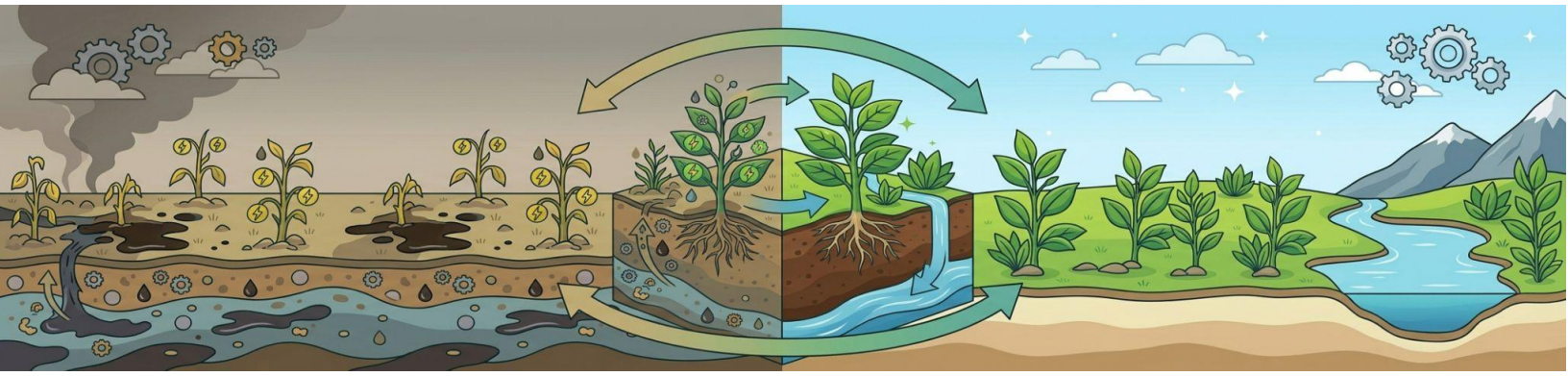


BOOK OF ABSTRACTS

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20 INTERNATIONAL PHYTOTECHNOLOGY SOCIETY

Celebrating 20 Years
2006–2026

CAES
The Connecticut Agricultural Experiment Station

Putting Science to Work for Society

150th ANNIVERSARY
1875 – 2025

Book of Abstracts: International Phytotechnology Conference (IPC19)

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Welcome to the 19th International Phytotechnologies Conference

The International Phytotechnology Society (IPS) and the Connecticut Agricultural Experiment Station (CAES) are delighted to welcome you to Providence, Rhode Island, for the **19th International Phytotechnologies Conference**.

The history of this conference began in May 2000, when the first International Phytotechnologies Conference was hosted by the U.S. Environmental Protection Agency in Boston, Massachusetts. Subsequent meetings were held in Chicago and Atlanta, and **in 2006, the International Phytotechnology Society was formally established**. In 2008, the conference expanded beyond North America for the first time, with a meeting in Nanjing, China. Since then, the conference has travelled around the world, bringing together researchers, practitioners, educators, students, government representatives, and industry partners from North America, Europe, Asia, and beyond. Our 10th conference was held in Syracuse, New York, in 2013, and in 2024 we celebrated another milestone with our first conference in Kerala, India. Today, we are pleased to celebrate the **20th Anniversary of the International Phytotechnology Society** at our 19th International Conference**.**

We have designed this 20th anniversary meeting to celebrate both the scientific foundations of phytotechnology and its growing impact in the real world. This year's theme emphasizes the connection between **innovative science and practical application**—bringing together research that advances our understanding of what plants can do with solutions that address the environmental challenges we face today.

As always, the conference will showcase the latest research into the remarkable ability of plants to **take up, transform, translocate, stabilize, and sequester contaminants** in our environment—including pollutants in our soils, waters, air, and food systems. But meaningful innovation does not always begin in the laboratory. Some of our most important advances emerge from field experience, practical challenges, and collaboration across disciplines. By bringing fundamental science and real-world application together, we can accelerate the development of technologies that contribute to a healthier, more sustainable, and more productive world.

This year's program reflects that breadth. We are pleased to welcome outstanding speakers from across North America, Europe, and Asia, including our distinguished plenary speakers: **Dr. Marshall Porterfield**, an internationally recognized space biologist; **Dr. Neil Bruce**, a leading environmental biotechnologist; and a panel of experts brought together as part of the USDA Closer-to-Zero initiative to address the important challenge of **reducing toxic elements in food**.

We have also expanded the interactive component of the meeting. In addition to traditional scientific presentations, we will feature several panel discussions designed to encourage conversation and, importantly, participation from our attendees. These include a **Career Panel**, a **Science Communication Panel**, and a **Phytoremediation Education Panel**. We hope these sessions will provide opportunities to exchange ideas, ask questions, share experiences, and perhaps challenge some of our assumptions about where phytotechnology is heading next.

Keynote Speaker - Narragansett Room B&C

Bioregenerative foundations for human life support and biologistics at the frontiers of human exploration

D. Marshall Porterfield

Purdue University

Sustained human exploration beyond low Earth orbit will ultimately be constrained not simply by transportation, but by biologistics: the capacity to continuously provide food, oxygen, water, nutrients, medicines, and other essential biological commodities while recycling wastes in environments where terrestrial resupply is increasingly impractical. Bioregenerative life support systems (BLiSS) offer a pathway from resupply-dependent exploration toward biologically sustainable habitation by integrating controlled-environment agriculture, microbial and fungal recycling, biomanufacturing, and environmental control into closed or partially closed ecosystems. The scientific foundations of bioregenerative life support from hydroponics and early controlled ecological life-support concepts to current technologies for lunar exploration. Particular attention will be given to the biophysical constraints imposed by reduced gravity, radiation, altered magnetic fields, and diffusion-limited transport on biological systems. NASA's Lunar Effects on Agricultural Flora (LEAF) experiment focuses on plant performance at the lunar surface, while emerging fungal technologies broaden the concept of space agriculture beyond crop production. Mycoponics—substrate-independent cultivation of fungi using controlled liquid nutrient delivery—to couple waste and nutrient recycling with production of food, nutritional compounds, pharmaceuticals, and functional biomaterials. Together, plants, fungi, sensing, systems biology, and biomanufacturing provide the foundations for an integrated biologistic architecture in which living systems become active components of exploration infrastructure. These approaches will be essential for enabling a bioregenerative economy for life on Earth while enabling resilient, long-duration human operations on the Moon, Mars, and beyond.

Science Communication Panel - Narragansett Room B&C
Keynote Talk

Visible Scientist: Making Science Seen, Understood, and Relevant

Renee Murphy, Ensolum LLC

Scientific work can be rigorous, important, and still remain invisible outside the circles already looking for it. Visible Scientist explores what happens when researchers take a more intentional role in how their work is communicated.

Drawing on her own transition from fashion and marketing into environmental science, Renee Murphy examines three elements of effective science communication: being visible, understandable, and relevant. She considers how audience, context, and communication style shape whether scientific ideas are noticed, understood, and remembered.

The talk also highlights scientists at different career stages who are using visibility in distinct ways, from building networks and research opportunities to creating public connection and becoming strongly associated with an area of expertise.

This plenary is not a call for every scientist to become an influencer. It is an invitation to think more deliberately about how scientific work travels, who it reaches, and what each scientist can do to make that work more accessible beyond traditional academic spaces.

Plenary Speaker - Narragansett Room B&C

Integrating Phytotechnology and Landscape Design: A Review of Current Case Studies

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This presentation will highlight recent case studies in the field of landscape architecture where phytotechnologies have been used together with creative design process to simultaneously improve environmental, spatial, cultural and aesthetic qualities of a place. The case studies will build on research compiled in 'PHYTO: A Resource for Site Remediation and Landscape Design' (Kennen & Kirkwood, Routledge 2015) that explores the creation of projective planting designs with preventative phytotechnology abilities, 'phytobuffering' potential future pollution from for particular site programs. Lessons learned about the performative plantings and site designs studied will be summarized. This presentation will cover aesthetic composition and consideration of natural and cultural systems and how they are integrated with the potential phytotechnology role of plants to assist landscape architects, engineers and site owners. The creation of productive landscapes is the ultimate objective; plantings that provide not only aesthetic functions, but enhance environmental and human-health conditions as well. The case studies presented will illustrate work that bridges the critical science and engineering associated with phytotechnology and its effective design use in the field.

Keywords: Landscape Architecture, Design, Phytotechnology, Phytoremediation

References

Kate Kennen & Niall Kirkwood, PHYTO: Principles and Resources for Site Remediation and Landscape Design, Routledge, 2015

Closing Speaker - Narragansett Room B&C

Defusing the Environment: Engineering Plants for the Phytoremediation of Explosives Pollution

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Timothy J. Cary, ERDC-CRREL US Army Corps of Engineers

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Explosive compounds such as 2,4,6-trinitrotoluene (TNT) and hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) are toxic munitions that progressively accumulate in soil, plants and groundwater. While addressing clean-up of these compounds is a priority for the U.S. Department of Defense, explosives pollution is a global issue, with large amounts of land and ground water contaminated by TNT and RDX, including polluted sites in Europe dating back to the First and Second World Wars. Consequently, there is a pressing need to develop sustainable in situ technologies to contain and treat these pollutants. Plants have a remarkable ability to extract compounds from their environment and have evolved complex signaling and enzyme systems to deal with a diverse range of toxic chemicals. By elucidating these plant molecular mechanisms alongside bacterial degradation pathways, we engineered transgenic plants able to remediate TNT and RDX contaminated environments.

Specifically, TNT detoxification involves direct conjugation to glutathione or reduction-initiated glycosylation, with these conjugates ultimately sequestered in root cell walls. Using *Arabidopsis thaliana* as a model plant species, we identified key response mechanisms and toxicity pathways, including the role of monodehydroascorbate reductase (MDHAR6). Furthermore, heterologous expression of a *Drosophila melanogaster* glutathione transferase and a bacterial nitroreductase significantly enhanced TNT glutathionylation and reduction-initiated glycosylation within Arabidopsis, allowing characterization of these detoxification pathways in planta. Finally, we demonstrate the successful translation of these engineered detoxification pathways into field-applicable species, offering robust plant systems that efficiently remove toxic concentrations of TNT and RDX from contaminated soil and water.

Keywords: Phytoremediation, Organic, Pollutant, Explosives, Detoxification, Metabolite Sequestration

Field Trip - The Stormwater Innovation Center
https://www.stormwaterinnovation.org/

The Stormwater Innovation Center (SIC) is a collaborative initiative dedicated to improving water quality and stormwater management in Rhode Island. From green infrastructure research to professional trainings to community science programs, we lead a wide range of initiatives addressing stormwater challenges comprehensively. Through collaborative projects with government, non-profits, and industry partners, we connect research, education, and real-world implementation to build a cleaner, more resilient future for Rhode Island's waterways.

- **Monitoring & Research:** The SIC conducts monitoring and research to enhance stormwater management and water quality in Roger Williams Park and its watershed. By assessing green infrastructure performance and tracking key water health indicators with partners and volunteers, we develop and apply best practices for sustainable, science-based stormwater solutions.

- **Water Quality Restoration:** Our watershed restoration projects focus on redesigning outdated stormwater systems, removing pavement, restoring shorelines with native plants, and applying innovative management techniques. From site retrofits to comprehensive master plans, we create sustainable, high-performing stormwater solutions.

- **Education & Outreach:** The SIC collaborates with local schools and environmental partners to help students explore the connection between stormwater, water quality, and wildlife through hands-on learning and creative projects like storm drain murals and painted rain barrels.

- **Training & Networking**: We provide expert-led trainings on stormwater and green infrastructure design, construction, and maintenance for municipalities, non-profits, businesses, and community members. Our experienced presenters offer both virtual and in-person sessions to share practical knowledge and industry best practices.



FDA's Role in Managing Toxic Elements in Foods and in Advancing International Harmonization of Standards

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FDA routinely monitors toxic elements (i.e., arsenic, cadmium, lead, and mercury) in domestic and imported foods, assessing if these contaminants pose a safety concern, and taking action as needed. In addition, FDA conducts initiatives such as Closer to Zero and Operation Stork Speed, which focus on contaminant exposures to babies and young children, whose small body size and metabolism make them more vulnerable to the harmful effects of toxic elements.

FDA conducts sampling and analysis through its Toxic Elements in Food compliance program, in-house surveys, Total Diet Study, and through cooperative initiatives with states. FDA also establishes action levels for toxic elements that provide guidance to industry regarding the level at which FDA may take regulatory action. However, FDA does not need action levels to take action if a contaminant level in a food is determined to be unsafe.

As part of FDA's efforts to manage and mitigate toxic elements, FDA collaborates with partners domestically and internationally. Within the US, FDA works with other federal agencies (e.g., USDA), states, industry, and academic researchers. Internationally, FDA is engaged with Codex, specifically the Codex Committee on Contaminants in Foods (CCCF). Through CCCF, FDA helps harmonize international standards consisting of maximum levels for contaminants and Codes of Practice that provide information to the food sector on methods to reduce contaminant levels. FDA is currently chairing work on a Code of Practice for reduction and prevention of cadmium in foods, including agricultural and aquacultural techniques.

This presentation will share FDA's ongoing work on addressing toxic elements in food and how this work helps advance the harmonization of international standards through its ongoing work with Codex.

Keywords: Toxic elements, Closer to Zero, Codex Committee on Contaminants in Foods

Predicting Rice Grain Accumulation of Arsenic

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Rice readily accumulates arsenic, a potent carcinogen, due to the flooded conditions under which rice is grown and the efficient silicon uptake pathway in rice. A majority of U.S. rice is grown in the Mid-South and has varying levels of arsenic in the grain. Here we describe two approaches for predicting the arsenic in rice grain. The first uses iron-oxide coated vinyl films, termed Indicator of Reduction in Soils (IRIS) devices. The iron-oxide coating dissolves under reducing conditions, resulting in a visible color change on the device. In field trials across 3 years we found positive correlations between IRIS Fe removal and rice grain arsenic. In a second study, we collected >50 paired rice and soil samples to identify soil factors that increase rice grain arsenic. These methods could be used to identify fields at particularly high risk of high grain arsenic and to incentivize mitigation measures, such as intermittent drainage of the rice fields.

Keywords: food safety, arsenic, redox, soil

Rapid and Cost-Effective XRF Measurement of Total and Inorganic Arsenic in High-Risk Foods

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Arsenic, particularly inorganic arsenic (iAs), is a carcinogenic contaminant of particular concern in rice and rice-based foods consumed by infants and young children. The U.S. FDA/USDA's Closer to Zero initiative emphasizes the need for improved methods to measure toxic elements at low concentrations in these foods. The objective of this research is to address this need through the development of rapid and cost-effective analytical methods based on energy-dispersive X-ray fluorescence spectroscopy (ED-XRF) for total arsenic screening and iAs quantification.

For total arsenic screening, milled rice and rice-based foods were pelletized and analyzed by ED-XRF. Partial least-squares regression provided strong predictive performance ($R^2 = 0.99$), with limits of detection and quantification of 27.76 and 92.52 ug/kg, respectively. Validation using a certified reference material yielded a prediction error of 8.96%. Because spectral overlap between arsenic and lead can compromise XRF quantification, an artificial neural network was further applied to model and correct this interference. The resulting approach quantified arsenic in lead-spiked commercial rice products with a mean absolute error of 14.11%.

Because XRF measures total arsenic, Gutzeit chemistry was applied to convert iAs to arsine gas. The arsine gas was captured and concentrated on a chemically treated membrane and subsequently quantified by XRF. The mercury bromide-based method provided results within 45 minutes, with detection and quantification limits of 1.9 and 5.7 ug/L, respectively. Replacing mercury bromide with silver nitrate reduced chemical hazards and improved the detection and quantification limits to 1.02 and 3.40 ug/L.

Future research will focus on developing and validating extraction procedures that enable selective Gutzeit-XRF determination of iAs in rice and rice-based infant foods. Together, rapid total arsenic screening and targeted iAs analysis could provide an accessible analytical framework supporting the FDA/USDA's Closer to Zero goals and efforts to reduce dietary arsenic exposure.

