Project Title:

Does composted hop waste enhance soil function and increase soil resilience to drought and heat stress?

Project Summary:

Agricultural production is challenged by increasing input costs and weather extremes such as heatwaves and increased frequency of drought. Improving soil health has been promoted as a pathway for enhancing biological nutrient cycling and ecosystem resistance (the ability to remain unchanged during a disturbance) and resilience (the ability to recover following a disturbance). Increasing organic matter through compost addition is one soil health practice linked to stimulating and increasing biological abundance, diversity, and activity, and increasing water and nutrient availability. Hop production in the Pacific Northwest (PNW) generates substantial crop residue, with approximately 284 million pounds of dry mass waste annually. Additionally, brewing byproducts including hop sediments (e.g., hot trub and spent hops) and spent brewers' grain are additional sources of organic nutrients and biological stimulants. **This research aims to evaluate the benefits of composting hop waste and spent hops to increase soil resistance and resilience to heat and drought stress and to close the nutrient loop in support of a circular economy for hop production.** Through our strong collaborative team with representatives from growers from the Willamette and Yakima Valleys, brewers, composters, and a hop supplier organization, we will analyze five different hop compost sources (three on-farm hop residue composts and two composts following brewing) for maturity, fertility, and bioassay for plant growth. Additionally, we will evaluate how addition of these composts influences the resistance and resiliency of soil to induced drought and heat stress under laboratory conditions with a focus on carbon and nitrogen cycling functions. Our short-term goal is to identify the organic amendment that maximizes soil carbon storage potential and enhances biological nitrogen fertility and soil resistance or resilience. Our long-term plans include applications of selected composts to hop yards to track yield, hop cone quality, and soil microbial activities and diversity. Results from this study will complement our existing soil carbon survey in PNW hopyards. Furthermore, we anticipate that these treatments will enhance soil health by increasing organic matter, improving nutrient retention, and enhancing soil structure. Ultimately, our findings will benefit the hop industry by promoting sustainable practices and reducing the agricultural climate footprint. This project aligns with the HRC's agronomic research priorities, aiming for **sustainable hop production** and **nutrient efficiency** that transforms waste into resources, supports soil health, and contributes to a carbon-neutral economy. Outcomes include a compost inventory representing on-farm and brewer composts, estimates of plant-available nitrogen released by each compost, estimates of key C- and N-cycling functions related to C decomposition and storage potential, N mineralization rates, and microbial shifts from compost additions as well as evaluating the influence of compost on conferring ecosystem resistance and resilience. Extension outcomes include the development of a factsheet on composting in hop production and a compost calculator.

Proposed Duration: New Proposal: One-year funding requested with plans for future requests for a total of 5 years.

Project Leader:

Jennifer M. Moore, Research Soil Scientist
USDA-ARS Forage Seed and Cereal Research Unit
3450 SW Campus Way, Corvallis, Oregon 97331
Email: jennifer.moore2@usda.gov
Phone: (541) 452-1812

Technical Assistance:

Kylie Meyer, Biological Science Technician
USDA-ARS, Forage Seed and Cereal Research Unit, 3450 SW Campus Way, Corvallis, Oregon 97331; Kylie.meyer@usda.gov; 541-738-4151

Griffin Fosback, Rayna Voltin, Rachel Huynh, Taylor Rhodig, Cooper Hurt
Oregon State University, Department of Crop and Soil Science, Corvallis, OR 97331

Collaborators:	Dr. Kristin Trippe, Research Soil Microbiologist USDA-ARS Forage Seed and Cereal Research Unit 3450 SW Campus Way, Corvallis, OR 97331 Kristin.Trippe@usda.gov | 541-602-7245
Cooperators:	Levi Wyatt Yakima Chief Hops 306 Division St Yakima, WA 98902 Levi.Wyatt@yakimachief.com | M:253-241-8605
	Goschie Farms Gayle Goschie 7365 Meridian Rd NE, Silverton, OR 97381 gayle@goschiefarms.com | 503-932-8119
	Coleman Farms Micah Chase Farm Manager – Alluvial Micah@colemanag.com / 541.731.1564 https://www.colemanag.com/
	Hopsteiner Ryan Gregory S.S. Steiner, Inc 1 West Washington Ave Yakima, WA 98903 RGregory@hopsteiner.com

	Block 15 3415 SW Deschutes St Corvallis, OR 97333 541-752-2337
	ColdFire Brewing Company 263 Mill St, Eugene, OR 97401 (541) 636-3889
	Rexius Eugene / Springfield Production Facility: 92574 N. Coburg Rd Eugene, 97408 (541) 342-1835

Amount Requested: **HRC: $23,987**

Other Funding Sources and Support: See budget below.

