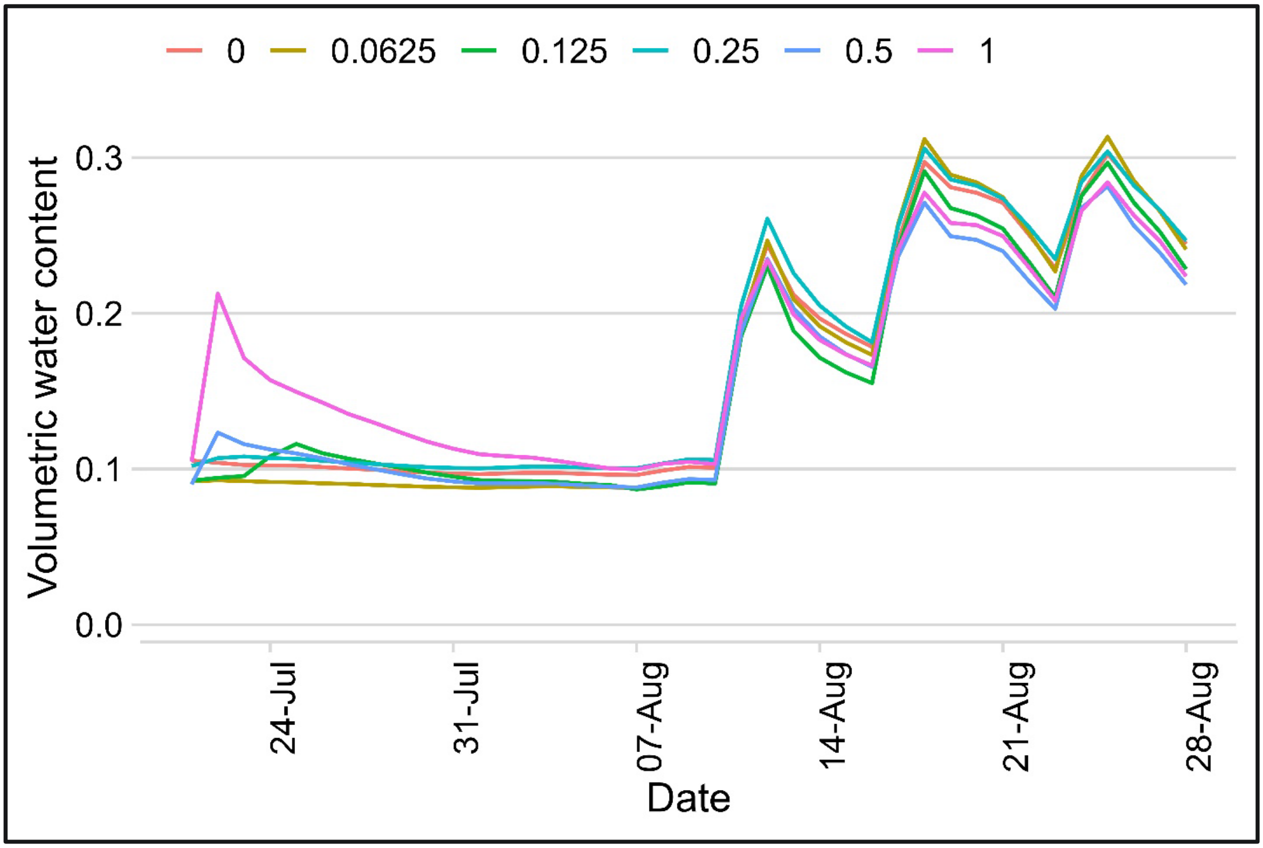


Figure 15. Volumetric water (0.1 corresponds to 10%) content of the soil at the study site from herbicide application to study terminations. The lines correspond to the 0, 0.0625, 0.125, 0.25, 0.5, and 1 inch of sprinkler irrigation water on the day of herbicide application.

Table 1. Observed Italian ryegrass and kochia control from delayed activation and the expected control from normal activation.

Herbicide	Italian ryegrass control (%)		Kochia control (%)	
	Observed	Expected	Observed	Expected
nontreated	0 c*	-	0 b	-
Tricor	8 c	50 to 80	95 a	70 to 80
Zidua	43 b	80 to 100	76 a	80 to 85
Prowl H2O	72 a	30 to 80	69 a	70 to 85
Dual Magnum	51 b	85 to 100	6 b	≤60

*Within column, means followed by same letters are not different according to Tukey's HSD (α=0.05).

USDA Research Weed Scientist Update for PNWHRI

Olivia Landau

Herbicide-resistant weeds, especially biotypes resistant to multiple different classes of herbicides, are only becoming more prevalent in the PNW and reducing the utility of the finite herbicides available for cereal-based cropping systems. The genetics underlying herbicide resistance mechanisms are not always well characterized, which is particularly true for mechanisms that are likely quantitative rather than qualitative traits. Additionally, there is also the desire to improve the understanding of the genetics of traits that contribute to the weed seed survival in the soil seed bank (i.e. seed dormancy and longevity) and determine how agricultural practices affect these traits with the overall goal of optimizing practices for weed seed bank management. Genetic information could be utilized to develop assays to detect and track the presence of alleles associated with weed seed survival and endowing herbicide resistance. Furthermore, this information could be utilized in the development of tools to predict the risk of herbicide resistance development and in novel weed control measures, such as gene drive or RNA interference. The hiring of a new USDA-ARS Research Weed Scientist is necessary, and the incumbent will collaborate with other researchers to address the following objectives:

1) Determine the genetic, physiological and biochemical factors that contribute to weed seed persistence in the soil seed bank.
2) Determine the relative importance of mutation, migration, selection, and random genetic drift in the spread of important traits, including herbicide resistance, in weed species in cereal-based cropping systems the PNW.
3) Identify loci of herbicide-resistant weed seed survival and develop tools to track movement of these genetic variants throughout the agricultural landscape.
4) Collaborate with others in the development of models to predict the risk of herbicide resistance development in weeds based on herbicide usage and cropping system.
5) Collaborate with others to determine how cropping systems, biotic and abiotic factors, and the soil microbiome affect seed longevity and survival in the soil seed bank.
6) Collaborate with extension, industry, and stakeholders to introduce best practices for weed seed bank management.