Keywords: Arsenic, XRF, rice, inorganic arsenic, Gutzeit chemistry

Reducing Cadmium Toxicity to the Human Gut Microbiota

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Cadmium (Cd) is a toxic element that accumulates in food crops and poses significant risks to human health. Most healthy individuals only absorb 3-8% of dietary Cd, leaving a majority of Cd to interact with the gut microbiota, where it disrupts microbial metabolism and intestinal barrier function. We investigated how gut microbiota composition influences susceptibility to Cd exposure, and evaluated dietary and microbial factors that may mitigate Cd toxicity. Human fecal microbiotas were cultured in vitro with and without Cd. The reduction in butyrate production, a beneficial microbial metabolite, with versus without Cd was used to classify microbiotas into Cd-sensitive, intermediate, or resilient groups. Further in vitro experiments evaluated the effects of carbohydrate concentration and zinc supplementation on sensitivity of the microbiota to Cd. Human gut microbiota-associated mice colonized with sensitive or resilient microbial communities were fed diets containing low- or high-Cd wheat for 14 weeks. Tissue Cd concentrations, changes in biomarkers of kidney and liver function, and gut microbiota composition were analyzed. Network analyses revealed greater disruption of microbial interactions in sensitive communities accompanied by increased acetate and lactate production compared with resilient microbiotas. The butyrate-producing genus Anaerostipes emerged as a key determinant of resilience; supplementation of sensitive microbiotas with Anaerostipes restored butyrate production during Cd exposure. Cd toxicity was greatest under high-carbohydrate conditions, while elevated zinc prevented Cd-induced reductions in butyrate production. In mice, microbiota composition significantly influenced Cd and zinc accumulation in blood and kidneys under high-Cd dietary conditions. Gut microbiota composition is a critical determinant of resilience to dietary Cd exposure. Cd-tolerant, butyrate-producing bacteria, particularly Anaerostipes, and nutritional interventions such as zinc supplementation show promise as microbiome-based strategies to mitigate Cd toxicity to the gut microbiota. These findings provide a foundation for developing approaches that reduce the adverse effects of toxic elements in the food supply.

Keywords: cadmium, gut microbiome, butyrate, Anaerostipes, zinc, heavy metals

Strategies for Mitigating Arsenic Accumulation in Food Crops

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Arsenic (As), a well-established human carcinogen, is a widespread environmental contaminant in rice-growing regions worldwide. Rice accumulates substantially higher levels of arsenic in grains than most other cereal crops, thereby posing significant risks to food safety and human health. To mitigate arsenic accumulation in rice and other food crops, we are developing innovative nano-biotechnological approaches aimed at reducing As uptake and translocation.

Using a biotechnological strategy, we investigated the role of aquaporins belonging to the Plasma Membrane Intrinsic Protein (PIP) and Nodulin 26-like Intrinsic Protein (NIP) subfamilies in arsenic transport in rice (*Oryza sativa*). Previously, four rice PIP genes (OsPIP1;3, OsPIP2;4, OsPIP2;6, and OsPIP2;7) were characterized in *Xenopus oocytes*, yeast, and *Arabidopsis thaliana*. Transgenic Arabidopsis lines expressing these genes exhibited enhanced tolerance to elevated arsenite [As(III)] concentrations without significant arsenic accumulation relative to wild-type plants. To elucidate their in-planta functions, RNA interference (RNAi) and overexpression approaches were employed to modulate OsPIP1;3 and OsPIP2;6 expression in rice. RNAi lines displayed significantly reduced transcript abundance and exhibited enhanced tolerance to As(III) under hydroponic and soil conditions, accompanied by a 16-30% reduction in arsenic accumulation compared with wild-type controls. In contrast, overexpression lines accumulated higher levels of arsenic. Furthermore, CRISPR/Cas9-mediated editing of the NIP transporters Lsi1 and Lsi2 reduced arsenic concentrations by 21-32% in roots and 62-74% in shoots, demonstrating their critical roles in root-to-shoot As translocation.

In parallel, we are exploring the use of novel nanomaterials to reduce arsenic accumulation. Nanoscale sulfur (NS), owing to its unique physicochemical properties, significantly enhanced rice tolerance to As(III) and reduced total arsenic accumulation in roots, shoots, and grains by more than threefold. Collectively, these technologies hold significant promise for reducing arsenic contamination in food crops and improving global food safety.

Keywords: Arsenic, rice, food safety, Genome editing, arsenic transporters

From Gene to Grain and Farm-to-Food Continuum: Integrating Plant Metal Biology and Synchrotron Science to Reduce Toxic Elements in Foods

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The accumulation of toxic elements in food crops poses a significant food safety challenge, particularly for products consumed by infants and young children. Addressing this challenge requires an integrated understanding of the biological mechanisms controlling contaminant accumulation and practical strategies that support both nutritional quality and consumer safety.

This presentation will highlight recent discoveries on the role of iron-regulated transporter 1 (IRT1) homologs in wheat and its proxy, Brachypodium distachyon, and their contributions to cadmium uptake and grain accumulation. These studies provide new insights into the transport pathways that govern the movement of essential nutrients and toxic elements in cereal crops and identify opportunities to breed crops with reduced cadmium concentrations in edible tissues.

An ongoing collaboration with infant food manufacturer Beech-Nut Nutrition seeks to identify critical control points across the farm-to-food continuum to reduce contaminant levels while maintaining nutrient density.

A central theme of the presentation will be applying synchrotron-based X-ray fluorescence (SXRF) imaging to visualize elemental distributions and determine chemical speciation in plant tissues, grains, and food products. These techniques provide unique insights into the localization and behavior of nutrients and contaminants, helping to guide crop improvement efforts and inform food processing strategies designed to produce safer, nutrient-rich foods.

Finally, I will introduce XLEAP (X-rays for Life, Environmental, Agricultural and Plant Sciences), a new NSF-funded beamline currently under construction at Cornell High Energy Source (CHESS). XLEAP will expand access to advanced X-ray imaging and spectroscopy capabilities and provide a powerful platform for addressing emerging challenges at the intersection of agriculture, environmental health, and food safety.

Keywords: cadmium, IRT1, brachypodium, wheat, Synchrotron X-Ray Fluorescence Microscopy, XLEAP

Let the Marsh Work: Natural Remediation in Tidal Wetland Systems

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Coastal marshes are dynamic, process-driven ecosystems that push back against disturbance-heavy remediation. When legacy contamination is present in a tidal wetland, the first question shouldn't be how to excavate or contain, it should be what the site is already doing, and whether the remedy can work with those processes rather than against them.

This presentation draws on a tidal marsh site to show how a multiple lines of evidence approach changes that conversation. Sediment and porewater chemistry, contaminant characterization, hydrologic data, ecological risk assessment, and long-term monitoring are read together to build a picture of where contamination is mobile, where it is stable, and where natural attenuation including microbial degradation, sediment accretion, tidal exchange, and vegetative recovery is already doing the work.

Phytoremediation fits naturally into this framework. Native marsh species are evaluated as candidates for vegetative uptake, rhizosphere-driven degradation, and sediment stabilization, particularly where contaminant mobility is low and ecological recovery is already underway. Rather than interrupting natural attenuation, phytoremediation builds on it. This presentation will review the multifaceted investigation and data collection effort within the marsh to document these processes.

Keywords: coastal resilience, wetlands, field study

La Goccia Urban Woodland - from a Polluted Spontaneous Ecosystem to a Public Green Area

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La Goccia is a large-scale urban regeneration project in Milan (Italy) which involves the innovative transformation of an 18-hectare former gasworks site into a new type of public park. The project focuses on applying a range of Nature-based Solutions (NbS) to remediate soils polluted by heavy metals and polycyclic aromatic hydrocarbons (PAHs), while preserving the forest that has grown spontaneously over the last few decades. The project began with an in-deep baseline analysis of the ecosystem (soil, flora, fauna and industrial remnants) and an integrated characterization of the site (chemical, agronomic, and microbiological). Based on the results of this two-year assessment, a NbS-driven remediation plan and landscape design were developed to transform the area into a public park. The site has been divided into lots, where different soil remediation technologies have been applied according to scalable timetables. Rhizodegradation and phytostabilisation interventions have been planned alongside physico-chemical remediation technologies. The whole project is founded on the principle of "working with the spontaneous forest", preserving and enhancing the effectiveness of the spontaneous vegetation and autochthonous microbiome in mitigating pollution. The soil restoration project is part of a larger plan, that values not only the existing natural ecosystem but also the industrial archaeological heritage. The area's intended use has enabled a pioneering approach to land reclamation, with the site gradually being returned to citizens and certain areas being left undisturbed by human activity in the long term. Since 2025, the project team has welcomed a large number of new partners, through the project EUI02-130 GOCCIA "Green opportunities to clean-up contaminants through an interspecies alliance", which is funded by the European Urban Initiative (EUI). The GOCCIA project partnership is developing extensive activities in the fields of communication and dissemination, stakeholder and citizen engagement, governance implementation, scientific studies, modelling and legacy transfer.

Keywords: Nature-based Solutions (NbS), contaminated brownfield, ecosystem monitoring, restoration, phytoremediation

Water Dynamics on a Landfill Phyto Cover Irrigated with Leachate

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This abstract reports the seasonal dynamics of evapotranspiration (ET) and evaporation (E) for water on the Mallard Landfill, Hoffman Estates IL. This evapotranspirative landfill cap (ETCap®) was planted in 2018. This landfill surface is 14 acres of trees irrigated with 5 million gallons of leachate per year.

This unlined pre-subtitle D landfill was closed in 1972; the surface and leachate collection systems were rebuilt in 2017. The landfill cover soil is ~4 ft deep. Six-foot tall poplar and willow trees with bare stems were planted to 42 inches bgs at a density 560 trees per acre.

The leachate is applied year-round via surface and subsurface drip irrigation. Evapotranspiration rates are highly seasonal. Subsurface soil moisture measurement documents water percolation into the subsurface and removal by evapotranspiration.

When well fertilized and irrigated, selected *Populus* (poplar) varieties typically grow about 8 to 10 vertical feet per year. As the trees gain height and leaf area, evapotranspiration increases, demonstrating the "clothesline effect." Large leaf areas moving in winds across the landfill surface increase potential transpiration. This evapotranspiration is sufficient to consume seasonal precipitation plus an additional twelve inches of irrigated leachate. Even with this added water, potential evapotranspiration further dewaters the root zone. Subsurface moisture measurements show that dormant-season water and snowmelt do not drain below the capillary fringe, beyond the reach of roots.

This landfill cover has had 35 million gallons applied in 8 growing seasons for savings to the owner of $1.4 million dollars in off-site treatment cost.

Keywords: landfill, poplar, leachate, clothesline effect

Paclobutrazol Enhances Phytoremediation Efficiency of *Sedum plumbizincicola* by Biomass Promotion and Flowering Inhibition

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Contamination of agricultural soils with cadmium (Cd) poses a serious risk to human health. One effective measure to improve the phytoremediation efficiency of the Cd/zinc (Zn) hyperaccumulator *Sedum plumbizincicola* is to increase biomass and prolong vegetative growth. Here, we investigated the regulatory effects of paclobutrazol (PBZ), a gibberellin synthesis inhibitor, on plant growth and flowering transition. Foliar application of 200 mg/L PBZ during vegetative growth increased branch number by 73.6%, stem biomass by 71% and leaf biomass by 94%, while enhancing antioxidant enzyme activities. Total Cd and Zn accumulation in shoots increased by 105% and 151%, respectively, due to the substantial biomass increase. During vernalization, it completely inhibited flowering when applied before flower bud differentiation, which extended vegetative growth by preventing seasonal senescence, thereby extending the metal uptake period. This study provides a low-cost and simple regulation strategy for enhancing phytoremediation of Cd-contaminated agricultural soils.

Keywords: paclobutrazol, *Sedum plumbizincicola*, growth promotion, flowering inhibition

Grass is a tattletale: using grass as a biomonitoring tool for remote sensing of coal combustion residue contamination

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Coal-fired power plants generate coal combustion residuals (CCRs), which are typically disposed of in landfills and surface impoundments that must be monitored to ensure that hazardous constituents such as arsenic (As) and selenium (Se) do not escape into the surrounding environment. Traditional methods for monitoring surface impoundments, such as sampling discharge of all outlets of hydraulic structures to approximate CCR concentrations, are highly resource-intensive and largely manual, posing a significant cost challenge for the stakeholders responsible for them. The use of grass species as bioindicators may offer a more efficient and sustainable method for long-term monitoring of CCR impoundments. In this study, we sought to determine whether three species of grass could serve as effective bioindicators for detecting changes in As and Se soil contamination profiles and provide an evaluation of three technologies used for evaluating plant health. *Lolium perenne*, *Panicum virgatum*, and *Paspalum notatum* were treated with As or Se and monitored with a spectroradiometer and multispectral camera to detect a spectral response to the chemical stress. Metal transfer analysis revealed that there was a significant change in metal concentrations in plant tissue across the grass species and different treatments, with *Paspalum virgatum* providing the best dose response after a week of Se treatment. *Lolium perenne* provided a response past the Se toxicity threshold of 5 mg/kg. We then expanded this study to a field scale to determine if our results would translate to an environmentally relevant scale. Unmanned aerial vehicle (UAV) results suggested *Lolium perenne* was efficient in determining whether CCR was present in soils but lacked sensitivity to differentiate between low and high loadings. Monthly sampling also revealed that metal concentration in plant tissue decreased as plants underwent senescence. Data collected with the UAV proved to be the most proficient method of determining a dose response.

Citric acid-driven Cadmium Uptake and Growth Promotion Mechanisms in *Brassica napus*

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Citric acid (CA) is widely recognized for alleviating cadmium (Cd) toxicity in plants; however, its mechanisms underlying growth promotion, Cd detoxification, and phytoremediation remain insufficiently understood. This study evaluated effects of exogenous CA (2.5 mM) on *Brassica napus* grown in Cd-contaminated substrate (30 mg/kg) using a controlled pot experiment. Cd exposure alone significantly impaired physiological parameters of *B. napus*. In contrast, CA application significantly ($p<0.05$) improved physiological traits, Cd tolerance, and detoxification via regulation of genes involved in photosynthesis and Cd transport, including Cd/Zn heavy metal-transporting ATPase 1 (HMA1) and light-harvesting chlorophyll a/b-binding 3 (LHCB3). Notably, CA increased Cd accumulation in stems (4%) and leaves (35%), enhancing bioconcentration factors (BCF) by 12% in stems and 40% in leaves while reducing root BCF by 10%. This translocation was associated with upregulation of HMA4, HMA2, and plant Cd resistance (PCR2) genes in leaves, enhancing Cd mobility within the plant.

Additionally, CA induced a 34% increase in phytochelatins and 32% upregulation of metallothioneins, accompanied by reduced oxidative stress markers, including a 40% decrease in hydrogen peroxide and a 44% decline in malondialdehyde in leaves. Enhanced antioxidant enzyme activity and osmolyte accumulation further improved Cd sequestration and photosynthetic efficiency, resulting in increased biomass and Cd tolerance. Transcriptomic analysis revealed 12,291 differentially expressed genes (DEGs), with 750 common genes downregulated in CK vs Cd and upregulated in Cd vs Cd-CA treatments. Moreover, CA modulated 11 DEGs associated with 32 gene ontologies in citrate pathway under Cd stress, indicating targeted metabolic regulation. Overall, CA enhances Cd phytoextraction efficiency in *B. napus* through integrated physiological, biochemical, and transcriptomic mechanisms, providing mechanistic insights for phytoremediation improvement and sustainable management of Cd-contaminated agricultural systems with improved environmental safety and crop productivity. These findings support CA as an effective eco-friendly amendment for enhancing phytoremediation strategies and reducing Cd risks.

Keywords: Cadmium, oilseed crops, organic chelators, phytotechnologies, soil health

Root-to-Fruit Partitioning of Silver Nanoparticles and Plant Elemental Homeostasis

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The increasing use of silver nanoparticles (AgNPs) raises questions about their uptake, translocation, and accumulation in crop plants, particularly their potential to reach edible tissues and influence the distribution of essential elements. While root uptake of AgNPs has been widely investigated, their partitioning across plant organs and potential relationships with plant elemental homeostasis and fruit characteristics remain less understood. In this study, we investigated the root-to-fruit distribution of Ag following exposure to AgNPs, ionic silver ($AgNO_3$) as a comparative treatment, and examined associated changes in the elemental composition of different plant tissues. Plants were exposed to 30 mg/L AgNPs or $AgNO_3$ for 30 days. Silver accumulation and elemental profiles were assessed in roots, stems, leaves, and fruits using ICP-MS, while synchrotron-based imaging and scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDX) provided spatial information on Ag and other elements within selected tissues. X-ray computed tomography and PhenoSight imaging were used to evaluate fruit structural and phenotypic characteristics. Ag accumulated predominantly in roots following both AgNPs and $AgNO_3$ exposure but was also detected in fruits and seeds, demonstrating root-to-fruit translocation. Exposure was further associated with tissue-specific changes in essential elements, with K, Cu, Mn, and Zn generally higher upon exposure to $AgNO_3$, followed by AgNPs, compared with controls. Together, these complementary analyses provide a plant-wide perspective on AgNP partitioning from roots to edible tissues and demonstrate that Ag exposure is accompanied by tissue-specific changes in elemental homeostasis. These findings advance our understanding of the implications of nanoparticle exposure for mineral nutrient distribution and the quality and safety of edible plant tissues.