Send Funding To: Agricultural Research Foundation
1600 SW Western Blvd., Suite 320
Oregon State University
Corvallis, OR 97333
Josh Kvidt
josh.kvidt@oregonstate.edu; 541-737-4066

Does composted hop waste enhance soil function and increase soil resilience to drought and heat stress?

Statement of Problem:

Healthier soils are often promoted to provide greater levels of fertility and provide resistance to drought and heat stress. Enhancing soil health can be achieved through adoption of practices that build soil organic matter, protect the soil surface, and stimulate soil microbes. Through the actions and interactions of soil microorganisms, increased soil organic matter also increases the availability of two of the most limiting factors for crop productivity, water and nitrogen.

Hop production in the USA is concentrated in the PNW states of Washington, Idaho, and Oregon where over 104 million pounds of hops were harvested in 2023 (National Agricultural Statistics Services (NASS), 2023). Bines, leaves, and cones are collected at harvest, each comprising approximately one-third of the total biomass, respectively (Rybacek, 1991). Total residues are estimated to weigh over 5200 pounds per acre or a total of 284 million pounds (dry mass). After cones are separated, this translates to over 190 million pounds (nearly 3500 lbs/acre) of crop residue, and its associated carbon and nutrient content, potentially removed from the system annually. For example, hop leaves are rich in nitrogen (N), phosphorus, and potassium reaching values of 40g/kg, 1.5 g/kg, and 15 g/kg, respectively.

During the decomposition of organic residues, soil microbes mineralize N to release plant-available ammonium-N and nitrate-N. Despite the accepted fact that N mineralization dynamics are complex and highly variable, a rough estimate of a 2% N mineralization rate is a typical value reported in standard soil tests. This means that for every 1% of soil organic matter, which contains approximately 1000 lbs of organic N/acre, an estimated 20 pounds of inorganic N is mineralized per acre annually.

Due to the large amount of organic waste produced during hop harvest, on-site composting of hop biomass provides a valuable organic fertilizer or soil amendment that can help close the nutrient cycle. Composting is a relatively low-investment technology that transforms biomass into a stabilized final product rich in organic matter and nutrients and, when composted properly, without a phytotoxicity effect on plants. In addition to the nutrients retained in composted materials, the added organic matter increases the water-holding capacity of the soil with greater effects reported during drought stressed.

In addition to crop residues, the byproducts of brewing, including hop sediments (e.g., hot trub and spent hops) and spent brewers' grain (SBG) offer additional opportunities to close the nutrient loop and create a more circular economy. In a pioneering effort, our collaborators have initiated a trial to compost these materials. The SBG is combined with other local green waste and composted aerobically over multiple months. The mature compost is tested and certified according to US Composting Council Seal of Testing Assurance, which is the gold standard in compost quality standards, is then reapplied to hop yards in the Willamette Valley. To date, further soil or laboratory assessments regarding the release of key nutrients (e.g., nitrate-N and ammonium-N) or microbial impacts have not been evaluated.

The final compost product is influenced by several factors including temperature, thermal phase duration, moisture content, initial carbon-to-nitrogen (C/N) ratio, oxygen concentration, pH, and particle size. Among these, temperature plays a critical role, as it affects the succession and activity of microorganisms that drive the composting process. Smaller particle sizes improve bacterial degradation by increasing surface area for microbial activity. Compost maturity and stability are key indicators of its quality, with immature compost potentially causing phytotoxicity in plants, while low microbial respiration is a sign of compost stability. To date, there is limited research on composting hop biomass or spent hops, making this study particularly relevant for hop-producing farms. The growing use of biodegradable twine has made it easily possible to compost hop waste on-farm. In response, this research follows established on-farm composting protocols while evaluating the effects of particle size and compost pile turning frequency. Unlike industrial composting, on-farm practices vary widely among growers and require tailored approaches.