Results/Accomplishments

Interviews were conducted in October 2023 and the new Research Weed Scientist, Dr. Olivia Landau, onboarded the position in April 2024. She is collaborating with both USDA-ARS and WSU scientists to design experiments to address previously outlined objectives. Additionally, she has recently hired two WSU post-doctoral researchers to help meet project goals. Current experiments involve characterizing pyroxsulam-resistant Italian ryegrass (*Lolium multiflorum*) populations that likely possess enhanced herbicide-detoxification or some other non-target site resistance mechanism, producing mapping populations to identify candidate genes endowing pyroxsulam resistance via genomic and transcriptomic analyses, developing Phenospex protocols for high-throughput phenotyping of soil-applied herbicides, and establishing a DNA extraction protocol for meta-genomic analysis of weed seed and soil microbiome.

In the future, seeds from a variety of problematic weed species will be collected from multiple sites around Washington for use in future research. The objective would be to identify and characterize populations with differences in traits of interest, such as emergence timing, seed dormancy, seed longevity, and herbicide resistance, and create mapping populations for use in genomic and transcriptomic analyses. After establishing a reliable DNA extraction protocol, the seed and soil microbiome of a given weed species can be evaluated for its responses to environmental factors and different agricultural practices, such as crop rotation and tillage, in field experiments to identify microorganisms that reduce or enhance seed longevity and germination and determine how the microbiome can be manipulated to the detriment of the weeds without negatively impacting the growth of crops.

Objective 1: Cross-Cutting Theme

Assessment of Light Systems for Weed Seed Deactivation

Joan Campbell

Four grass weed species (wild oat, rattail fescue, Italian ryegrass and downy brome) and two broadleaf weed species (prickly lettuce and Russian thistle) were combined with wheat chaff and subjected separately to high-intensity infrared and blue light through a bench top model prototype. The heat, which determines the IR intensity, was set at 300 and 350 F and replicated three times for each weed species. Wild oat was also tested at 400 F. Untreated controls were processed through the machine without light or heat. Chaff containing the seeds were planted in flats in the greenhouse and seedlings were counted. Rattail fescue, Italian ryegrass, and downy brome were controlled 99% or better at 350 F. Control averaged 86% for these species at 300 F. Wild oat control was 93, 60, and 40% at 400, 350, and 300 F, respectively. Prickly lettuce and Russian thistle control was 100% at 300 and 350 F. Volunteer wheat control ranged from 16 to 53% at 300 F, 40 to 86% at 350 F, and was 93% at 400 F.

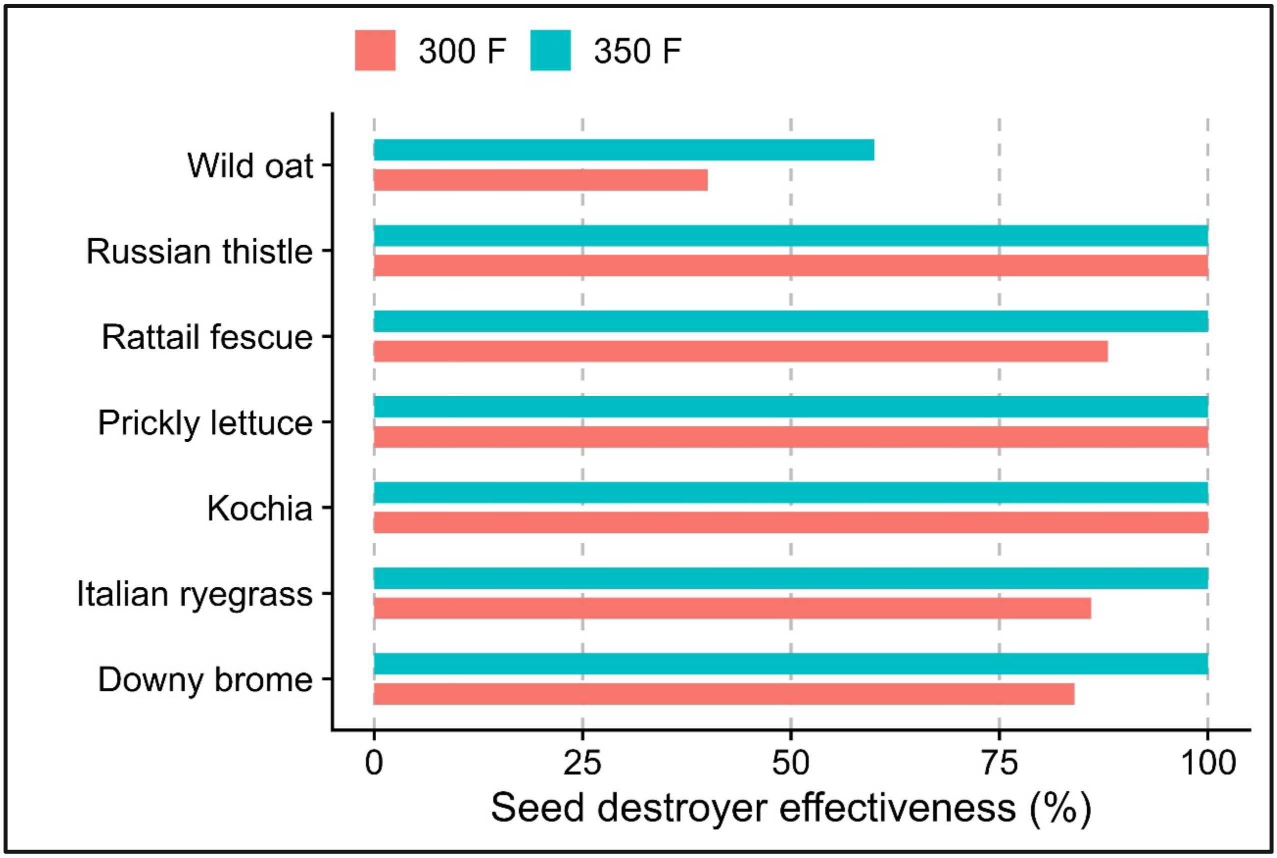


Figure 16. Effect of temperature on the effectiveness of seed termination, by species.

Outcomes/Impacts. Harvest weed seed control provides a reduction in the soil seed bank which results in fewer weeds in the field. HWSC mills require a minimum of 100 horsepower and additional fuel. The IR/blue light system is not as heavy and requires 8 to 10 horsepower. The use of IR and blue light energy systems reduces the amount of energy needed by the combine. This system has the potential to reduce the weed seeds in the field at a lower cost than impact mills.