Keywords: elemental homeostasis, elemental partitioning, fruit quality, food safety

Assessing the Efficacy of Cellulose Nanofibers Soil Amendment in Reducing Heavy Metal Bioavailability and Accumulation in Lettuce

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Heavy metal contamination of agricultural soils poses serious risks to food safety and crop productivity. While metal-based nanomaterials have shown promise in reducing heavy metal uptake in crops, their potential phytotoxicity over time remains a concern. Cellulose nanofibers (CNF) fabricated by nitro-oxidation of jute (*Corchorus olitorius*) offer a biodegradable alternative with demonstrated efficacy in removing heavy metals from water. This study investigates whether CNF incorporation in contaminated soil can similarly reduce heavy metal bioavailability and plant uptake.

We hypothesized that CNF would adsorb and chemically bind heavy metals from the soil solution, reduce the bioavailable contaminant fraction, and consequently improve plant growth while limiting accumulation.

A loamy sand soil was spiked with sodium arsenate, cadmium chloride, and lead nitrate to achieve individual contamination levels of 50 ppm arsenic (As), 50 ppm cadmium (Cd), and 200 ppm lead (Pb), as well as a mixed contamination treatment (As & Cd: 10 ppm; Pb: 40 ppm). CNF was incorporated at 1% dry weight, and soils were equilibrated for one week at 60% water-holding capacity. Three-week-old lettuce (*Lactuca sativa*) seedlings were transplanted and grown for six weeks. The experiment was simultaneously conducted in a clay-rich soil to assess the influence of soil texture on CNF efficacy. Plant and soil samples will be analyzed for metal fractionation and total accumulation, while the mechanism of action of CNF will be parsed out by biochemical and molecular studies of the plant samples.

This work explores the potential of a novel, biodegradable strategy for heavy metal immobilization in agricultural soils, with implications for sustainable remediation and food safety.

Keywords: Cellulose Nanofibers, Heavy Metals, Soil Amendment, Food Safety

Phytoremediation of Sb-contaminated soils enhanced by the addition of organic acids and irrigation supplemented with oxygen-nanobubbles

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Antimony (Sb) is considered to be a toxic metalloid of increasing prevalence in the environment. Although several phytoremediation studies have been conducted, research regarding the mechanisms of Sb accumulation and translocation within plants remains limited. Phytoremediation presents a promising technology for treating shooting range soils contaminated with toxic metalloids. Experimental results from an earlier hydroponic study demonstrated that both *Tamarix smyrnensis* and *Nerium oleander* plants are suitable for phytoremediation due to substantial Sb accumulation without visible Sb toxicity. In this study, soil from a shooting range was collected with an initial Sb(III) concentration of 50 mg/kg. An experiment was conducted to investigate whether *Nerium oleander* could accumulate Sb in the root and further translocate it to the aboveground tissues. Biostimulation of the soil was performed by the addition of organic acids (OAs), consisting of citric, ascorbic, and oxalic acid at low (7 mmol/kg) or high (70 mmol/kg) concentrations. The impact of irrigation with water supplemented with oxygen nanobubbles (O_2NBs) was also investigated. The results demonstrate that there was a loss in plant growth in all treatments and the presence of OAs and O_2NBs assisted the plant to maintain the water content at the level close to the control. The plant was not affected with regards to chlorophyll content in all treatments, while the antioxidant enzyme activity of guaiacol peroxidase (GPOD) in the roots was found to be significantly higher in the presence of Sb. Results revealed that Sb accumulation was greater in the treatment with the highest OAs concentration, with a bioconcentration factor greater than 1.0. The translocation of Sb for every treatment was very low, confirming that *N. oleander* plant cannot transfer Sb from the root to the shoots. A higher amount of Sb was accumulated in the plants that were irrigated with the O_2NBs, although the translocation of Sb was not increased. The present study provides evidence for the phytoremediation capacity of *N. oleander* to bioaccumulate Sb when assisted by biostimulation with OAs and irrigated with nanobubbles. Experimental results by the halophyte *T. smyrnensis* bioaugmented with the endophytic community suggest that *T. smyrnensis* represents a promising alternative for remediating shooting range soils especially in areas impacted by salinity.

Soil Dieldrin Removal by Phytoextraction: a Promising Approach for Agricultural OCP-contaminated Soil Management and Remediation

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Dieldrin, an organochlorine pesticide (OCP) once widely used in agriculture, was banned in France in 1972 for agricultural purposes and later classified as Persistent Organic Pollutants (POPs) under the Stockholm Convention in 2001. Despite its prohibition, dieldrin remains in agricultural soils due to its persistence, posing risks to food safety, farm sustainability, and other environmental issues. Certain plant species, especially those from the Cucurbitaceae family, are known to uptake and accumulate dieldrin in above-ground plant parts, sometimes exceeding regulatory Maximum Residue Limits (MRLs) in fruits. Given its toxicity, solutions are urgently needed to ensure safe crop production and remediate contaminated soils.

In previous works, dieldrin accumulation in *Cucurbita pepo* sbsp. pepo was higher in vegetative shoots, with dieldrin concentration of about 2000 and 8000 µg/kg DW in stem and leaves, respectively, and between 200 and 1500 µg/kg DW in fruits. This suggested that it is possible to both extract dieldrin from soil and produce zucchini with low dieldrin content (below MRL of 1000 µg/kg DW) by cultivar selection. This study aimed at demonstrating the feasibility of this phytomanagement and remediation technique in real field conditions. The "Courgette verte non coureuse des maraichers" aka "Noire maraichre" presenting low dieldrin accumulation in fruit was selected and grown in open field on a soil with historical dieldrin contamination. Two successive growth were conducted with a plant density slightly below 3 plant/m2. The dieldrin content was determined in fruit (intended for sale), in the harvested shoots (to figure soil dieldrin removal) and twice in soil (before and after the plant growth).

This study is ongoing and the results will be acquired by the end of summer 2026. They should demonstrate that it is possible to grow *C. pepo* sbsp.pepo on soil historically contaminated with dieldrin, producing zucchini fruit with dieldrin concentration below the MRL, whilst removing bioavailable dieldrin from the soil via phytoextraction through the successive harvesting of the plant's above-ground parts.

Keywords: Organochlorine pesticides, soil contamination, phytoextraction, phytomanagement

Early Uptake Dynamics and Stress Responses of *Plantago coronopus* during Exposure to Key Pharmaceutical Micropollutants

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Pharmaceutical residues such as carbamazepine (CBZ) and gemfibrozil (GEM) are recurrently reported in treated effluents and receiving waters, reflecting their limited removal in conventional wastewater treatment. This work investigates the early behavior of these compounds in a hydroponic plant-based system, using *Plantago coronopus* as a model species. Plants were exposed to a CBZ-GEM mixture (10 µg/L each) for up to 7 days, and pollutant removal, plant uptake and physiological responses were monitored over time.

The presence of *P. coronopus* substantially accelerated CBZ dissipation from the aqueous phase, with removal efficiencies exceeding 80% at the end of the exposure period, in clear contrast to abiotic controls. In the case of GEM, removal was largely governed by non-biological processes, although transient plant-related effects were detected during the initial exposure stages. Both pharmaceuticals were taken up by the plants, displaying distinct accumulation and translocation patterns: CBZ progressively increased in aerial tissues, whereas GEM remained mainly confined to roots. These trends were reflected in time-dependent increases in bioconcentration factors, particularly for CBZ.

Exposure to the pharmaceutical mixture triggered early physiological adjustments in *P. coronopus*, including changes in oxidative stress indicators, soluble protein and phenolic levels, and photosynthetic pigments. Together, these findings underline the capacity of *P. coronopus* to contribute to the attenuation of persistent pharmaceuticals and provide insight into the short-term dynamics and plant responses underpinning phytoremediation processes.

Keywords: Phytoremediation, Uptake dynamics, Translocation factor, Bioconcentration factor, Plant physiological responses

Phytoforensic Analysis of 1,4-dioxane to Assess Plant Uptake and Bio-augmented Rhizodegradation

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1,4-dioxane (dioxane) is a persistent groundwater contaminant, classified as a probable carcinogen, that presents challenges for both remediation and analytical detection because of its unique physicochemical properties. As part of a pilot-scale testing of a bio-augmented treatment system, phytoforensics approaches are developed to monitor treatment efficacy and evaluate lab-scale assessment of our mechanistic understanding. We demonstrate HS-SPME/GC-MS approaches for plant-based sampling as a minimally invasive, cost-effective means to detect low dioxane concentrations (0.5 ppb) in plant tissues and in aqueous samples and as an early indicator tool to guide sampling and remediation. Bioaugmented phytoremediation is a promising alternative for treating dioxane-contaminated groundwater. We present an application of phytoforensic analysis of dioxane to assess plant uptake and rhizodegradation at a pilot-scale demonstration using Phyto Attached Growth Reactors (PhAGRs) planted with poplar and willow and bioaugmented with *Rhodococcus ruber* 219 and with variable biochar amendment to treat dioxane-contaminated groundwater at the former Twin Cities Army Ammunition Plant (TCAAP), Arden Hills, MN, USA.

Keywords: Phytoforensics; 1,4-dioxane

Bioaccumulation and Seasonal Cycling of PFAS in Native Chesapeake Bay Aquatic Vegetation

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Per- and polyfluoroalkyl substances (PFAS) are persistent contaminants widely detected in aquatic ecosystems, yet their interactions with submerged aquatic vegetation (SAV) remain poorly understood. Because SAV constitutes a major component of estuarine biomass, uptake and release of PFAS by aquatic plants may influence contaminant cycling and food-web exposure. This study investigated seasonal bioaccumulation of PFAS in two native Chesapeake Bay macrophytes, wild celery (*Vallisneria americana*) and coontail (*Ceratophyllum demersum*), and evaluated their potential role in PFAS cycling.

Plant and water samples were collected from two sites in the tidal Potomac River during four sampling campaigns spanning the SAV growing season. Samples were analyzed for 24 PFAS congeners using LC-MS/MS. Additional laboratory depuration experiments were conducted to assess potential PFAS release from plant tissues.

Seventeen PFAS congeners were detected in plants and eleven in surrounding waters. Short-chain PFAS dominated both matrices, with perfluorobutanoic acid (PFBA) representing the most abundant congener. Total PFAS concentrations in aquatic plants decreased significantly during the growing season, from 42 ± 30 ng/g dry weight in May to 9 ± 8 ng/g in September, whereas concentrations in water increased from 104 ± 4 ng/L to 247 ± 3 ng/L. Bioconcentration factors were highest during early growth stages and declined as plants matured. Coontail accumulated significantly higher PFAS concentrations than wild celery, indicating species-specific differences in uptake and retention.

Depuration experiments demonstrated sustained release of PFAS from plant tissues over 36 days, producing PFAS water concentrations of up to 360 ng/L and 260 ng/L from coontail and wild celery, respectively. These findings suggest that SAV functions both as a temporary sink and a secondary source of PFAS. Seasonal uptake and release by aquatic plants may therefore contribute to PFAS cycling in estuarine ecosystems and should be considered in future monitoring and risk assessment efforts.

Keywords: Per- and polyfluoroalkyl substances (PFAS), submerged aquatic vegetation (SAV), Chesapeake Bay

Immobilization and Phytoextraction: Strategies to limit PFAS food contamination or improve soil remediation

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Effective strategies are urgently needed to mitigate the environmental and health risks posed by per- and polyfluoroalkyl substances (PFAS). Here, we present two approaches for PFAS management that leverage material- and plant-based interventions.

The first approach focuses on immobilizing PFAS in soil using hemp-derived biochar fortified with iron (FBC), designed to reduce mobility and limit PFAS bioavailability. We evaluated PFAS accumulation in radish (*Raphanus sativus* L.) grown in polluted soil (~580 ng/g total PFAS) amended with 2 wt.% FBC. The FBC amendment reduced PFAS accumulation in radish bulbs by 26%, demonstrating that this confining strategy can limit PFAS uptake by crops, mitigating risks to food safety.

The second and opposite approach focuses on enhancing PFAS phytoextraction using ultraporous mesostructured silica nanoparticles (UMNs) functionalized to tune hydrophobicity and surface charge. Tuning surface charge was more effective for enhancing PFAS removal than modifying UMNs' hydrophobicity. Nonetheless, molecular modeling results highlight the importance of combining hydrophobic and electrostatic interactions to drive PFAS uptake.

Together, these findings advance understanding of plant-material-PFAS interactions, providing a basis for the design of sustainable strategies to limit PFAS mobility or enhance their removal from the environment.

Keywords: Food safety, immobilization, PFAS, phytoremediation, phytoextraction

Uptake, Translocation, and Thermal Degradation of Perfluoroalkyl Substances in Plants: Implications for Food Security and Phytoremediation

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Per- and polyfluoroalkyl substances (PFAS) are known to persist in many environments and can accumulate in plants, impacting food security. A matrix-assisted laser desorption/ionization mass spectrometry imaging (MALDI-MSI) technique was used to assess the fate of PFAS in vascular plants, specifically to investigate root uptake, xylem translocation, and accumulation. Poplar tree cuttings and tomato plants after their root formation were grown with a dosing solution containing 1 ppm each of 4 PFAS compounds (PFBS, PFHxS, PFOS, and PFOA). MALDI-MSI revealed that four PFAS had notably different fates in transport and highly varied distribution in tissues. PFAS were mainly retained in the epidermis and cortex of roots, with the long-chain PFOS predominantly retained at the root membrane interface and at the Casparian strip due to its hydrophobicity and affinity for the interfaces and selective barriers to transport into the food chain. In contrast, the short-chain PFBS tended to penetrate inward in root and was transported upward in the xylem tissues, showing substantial accumulation at leaf tip and distal margins. Their heterogeneous distribution in roots, stems, and leaves is a unique finding and lends insight into the fate of PFAS in plant tissues. The results from LC-MS/MS analysis of extracted samples also validated the tissue-specific PFAS translocation and accumulation. High-temperature treatment of the PFAS dosed poplar cuttings yielded >99% thermal degradation efficiency for all 4 PFAS. Our findings contribute to a comprehensive understanding of the fate of PFAS in plants and provide insight into mechanisms of root uptake, translocation, tissue-specific accumulation, and, most importantly, the sub-tissue accumulation at vascular interfaces in the plants. Subsequent thermal degradation of the PFAS accumulated plants provides a potentially feasible disposal pathway for phytoremediation.

Keywords: Per- and polyfluoroalkyl substances, matrix-assisted laser desorption/ionization mass spectrometry imaging, phytoremediation, food risk, spatial distribution.

Phytoremediation of PFAS: Critical Evaluation of Mechanisms, Performance, and Sustainable Field Applicability

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As regulatory standards for per- and polyfluoroalkyl substances (PFAS) continue to evolve and the number of impacted sites grows, remediation professionals face increasing pressure to identify solutions that balance effectiveness, cost, and long-term stewardship. While conventional treatment technologies can capture and concentrate PFAS, they are often energy-intensive and difficult to scale across large or diffuse plumes. In addition, many impacted areas present physical or operational constraints that limit the use of engineered remediation systems. These challenges have renewed interest in phytoremediation as a complementary strategy for sustainable site management.

This presentation draws on both peer-reviewed research and empirical evidence from ongoing research and development efforts to examine plant uptake and translocation of PFAS. Published studies indicate that short-chain PFAS tend to accumulate in aboveground plant tissues, while longer-chain compounds are more commonly retained in root systems. These patterns have important implications for plume stabilization and contaminant mass management and provide a foundation for evaluating phytotechnology performance under field conditions.

Building on this body of research, the session will highlight emerging work investigating plant-associated microbial endophytes and their potential role in influencing contaminant uptake, transformation, and plant tolerance under PFAS exposure. Ongoing laboratory and applied research efforts are evaluating whether endophyte-plant partnerships can enhance phytoremediation performance and expand the range of conditions under which vegetation-based systems may be effective. Additional investigations are examining the spatial distribution of PFAS within foliar tissues to better understand compound accumulation at the tissue scale and inform biomass management and harvesting strategies.

These research efforts are particularly relevant for large or operationally constrained sites where installation of engineered treatment systems may be impractical, including extensive PFAS-impacted soils associated with firefighting training areas and other active infrastructure. By connecting mechanistic research with applied implementation considerations, this work highlights the potential for phytoremediation to contribute to next-generation PFAS site management.

Keywords: PFAS

A Phyto-Enhanced In-Situ Retention (PEIR) Barrier to Intercept a Groundwater PFAS Plume -- The First Step in Creating a Circular Economy PFAS Remedial Approach

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Per- and polyfluoroalkyl substances (PFAS) are recalcitrant contaminants due to their unique fate and transport, long half-lives, high toxicity, and widespread distribution in the environment. The difficulty in destroying PFAS in-situ means that current PFAS remedies rely on expensive/energy intensive ex-situ treatment (e.g., pump and treat, thermal desorption), making PFAS remediation a daunting and seemingly "forever" proposition. Translocation of PFAS in the environment to plants is well established and offers a more sustainable means to address PFAS. But then what? Do we create unintended exposure pathways or secondary waste streams?

We developed a phyto-enhanced in-situ retention barrier (PEIR Barrier™) approach to capture PFAS impacted groundwater while reducing risks related to secondary exposure and waste stream management. Our approach primarily captures PFAS in sorption media placed in the impacted aquifer. The phyto-component of the PEIR Barrier generates inward directed gradients to enhance capture, facilitate retention of hard-to-treat short chain PFAS and extend the remedy lifecycle. The retention media purposefully limits undesired uptake of long chain PFAS into tree tissue.