The findings from this study will help improve composting treatments and assess the quality of compost derived from hop biomass, contributing to more sustainable and practical waste management strategies for hop producers. To date, although research on hop compost has been conducted in Europe (Afonso et al., 2021; Kopeć et al., 2021; Luskar et al., 2022; Čeh et al., 2023), we know of no formal research studies evaluating composts for hop production in the PNW-USA.

Justification and Importance of Proposed Research:

The HRC lists "***Strategies to improve overall soil health/plant health (sustainability)"*** and "**Most efficient methods of nutrient application and timing thereof *(sustainability)***" as the top two priorities under the ***Agronomic Research*** category. Our proposed research project aims to quantify the environmental and production benefits of composted hop residues and spent hops following brewing. **We propose that composted hop residues post-harvest and hop sediments from beer production applied to hopyards provide a "triple win" solution to reduce agricultural waste, recycle valuable nutrients, and create an agronomic system that is resilient and resistant to environmental stressors.**

This work will complement our HRC-funded project where we are conducting a survey of soil health and carbon stocks in the Yakima and Willamette Valleys. This composting survey will provide direct evidence of the benefits and potential trade-offs for composted agricultural wastes in hop production.

We address HRC priorities in the areas of ***Agronomic Research*** by focusing on:

(i) Evaluating the **improvement of soil health and plant health** through the recycling of biowastes and application to hopyards through increased soil organic matter. Soil organic matter is a fundamental soil property that positively affects soil and crop health by increasing water and nutrient retention and availability, increasing microbial activity, and improving soil structure and aggregate stability. The overall sustainability of the system at a regional scale is enhanced because agronomic wastes produced on farms transform from waste to value-added products, reducing the overall carbon and energy footprint.

(ii) Examining a potentially **efficient method of nutrient application and timing** through biological nutrient cycling of organic nitrogen.

OBJECTIVES:
Our short-term goal is to identify which compost best enhances soil function related to biological N fertility, soil C storage, and system resiliency or resistance to environmental stress (e.g., heatwave and drought). To achieve this goal, we propose five objectives in year 1, which focus on understanding how compost sources and production conditions influence soil fertility and microbial interactions under controlled laboratory conditions. These initial experiments are designed to identify composts with distinct influences on soil dynamics, enabling us to prioritize those likely to show divergent effects in the field—ultimately helping to reduce the number and cost of field trials required. In years 2-5, we intend to apply composts under replicated field trials to evaluate their effect on hop yield and quality, soil moisture and temperature, and soil functional health.

Year 1:

(1) Quantify the initial maturity, nutrient content, and conduct a germination test of composted sources.
(2) Quantify the cycling rates of carbon and nitrogen from composted sources added to soil during a lab incubation.
(3) Evaluate how addition of composts from different sources influences the resistance and resiliency of soil to induced drought and heat stress.
(4) Identify key management strategies of on-farm hop compost and brewers' waste that influence fertility, carbon storage potential, microbial activity, and resilience and resistance to drought.
(5) Communicate and extend project findings to industry stakeholders and partners.

Years 2-5: Establish field trials to monitor hop yield and quality, soil moisture and temperature, and soil health on two Willamette Valley hopyards and at least one Yakima Valley hopyard with and without composted spent hop waste and an on-farm compost (for a total of 3 years).

Procedures/Methods to Accomplish Objectives in Year 1
For all objectives, we will collect a minimum of five 'mature' hop composts (based on collaborator expertise) from the following sources:

- On-farm compost following harvest from Goschie Farms. According to conversations with the grower, they monitor compost temperature and have a compost turner that results in mature compost within a few months.

- On-farm compost following harvest from Coleman Farms. According to conversations with the grower, hop residues are minimally managed with infrequent turning. They tend to rely on longer periods (one or more years) of composting to ensure maturity.
- On-farm compost following harvest from Hopsteiner (management details pending). We will work with Hopsteiner to identify their source and management practices for hop compost.
- Composted brewers' waste from collaboration with Yakima Chief Hops, ColdFire Brewing, Coleman Farms, and Rexius Landscaping. Details of this compost are pending.
- Composted brewers' waste from Block15. Details of this compost are pending.