Use of a Machine Learning Object Detection Tool to Identify and Count Weed Seeds

Shahbaz Ahmed and Ian Burke

Accurate identification and counting of weed seeds in a farmer's field is essential for gauging the weed population. The is a crucial insight that will help farmers tailor their weed management strategies. Traditionally this task involves a labor-intensive and time-consuming process of manual examination of seeds under the microscope. This project aims to accelerate the process of identification and quantification of weed seeds using machine learning object detection tools such as YOLOv8 (You Only Look Once). This workflow of seed detection and quantification begins with the acquisition of high-resolution images of 19 weed species common in eastern Washington captured using a digital microscope. These images were manually labeled to create a ground truth dataset, which was then used to train and validate the YOLOv8 model (Figure 1). The training of model is an iterative process used to refine the model's ability to accurately identify seeds within images. The model's training involved transfer learning from pre-trained weights, with performance assessed using precision, recall, F1 score, and mean Average Precision (mAP).

Once the model was trained, it demonstrated promising results in classifying and detecting weed seeds using high-resolution images from the IVESTA3 digital microscope. Overall, the model achieved high accuracy for many species, particularly larger and more distinct ones (Figure 2). Precision improved significantly throughout the training process, reflecting better performance in both detection and classification. The trained model allowed us to carry out precise detection on images or live videos in real-time. This implementation of object detection model for weed seed identification not only enhances our accuracy of detection and quantification but also significantly accelerates the analysis process. As we continue to train the model on images from different field conditions, our goal is to enable researchers and extension officers to handle large datasets in a fraction of the time required by traditional methods (Ahmed et al., Accepted)

Figure 17. labelImg generated bounding boxes drawn around weed seeds belonging to different classes used in the training process

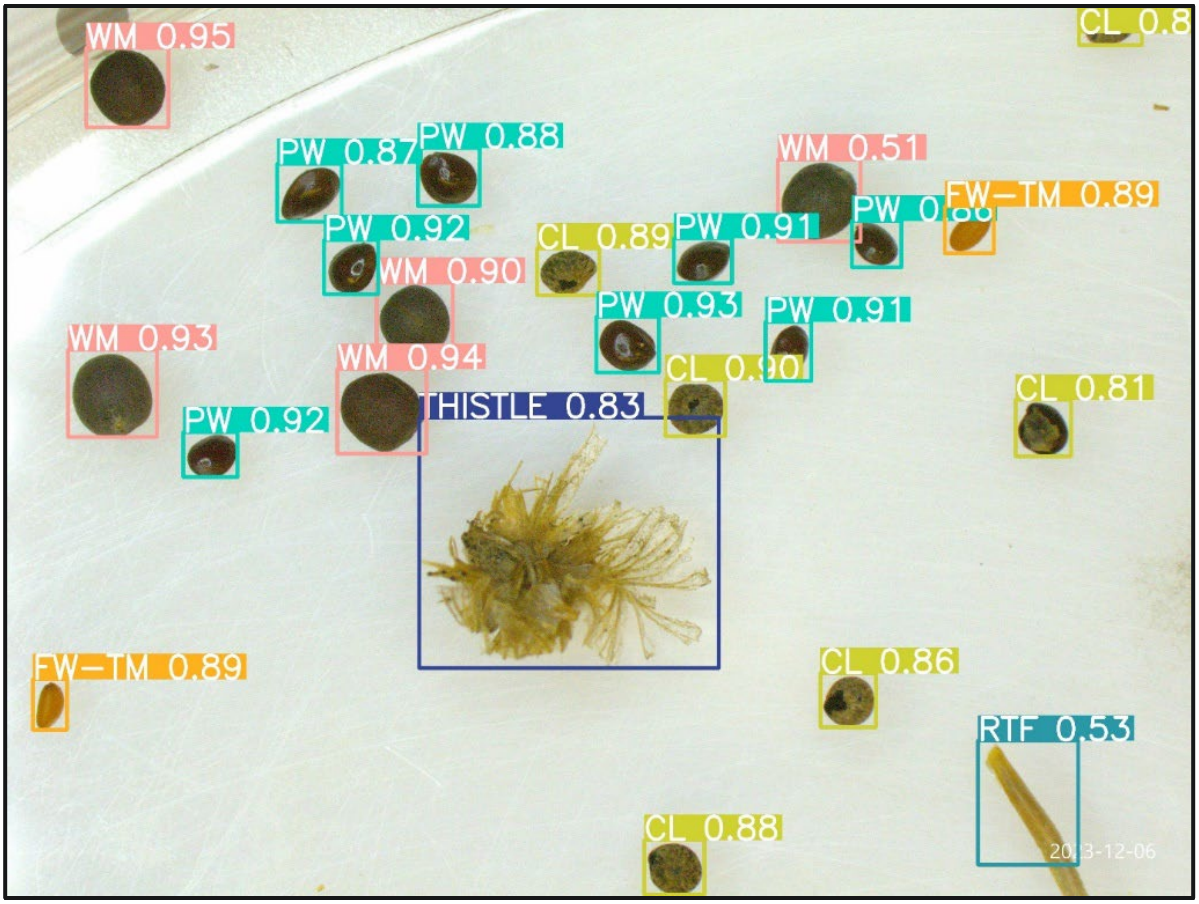


Figure 18. Example detection results generated by the model, with bounding boxes drawn around different weed seeds. Each bounding box indicates the location and size of a detected seed with a confidence score.

Developing Transformation Protocol for Downy Brome

Shahbaz Ahmed and Ian Burke

Downy brome, or cheatgrass, is a widespread weed in agriculture that competes aggressively with crops for water, nutrients, and sunlight, often outcompeting desirable plants and reducing crop yields. In the study of genetic mechanisms underlying herbicide tolerance, model plants like Arabidopsis thaliana play a crucial role due to their well-characterized genome and amenability to genetic manipulation. Researchers utilize Arabidopsis and other model plants to identify genes and pathways involved in herbicide tolerance through techniques such as forward and reverse genetics, transcriptomics, and genome editing. However, to directly study herbicide tolerance in problematic weeds like downy brome (*Bromus tectorum*), there is a pressing need to develop protocols and resources specific to these plants.