We present a 2022 PEIR Barrier pilot implemented to address a groundwater PFAS plume in Michigan. The pilot combined soil-mixed Bioavailable Absorbent Media™ (engineered biochar) with engineered Treewell® phytoremediation. Over four seasons of monitoring, total PFAS (>5,000 ng/L) are reduced in groundwater by >99% and in treated leaf tissue by 68% to >99%. Short chain PFAS are retained in the rhizosphere possibly as part of the seasonal nutrient cycle. Endophyte inoculations also show promise for increased PFAS retention in the barrier. End of life PFAS destruction by pyrolysis offers a sustainable means to close the PFAS loop by generating retention media for future use at the site. The PEIR Barrier was extended by 580 feet in 2025-2026 and its lifecycle cost is estimated to be <75% of a pump and treat system.

Keywords: PFAS, Phytoretention, Circular Economy, Remediation

Engineering High-Biomass Plant Platforms for Critical Element Recovery

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Technology critical metals like platinum group metals (PGMs), noble metals, nickel and rare earth elements (REEs) are essential for developing technologies; however, their mining has significant environmental impacts, including high carbon emissions and pollution. Mine wastes can still contain significant levels of these valuable elements, but at concentrations that are generally too low for economic extraction through traditional mining. Combining phytoremediation with phytomining could restore damaged land and recover these valuable technology-critical metals.

Hyperaccumulators are plant species that have evolved to thrive in geologically metal-rich regions by storing metals within their aerial tissues to many thousand-fold higher than their background environment. This phenomenon is already being commercially harnessed for examples, to recover nickel from Serpentine regions in Southern Europe. However, while hyperaccumulators exist for nickel, there are no high-biomass species capable of establishing in the swathes of polluted soils and tailings produced by the mining and associated industries across the Northern Hemisphere. Furthermore, and perhaps unsurprisingly given their rarity and chemical insolubility, there are no known hyperaccumulators for PGMs and gold.

Metal uptake by plants is limited by their solubilization in the rhizosphere, with subsequent uptake controlled by transporters. Once inside the plant, a suite of endogenous detoxification strategies bind, transport and sequester the metals. Together, these processes are carefully regulated.

Biotechnological advances, such as genetic engineering and synthetic biology, offer enormous opportunities to enhance the natural capabilities of plants to selectively recover specific metals. Our research is focused on understanding the biology behind metal hyperaccumulation; solubilization, uptake, detoxification and sequestration, to ultimately develop artificial hyperaccumulators. We work on model molecular biology species such as *Arabidopsis thaliana* but also "real world" species including biomass hybrid willow (*Salix* sp.), poplar (*Populus* sp.) and *Phytolacca america* (pokeweed). Beyond metal accumulation, we look to valorize metal-rich biomass using the presence of these catalytically-active *in planta* metals to enhance production of biofuels and platform chemicals, and enhance the financial viability of environmental restoration.

Keywords: Phytomining, Phytoremediation, Synthetic Biology, Critical Raw Materials, Biomass Valorization

A Multiscale Platform for Imaging and Chemical Characterization of Rare Earth Elements in Plants

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Rare earth elements (REEs) are essential components of modern technologies, yet the biological mechanisms governing their uptake, transport, and sequestration in plants remain poorly understood. Hyperaccumulator species provide a unique opportunity to investigate these processes while informing sustainable approaches to REE recovery from low-grade resources. However, determining not only where REEs accumulate within plant tissues but also their chemical coordination environment remains a significant challenge.

We are developing an integrated platform that combines quantitative elemental analysis, fluorescence-based imaging, and synchrotron spectroscopy to characterize REE accumulation across multiple spatial and chemical scales. Building on a recently developed dysprosium fluorescence detection method, this workflow enables high-throughput non-destructive screening for REE uptake, determines REE localization within plant tissues, and guides targeted chemical characterization. We are optimizing our fluorescence detection to identify additional REEs and are incorporating synchrotron X-ray absorption spectroscopy studies to evaluate the coordination environment of REEs within plant tissues and compare plant-associated REEs with relevant reference compounds.

Together, these complementary approaches establish a framework for linking elemental localization with chemical speciation, providing new insight into plant-REE interactions and laying the foundation for improved understanding of REE hyperaccumulation and phytomining.

Keywords: Rare earth elements, phytomining, imaging

Exploring Rare Earth Element Uptake and Localization in Hyperaccumulating Plants

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Rare earth elements (REEs) are essential components of modern technologies, yet remarkably little is known about how they interact with biological systems. Some plant species accumulate substantial concentrations of REEs, providing opportunities to investigate how these elements are taken up, distributed, and retained within plant tissues. Understanding these processes has implications for both fundamental plant biology and the development of sustainable approaches for REE recovery from low-grade resources.

In this study, we examine REE accumulation in Phytolacca species using elemental analysis to quantify the abundance of individual REEs in plant tissues following controlled exposures. By comparing multiple REEs under standardized growth conditions, we establish a framework for evaluating accumulation patterns and plant-to-plant variation, and provide baseline measurements for future mechanistic studies.

This work contributes to a growing understanding of plant-REE interactions and provides a quantitative foundation for ongoing efforts to investigate REE transport, imaging, and recovery methods in biological systems, which can be leveraged to improve phytomining, environmental remediation, and our understanding of REE biology.

Keywords: Rare earth elements, phytomining

Long-Term Amendment-Assisted Phytoremediation and Geochemical Stabilization of Pb/Zn/Cu Mine Tailings

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Innovative revegetation strategies can improve plant establishment on mine tailings while promoting ecosystem restoration and soil development. Previous greenhouse studies showed that biosolids amendments significantly improved both plant growth and tailings properties. However, biosolids alone may not sustain long-term vegetation because of nutrient lability and rapid decomposition. To address this limitation, a long-term greenhouse study was conducted to evaluate whether the synergistic co-application of biosolids with recalcitrant organic amendments such as biochar, together with arbuscular mycorrhizal fungi (AMF) as a biological amendment, could prolong amendment benefits, improve tailings properties, and support sustainable plant establishment while stimulating soil-forming processes.

Tailings were collected from a Pb/Zn/Cu tailings impoundment in Viburnum, Missouri, USA. Experimental substrates were prepared by amending only the upper 8 cm, while the lower 12 cm remained untreated tailings. After 7 years of sustained growth of the native species purple prairie clover (*Dalea purpurea*), treatment combinations resulted in significant differences in agronomic and geochemical properties. Inoculation with native AMF strains played an important role in shaping soil microbial communities, as assessed by phospholipid fatty acid analysis (PLFA), particularly microbial groups associated with carbon and nutrient cycling. Organic carbon accumulation followed a similar pattern, with greater accumulation observed in AMF-inoculated treatments. These effects extended into deeper, unamended tailings layers, suggesting that surface amendments and soil-root-microbe interactions stimulated belowground development beyond the treated zone.

Patterns in microbial community abundance indicated that AMF-inoculated plant roots promoted microbial colonization in severely degraded substrates that would not otherwise support vegetation. Overall, the results demonstrate that synergistic amendment-assisted revegetation can enhance ecological function and geochemical stabilization in metal-bearing mine tailings, with implications for reducing environmental risk and guiding long-term restoration of highly degraded mine wastes.

Keywords: Phytostabilization, Revegetation, Arbuscular mycorrhizal fungi, Biochar, Mining-impacted lands

Environmental Impact Assessment of Critical Mineral Extraction from Legacy Mine Tailings

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Legacy mine tailings are increasingly being considered as secondary sources of critical minerals; however, the environmental risks associated with residual materials generated during reprocessing remain poorly understood. This study evaluated the environmental impacts of reprocessing two tailings types: copper mine tailings and multimetal Zn/Pb/Cu mine tailings. A phytotoxicity-based framework, consisting of petri dish and pot experiments, was used to compare germination, root elongation, and overall plant responses of reprocessed residuals relative to unprocessed raw tailings using two native species, Illinois bundleflower (*Desmanthus illinoensis*) and little bluestem (*Schizachyrium scoparium*). These tests capture interactions among residual composition, water, and metal bioavailability and provide an efficient screen for environmental risk through root uptake from contaminated media.

In petri dish experiments, seedlings were exposed to low- and high-concentration leachates derived from raw tailings and residual tailings generated using different extraction and flotation approaches, including conventional extractants, chitosan-based green extractants, and sodium hydrosulfide (NaSH)-associated extractants. Shoot traits were quantified using PlantCV, and root traits were measured using WinRHIZO. Across treatments, leachates from reprocessed copper tailings generally supported greater seedling growth than raw tailings, indicating lower phytotoxicity of several residual materials relative to untreated tailings, whereas the opposite trend was observed for Zn/Pb/Cu tailings. For both tailings types, however, chitosan-based treatments promoted enhanced seedling growth. Similarly, NaSH-associated treatments were linked to enhanced root development, consistent with a possible low-dose stress-mitigating effect on plant tolerance.

Ongoing work is extending this study through pot experiments using biosolids, compost, and arbuscular mycorrhizal fungi, together with sequential extraction analyses to assess metal fraction shifts, bioavailability, and long-term environmental risk. These results show that the environmental behavior of reprocessed tailings depends strongly on tailings composition and extraction chemistry, informing more environmentally responsible critical mineral recovery and guiding management and restoration of reprocessed tailings.

Keywords: Critical mineral recovery, Legacy mine tailings, Phytotoxicity, Metal bioavailability, Environmental risk

Investigating Myco-Phytoremediation in a Restored Multi-Functional Riparian Forested Buffer

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A restoration project tested whether mycorrhizae can improve phosphorus (P) mitigation, and pollinator functions of degraded riparian forested buffers (RFBs) on a Vermont farm while facilitating Wabanaki ancestral land access. Six plots within a degraded RFB were restored with a multi-functional plant community. Three restored plots were inoculated with endemic mycorrhizae (RVM), three restored plots were not inoculated (RV), and three control plots (OIV) remained in their degraded state, dominated by *Rhamnus cathartica*. The restoration palette consisted of 42 (10 tree, 6 shrub, 16 herbaceous,10 groundcover) species which were pollinator hosts and beneficial to Abenaki, offering P removal opportunities through honorable harvest. While total soil P, Mehlich III extractable P, and water extractable soluble reactive P (WEP-SRP) in RV & RVM treatments were not significantly different, soil concentrations in OIV were significantly higher ($p < 0.001$) than in the restored plots. This consistent pattern across P metrics suggests restoring a degraded RFB with a diverse, multi-synusial palette can mitigate P while providing pollinator habitat, and lifeways. While there was no statistically significant difference for plant P uptake in restored treatments, phytoextraction via cyclical harvest has promising implications for reducing P concentrations in runoff and percolate. Plant P uptake data can be incorporated into models which quantify P removed via phytoextraction, recompensing land managers in Pays for Performance programs. Plant diversity was significantly different between the control and restored plots ($p < 0.001$), as expected, but not between restored plots. Within 3 years of restoration, a mean 33 volunteer plant species appeared. 43 genera of pollinators were recorded across restoration treatments, including globally vulnerable (G3) *Bombus terricola* and VT imperiled (S2) *Bombus citrens*. Restoration with native, polyculture palettes, non-chemical removal of *R. cathartica*, and strategically timed plant harvest maximizes RFB's ecological resilience and begins socio-ecological reconciliation of colonial agriculture's legacy

Keywords: phytoremediation, waterquality, riparianforestedbuffers, ecologicalrestoration, multifunctional

Arbuscular Mycorrhizal Symbiosis in Miscanthus: Responses to Extreme Soil Metal Contamination

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Arbuscular mycorrhizal fungi (AMF) play a central role in plant adaptation to abiotic stress, yet their functioning in perennial bioenergy crops cultivated on heavily contaminated soils remains insufficiently understood. This study provides an integrated overview of AMF colonization patterns, community structure, and plant-fungus interactions in *Miscanthus x giganteus* and seed-based hybrids grown under mercury, lead, cadmium, and zinc contamination. Across controlled pot and multi-season field experiments, heavy metal stress significantly influenced AMF root colonization. Under extreme Hg contamination, both the frequency and intensity of colonization declined, indicating that severe metal toxicity constrains symbiotic development. In field conditions contaminated with Pb, Cd, and Zn, colonization levels varied among genotypes and decreased in response to combined environmental stressors such as drought. Distinct differences among Miscanthus hybrids were observed, suggesting that host genetic background shapes mycorrhizal establishment and stability under metal stress. High-throughput sequencing of the LSU rDNA region revealed clear contamination-driven shifts in AMF community composition within *M*. x *giganteus* roots. Highly contaminated soils were characterized by the predominance of genera such as *Diversispora* and *Claroideoglomus*, whereas moderately contaminated and uncontaminated sites showed communities dominated by *Rhizoglomus*. Several AMF taxa were detected exclusively in roots from contaminated areas, indicating ecological specialization and potential metal tolerance within specific fungal lineages. Heavy metal stress also coincided with reduced photosynthetic performance and biomass production, alongside diminished mycorrhizal colonization, underscoring the sensitivity of the symbiosis to extreme conditions. Nevertheless, the persistence of adapted indigenous AMF taxa demonstrates that functional plant-fungus associations can be maintained even in highly degraded soils. Overall, the results highlight the dynamic and genotype-dependent nature of AMF-Miscanthus interactions under heavy metal stress and emphasize the importance of understanding AMF community assembly and resilience in perennial cropping systems exposed to long-term contamination.

Keywords: Arbuscular mycorrhizal fungi; Diversity; Heavy metals; *Miscanthus x giganteus*

Fungi Increase Lead, Arsenic and Hexavalent Chromium Phytoremediation from Contaminated Soils in Los Angeles

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Urban soils in Los Angeles are frequently impacted by legacy contamination, including lead (Pb), arsenic (As), and hexavalent chromium (Cr), posing ongoing risks to human and ecosystem health. Nature-based remediation strategies that are both effective and resilient to climate stressors are urgently needed. This study evaluates the role of arbuscular mycorrhizal fungi (AMF) and the decomposer fungus Pleurotus ostreatus in enhancing phytoremediation outcomes across three contaminated brownfield sites in Los Angeles, with a focus on comparing stimulation of native AMF communities versus augmentation through inoculation.

Field trials were conducted under both drought and irrigated conditions to assess the performance of AMF-plant partnerships in water-limited environments. Results demonstrate that AMF inoculation significantly increased plant biomass, establishment, and survival across all sites, particularly under drought stress. Inoculated systems also showed enhanced phytoextraction of Pb and As, indicating improved metal uptake relative to non-inoculated and stimulated-only treatments. Unexpectedly, inoculation with the decomposer fungus also increased phytoextraction of Pb.

In addition to trace metal uptake, AMF treatments contributed to measurable reductions in hexavalent chromium [Cr(VI)] concentrations, alongside evidence suggesting shifts in chromium redox dynamics toward less oxidized forms. These findings highlight the dual role of AMF in both facilitating plant-mediated contaminant removal and influencing soil geochemical processes.

Overall, this work underscores the potential of AMF-based approaches as scalable, climate-resilient tools for ecological remediation of contaminated urban soils. Integrating AMF inoculation into phytoremediation design may significantly enhance remediation efficiency, particularly in semi-arid regions facing increasing drought stress.

Keywords: lead, phytoextraction, enhancement, arbuscular mycorrhizal fungi, hexavalent chromium

E-Flux Clear-Wells: Field Applications for Micro-scale In-Situ Root Imaging

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Background/Objectives. High Resolution Site Characterization (HRSC) tools, like laser induced fluorescence (LIF) and similar probe-based technologies and down-hole optical platforms have been used for some time for imaging sub-surface conditions, including presence of contaminants, soil structure, and presence of roots. A new imaging platform "Clear-Well" developed by E-Flux (Fort Collins, Colorado) consists of coupled optically transparent Pyrex (borosilicate) glass tubes deployed in boreholes, which allows advancement of an imaging probe that uses an LED board (including UV and visible lights), and camera for real-time documentation of sub-surface conditions. The system can measure pore-scale (< 20 microns, or about the thickness of human hair) soil artifacts, including fine root structure. Furthermore, the system enables repeated measurements on the glass tubes, making it suitable for remedy performance monitoring.

Both bench-scale and fields applications have been tested with the intent to understand capabilities of the system for root-zone imaging.

Approach/Activities. One 14-day bench-scale tank experiment documented the germination and root advancement of basil (*Ocimum basilicum*) growing in porous media. Field deployments of the Clear-Well system at two phytoremediation sites in Alaska and Montana were implemented in 2025, and offer contrasting sub-surface conditions, different trees, and varying presence of existing vegetation.