Acquisition of composts and detailed management information will be **completed in Mar 2026** to determine how compost pile management influences the initial chemical and biological properties.

Y1.Obj1: Quantify the initial maturity, nutrient content, and conduct a germination test of composted sources. **Completion date: May 2026.** Initial compost analyses will be performed by Soil Test Lab in Moses Lake, WA (https://soiltestlab.com/environmental/compost-tests/), which is the only Seal of Testing approved laboratory in the Northwest for analyzing compost by the US Composting Council. Samples will be analyzed for "Compost Stability and Maturity" which includes measurements of pH, electrical conductivity, moisture, total nitrogen, total organic carbon, C:N ratio, nitrate-N (NO_3^--N), ammonium-N (NH_4^+-N), organic matter, CO_2 evolution and a bioassay germination test. Additionally, evaluation of total agronomic minerals will include P_2O_5, K_2O, Ca, Mg, Na, S, B, Zn, Mn, Cu, Fe. Compost piles will be sampled according to the guide provided by Soil Test Lab, where the stratified sampling approach will be used which results in three subsamples per pile.

Y1.Obj2. Quantify the cycling rates of carbon and nitrogen from composted sources added to soil during a lab incubation. **Completion date: Summer 2026.** Net C and N mineralization from the composted residues mixed with soil from a representative hopyard will be determined following a 70-d incubation. Moisture content, total C and N content, and initial inorganic C content will be measured on amendments before application. An unamended control will also be included. Amendments will be added at equal rates based on N content and typical field application rates (e.g., typical application rates are 5-10 tons of composted residues per acre). The samples will be brought to uniform moisture content and incubated at 22°C. Subsamples will be destructively harvested at 0, 14, 21, 42, and 70 d of incubation and analyzed for NO_3^-N and NH_4^+-N, to calculate a N mineralization rate. We will include five compost sources x five replicates, for a total of 25 incubation microcosms. Mineralized C will be measured as CO_2 released daily for the first week and then weekly for the remainder of the incubation.

Y1.Obj3. Evaluate how addition of composts from different sources influences the resistance and resiliency of soil to induced drought and heat stress. **Completion date: Summer/Fall 2026.** We will follow the procedure described in a recent publication by (Lazicki et al., 2023, 2025). Briefly, soil microcosms are brought to 60% water-holding capacity and pre-incubated for 7-d at 22°C. The microcosms for drought (D) and heat plus drought (H + D) treatments will be allowed to dry naturally while reference (REF) cores will be maintained at constant moisture. After 14 d of drying at 25 °C, H + D cores are moved to a 30 °C incubator. At day 28 all microcosms are brought to 60% WHC and maintained at constant moisture and 22°C for 28 d. Microcosms (n = 5 per compost source and treatment) will be destructively harvested just before rewetting for **resistance** assessment, and 14 and 28 d after rewetting for **resilience** assessment.

To assess resistance and resilience, a total of ten C- and N-cycling microbial soil health functions will be evaluated. These include cumulative total respiration (CO2), microbial biomass C and N (MBC and MBN), CO_2-C mineralized over 24 h per unit MBC (an indicator of microbial stress), dissolved organic C and total N, and microbial enzyme activities involved in cellulose (C) and chitin (C and N) decomposition, mineral N (NH_4^+ and NO_3^-), and N mineralization rate. All analyses will be conducted at the USDA-ARS Soil Health and C Cycling laboratory in Corvallis with existing equipment and managed by PI Moore.

Y1.Obj4. Identify key management strategies of on-farm hop compost and brewers' waste that influence fertility, carbon storage potential, microbial activity, and resilience and resistance to drought. Completion date: Fall/Winter 2026. We will analyze management data relevant to composting conditions in combination with results from Objectives 1-3 above using descriptive statistics and graphical visualizations to understand the data structure, correlations among variables, and relationship to management. These results will help inform the best compost management strategies as they relate to providing nutrients, C storage potential, microbial activity, and resilience and resistance to heat stress and drought.