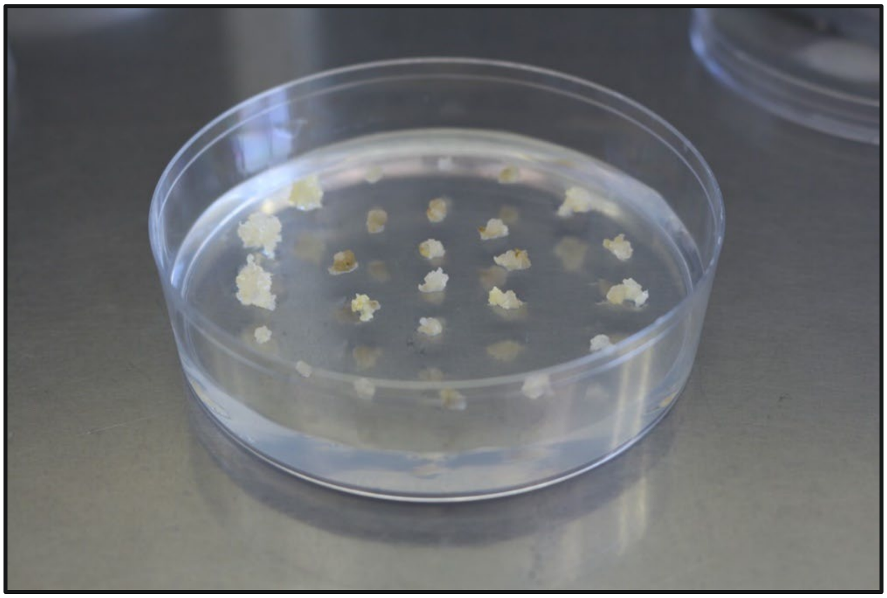


Figure 19. Callus generation from embryos.

We believe it is time to bring agricultural weeds into the lab to study their resiliency. This approach will enable us to understand how weeds are surviving and evolving at a much quicker pace. There is also a need to develop tools to study weeds as we study model plants, helping us understand why certain weeds survive rather than developing new herbicide chemistries. This involves establishing transformation methods, genome sequencing, and gene editing tools tailored to downy brome and other problematic weeds.

With a transformation protocol in place, researchers could introduce foreign genes or modify endogenous genes in downy brome to study their functions and roles in herbicide tolerance and other related traits. This would enable targeted investigations into the genetic mechanisms underlying herbicide resistance, allowing scientists to identify key genes and pathways involved. The application of molecular tools would also allow us to identify genes and pathways that make these weeds more resilient than field crops. These genes could be an important source for developing climate-resilient crops.

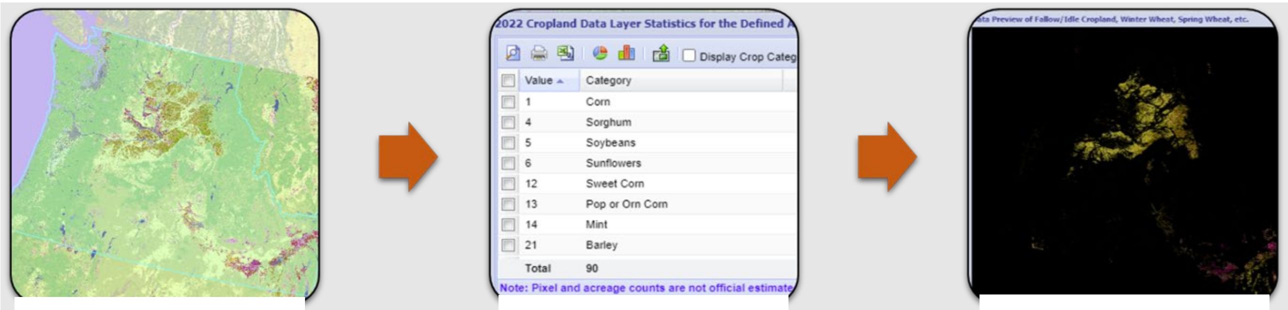
So far no protocol has been developed to study genetic mechanisms directly in the weed species such as downy brome. In this project, we are working on developing transformation techniques for this species. So far, we have successfully developed a protocol for growing plants from tissue culture (Figure 1, 2). With this tissue culture protocol in place, our next step will be to experiment with Agrobacterium-mediated transformation to produce transgenic plants.

Figure 20. Regenerated plants in rooting media.

Tracking Herbicide Resistance with GIS in the Pacific Northwest Summary

Pete Berry and Jamie Burroughs

Using George Mason University's Center for Spatial Information Science and Systems – CropScape – Cropland Data Layer (https://nassgeodata.gmu.edu/CropScape/), we collected crop data in Oregon, Washington, and Idaho from 2020-2022. We chose the following crop data to collect and export for processing: Spring Wheat, Winter Wheat, Barley, Triticale, and Fallow/Idle Cropland. The data from CropScape was exported as a TIFF raster file.



CropScape Crop Selection Raster Data

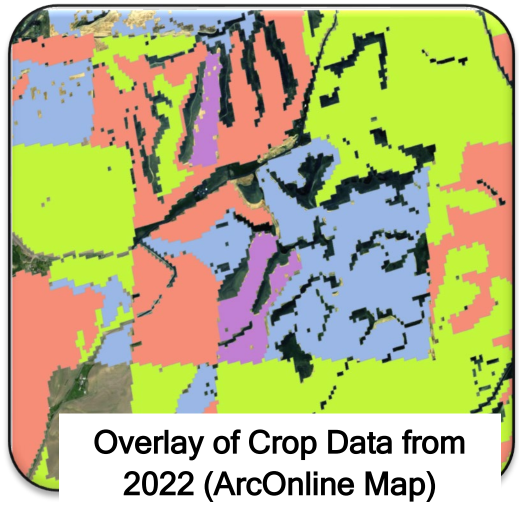
The crop data was then uploaded into ArcGIS Desktop and projected to Oregon Statewide Lambert (Intl Feet). Each crop was then extracted from the original raster file exported from CropScape to create a new raster file of the specific crop. The new raster files were then converted to vector (polygon) shapefiles for easier manipulation and processing.
Once the data was in a vector format, all polygons that were less than 5 acres were removed from the data to reduce the number of polygons within the data and to focus on commercial sized areas. Each polygon was then edited and adjusted to fall within their state and county boundaries (boundaries used were exported from the U.S. Census Bureau). The following data was then added to each polygon's attribute table: crop name, crop type (cereal or fallow), acres, county, and state. Once each crop was completed, each of the crops were then merged into a new polygon file for their specific calendar year (2020-2022).

After processing the crop data and creating the final products, the shapefiles were then uploaded to ArcOnline and an online map was created. A dashboard was then created using the online map, that can be accessible by the public without the risk of edits being accidentally made by other users.