Results/Lessons Learned. Both bench- and field-scale deployment and assessment of Clear-Well system demonstrate imaging of sub-surface root structure at a micro-scale resolution. The system also identified root penetration through contaminated soils evidenced through light non-aqueous phase (LNAPL) fluorescence. Some of the challenges of the Clear-Well system include operation in cold-weather (subfreezing) conditions and deployment in cohesive soils which inhibit formation collapse peripheral to the glass observation tubes. The ports installed in the ground will enable future root imaging to track plant growth and potential interactions with the LNAPL contaminant.

Keywords: Clear-Wells, Root Imaging

Engineering Plant-mediated Nickel Solubilization in the Rhizosphere

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Metals, such as nickel, are essential for the transition toward a low-carbon economy via the production of green infrastructure and renewable energy technologies such as electric vehicle batteries. However, their mining has significant environmental impacts, including the accumulation of land and tailings contaminated with complex metal mixtures. Plant based remediation and recovery approaches could restore lands and recover technology critical metals, with genetic engineering and synthetic biology presenting timely opportunities to further enhance these natural capabilities.

Metal uptake by plants is limited by its solubilization into metals ions. Cyanide has been shown to function as a highly selective lixiviant solubilizing nickel, along with gold, silver and copper, from mixed metal polluted soils, and can enhance plant uptake. This work focuses on engineering the cyanide biosynthetic pathway in Arabidopsis root hairs to enhance nickel uptake. To achieve this, we have generated constructs to express the pathway, which comprises two multifunctional P450s and a beta-glucosyltransferase, to produce a cyanoglucoside that is stored in the vacuoles of root hair cells. Upon damage, the cyanoglycoside is predicted to be enzymatically cleaved, releasing the cyanide into the rhizosphere for the solubilization of target metals for plant uptake.

We will present results on fluorescent tagging and confocal microscopy demonstrating root hair localization, production of cyanogenic intermediates and effect of hydrogen cyanide on nickel uptake.

Keywords: Metals, Phytomining, Phytoremediation, Engineering Biology

Integrated Transcriptomics and Metabolomics Provide Insights into the Nickel Hyperaccumulation Trait of *Odontarrhena chalcidica*

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The global transition to renewable energy sources is driving up demand for nickel (Ni), particularly in energy storage and electric vehicles. The United States Ni market, estimated at $11.7 billion in 2025, is projected to reach $15.8 billion by 2034. Growing concerns about sustainability are shaping the Ni supply chain, with an emphasis on responsible mining practices, transparent supply chains, and environmentally conscious refining processes. Phytomining is an emerging, environmentally sustainable method for Ni production. More than 500 plant species have been identified as Ni hyperaccumulators, demonstrating significant adaptation to ultramafic soils. The molecular mechanisms underlying the evolution of these traits are not yet fully understood, which impedes the scalability of phytomining. To elucidate the mechanism of Ni hyperaccumulation, we have generated high-quality transcriptome and untargeted metabolomic data from root, stem, and leaf of Ni-treated and untreated *Odontarrhena chalcidica* plants. Because the *O. chalcidica* whole-genome sequence was unavailable, de novo transcriptome assembly was used. This approach identified 14,960 differentially expressed genes (DEGs) in Ni-treated roots, 1,985 in stems, and 529 in leaves. A substantial number of DEGs were linked to biological processes such as photosynthesis, metal accumulation, transport, and tolerance. Additionally, metabolomics analysis revealed 375, 519, and 332 differentially accumulated metabolites in Ni-treated root, stem, and leaf samples, respectively, compared to untreated controls. These metabolites are enriched in the metabolic pathways of glycolysis, TCA cycle, amino acid metabolism, and the biosynthesis of specialized metabolites. Our findings indicate a correlation between Ni hyperaccumulation and increased accumulation of metabolites involved in metal chelation and tolerance, and decreased accumulation of metabolites involved in the defense response. Future studies will lay the foundation for further research and applications, such as the transgenesis of key genes to convert non-hyperaccumulators into hyperaccumulators, opening new paths for research and innovation in phytomining of critical minerals and metals.

Keywords: Nickel, Phytomining, Hyperaccumulator, *Odontarrhena chalcidica*, critical minerals

Omics-Guided Insights into Nickel Tolerance and Accumulation Mechanisms in *Camelina sativa* for Sustainable Phytomining

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The global transition toward renewable energy technologies has substantially increased demand for nickel (Ni), a critical component of batteries and energy storage systems. The United States nickel market, valued at approximately $11.7 billion in 2025, is projected to reach $15.8 billion by 2034. Increasing concerns regarding environmental sustainability and responsible resource extraction have accelerated interest in alternative approaches for metal mining and recovery. Phytomining, the use of plants to extract valuable metals from contaminated or low-grade mineralized soils, represents a promising and environmentally sustainable strategy. Although more than 500 hyperaccumulator species have been identified worldwide, most possess limited agronomic value. *Camelina sativa*, a non-food and short duration oilseed crop widely recognized for biofuel production, offers potential as a dual-purpose phytomining and bioenergy crop. In this study, we evaluated the Ni tolerance and accumulation potential of *C. sativa* under soil and hydroponic conditions using increasing concentrations of nickel chloride. Plant growth, biomass production, and tissue Ni accumulation were assessed to characterize physiological responses to Ni stress. Increasing Ni exposure resulted in reduced biomass accumulation and greater Ni uptake, indicating a concentration-dependent trade-off between growth and metal accumulation. To investigate the molecular mechanisms underlying Ni adaptation, transcriptomic and metabolomic analyses were performed on root and shoot tissues exposed to Ni stress. Transcriptome profiling identified 15,196 and 21,993 significantly differentially expressed genes in shoots and roots, respectively, while metabolomic analysis detected 1,200 and 345 significantly altered metabolites. Integrative multi-omics analyses revealed extensive reprogramming of pathways involved in metal transport and ion homeostasis, ABC transporters, amino acid metabolism, phenylpropanoid and glutathione metabolism, hormone signaling, and secondary metabolite biosynthesis. Multi-omics integration further identified regulatory modules potentially associated with Ni uptake, transport, sequestration, and tolerance. Together, these findings provide new insights into Ni stress adaptation in *C. sativa* and establish a foundation for future engineering strategies aimed at developing improved nickel-accumulating cultivars for sustainable phytomining, phytoremediation, and bioenergy applications.

Keywords: Nickel, phytomining, multiomics, *Camelina sativa*

Integrating Plant Selection and Cultivation Management to Develop *Streptanthus polygaloides* for Nickel Phytomining

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Phytomining offers a plant-based approach for recovering nickel (Ni), a critical mineral, from ultramafic soils. Development of practical phytomining systems requires plant material that maintains both elevated shoot Ni and harvestable biomass across cultivation environments. We evaluated natural variation and cultivation responses in *Streptanthus polygaloides*, a Ni hyperaccumulator native to the Sierra Nevada foothills of California. Serpentine soils found in this area are characterized by high total Ni, low concentrations of most other nutrients and low organic matter. Soil pH, harvest timing, and fertilization were assessed in the greenhouse for impact on Ni concentration, biomass production, and total Ni per plant. Substantial variation occurred among plant groups and cultivation conditions. Some groups expressed greater tissue Ni concentrations, whereas others produced greater biomass and total Ni recovery, demonstrating that concentration alone was not a reliable indicator of phytomining performance. Management influenced plant growth more consistently than tissue Ni concentration, while the growth chamber screening confirmed that elevated Ni accumulation could be maintained across diverse plant material and cultivation conditions. Collectively, these studies demonstrate that plant selection and cultivation management should be evaluated together when developing *S. polygaloides* as a native Ni crop for phytomining. Ongoing work is focused on improving the consistency and scale-up potential of this system while maintaining robust biomass production and Ni uptake. We are also assessing cultivation and management practices focused on commercial production.

Keywords: Nickel hyperaccumulation, phytomining, *Streptanthus polygaloides*, serpentine soils, critical minerals

Isolation and Characterization of Endophytic Bacteria and Fungi Capable of Enhancing Phytoremediation of Hydrocarbon Polluted Soil from the Medicinal Plant, *Vernonia amygdalina* Delile.

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Many plants used for medicinal purposes are potential hosts to useful microorganisms such as bacteria, fungi and yeast. Endophytic bacteria and fungi are prospective sources of biodegradation agents which are important for the degradation of a range of contaminants. *Vernonia amygdalina* Delile is a common medicinal plant in tropical Africa and other parts of the world. In this study, fifty bacteria and fungi endophytes were isolated from *Vernonia amygdalina* plants grown in a greenhouse at the University of South Africa. The isolates were characterized by ITS gene sequencing for fungi and 16S rRNA gene sequencing for bacteria. Genomic DNA was extracted by using the Quick-DNA Fungal/Bacterial Miniprep Kit (Zymo Research, Catalogue No. D6005). The 26 fungi isolated includes *Alternaria alternata, Alternaria infectoria, Alternaria tenuissima, Didymella sp., Didymella pinodella, Phomopsis theicola, Fusarium equiseti, , Diaporthe parapterocarpi, Diaporthe psoraleae, Paraphaeosphaeria sp., Colletotrichum nigrum, Colletotrichum coccodes, Talaromyces pinophilus, Talaromyces cellulolyticus, Neocosmospora sp., Fusarium tonkinense, Fusarium oxysporum, Dactylonectria pauciseptata, Diaporthe chamaeropis, Neofusicoccum parvum, Sporothrix stenoceras*. The 24 bacteria isolated includes *Stenotrophomonas maltophilia, Paenarthrobacter sp., Paenarthrobacter nicotinovorans, Providencia rettgeri, Glutamicibacter mishrai Achromobacter spanius, Shinella sp., Shinella zoogloeoides*. The results show that *Vernonia amygdalina* is a reservoir for endophytes that may contribute to different physiological activities in the body of the plant including phytoremediation. Some of the isolates are known to have the capability to enhance plant growth and also degrade hydrocarbons e.g. Talaromyces, Fusarium, Alternaria and Achromobacter and enhance metal removal from the environment.

Keywords: Endophytes, hydrocarbons, phytoremediation, soil pollution, *Vernonia amygdala*

Going Deeper: Insights for Phytoremediation from Recent Plant Rooting Depth Research

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Two primary limitations on phytoremediation applicability are 1) the depth of remediation, in part controlled by plant rooting depth (RD) and 2) the species available for selection, in part controlled by the species' capacity to root deep. Recent research on RD sheds light on the environmental conditions that promote deep roots and the species capable of rooting deep, with implications for applied phytoremediation. Results indicate that many plants regularly root deeper than prescribed phytoremediation depths, raising the possibility of deeper phytoremediation. They highlight the nexus of specific climate, drainage and substrate conditions that facilitate deep roots. Here, we recommend consideration of these conditions when assessing a site for deep phytoremediation and propose potential strategies for site manipulation to allow for deeper rooting and phytoremediation applicability. We also identify a diverse range of taxa which have the capacity to root deep, provided the appropriate environmental conditions exist, expanding the potential list of species for phytoremediation selection.

Keywords: plant roots, rooting depth, deep phytoremediation

Dynamic Characteristics of Fomesafen Dissipation in Soybean Rhizosphere and the Underlying Microbial Mechanisms: A Multi-omics Perspective

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Rhizosphere metabolites regulate organic pollutant dissipation through microbiome modulation, yet dynamic interrelationships among metabolite shifts, microbial assembly, and pollutant removal remain unclear. Using multi-omics (16S rRNA sequencing, metabolomics, and metagenomics), this study deciphered the temporal dynamics of rhizosphere metabolites and microbiome during the dissipation of fomesafen in soybean pots. Fomesafen dissipation exhibited biphasic kinetics during soybean growth, with an initial rapid phase followed by prolonged stabilization, which was synchronized with time-dependent microbiome perturbations of initial enrichment and subsequent attenuation. Metabolomics revealed fomesafen-induced shifts in rhizosphere metabolites, with 2-naphthalenesulfonic acid (decreased by 20.84%) and 2-hydroxyoctadecanoic acid (-increased by 13.30%) exhibiting opposing effects on microbial assembly, which ultimately affect fomesafen dissipation, as outlined in our conceptual model. Microcosm experiments further demonstrated 2-naphthalenesulfonic acid enhanced while 2-hydroxyoctadecanoic acid inhibited fomesafen dissipation. Our findings highlight the significance of rhizosphere metabolite-mediated interactions between core microbes and potential fomesafen-degraders in governing fomesafen dissipation.

Keywords: Herbicide degradation; rhizosphere microbiome; metabolome; temporal dynamics; response-active reduction-adaption; shotgun metagenomics

Endogenous Biohydrogen from a Rhizobium-legume Association Drives Microbial Biodegradation of Polychlorinated Biphenyl in Contaminated Soil

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Endogenous hydrogen (H2) is produced through rhizobium-legume associations in terrestrial ecosystems worldwide through dinitrogen fixation. In turn, this gas may alter rhizosphere microbial community structure and modulate biogeochemical cycles. Symbiotic rhizobium-legume associations are also important in the elimination of environmental persistent organic pollutants (POPs) from soils. However, very little is understood about the role that this H_2 leaking to the rhizosphere plays in shaping the POPs degrading-microbes in contaminated soils. Here, we combined DNA-stable isotope probing (DNA-SIP) with metagenomics to explore how endogenous H_2 from the symbiotic rhizobium-alfalfa association drives the microbial biodegradation of tetrachlorobiphenyl PCB 77 in a contaminated soil. The results showed that PCB77 biodegradation efficiency increased significantly in soils treated with endogenous H_2. Based on metagenomes of 13C-enriched DNA fractions, active PCB degraders are diverse in polluted soil and endogenous H_2 selected bacteria harboring PCB degradation genes. Functional gene annotation allowed the reconstruction of several complete pathways for PCB catabolism, with different taxa conducting successive metabolic steps of PCB metabolism. Key taxa growing hydrogenotrophically by using electrons derived from H_2 for carbon fixation were demonstrated to play an important role in promoting the degradation of PCB77 by endogenous rhizosphere H_2. In particular, the enrichment of hydrogenotrophic Pseudomonas, Magnetospirillum and likely other taxa encoding biphenyl oxidation genes drives PCB biodegradation primarily through endogenous H_2 in the rhizosphere. This study proves that endogenous H_2 is a significant energy source for active PCB-degrading communities and suggests that elevated H_2 can influence the microbial ecology and biogeochemistry of the legume rhizosphere.

Keywords: Legume-rhizobium symbiosis, biohydrogen, soil, polychlorinated biphenyls, biodegradation

Remediation of Contaminated Soils Combining Biochar with Bioaugmentation and Phytoremediation Techniques

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Biochar, a vegetal form of black carbon produced through biomass pyrolysis, is increasingly recognized as an effective amendment for soil remediation. Its high specific surface area and porous structure confer strong adsorption capacity, enabling the immobilization of toxic compounds. When integrated with biological strategies that stimulate microbial activity, such as rhizoremediation and bioaugmentation, biochar can markedly enhance the degradation of organic pollutants in contaminated soils.

This study aimed to assess the remediation performance of soils polluted with petroleum hydrocarbons (PHs) and copper (Cu) using several treatments: biochar alone (SB) and biochar combined with microbial bioactivators (SBB), each applied with or without plants (P). The experiment was conducted under controlled greenhouse conditions for nine months. Throughout the study, PH and Cu concentrations, soil physicochemical properties, microbial abundance and viability, and plant biomass were measured at various stages.

After nine months, natural attenuation yielded a 47% reduction in hydrocarbons, whereas biochar-based treatments enhanced degradation up to 90%. Biochar application also substantially increased the Cu fraction bound to organic matter (by 1.4- to 2-fold), thereby decreasing its potential bioavailability. Significant shifts in microbial community composition were observed among treatments and over time. The combined application of biochar and bioactivators promoted microbial abundance and plant growth, likely facilitated by elevated soil phosphorus availability.

Overall, these findings improve understanding of the interactions among biochar, pollutants, vegetation and soil microbial communities, and underscore biochar-based approaches as promising tools for future brownfield revegetation and remediation initiatives.

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Keywords: *Melilotus officinalis*, Hydrocarbons, Copper, Bioavailability, Bioactivators

Effects of Soil Amendments on Carbon-Based Indicators of Ecosystem Recovery in Revegetated Mine Soils: Integrating Labile Carbon, Total Organic Carbon, and CO_2 Flux

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Mining operations impair soil carbon cycling through topsoil removal, mechanical compaction, and systemic organic matter depletion. Despite these impacts, unified quantitative frameworks that integrate multiple carbon indicators to monitor biogeochemical recovery in post-mining landscapes remain underdeveloped. This study assessed how five soil amendment treatments modulated permanganate-oxidizable carbon (POXC), total organic carbon (TOC), and soil CO_2 flux in revegetated mine soils at Sweetwater Mine, a lead-zinc operation in the Ozark Highlands of Missouri, USA. Using a completely randomized design (15 plots, 45 collars), we quantified soil respiration via an automated LI-8100A system across 14 sampling events over 17 weeks (n = 630). Within-season composite soil samples (n = 45) were used to quantify POXC and TOC concentrations. We utilized linear mixed-effects models (LMMs) to analyze CO_2 flux dynamics--incorporating treatment, temperature, moisture, pressure and week as fixed effects--while parallel models assessed POXC and TOC using plot-level random intercepts. Amendments significantly impacted CO_2 flux ($p = 0.022$), POXC ($p = 0.018$), and TOC ($p = 0.036$). Specifically, the woodchip-augmented treatment (Lime + Manure + Woodchips) produced the highest estimated marginal means for CO_2 flux (3.61 µmol/m²/s), POXC (597 mg/kg), and TOC (9.01 g/kg). When POXC was included as a covariate, the treatment F-statistic was reduced by 53.8%, indicating that labile carbon differences were associated with a substantial portion of the treatment effect. This integrated framework provides a promising approach for evaluating functional ecosystem recovery in post-mining landscapes.