Y1.Obj5. Communicate and extend project findings to industry stakeholders and partners. Completion date: Winter 2026/2027. Regular industry updates will occur at commission and industry meetings, field events, professional meetings, and informally during on-farm sampling. With our stakeholder group, we hold a planning meeting at the project onset and project updates quarterly. We will develop a factsheet on the benefits and limitations of composts for hop production and a "Compost calculator (see below)".

Procedures/Methods for future objectives in Year 2 (establishment) through Year 5 (monitoring). Y2 (establishment): Using information obtained from Year 1 and in consultation with our stakeholders, we will determine the best combination of compost treatments (e.g., which sources and rates), locations (e.g., baby hopyard vs. mature yard and hop rows only vs. broadcast application), timing, and rate. **Y2-5 (monitoring):** Monitor hop yield and cone quality, soil moisture and temperature and soil health (microbial, C, and N functions, and aggregate stability) on two Willamette Valley hopyards and at least one Yakima Valley hopyard with and without composted spent hop waste and an on-farm compost (for a total of 3 years).

Outcomes:

1. We will provide the industry with an inventory of compost fertility, maturity, and bioassay data that when coupled with management information will help identify key practices that support high quality end-products.

2. Our laboratory incubations will estimate the quantity and timing of N released from hop composts organic residues. This information will help inform how to quantify the N fertility credit from the organic amendments.
    a. Potential pitfall: Although incubation studies can't replicate all conditions found in the field, many studies conducted under similar moisture and temperature conditions reliably predicted mineral fertilizer effectiveness in the field (Gale et al., 2006; Delin et al., 2012).
3. We will also provide growers with critical information about compost's influence on conferring resistance and resilience to drought and heat stress. As extreme weather events become more frequent, it is paramount that we help support growers with information that can help their farms adapt to these conditions.
    a. Potential pitfall: The relationship between soil health and crop response varies widely in the literature. However, the interactions between increased organic matter and soil moisture and temperature have been linked to increased resiliency and yield stability (Lotter et al., 2003; Williams et al., 2018). These impacts will save money, conserve precious resources, reduce dependency on the volatile fertilizer industry, and sustain hop farm viability.
4. Results from this study will complement and expand our soil C survey in PNW hopyards. We will quantify how organic amendments change soil C storage potential, providing valuable data for growers interested in C and ecosystem markets.
5. By recycling local hop wastes, we are addressing a major industry goal of reducing its ecological footprint, converting waste into an asset that enhances ecosystem function and saves growers money.

Extension and Outreach Activities:

In addition to annual reports, industry presentations, and scheduled meetings with our stakeholders, we will develop a factsheet on the benefits and limitations of using composts in hop production. The factsheet will also highlight incentive programs that provide technical assistance and cost share for compost applications. A "Compost Calculator" will be developed that will help hop growers to estimate carbon and nutrient contributions from compost applications.

PROJECT BUDGET:

Expenditure	Hop Research Council Request	Commission/Other State: Amount (cash or in-kind)	Commission/Other Other: Amount (cash or in-kind)	Total Amount Requested
Salaries[1]				
Temporary or hourly workers				
(2) student research assistants for a total of 320 hours at $18/hr	$ 11,520		$ 5,160	$ 16,680
Employee Benefits (OSU required fringe rates):				
Temporary assistant: 10%	$ 1,152			$ 1,152
Travel:				
PI travel to HRC meetings: $1200	$ 1,200			$ 1,200
Two visits to field sites for assistants and PI: $300/trip x 2 people x 2 trips	$ 1,200		$ 1,000	$ 2,200
Equipment				
Other (specify)				
Initial compost analyses ($261/sample)	$ 3,915			
Soil incubation supplies	$ 300			
Soil analyses	$ 4,700			$ 4,700
Soil collection and processing			$ 1,500	$ 1,500
Total	**$ 23,987**		**$ 7,660**	**$ 31,647**

[1] Fringe benefit rates are compulsory and set by Oregon State University. Benefit rates can be verified at https://research.oregonstate.edu/osraa/forms-and-rates/other-payroll-expense-ope-information-and-estimated-rates.