Crop	State	Acres	County
Winter Wheat	Oregon	17426	Umatilla
Fallow	Oregon	16640	Sherman
Winter Wheat	Washington	16119	Walla Walla
Winter Wheat	Washington	14337	Benton
Winter Wheat	Oregon	12153	Umatilla
Fallow	Oregon	10154	Morrow
Winter Wheat	Oregon	10131	Morrow
Fallow	Oregon	8595	Gilliam
Fallow	Washington	8520	Adams
Winter Wheat	Washington	8427	Grant
Winter Wheat	Oregon	7983	Umatilla
Winter Wheat	Oregon	7894	Sherman
Winter Wheat	Oregon	7802	Umatilla
Winter Wheat	Oregon	7772	Sherman
Fallow	Oregon	7539	Umatilla
Fallow	Oregon	7395	Morrow

Additional Crop Data Associated with Each Polygon

Satellite Imagery Overview of Fields in Idaho

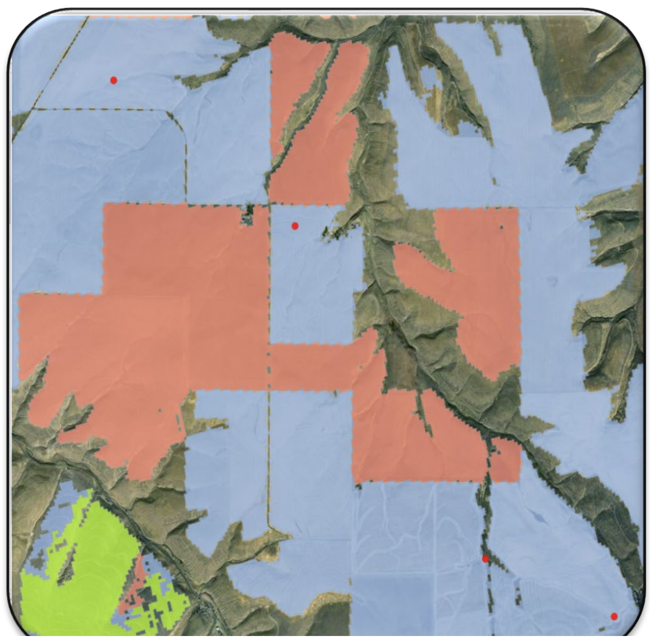


Overlay of Crop Data from 2022 (ArcOnline Map)

Within the online map, collected data points of potential resistant weed populations from Oregon State University, Washington State University, and the University of Idaho were added as point shapefiles. As resistance is confirmed among the different populations, the point data will be updated.

Objectives

- An up-to-date ArcOnline dashboard accessible by the public to view the most recent collection data and locations.
- Use of Esri Field Maps phone app to allow PNWHRI users to upload precise locations of weed populations in a research area directly to the ArcOnline map, and to obtain the ability to add photos of the population to be seen on the dashboard.
- Add new crop data every biennium (next 2023-2025) using the same methods but with the most up to date software (most likely ArcGIS Pro).
- Create and maintain a model for a publicly available, user-friendly database to track herbicide resistant weeds outside of the PNW.



Known Resistant Weed Populations in Oregon Overlaid on Crop Data from 2022

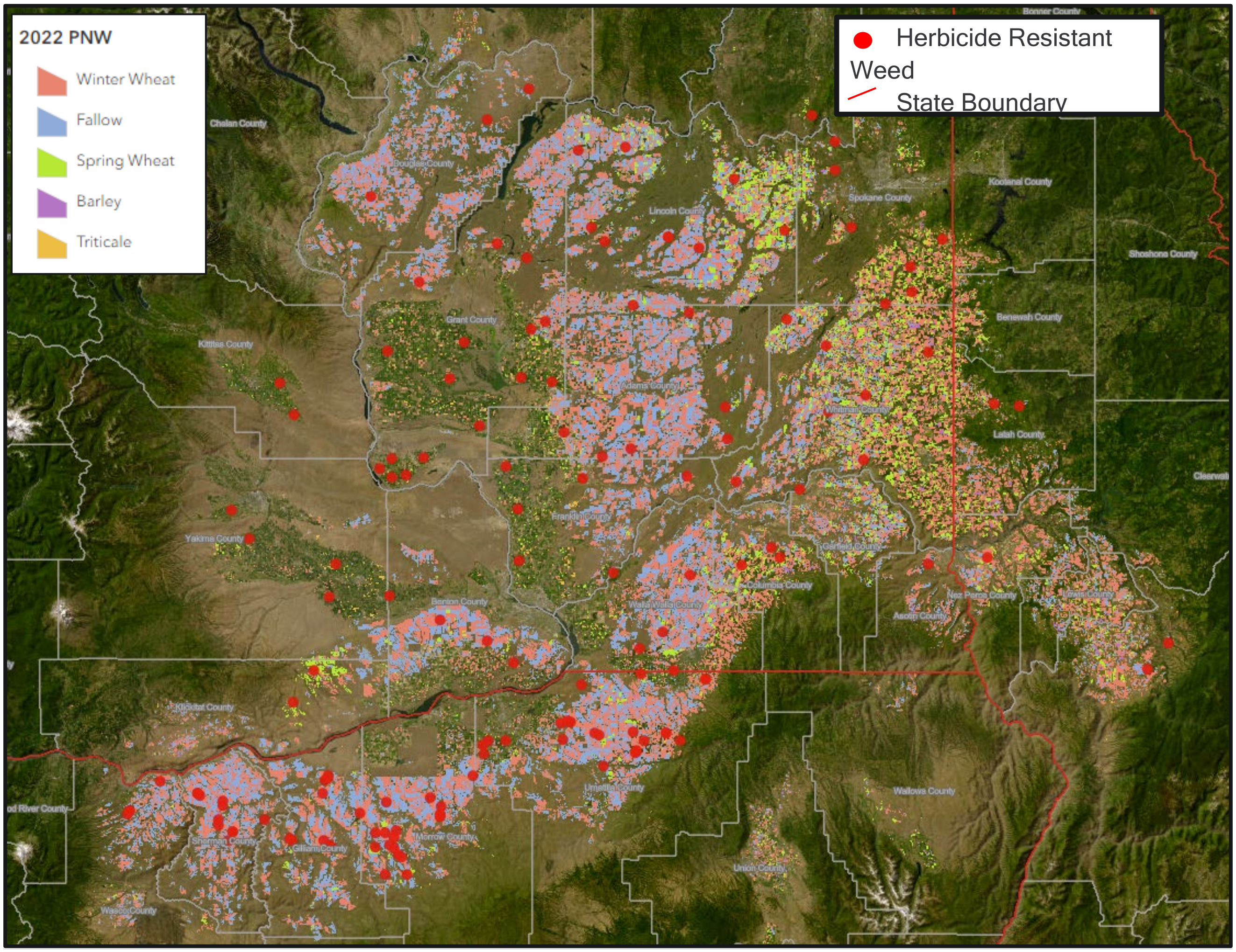


Figure 21. Overview of collected populations of herbicide resistant weeds in the Pacific Northwest from 2021 to 2023.