Keywords: Mine Reclamation, Soil CO_2 Flux, Permanganate-Oxidizable Carbon, Total Organic Carbon, Linear Mixed Model, Soil Amendments, Ecosystem Recovery

Comprehensive Monitoring of an Endophyte-Assisted-Phytoremediation System Using Advanced Methods

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A phytoremediation system was pilot tested to replace a recovery trench installed to remove light non-aqueous phase liquid (LNAPL) and petroleum hydrocarbon impacted groundwater. The phytoremediation system consisted of 148 hybrid poplar trees (*Populus deltoides X Populus nigra*) inoculated with endophytes.

Multiple monitoring and data collection approaches were implemented to track plant health and assess effectiveness during the pilot test. The tree plot was monitored using drone imaging (aerial and multispectral) and ground scan LiDAR imaging to assess the tree health using normalized difference vegetation index (NDVI) and quantifying carbon storage in the above and below ground biomass. Groundwater level monitoring was conducted using continuous transducer measurements to assess drawdown and evaluate changes in the groundwater levels over time as the trees reach maturity. Tree root imaging was conducted using monitoring locations constructed of transparent polycarbonate casing and using a CI-600 camera for 360-degree, continuous vertical image capture to confirm tree root growth into groundwater. Groundwater samples were collected from monitoring wells located upgradient, within, and downgradient of the tree plot and analyzed for dissolved petroleum hydrocarbons. Dissolved gases and anions and well headspace soil gas measurements were collected to evaluate the subsurface impact of a developing rhizosphere as the trees mature.

The remote sensing multispectral and photogrammetry analysis showed trees may be exhibiting more signs of stress in the northern portion of the south plot where hydrocarbon impacts are greatest. Root zone imaging shows an established root network that extends into the beginning of the saturated zone while dissolved gas and anions composition results show difference in degradation conditions within the tree plot compared to upgradient.

Keywords: phytoremediation, endophytes, monitoring, petroleum, hydrocarbons

Long-Term Field Study of VOC Phytoremediation in an Urban Environment

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Since 2018, the VOC plume at a former manufacturing facility adjacent to a river in the Seattle, WA metropolitan area has been treated with a phytoremediation system pumping groundwater from the surficial aquifer to a tree buffer (EBuffer, Ecolotree Inc.) consisting of specific poplar and willow cultivars via drip irrigation. Groundwater monitoring documents no significant contamination of the surficial aquifer beneath the EBuffer. Soil moisture monitoring shows significant available water capacity after annual irrigation of up to 2,000 gpd. Tree canopy appears healthy with no indications of stress. Potential application for hydraulic plume control.

Keywords: VOCs, phytoremediation, irrigation, plume control

Integrating Phytotechnology and AI/ML to Assess Post-Remediation Ecosystem Recovery at a Legacy Petroleum Site in Michigan

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Following the successful remediation and regulatory closure of a legacy petroleum-impacted midstream facility in Kalkaska County, Michigan, AECOM initiated an integrated phytotechnology-based restoration effort and biodiversity assessment to evaluate and document post-remediation ecological recovery.

The 2.3-acre site was restored using soil amendments, a diverse native seed mix exceeding 13.6 million seeds and supplemental white pine plantings to reestablish restoration. Post-restoration vegetation surveys conducted in 2024 and 2025 evaluated plant community composition, succession trends and carbon sequestration.

AECOM deployed phytotechnology-aligned monitoring tools including AI-enabled trail cameras, bioacoustic sensors, and metagenomics. AI/ML wildlife detection was used to track mammalian activity, while bioacoustics characterized seasonal avian communities. Aquatic and terrestrial eDNA sampling was conducted across restored uplands and adjacent wetlands to characterize microbial, fungal, algal, invertebrate, and vertebrate assemblages.

Vegetation monitoring documented strong establishment of native forbs, grasses, sedges, and shrubs, with a corresponding decline in invasive species. The restored plant community contributed an estimated 1,810 kg of annual CO_2 sequestration and is supporting phytotechnology-driven processes including enhanced microbial activity and root-supported nutrient cycling that promote ongoing degradation of residual petroleum hydrocarbons.

AI/ML-assisted wildlife monitoring revealed consistent mammalian use and recorded seasonally distinct bird communities, including the federally listed species. eDNA analyses identified diverse and functionally important biological groups, including nitrogen-cycling archaea (Nitrososphaeraceae), cellulose-degrading bacteria (Cellvibrio), chitin-degrading taxa (Terrimonas), diverse fungi (Pleosporales, Nectriaceae and others), and sensitive aquatic indicators such as Cottidae (sculpins).

The combined results demonstrate that phytoremediation-supported restoration, enhanced by AI/ML monitoring and eDNA-based biodiversity diagnostics, provides a robust framework for tracking ecosystem recovery following remediation of petroleum-impacted sites.

Keywords: AI, Biodiversity, Metagenomics, eDNA

Use of Large Language Models (LLM) in the Design and Assessment of Performance Monitoring Data at Phytoremediation Sites

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Background/Objectives. Large language models (LLMs) have rapidly transitioned from research tools to commercially available platforms capable of transforming how environmental data are analyzed and interpreted and how remedial designs are constructed for practical deployment. At phytoremediation sites, LLMs enable rapid pattern recognition across complex, multivariate time-series datasets, including microbiomics, geochemical, chemical concentrations and performance monitoring data to support phytosystem installation and management.

These capabilities support automated trend detection, fast anomaly identification, and hypothesis generation at scales once impractical with conventional methods. In parallel, LLMs can inform the design of irrigation systems, planting layouts, and tree stand configurations by integrating existing site data, operational constraints, and agronomic principles. Our objectives were exploratory in nature to determine effectiveness in using LLM to support phytoremediation.

Approach/Activities. AECOM phytoremediation practitioners widely used Microsoft 365 Copilot for AI-assisted analytics. Applications included Bray-Curtis analysis of large microbiomics data set of rhizospheric bacteria, trend analysis of soil electrical conductivity and moisture data from a poplar plantation, development and execution of an AI-assisted bench-scale irrigation system, screening of select vegetation, and cataloguing chemical tolerances in various woody species.

To assess variability in results, the datasets were evaluated using multiple LLM platforms including 1) Microsoft 365 Copilot, 2) Claude Sonnet 4.5, 3) Grok 4.1 and 4) a base version of Perplexity.

Results/Lessons Learned. LLM are particularly nimble in identifying patterns and anomalies in large datasets. A sensitivity analysis was performed to assess how different models, using same input of data and how prompting approaches will output and describe analytical findings are forthcoming. Our initial findings suggest that human-in-the-loop oversight remains necessary and that subject matter expert review is critical for validation, regulatory defensibility, and decision sign-off. As of January 2026, AECOM's phytoremediation team use LLM-interfacing 30-40 times a day, with more frequent use during the screening (desktop) phases of work. The main takeaway is that LLMs can support phytosystem installations and monitoring by rapidly assessing input data. However, the project team must recognize limitations of LLMs and determine how to best use them for each project without substituting expert judgment.

Keywords: Artificial Intelligence, Large Language Models, Microbiomics, Phytoremediation Performance Metrics

Micro-nanoscale polystyrene and polyvinyl chloride co-exposure impacts the uptake and translocation of toxic elements and pesticides by lettuce and wheat

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The ability of MNPs to influence the fate and effects of other environmental pollutants (EPs) in terrestrial environments is of great concern. Investigations were conducted to evaluate if co-exposure to MNPs (polystyrene, PS; 20 or 1000 nm; or polyvinyl chloride, PVC, <10 µm, unaged or aged) had an impact on the accumulation of other EPs (arsenic, lead, chromium, boscalid, PFOS) in lettuce or wheat. Under hydroponic conditions, lettuce was co-exposed to PS at 10 or 50 mg/L, and to 1 mg/L of each EP. In a soil study with lettuce, the PS and EPs were at 50 and 10 mg/kg, respectively. Phytotoxicity was enhanced by PS under both growth conditions, particularly nanoscale PS (nPS), although impacts were less in soil. Nanoscale PS had a greater impact than microscale PS (µPS) on As fate; the As translocation factor from roots to shoots was increased 3-fold in plants co-exposed to nPS (50 mg/L). PS dose and size had a variable impact on boscalid uptake and translocation. Fluorescent microscopy of lettuce co-exposed to MNPs and EPs suggests that nPS enters the roots and translocates to the leaves, while µPS remains mostly in the roots. Pyrolysis-GC/MS showed that in soil, EPs increased the translocation of nPS in lettuce shoots from 4.43±0.53 to 46.6±9.7 mg/kg, while the concentration of µPS in the shoots was unchanged with EPs. Separately, co-exposure to unaged PVC increased the root and shoot accumulation of As, Cr, and Pb by 3.1-, 2.1-, and 1.5-fold, respectively; for aged PVC, toxic element increases were 3.9-, 2.6-, and 2.1-fold, respectively. Soil-based experiments with wheat under similar conditions are ongoing, as are molecular analyses to elucidate mechanisms of action. These findings demonstrate that co-exposure of MNPs with other EPs can significantly impact co-contaminant accumulation and toxicity, presenting an unknown risk to humans and other receptors.

Sustainable Production of Selenium-rich and Cadmium-safe Rice by nZVI-melatonin Synergy via Coordinated Plant-microbe Regulation

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Developing environmental regulation strategies to reduce cadmium (Cd) accumulation in rice while promoting selenium (Se) enrichment is crucial for global food safety and remains a significant challenge. Here, we evaluated a stage-specific co-application approach involving nanoscale zero-valent iron (nZVI) amendment to soil and foliar spraying of melatonin (MT), which decreased grain Cd concentrations by up to 64% while elevating grain Se content by up to 74% in pot experiments. It also enhanced the Se bioconcentration factor (~63%) and the leaf-to-grain translocation factor (~77%), indicating improved uptake and redistribution under Cd stress. Mechanistic analyses revealed synergistic metabolic reprogramming: antioxidant defenses were strengthened by elevated ascorbate peroxidase activity, which reduced hydrogen peroxide and restored redox homeostasis. Transcriptomic profiling revealed suppression of Cd influx transporters and activation of genes involved in vacuolar sequestration, antioxidant metabolism, and Se transport, thereby restricting Cd translocation while promoting Se accumulation. Rhizosphere microbiomes were enriched with beneficial taxa, including Pseudomonadota, Acidobacteriota, and Bacillota, which contributed to Cd stabilization and Se bioavailability. This nZVI-MT combined strategy offers a viable strategy for producing safe and nutritious rice.

Keywords: selenium, cadmium, rice, nZVI, and melatonin

Optimizing Rice Growth and Soil Heavy Metal Removal with Agroforestry Waste Biomass-Derived Composite Washing Agent

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The utilization of organic matter derived from agroforestry waste biomass for soil washing represents an innovative and promising sustainable remediation strategy for the permanent removal of heavy metals from agricultural soils. However, field application of current research on single biomass-derived washing agents remains constrained by excessive material requirements, high liquid-to-solid ratios, low metal removal efficiency, and a lack of comprehensive post-remediation crop performance assessment. To address these challenges, we have developed a novel composite washing agent (CA+PP) composed of pineapple peel (PP) and citric acid (CA). Pot experiments conducted on two Cadmium (Cd) contaminated soils (Fe-accumulic-Stagnic Anthrosols and Shajiang Calci-aquic Vertosols), assessed rice growth and Cd accumulation following CA+PP pretreatment. Analysis of soil solution chemistry and post-harvest bioavailable Cd ($CaCl_2$/NH_4OAc-extractable) demonstrated that CA+PP significantly reduced soil Cd by 21.26-28.78%. Rice tissue (roots, straw, brown rice) Cd decreased by 31.22--49.11%, with total plant Cd uptake declining to 3.21--6.43 μg per plant (47.00-75.75% reduction). Though organic acids such as acetic acid temporarily inhibited seedling growth, the agronomic performance was successfully restored by pH adjustment through water washing or $Ca(OH)_2$ application. The combined approach of whole-plant removal and CA+PP washing substantially decreased bioavailable Cd, achieving a reduction of 25.22% to 28.86% in total soil Cd. This synergistic remediation strategy provides valuable technical insights for the environmentally sustainable remediation of moderately Cd-contaminated agricultural soils.

Keywords: farmland, Cadmium, biomass, washing, rice

The Effect of Biomaterials Coating on Sensory Properties of Potatoes During Storage

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Under the current circumstances, there are many changes in the quality and sensory properties of food products. So, this work focused on potato due to it being the fourth most important food crop in the world after rice, wheat, and maize and the second drop after wheat in Jordan. We improved these characteristics of these products by renewable raw materials derived from agro-food (whey protein concentrate) waste as an edible coating on the surface of potatoes that the consumer can eat as a part of the whole product during 120 days of storage at different conditions of storage. Chitosan, whey protein, and coconut oil (lipid) have been used. Along with uncoated (control) potato bulbs, the coated tubers were kept. They evaluated various quality characteristics such as texture, color, visual appearance, and decay percentage. According to the findings, potatoes that had been coated had better results compared to control by delay texture, visual appearance decay percentage, and color changes.

Keywords: Keywords: edible coating, whey protein concentrate, chitosan, potato, quality

Integrated Phytoremediation and Rhizosphere Microbial Characterization of Saline Industrial Soils

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A multi-year field investigation is underway to assess the effectiveness of native halophytic species for the phytoremediation of highly saline soils at a former oil and gas battery site located approximately 100 km southeast of Edmonton, Alberta. Preliminary site characterization identified chloride concentrations exceeding 1,100 mg/kg in fine-textured soils composed of 43% clay and 35% silt. The study evaluated three native halophytes: *Chenopodium album* (lamb's quarters), *Puccinellia distans* (weeping alkaligrass), and *Distichlis spicata* (inland saltgrass). Experimental plots were seeded annually in May alongside an unplanted control plot of equivalent dimensions. Soil samples were collected from planted and control plots at depths of 0-15 cm and 15-30 cm. At the conclusion of the 2025 growing season, plant tissues were harvested, homogenized, and analyzed for chloride content using ion chromatography. Established halophyte plots exhibited substantially lower mean soil chloride concentrations (467 mg/kg) relative to the unseeded control plots (1,041 mg/kg) across both sampling intervals. Among the evaluated species, *C. album* demonstrated the greatest chloride accumulation capacity (22,889 mg/kg), followed by *P. distans* (9,880 mg/kg). *D. spicata* failed to establish during the 2025 season, suggesting limited suitability under prevailing site conditions. Biomass production was highest for *C. album*, corresponding to an estimated maximum salt removal rate of approximately 14.3 g/m^2. These findings emphasize the importance of species selection in optimizing phytoremediation performance for saline industrial soils. A complementary growth chamber experiment was conducted to characterize rhizosphere bacterial communities associated with *D. spicata* and *P. distans* under varying salinity conditions. Following three months of growth, DNA was extracted, amplified, and sequenced to evaluate microbial community composition. While alpha diversity did not differ significantly among salinity treatments, beta diversity analyses revealed significant differences associated with both salinity and plant species. These findings suggests that plant host selection and soil conditions may play a greater role in shaping rhizosphere microbial communities than salinity alone and should therefore be the focus of future work when attempting to identify bacterial strains that promote halophyte growth. Data collection is ongoing through the 2026 field season and two years of field data will be reported on.

Keywords: Phytoextraction, Halophytes, Chloride, Salinity

Halophyte-Based Remediation of Saline Environments: Case Study Perspectives

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In Canada, salinization of soils and water resources is an increasing environmental challenge in urban, industrial, and transportation corridors, driven by the widespread use of de-icing salts, industrial activities, and saline storm water runoff. Halophytes are receiving growing attention for the treatment and mitigation of salt-impacted soils and waters due to their capacity to tolerate, accumulate, and/or excrete high salt loads while maintaining productivity under elevated salinity conditions. This presentation summarizes several ongoing collaborative projects evaluating halophyte-based approaches for the remediation and management of saline environments. Case studies include the rehabilitation of road salt-affected soils, phytomanagement of a highly saline industrial site, integration of halophytes into bioretention and stormwater treatment systems designed to intercept saline effluent, and the establishment of roadside halophytic buffers to mitigate salt spray impacts on adjacent vegetation. The presented case studies illustrate both the opportunities and practical considerations associated with deploying halophytes as components of an overall remediation strategy.