Explanatory Notes:
Other Expenses are the estimated total costs of this project.
Estimated cost for compost analysis is $261 per sample from Soiltest Labs. 3 subsamples per compost source x 5 sources = 15 samples x $261 = $3915 (excludes shipment). We expect the cost per sample to be lower as the two test packages described above include overlapping analyses (e.g., both include moisture, total nitrogen, and total organic carbon). We will work with the testing lab to ensure the best price is achieved.

USDA-ARS base funds ($7600) from PI Moore will provide additional undergraduate (UG) student assistance for sample analyses and to supplement travel costs (e.g., mileage for work vehicle, lodging, per diem, etc.).

Funding for proposed years 2-5 is estimated to be between $20-$30K per year.

TIMETABLE

	2026/2027												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Award announcement		X											
Planning and stakeholder communciation		X											
Acquire on-farm and spent hop composts			X										
Analyze initial composts for maturity and nutrients and growth assays			X	X	X								
Collect soil samples for incubation				X									
Initiate incubation						X	X						
Analyze samples & Complete incubation						X	X	X					
Data analysis									X	X			
Report preparation											X	X	
Industry and profession society meetings							X			X			X

Literature Cited:

Afonso, S., Arrobas, M., Pereira, E.L., Rodrigues, M.Â., 2021. Recycling nutrient-rich hop leaves by composting with wheat straw and farmyard manure in suitable mixtures. Journal of Environmental Management 284, 112105. doi:10.1016/j.jenvman.2021.112105

Čeh, B., Luskar, L., Polanšek, J., Klančnik, A.K., Trošt, Ž., Čeh, B., Luskar, L., Polanšek, J., Klančnik, A.K., Trošt, Ž., 2023. Increasing the Value of Waste Hop Biomass by Composting: Closing the Nutrient Cycle on Hop Farms, in: Organic Fertilizers - New Advances and Applications. IntechOpen. doi:10.5772/intechopen.1001340

Delin, S., Stenberg, B., Nyberg, A., Brohede, L., 2012. Potential methods for estimating nitrogen fertilizer value of organic residues. Soil Use and Management 28, 283–291. doi:10.1111/j.1475-2743.2012.00417.x

Gale, E.S., Sullivan, D.M., Cogger, C.G., Bary, A.I., Hemphill, D.D., Myhre, E.A., 2006. Estimating Plant-Available Nitrogen Release from Manures, Composts, and Specialty Products. Journal of Environmental Quality 35, 2321–2332. doi:10.2134/jeq2006.0062

Kopeć, M., Mierzwa-Hersztek, M., Gondek, K., Wolny-Koładka, K., Zdaniewicz, M., Suder, A., 2021. The Application Potential of Hop Sediments from Beer Production for Composting. Sustainability 13, 6409. doi:10.3390/su13116409

Lazicki, P., Lee, J., Mengistu, A., Jagadamma, S., 2025. Do soil health indicators predict carbon and nitrogen functional stability under drought and heat? PLOS ONE 20, e0325128. doi:10.1371/journal.pone.0325128

Lazicki, P., Lee, J., Mengistu, A., Jagadamma, S., 2023. Drought, heat, and management interact to affect soil carbon and nitrogen losses in a temperate, humid climate. Applied Soil Ecology 189, 104947. doi:10.1016/j.apsoil.2023.104947

Lotter, D.W., Seidel, R., Liebhardt, W., 2003. The performance of organic and conventional cropping systems in an extreme climate year. American Journal of Alternative Agriculture 18, 146–154. doi:10.1079/AJAA200345

Luskar, L., Polanšek, J., Hladnik, A., Čeh, B., 2022. On-Farm Composting of Hop Plant Green Waste—Chemical and Biological Value of Compost. Applied Sciences 12, 4190. doi:10.3390/app12094190

Rybacek, V., 1991. Hop Production, 1st ed. Elsevier.

Williams, A., Jordan, N.R., Smith, R.G., Hunter, M.C., Kammerer, M., Kane, D.A., Koide, R.T., Davis, A.S., 2018. A regionally-adapted implementation of conservation agriculture delivers rapid improvements to soil properties associated with crop yield stability. Scientific Reports 8, 8467. doi:10.1038/s41598-018-26896-2