Objective 2 – Social Science

Socioenvironmental Dimensions of Herbicide Resistance

Nick Bergmann and Ian Burke

Most weed science research prioritizes understanding the chemical and biological characteristics of herbicides and weeds populations. It is impossible, however, to separate human and other environmental dynamics from the growing problem of weed resistance to herbicides. Incorporating "social" dimensions into herbicide resistance management is not a new phenomenon. Thus, we conducted a global literature review of research related to the social and economic dimensions of herbicide resistance management from the past 30 years to gain a thorough understanding of the strengths and weaknesses of existing scholarship. This intellectual foundation has strongly positioned the social science portion of the PNWHRI to make novel scholarly contributions conceptually furthering socioenvironmental understanding of herbicide resistance management and to create high functioning community-engaged research projects focused on solving farmer driven research questions and priorities through co-innovation.

Common Pool Resource Theory

Beginning in the 1980s, political scientist Elinor Ostrom pioneered the development of a robust theoretical framework for understanding the material characteristics and governance dynamics associated with "commons" resources such as forests, pastures, inshore fisheries, and groundwater basins. This conceptual framework – known as common pool resource theory – was a direct response to Garrett Hardin's infamous popularization of the tragedy of the commons hypothesis. In short, common pool resource theory proved that local management of shared natural resources is possible – if not preferred – in many scenarios and that privatization or state control of "commons" resources is not necessarily the solution to minimizing or stopping resource degradation. Consequently, approximately a decade ago social scientists studying herbicide resistance in the United States began to conceptualize the problem of herbicide resistance through both the tragedy of the commons hypothesis and common pool resource theory. In this framing, the "commons" or shared resource in jeopardy of degradation was the susceptibility of a weed populations to a herbicide. The idea these scholars championed was that local community control of this shared resource may be a preferable solution to reduce the rate and extent of its degradation as opposed to a government regulatory approach. Thus, scholars began researching the efficacy of "community-based herbicide resistance management" to conserve the susceptibility of weed populations to herbicides.

In a recent article in the journal Weed Science, we published a critical review of the application of common pool resource theory to herbicide resistance management. This article argued that existing scholarship underemphasized certain elements of common pool resource theory, which resulted in its application to weed resistance being underdeveloped. Specifically, scholars have not identified the herbicide itself as a commons resource and placed too much emphasis on other aspects of common pool resource theory (e.g., Ostrom's design principles). Furthermore, we reviewed the applicability of common pool resource theory as a framework for community-based herbicide resistance management and concluded that other community-scale approaches such as participatory action research and co-production of knowledge offer an improved approach for future research. This publication serves as the foundation for additional research on both the governance of herbicide resistance as well as its fundamental spatial characteristics. Currently, there is a transdisciplinary collaboration between Nick Bergmann (Washington State University/University of Idaho), Ian Burke (Washington State University), Pete Berry (Oregon State University), and Sam Revolinski (University of Kentucky) focused on merging concepts and methods form weed science and environmental social science to further common pool resource theory and understanding of the spatial dynamics of herbicide resistance across the landscape.

Co-Production of Knowledge

We applied a new framework to researching and conducting community-based herbicide resistance management through our community-engaged research with farmers in the PNW. Instead of grounding our research in common pool resource theory, we adopted a co-production of knowledge approach. As a well-established method used to conduct participatory research, co-production of knowledge reworks the fundamental relationship between scientific experts and resource users. Specifically, the experiential knowledge of agriculture producers is elevated to that of weed and plant scientists and as a result traditional social power dynamics embedded within the knowledge creation are reworked. We facilitated three farmer-centered community working groups across the PNW grounded in a co-production of knowledge framework. The goal of these groups was to brainstorm and create innovative, place-based approaches to herbicide resistance management. Ultimately, these three groups developed into two distinct community-engaged research projects: 1) Cropping Systems Diversification and 2) Harvest Weed Seed Control.

Cropping Systems Diversification

The farmer-centered herbicide resistance management working group we facilitate in North-Central Washington (low to intermediate rainfall zone) is a highly functioning community-engaged research project focused on co-innovating solutions to herbicide resistance that are both place-based and scalable across dryland PNW cropping systems. This group of farmers, scientists, agronomists, grain handlers and marketers, conservation professionals, and other community members initially spent eighteen months working together to co-innovate different ideas for herbicide resistance management solutions. The group eventually settled on cropping systems diversification as the primary focus and is currently carrying out two-year field-scale research experiments involving grain sorghum. Results from the first year showed promise (Figure 1), so a second year of the group growing and researching grain sorghum is currently in process.

The working group ultimately settled on growing grain sorghum at the field-scale for several key reasons. First, many farmers in the group have grown mixtures of cover crops that contain warm season grasses that have performed well in North Central Washington. Farmers saw potential for different species of millets and sorghums to be adapted to a cash crop and integrated into their rotations. Second, the taller height of grain sorghum when compared with proso millet was an attractive option to many farmers in the area because of the significant presence of rocks and rock piles within their fields. Third, grain sorghum is more robust and flexible market opportunities than proso millet. Fourth, improving crop rotations is a key component of successful Integrated Weed Management (IWM). Fifth, grain sorghum offers herbicide options previously unavailable to the wheat-based cropping of the PNW. Farmers insisted on prioritizing the value of growing grain sorghum (themselves) at the field scale. This challenged researchers to create innovative methods for collecting meaningful data across many field sites (Figure 2 and Figure 3).

Figure 1. Researchers and Farmers Co-Producing Knowledge. Mature Grain Sorghum. September 2023. Okanogan County, WA.

Figure 2. A researcher and a farmer installing monitoring equipment to remotely track weather, soil conditions, and crop growth. June 2023. Douglas County, WA.