In parallel with these field-scale case studies, my ongoing research is: i) evaluating the feasibility of recovering chloride from salt-laden biomass, and ii) characterizing the rhizosphere microbial communities associated with halophytes growing in saline environments and exploring endophytic microorganisms residing within plant tissues. For the former, effective recovery of chloride from salt-accumulating biomass will create opportunities for its beneficial reuse in applications where salt is routinely required, thereby supporting a more circular approach to salinity management. For the latter, microbial assemblages may contribute to plant salt tolerance, nutrient cycling, stress mitigation, and contaminant transformation, thereby influencing overall remediation performance. This integrated approach to salt management using halophytes combines applied remediation with salt recovery and microbial characterization to better understand and enhance the capacity of halophyte systems to remediate saline environments.

Keywords: halophytes, salt remediation, saline environments, microbial characterization

Biological Humidification: A Nature-Based Strategy for Solar Desalination using Vertical Halophyte Farming

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Smallholder farmers in arid and semi-arid regions face escalating challenges from water scarcity and soil salinization. This study, conducted under the EU-funded DIVAGRI project, evaluates a novel nature-based solution: the Solar Desalination Greenhouse (SDGH) integrated with vertical halophyte cultivation. Unlike traditional humidification-dehumidification systems that rely on inorganic evaporative pads, this prototype utilizes biological humidification--the process of using plant-based evapotranspiration to drive a closed-loop freshwater recovery cycle.

The 123-day study compared three halophyte species -- *Salicornia europaea*, *Portulaca oleracea*, and *Crithmum maritimum* -- irrigated with high-salinity water (15 mS/cm) within a vertical farming system. Freshwater was recovered through a hybrid system combining active condensation (repurposed vapor-compression units) and passive radiative cooling surfaces utilizing IR-reflective coatings and OPUR pigments.

Results demonstrated that Salicornia europaea provided the highest humidification capacity, reaching a maximum cumulative evapotranspiration of 174.4 L and yielding 5.2 kg of fresh biomass. Portulaca oleracea, while exhibiting lower total transpiration, showed the highest freshwater productivity at 60.31 kg FW/m³, suggesting superior conversion efficiency in water-limited contexts. The system recovered 191 L of freshwater, achieving a condensation efficiency of 54% relative to total evapotranspiration. While active units provided consistent yields, passive systems contributed localized recovery peaks, particularly when combining OPUR and IR-reflective coatings.

This research underscores the potential of halophytes not merely as salt-tolerant crops, but as active drivers of decentralized desalination cycles. The SDGH offers a dual-benefit framework, producing mineral-rich biomass for food or feed while generating freshwater for subsequent irrigation of glycophytic crops. By addressing the water-energy-food nexus through nature-based engineering, this system provides a scalable, low-cost pathway to enhance agricultural resilience in saline-affected drylands.

Keywords: Biological Humidification, Water Productivity, Halophytes, Solar Desalination Greenhouse (SDGH), Water-Energy-Food Nexus

Identification of Plant Species for the Utilization of Simulated Saline Effluent Produced from Reverse Osmosis

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Disposal of saline reverse osmosis (RO) effluent produced in the westside of central California can be problematic due to the high levels of naturally occurring salts, including boron (B) and selenium (Se), which are potentially toxic to crop production and the biological ecosystem, respectively. The overall objective of the multi-year micro-field project is to identify alternative salt and B tolerant crops that can utilize irrigation with simulated levels of saline RO effluent. For the study, field lysimeters (2.0 m deep x 0.6 m) were prepared as follows: clay loam soil was collected from a typical saline field site (average soil Ec of 5.0 dS/m and soil B of 5.0 mg B /L) used to fill 120 lysimeters that were planted in a complete randomized design with following moderate salt and B tolerant plant species: (sorghum (*Sorghum bicolor*) canola (*Brassica napus*), Indian mustard (*Brassica juncea*), Prince's Plum (*Stanleya pinnata*), wheat grass (*Thinopyrum ponticum* (cv. 'Jose'), elephant grass (*Cenchrus purpureus*), saltbush (*Atriplex nummularia*) and poplar trees (*Poplus deltoides x nigra*). Based upon individual water requirements, plants were irrigated with simulated saline RO effluent levels (dS/m): low (0.8), medium (4) and high (8). After two growing seasons, mean annual yields (g DW/tile) were as follows with low, medium, and high saline irrigation treatments: Indian mustard (249, 250, 230); canola (322, 282, 317); Princes Plum (68, 48, 46); sorghum (2983, 2063, 1277); wheatgrass (446, 403, 363), saltbush (1262, 1195, 1571) and elephant grass (3493, 2251, 1362). The important salt ion concentrations (sodium and chloride) were as follows (mg/kg DW) for each species at low, medium and high treatments : canola (Na-5649, 5635, 6990 and Cl-14852, 20890, 24837); Indian mustard (Na-4834, 7590, 8861 and Cl-12157, 22932, 25304); Prince's Plum (Na-6474, 14367, 23522 and Cl-6180, 14253, 22128); sorghum (Na-2928, 3717, 4636 and Cl-29, 45, 49); wheatgrass (Na-4951, 8143, 9390 and Cl-17070, 21037, 22935); elephant grass (Na-127, 192, 312 and Cl-3122, 5858, 8543); saltbush (Na- 26796, 29820, 34638 and Cl- 23209, 31119, 39411); and poplar leaves (Na-245, 1808, 19613 and Cl-531, 2789, 19205). The observed salt tolerance for the crops indicated by high biomass yields, and despite increasing tissue Na and Cl tissue concentrations with increasing saline irrigation treatments, indicates the potential of using a combination of these plant species as recipients for irrigation with RO effluent at different saline levels. Sustainable irrigation with RO effluent will require crop rotation, soil salinity management, and important consideration for the economic use of plant material as supplemental animal feed sources.

Tracing and Quantification of Uptake and Distribution of Micro and Nanoplastics in Plants

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Microplastics (MPs) and nanoplastics (NPs) are abundant in agricultural soil, but it is difficult to trace and quantify their uptake, transport and distribution in plants grown in soils. Understanding the uptake and distribution of MPs and NPs in plants is crucial for assessing their soil ecosystem impact and food-chain risk. This can be conveniently achieved using fluorescently labeled materials (stable lanthanide (europium) chelates). Here, we report a study quantitatively investigated the uptake and translocation of lanthanide chelate-labeled submicrometer plastics (polystyrene, PS) particles with a diameter of 200 nm into two crop plants, wheat (*Triticum aestivum*) and lettuce (*Lactuca sativa*). PS particles were doped with the europium chelate Eu-β-diketonate (PS-Eu), which was used to quantify PS-Eu particles uptake by the plants, grown hydroponically and in sandy soil using inductively coupled plasma mass spectrometry. PS-Eu particles accumulated mainly in the roots, while transport to the shoots was limited (for example, <3% for 5,000 ug PS particles per liter exposure). Visualization of PS-Eu particles in the roots and shoots was performed with time-gated luminescence through the time-resolved fluorescence of the Eu chelate. The presence of PS-Eu particles in the plants was further confirmed by scanning electron microscopy. Doping with lanthanide chelates provides a versatile strategy for elucidating the interactions between microplastics and plants. However, it needs to be pointed out that it is designed specifically for hypothesis-driven research using well-defined, labeled model particles and is not intended for the environmental monitoring of unlabeled plastics in field samples. It is also important to note that interactions of MPs and NPs with clay minerals and natural organic matter in soil environments can substantially alter particle heteroaggregation and bioavailability. Therefore, future adaptations of this method for soil-based systems should explicitly account for these matrix effects when interpreting uptake and accumulation.

Keywords: Microplastics, Plant, Stable lanthanide (europium) chelates, Tracking and Quantification, Uptake

Biofilm Formation and the Underlying Mechanisms Involved in Microplastic Biodegradation

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As an emerging class of persistent contaminants, microplastics are now widely distributed across diverse environmental compartments, including soils, marine and freshwater systems, and the atmosphere. Upon entering the natural environment, microplastic surfaces are rapidly coated with dissolved organic matter, forming a conditioning film that facilitates microbial colonization. The colonizing microorganisms subsequently secrete extracellular polymeric substances (EPS), leading to the development of attached biofilms with complex three-dimensional structures. This microscale ecosystem, comprising the plastic substrate, associated microorganisms, EPS matrix, and the surrounding interfacial microenvironment, is commonly referred to as the "plastisphere."

The formation of the plastisphere is a critical process that reshapes the interfacial properties, environmental fate, and ecological effects of microplastics. Previous studies have demonstrated that biofilm formation can alter microplastic surface roughness, wettability, surface charge, and interfacial functional-group composition, thereby affecting particle aggregation, settling and resuspension, contaminant adsorption and desorption, and bioavailability. Meanwhile, plastisphere-associated microorganisms can, through EPS-mediated adhesion, heteroaggregation, interfacial transformation, and enzymatic degradation, regulate the transport pathways and environmental residence times of microplastics.

This presentation provides an overview of biofilm formation on microplastic surfaces, the principal methods used to investigate these biofilms, and their effects on the physicochemical and biological properties of microplastics. Particular emphasis is placed on the enhanced degradation of microplastics by biofilms formed by plastic-degrading microorganisms, as well as the underlying mechanisms.

Keywords: microplastics, biofilm, plastisphere, surface change, biodegradation

Clay Minerals Limit Nanoplastic Uptake in Wheat Plant

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The effects of nanoplastics on crop plants have attracted growing attention. Studies have indicated that many terrestrial plant species can take up and transport nanoplastics. However, little is known about the effect of clay minerals on the uptake of nanoplastics by crop plants. This study investigated the influence of two common clay minerals (kaolinite and montmorillonite) on the uptake and transport of fluorescent polystyrene (PS, 200 nm) nanoplastics by wheat seedlings in hydroponic solutions. Clay minerals can limit the uptake of nanoplastics in wheat by forming heterogeneous aggregates with nanoplastics or competing for uptake pathways in new lateral root cracks of wheat. Our results confirmed that micrometer-sized kaolinite and montmorillonite particles enter the root steles of wheat seedlings from lateral root emergence sites and are subsequently transported upward to the shoots and leaves through the vasculature via the transpiration stream. Europium (Eu)-doped PS (200 nm) was used to quantitatively assess the effect of clay minerals on the uptake of nanoplastics by wheat. Compared with kaolinite, montmorillonite (larger size and specific surface area) has a more significant limiting effect on plant uptake of nanoplastics. By comparing the transfer factors (TFs) of microplastics in wheat, it was found that clay minerals promoted the transfer of nanoplastics from roots to shoots. These findings demonstrate that both kaolinite and montmorillonite reduce the uptake of 200 nm PS-NPs in wheat seedlings through dual mechanisms: (1) hetero-aggregation in the rhizosphere and (2) competitive occupation of lateral root crack-entry pathways. This study reveals the important role of clay minerals in mitigating NP uptake by crop plants, provides insights into how clay minerals can alter the environmental risk posed by NPs, and establishes a foundation for future research on plant interactions with complex environmental particles.

Keywords: Wheat; Nanoplastics; Clay minerals; Uptake; Transport

Phytoremediation Feasibility and Defensible Evidence for Field Studies

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This presentation addresses two central questions frequently raised in the application of phytoremediation: how to determine whether it is feasible for a given site, and how to demonstrate that it is performing effectively once implemented. Feasibility depends on aligning plant species, site conditions, and contaminant characteristics to ensure that plant-driven mechanisms can operate as intended. Critical considerations include hydrogeologic predictability, soil structure and fertility, contaminant bioavailability, and the rooting depth required to intercept impacted zones. Engineered enhancements such as endophytes, mycorrhizae, optimized planting configurations, and subsurface irrigation can further increase plant tolerance, growth, and degradation capacity, expanding the range of viable applications.

Establishing defensible evidence of performance requires a multi-line-of-evidence monitoring framework. Key indicators include soil and groundwater concentration trends, plume stability, plant tissue accumulation, nutrient and salinity conditions, and measures of plant vitality and biomass. Complementary tools such as pressure transducers, transpiration estimates, microbial community analyses, and rooting-depth verification provide additional insight into hydraulic influence, degradation pathways, and long-term system resilience.

The presentation will also reference several case studies that demonstrate phytoremediation's effectiveness across diverse climatic, hydrogeologic, and contaminant settings. These examples highlight measurable plume reduction, enhanced biodegradation, hydraulic containment, and cost-effective long-term management. Collectively, they underscore phytotechnology's capacity to serve as a reliable, adaptable, and sustainable remedial option when matched appropriately to site conditions and supported by robust monitoring.

Keywords: Feasibility, Performance, Evaluation, Evidence, Examples

Trees and Microbes as a Sustainable Phytoremediation Solution for Petroleum Hydrocarbon and Mixed Waste Impacted Sites

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Background/Objectives. To present advanced microbial endophyte technology and design methodology that improves the success rates of phytoremediation and applications on higher concentrations of contaminants than previously thought possible.

In 2014, Intrinsyx Environmental collaborated with NASA-Ames and the US EPA to introduce endophytic bacteria from Dr. Sharon Doty (University of Washington) into hybrid poplar trees to better metabolize TCE from groundwater contamination at the MEW Superfund site (Doty et al., 2017). The success of this first pilot installation has expanded into full-scale endophyte-assisted phytoremediation deployments on Superfunds, state-mandated clean-ups, and Fortune 500 redevelopment sites on over 45 sites across the US, Austria and South Africa.

Endophyte-enhanced tolerance, degradation and appropriate selection of unique varieties of trees, plants, and grasses are all keys to successful phytoremediation on polluted sites with phytotoxic concentrations of various contaminants.

Approach/Activities. This presentation covers selection and integrated design methodologies with data from full-scale phytoremediation on several petroleum hydrocarbon and mixed waste installations utilizing Endophyte-Assisted Phytoremediation Systems (EAPS). These synergistic bioremediation tools and innovative techniques have been deployed to address several classes of pollutants, including chlorinated VOCs, petroleum hydrocarbons, 1,4-dioxane, and more (mixed wastes).

Results/Lessons Learned. Data and lessons learned are highlighted from sites across the U.S. where EAPS is currently installed to treat petroleum hydrocarbons and mixed wastes in soil and groundwater. Lessons learned include confirmation that endophytes contribute to phytoremediation success through improved plant tolerance, establishment, in-planta biodegradation, and enhanced source-zone depletion rates. Data suggests that the selection and application of appropriate endophytes are the key factor in plant establishment on sites with phytotoxic concentrations. Additionally, selecting site-appropriate tree varieties and providing them with consistent care was vital for initial establishment and long-term success. EAPS represents a standalone primary treatment for mitigating contaminant migration and enhances in-situ biodegradation of soil and groundwater contaminants.

Keywords: endophytes, mixed waste, petroleum, TCE

Fast-Track Brownfield Remediation and Sustainable Closure Using Phytoremediation

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Endophyte-assisted poplar and willow trees were strategically installed at a former manufacturing facility in east-central Illinois to diminish chlorinated VOC groundwater impacts (TCE, TCA and related daughter products) to achieve closure under Illinois EPA's voluntary Site Remediation Program. The site is located immediately upgradient of a residential area with six defined on-site source areas which combined to create two shallow groundwater plumes within a heterogeneous geologic setting. Several interim remedial treatment methods were utilized at the site historically, including in-situ injection and a permeable reactive barrier. Although successful as implemented to mitigate leading edge plume conditions, they were not designed to achieve final regulatory closure of the site. Full-scale implementation of standard remedial technologies to pursue closure was considered; however, in consultation with the client an alternate strategy utilizing a nature-based solution was implemented which successfully aligned the site for closure in a relatively short time-frame.

Keywords: nature-based solution, fast track, sustainable

Poster #1

Evaluating the Phytotoxicity of Beet Juice-Amended Road Deicers on Roadside Vegetation Compared to Traditional Deicing Salts

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The use of alternative road deicers, such as beet juice amended salt brines, has increased in recent years as transportation agencies reduce their reliance on traditional chloride-based salt deicer. However, limited data exist on their direct impacts on infrastructure, vehicles, and on roadside vegetation and waterways. This study, conducted in collaboration with the Missouri Department of Transportation (MoDOT), evaluates the effects of beet juice deicer compared to conventional road salt on native plant species commonly found along Missouri roadways.

Laboratory experiments were performed using Illinois bundleflower (*Desmanthus illinoensis*) and little bluestem (*Schizachyrium scoparium*) to assess plant response across multiple growth stages. Germination was conducted in Petri dishes using varying concentrations of salt and beet-amended brine to evaluate germination rate and percent. Seedling studies followed, where pre-germinated seeds were exposed to treatments simulating roadway spray and runoff. In third phase studies, a small pot study, where established plants are grown in Missouri soil dosed with deicer treatments to assess impacts on mature plant systems. Plant response was evaluated with traditional observations and a novel application of image-based, computer visualization analysis (PlantCV), including germination success, growth rate, leaf area, height, width and color as indicators of induced stress. Findings indicate that increasing sodium chloride concentrations inhibit germination and early development, while beet juice amended treatments show delayed initial growth but improved overall establishment compared to salt only treatments. Illinois bundleflower demonstrated greater tolerance under beet-amended conditions, whereas little bluestem exhibited higher sensitivity to salt. This work provides experimental insight into the vegetation impacts of organic road deicer and supports the development of more sustainable winter road maintenance strategies.