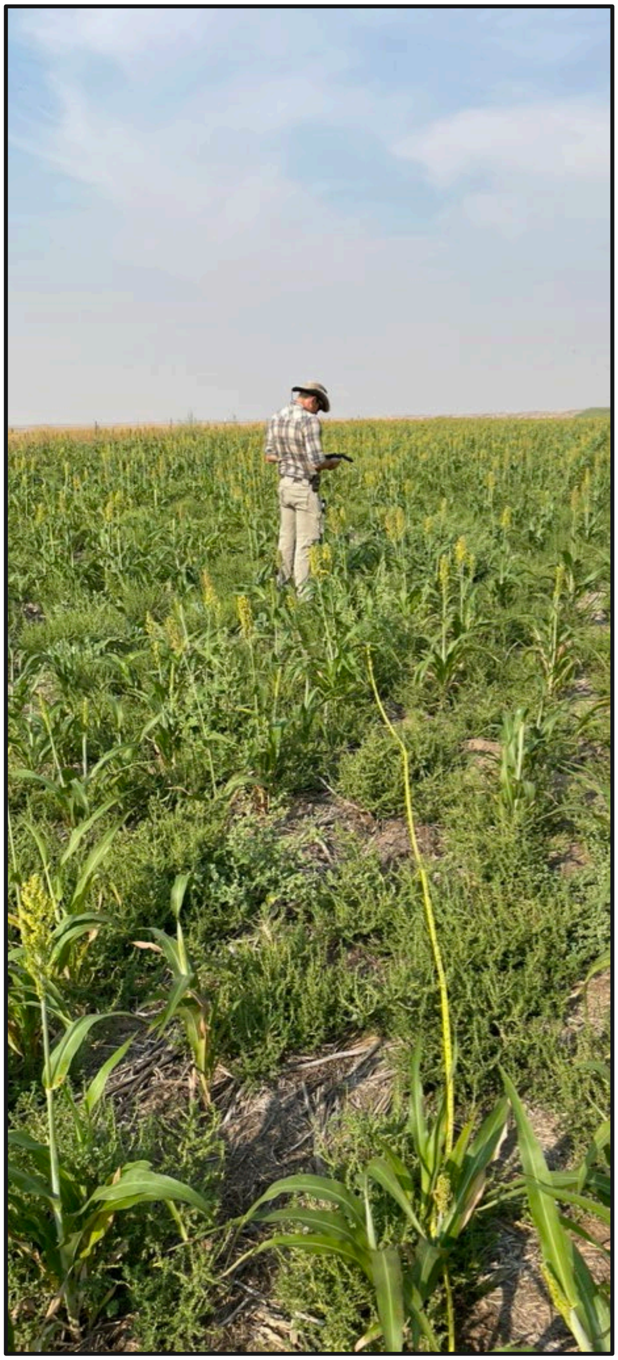


Figure 22. Field monitoring to track crop growth, weed populations, and soil conditions across multiple field sits using ArcGIS for data management. August 2023, Lincoln County, WA.

Our community-based approach has enabled a level of co-innovation between farmers and researchers that may transform the region's ability to successfully adapt to the growing spread and intensification of herbicide resistant weed populations. We are not yet sure of the viability of grain sorghum as an alternative cash crop for dryland cropping systems diversification in areas of the PNW. However, finding potential workable solutions such as grain sorghum would not have been possible without a co-production of knowledge approach to herbicide resistance management elevating farmer experiential knowledge with that of scientific expertise. Consequently, this social science component of PNWHRI is merging both community-engaged and transdisciplinary research in novel ways to improve herbicide resistance management.

Harvest Weed Seed Control

The PNW has the highest adoption of impact mills for harvest weed seed control of any region in the United States (Figure 4). Harvest weed seed control refers to a variety of harvesting practices that minimize the spread and maximize the neutralization of weed seed viability. Impact mills represent one approach to harvest weed seed control. Specifically, they are a mechanical device that is mounted on the back of a combine. After the grain is threshed, the chaff runs through the impact mill and pulverizes remaining weed seeds. Despite early adoption by producers across the region, there is little existing research about the efficacy of these machines for weed management in the PNW. This is problematic because impact mills cost a significant amount of money to buy and install ~$80,000 and have additional operational and maintenance costs.

Figure 23. A Seed Terminator unit mounted on a combine for harvest weed seed control. July 2023. Whitman County, WA.

Farmers in eastern Washington and northern Idaho (Palouse and Camas Prairie) reached out to members of the PNWHRI expressing their desire to partner for a coordinated, on-farm evaluation of their impact mills. To develop a set of innovative research questions and methods, we implemented a community-engaged participatory research approach. Specifically, we coordinated and facilitated two meetings last winter with producers from three local farms to co-produce a research agenda. At these meetings, researchers and farmers collaboratively developed an on-farm research agenda focused on understanding the efficacy of impact mills for weed control as well as an analysis of their economic benefits and costs. Consequently, we are currently conducting a pilot study across the three farms to understand the effect of impact mills on weed patches using aerial imagery, seedbank sampling, and weather and soil monitoring (Figure 5). Our team is also in the process of developing a semi-structured interview protocol to systematically understanding the key factors influencing producer adoption of impact mills as well as developing an innovative approach to understanding the benefits and costs of impact mills for PNW farms.

Figure 24. Flying a drone to collect aerial imagery in order to track the spatial dynamics of weed populations in a spring wheat field. June 2023. Whitman County, WA.

Objective 3 – Extension and Outreach

PNWHRI Extension and Outreach Activities

Douglas Finkelnburg

In 2023-2024, PNWHRI-sourced information was shared at University and Industry Growers Meetings, Crop Tours, Noxious Weed Board Meetings, Pesticide Applicator Recertification Clinics and a western regional Extension organization conference. To maintain project cohesion and momentum, bi-weekly meetings with PNWHRI Extension & Outreach members have been held. These regular meetings serve as valuable communication and networking opportunities for members.
A project website was developed and launched by contracting with the Research Computing and Data Services center at University of Idaho. This site will serve as a public facing platform to house information produced by the project including publications, links to relevant information and educational content. The site was launched in the early winter of 2023 and can be found at https://pnwhri.org/.

Pete Berry, Oregon State University Extension Weed Scientist, is building a web-based decision support tool which displays known herbicide resistance occurrences by weed species at the county level in Oregon, Washington and Idaho. This interactive mapping tool will serve to educate producers and agricultural professionals as to where herbicide resistance occurs across the landscape. It is being populated with data produced by OSU, WSU and UI herbicide resistance screening performed by weed science programs at the three land grant universities and will be linked to the Initiative website when completed and updated as new information becomes available.

A part-time communications and video production consultant was hired to help develop educational videos which will be housed on the Initiative website. These videos will serve as another method of translating important information in an entertaining visual medium. Currently, three videos concerning Russian thistle, Palmer amaranth, and Prickly lettuce management in wheat systems are housed on the website. Videos on Italian rye and, Downy brome are under production. The short, targeted videos can be accessed at https://pnwhri.org/videos.

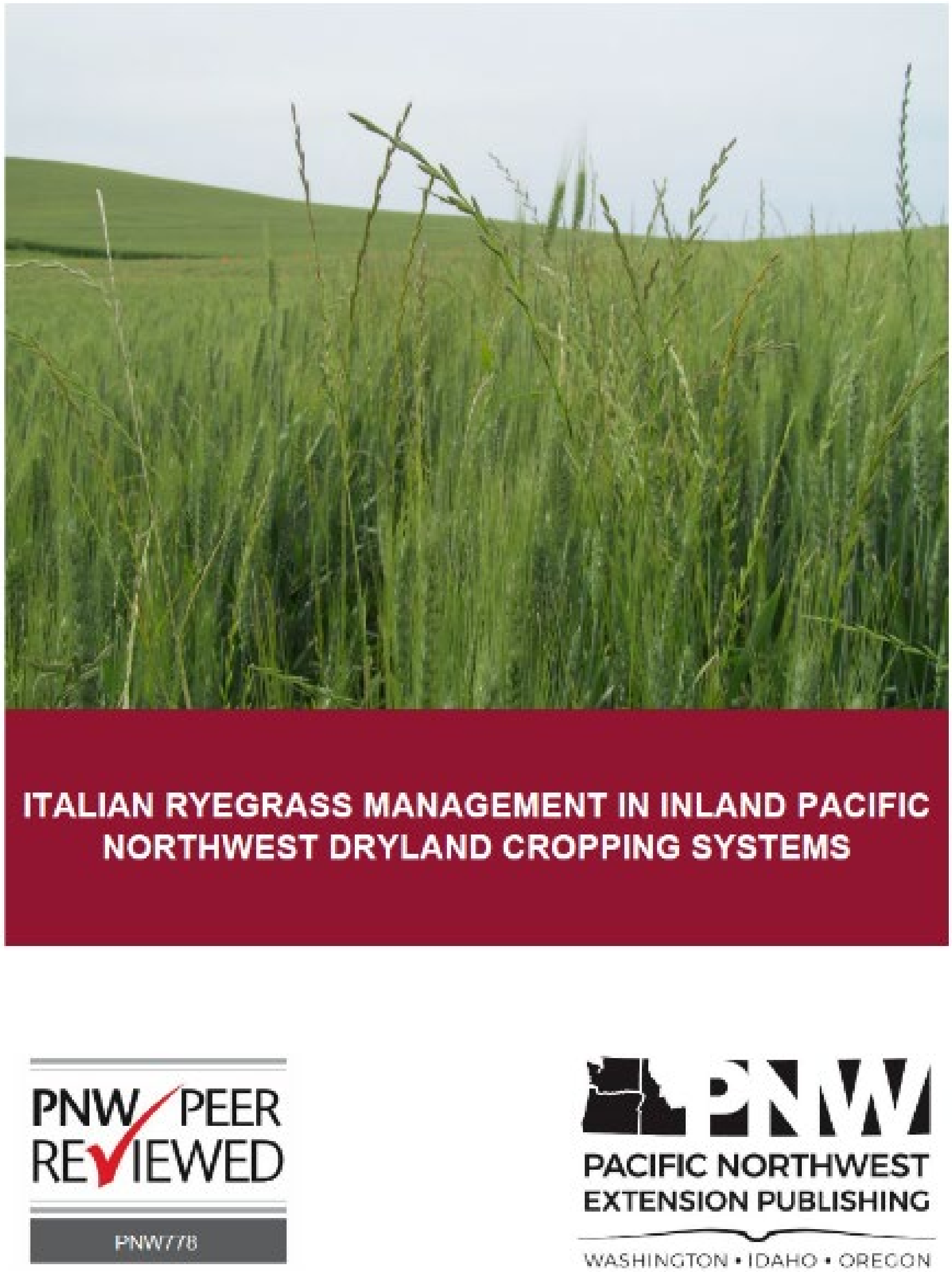


Figure 25. Cover page of the most recent extension bulletin published by team members.

Equipment Purchased with PNWHRI Funding

- Germination Table (UIdaho)
  - Allows for assessing weed and crop seed germination under different temperatures (5 to 99 F), and how soil temperature may affect the activation of soil-applied herbicides.
- Elmor C3 High Sensitive Seed Counter
  - Can count seeds 1/250 to 7/10 inch in size, allowing us to count very small to large weed and crop seeds. The seed counter can count up to 50,000 seeds per hour, allowing us to efficiently count weed seeds for germination studies.
- Soil moisture and temperature sensors + data loggers
  - These sensors would allow us to monitor volumetric water content and soil water potential on an individual plot basis, for assessing the impact of soil moisture and temperature on herbicide activation for effective weed control.
- Blue light for reducing weed seed viability
  - This prototype allows us to assess the effectiveness of using blue light and infra-red heat for harvest weed seed control during grain harvest.
- Seed elutriators (UIdaho and WSU)
  - Allows for efficient elutriation of 48 soil samples (approximately 100 g of soil) at a time. Hundreds of samples can be processed within a week and quickly proceed to the next step of weed seed identification.
- IVESTA3 digital microscope (WSU – purchased with Cook Endowment funds)
  - This microscope was crucial for obtaining high-resolution images of seeds from different weed species. The detailed imagery of small weed seeds enabled precise annotation and training of the YOLOv8 object detection model.
- Phenospex TraitFinder (WSU and ARS-Pullman)
  - This machine will be utilized for high-throughput herbicide injury phenotyping and characterizing herbicide-resistant weed populations. One scan with this equipment can collect data for over 20 parameters, which will allow researchers to increase the size and speed of experiments.
- Conviron Gen1000 Growth Chambers (WSU and ARS-Pullman)
  - Provide a controlled environment for the propagation of plants or seeds that may be more sensitive to higher light intensity of a greenhouse, such as transplanted seedlings or regenerating plants from callus tissue.
- Quantstudio 7 Flex (ARS-Pullman)
  - A real-time PCR system that will allow for high-throughput SNP genotyping and measuring of gene expression for genes of interest.
- KingFisher Apex (ARS-Pullman)
  - A robot capable of consistent extraction of high-quality DNA, RNA or protein from 96 plant tissue samples per run.

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