Keywords: Phytotoxicity, Beet juice deicer, Roadside vegetation, Image-based analysis, Sustainable infrastructure

Poster #2

Diesel Fuel Uptake in Phytoremediative Feltleaf Willow

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Common soil remediation strategies for petroleum contamination are financially and logistically prohibitive for remote communities without road access. Phytoremediation is an attractive option in these circumstances, particularly when utilizing native, locally available plants. Feltleaf willow (*Salix alaxensis*) is distributed widely across Alaska, and has been studied and implemented as an effective solution to remediate petroleum products when responsible parties cannot overcome barriers to traditional soil remediation tactics. Research indicates that feltleaf willow primarily remediates via rhizodegradation, however to date there are no studies addressing the potential for diesel fuel to translocate from contaminated soil into the plant. Translocation to aboveground plant tissue without significant degradation into less toxic components is especially concerning because of the plant's cultural and ecological significance to Alaska Native communities. These concerns can, justifiably, deter the use of phytoremediation.

In the greenhouse portion of this study we harvested and rooted 100 feltleaf willow cuttings, and planted them in two treatments: 60 in soil contaminated with 5,000 mg/kg diesel fuel, and 40 in clean soil. After 73 days, the surviving 15 contaminated plants, and 15 randomly selected clean plants were destructively harvested. A field study was also conducted at a phytoremediation plot that was established in 2018 after a domestic heating oil spill near Fairbanks, Alaska. Twelve feltleaf willow samples were taken in the plot, and twelve were taken from willows outside of the plot. Stems and leaves from both studies were processed using a lab protocol modified from Alaska Method AK102 and Collina et al. (2021), and analyzed by gas chromatography-mass spectrometry.

This study aims to assess whether petrogenic diesel range organics (DRO) can be detected in stems and leaves of phytoremediative willows in order to empower and inform communities, environmental professionals and regulatory agencies who employ phytotechnologies in Alaska.

Keywords: diesel, Alaska, petroleum, willow, phytoremediation

Poster Session - Narragansett Room B&C

Poster #3

Assessing the Feasibility of Hybrid Poplars for Sulfate Phytoremediation at a Northern Minnesota Site

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Sulfate loading in freshwater ecosystems is a growing environmental concern due, in part, to its potential role in formation of neurotoxic methylmercury and the elevation of toxic sulfides in sediments. While treatment technologies exist for high-strength sulfate waste streams, options capable of reducing medium-range sulfate concentrations to freshwater levels (commonly 3-30 mg/L) remain limited. One promising technology is phytoremediation utilizing fast-growing hybrid poplar trees (*Populus* spp.), whose physiology supports contaminant uptake and transformation. Poplar-based systems have previously demonstrated efficacy in remediating inorganic and organic pollutants, but little research has examined hybrid poplars for sulfate phytoremediation. We hypothesize that moderate sulfate loading will have minimal effects on tree growth and physiology, supporting their suitability for sulfur remediation.

To test the efficacy of hybrid poplars for sulfate remediation, we established a field study in Aurora, Minnesota that examines associated tree growth and physiological responses. The site is located beside a mine pit lake containing ~400 mg/L sulfate. The field experiment, established in 2025, includes four hybrid poplar clones ("99007115", "9732-31", "DN34", "InnovaTree") belonging to the *Populus deltoides* Bartr. ex Marsh x P. nigra L. 'DN' genomic group, and two treatments (irrigation with mine pit lake water and biochar amendment) across 144 trees. The clones were selected based on greenhouse phyto-recurrent selection experiments. Sulfate treatments will begin during the 2026 growing season. Half of the trees will be irrigated with mine pit lake water. Throughout the growing season, soil samples will be collected periodically for sulfur quantification and speciation, along with measurements of plant growth and chlorophyll content. Leaf water potential and light- and dark-adapted chlorophyll fluorescence will be measured once in August. Findings from this study will support the implementation of poplar-based phytoremediation as an efficient, environmentally sound, and cost-effective strategy for reducing sulfate concentrations in natural aquatic systems.

Keywords: Phytoremediation, sulfate, poplar, biochar

Poster #4

Characterization of AtLAP1 Gene in Arabidopsis to Unravel its Role in Abiotic Stress Tolerance

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Toxic elements such as cadmium (Cd), arsenic (As), and mercury (Hg) disrupt cellular homeostasis and impair plant growth, largely through oxidative stress and interference with essential physiological processes. The γ-glutamyl cycle contributes to glutathione (GSH) turnover and homeostasis, supporting detoxification through reactive oxygen species (ROS) scavenging and metal chelation followed by vacuolar sequestration.

This study investigates the role of leucine aminopeptidase 1 (AtLAP1) in *Arabidopsis thaliana*, which is hypothesized to contribute to GSH-mediated detoxification. AtLAP1 may function in GSH degradation by cleaving the cysteine-glycine (Cys-Gly) bond and may act in coordination with other GSH catabolic genes such as AtOXP1 and GGCT. To evaluate AtLAP1 function under metal stress, we analyzed homozygous atlap1 T-DNA insertion mutants. PCR-confirmed mutants showed reduced growth on control ½ x MS medium and increased sensitivity to heavy metal exposure. Compared with wild type under the corresponding condition, atlap1 mutants showed a 24.1% reduction in shoot biomass on ½ x MS medium and a 42.33% reduction under Hg stress. Root biomass was also reduced by 45.28% under Hg treatment. Cd and AsIII exposure caused greater reductions in shoot biomass, at 45.64% and 59.9%, respectively, while root biomass declined by 59.42% under Cd and 68.55% under AsIII, indicating that loss of AtLAP1 severely impairs growth under metal stress.

Ongoing work aims to further define the role of AtLAP1, including whether its overexpression enhances Cys-Gly cleavage, improves tolerance to heavy metal stress, and alters metal accumulation in plant tissues. We are also examining its role under other abiotic stresses such as drought and salinity, where mutants likewise show reduced growth relative to wild type. Overall, characterization of AtLAP1 may help identify targets for engineering crops with improved abiotic stress tolerance.

Keywords: Abiotic Stress, Heavy metal, Glutathione, Arabidopsis

Poster #5

Dual Cu and Zn Phytoremediation Potential of *Atriplex lentiformis* under Sequential Metal Exposure-Harvest Cycles

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The arid and semi-arid landscapes of the southwestern United States host one of the world's densest clusters of legacy mine sites, where complex mixtures of residual metals (including Cu and Zn) exacerbate ecosystem stress under intensifying climate extremes. In these drylands, limited moisture, salinity, and low soil fertility further hinder plant establishment and phytoremediation, making the selection of resilient native species critical for long-term ecological restoration.

Atriplex lentiformis, a native halophytic shrub, was evaluated for its ability to tolerate and accumulate Cu and Zn through sequential amendment-harvest cycles (Cu: 50-750 mg/kg; Zn: 400-2000 mg/kg). The species maintained stable biomass across high metal concentrations and exhibited distinct metal distribution patterns, with Cu primarily retained in roots - supporting phytostabilization, and Zn showing increased translocation to leaves across cycles - indicating phytoextraction potential. Nutrient balance remained largely preserved despite severe metal exposure.

By sustaining growth and physiological stability under elevated Cu and Zn concentrations, *A. lentiformis* demonstrates strong functional tolerance in contaminated soils, positioning the species as a promising candidate for remediation in arid and semi-arid regions. Future research should focus on field validation, assessing metal recovery efficiency, and integrating this species into multi-species restoration efforts.

Keywords: Phytoremediation, Zinc, Copper

Poster #6

Evaluation of Ni Absorption and Accumulation Capacity in the Cd Accumulator *Salix matsudana* var. tortuosa Towards Ni Phytomining

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Nickel (Ni) is widely used in lithium-ion batteries and other industrial applications. It is considered a critical metal resource with few viable substitutes. Consequently, demand for Ni is projected to continue increasing, making it one of the most economically valuable metal resources. In this study, we focused on using plants to recover Ni resources. This recovery method, known as phytomining, is highly efficient because plants require minimal maintenance during growth, allowing resources to be extracted simply through harvesting.

Therefore, resources can be easily recovered simply by harvesting the plants. This recovery method is known as phytomining. Phytomining requires hyperaccumulator plants capable of accumulating high concentrations of Ni; however, since only three such species are native to Japan, it is difficult to select suitable plant species for application in diverse local environments. Therefore, this study aimed to discover new Ni hyperaccumulator plants suitable for phytomining, with a specific focus on cadmium (Cd) accumulator plants. Since the Cd transport pathways in plants are also utilized for Ni transport, Cd-accumulating plants are expected to selectively absorb and accumulate Ni. In this study, we cultivated the Cd-accumulating plant *Salix matsudana* var. tortuosa in a solution containing 200 µg/L Ni for 21 weeks. During the cultivation period, the nutrient solution was completely renewed every week. After cultivation, the Ni concentration in the plant tissues was measured using ICP-AES. The results confirmed that the plants accumulated up to 953.6 mg/kg-DW of Ni. Additionally, we also monitored the growth of the plants' aboveground biomass throughout the cultivation period.

Keywords: Phytomining, Nickel, *Salix matsudana* var. tortuosa

Poster #7

From Brownfield to Phytoremediation Pilot: Willows, Poplars, and Tribal Stewardship on the Yaquina River on the Oregon Coast

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The Yaquina Terrace Waterfront Property in Toledo, Oregon, is a Tribal riverfront Brownfield where wetlands, shallow groundwater, volatile organic compounds (VOCs), petroleum hydrocarbons (PHCs), and coastal constraints have shifted planning from conventional redevelopment toward long-term stewardship. The Confederated Tribes of Siletz Indians are exploring a small, regulator-credible phytoremediation pilot using candidate willow and poplar species/clones to evaluate plant survival, rhizosphere interaction, shallow groundwater behavior, and contaminant response.

This poster presents the site context, pilot design needs, monitoring questions, and technical uncertainties that must be resolved before phytoremediation can be considered a Brownfields remedy tool. The Tribe seeks technical partners to help design a defensible pilot, select appropriate species/clones, define monitoring methods, avoid wetland and contamination-disturbance risks, and determine whether the approach can support future cleanup, restoration, and Tribal stewardship decisions.

Keywords: Mill site Brownsfield Cleanup Phytoremediation

Poster #8

Functional Complementation of ArsC-Deficient *Escherichia coli* Mutants with Arsenate Reductases from *Crambe abyssinica*

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Arsenic contamination, primarily in the forms of arsenate [As(V)] and arsenite [As(III)], poses significant environmental and agricultural concerns. In plants, arsenate reductases, including Arsenate Reductase 2 (ACR2) and High Arsenic Content 1 (HAC1), catalyze the reduction of As(V) to As(III), thereby regulating arsenic detoxification and distribution. Previous studies demonstrated that suppression of Arabidopsis ACR2 increased arsenic translocation to shoots while reducing root retention, highlighting the potential of manipulating arsenate reductases to improve phytoremediation.

In this study, we investigated the functions of *Crambe abyssinica* arsenate reductases, CaACR2 and CaHAC1, and evaluated their ability to functionally complement ArsC-deficient Escherichia coli mutants. *C. abyssinica*, a high-biomass, fast-growing member of the mustard family, is a promising candidate for phytoremediation of arsenic-contaminated soils. We hypothesize that RNAi-mediated suppression of CaACR2 and CaHAC1 will enhance arsenic translocation to shoots by preventing As(V) reduction in roots, whereas shoot-specific overexpression will promote arsenic accumulation in aerial tissues.

RNAi and overexpression constructs for CaACR2 and CaHAC1 were generated for Agrobacterium-mediated transformation of *C. abyssinica*. In parallel, native and site-directed mutant versions of CaACR2 and CaHAC1 were expressed in ArsC-deficient E. coli strains lacking endogenous arsenate reductase activity. Sequence analysis identified conserved catalytic motifs, $HC(X_5)R$ in CaACR2 and $C(X_4)R$ in CaHAC1. Mutation of the conserved catalytic cysteine residues abolished bacterial arsenate resistance, whereas expression of the native proteins restored resistance, demonstrating successful functional complementation and confirming the essential role of these catalytic residues in arsenate reduction.

These findings establish CaACR2 and CaHAC1 as functional arsenate reductases and provide a molecular foundation for engineering *C. abyssinica* to enhance arsenic phytoremediation while minimizing arsenic accumulation in edible crops.

Keywords: Arsenic, Arsenate reductases, *Escherichia coli*, *Crambe abyssinica*

Poster #9

Influence of Fruit Color and Seed Origin on Zucchini Contamination by Dieldrin

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Dieldrin, an organochlorine pesticide (OCP) once widely used in agriculture, was banned in France in 1972 for agricultural purposes and later classified as Persistent Organic Pollutants (POPs) under the Stockholm Convention in 2001. Despite its prohibition, dieldrin remains in agricultural soils due to its persistence, posing risks to food safety and farm sustainability. Certain plant species, especially those from the Cucurbitaceae family, are known to take up and accumulate dieldrin in above-ground plant parts, sometimes exceeding the Maximum Residue Limits (MRLs) in fruits. Given its toxicity, solutions are urgently needed to ensure safe crop production and reduce human exposure.

Previous works suggested that dieldrin accumulation differs in zucchini's fruits depending on peel color. Besides, as some cultivars are in public domain, some zucchini varieties presenting different phenotype traits can be sold with the same appellation. In order to investigate the influence of fruit color and seed origin on zucchini contamination by dieldrin, 18 zucchini varieties presenting different fruit color and/or provided by different seed makers were selected and grown in open field on a soil with a historical dieldrin contamination (~100 µg/kg DW). Fruits were harvested at marketable size and their peel and pulp were analyzed for their concentration in dieldrin, chlorophyll A, chlorophyll B and carotenoids.

Results: the pigment content of fruit has no influence on its dieldrin content but there was a strong relationship ($p<0.001$) between peel and pulp contamination. Moreover, between 17 and 35 % of dieldrin was located in the peel while it represented less than 15 % of fruit biomass. Besides, the seed origin, especially their genetic makeup and its expression greatly influenced the fruit contamination. Thus, selecting zucchini varieties with low dieldrin accumulation in fruits as well as removing the fruit epidermis can significantly reduce human exposure to dieldrin.

Keywords: Organochlorine pesticide, soil contamination, Zucchini accumulation, human exposure

Poster #10

Molecular and Physiological Responses of Arabidopsis thaliana to Nanoplastic Exposure

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The presence of plastics in terrestrial ecosystems is of growing concern due to their expansive distribution and observed threats to humans and wildlife. Plastics of larger sizes may further break down into microplastics (MPs) and nanoplastics (NPs) through chemical and physical degradation processes. Plastics smaller than 100nm, NPs, are of particular concern as they have proven difficult to detect in natural environments and the full extent of their impacts are not yet known. Once in soil, NPs may be absorbed by plant roots and accumulated in plant tissues, presenting a food safety risk. This study aims to understand how NPs exposure impacts terrestrial plant development at the physiological and molecular levels, using Arabidopsis thaliana as a model organism. *Arabidopsis thaliana* seeds variant Columbia-0 obtained from Arabidopsis Biological Research Center will be used in this study. After initial seed germination assessment, several concentrations of 50nm NPs will be used to determine IC50 which will be further used throughout the study. Uniform seedlings grown for two weeks will then be exposed to the selected concentration of NPs until reproductive stage. The plants will then be used for phenotyping, physiological, molecular, and elemental analysis. Physiological responses will include oxidative stress and antioxidative responses as well as growth and photosynthetic rate. To understand the potential impact of NPs on plants at the molecular level, RNA-seq will be performed. The concentration of essential elements will be analyzed to determine the impact of NPs on essential nutrients. This multifaceted study will provide extensive information about the impact of NPs on plants and be used to understand the food safety risks associated with exposure to NPs. The results of this study will demonstrate the consequences of NPs exposure on a model plant species, highlighting the plant components most threatened by NPs and the need for further inquiry.

Keywords: *Arabidopsis thaliana*, food safety, nanoplastics, phytotoxicity

Poster #11

Integrating Onsite Headspace GC-PID Analysis of Tree Cores with Passive Sampler Evaluation for Subsurface Chlorinated Volatile Organic Compounds Monitoring

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Chlorinated volatile organic compounds (Cl-VOCs) are persistent environmental contaminants that require rapid and adaptable monitoring strategies. This study presents an integrated approach combining portable gas chromatography-photoionization detector (GC-PID) analysis of tree core samples with passive solid-phase samplers (PDMS tubing and dowel wood rods) for subsurface Cl-VOC assessment. Headspace GC-PID analysis demonstrated strong analytical performance, including high linearity ($R^2 > 0.99$), retention time reproducibility (RSD < 0.12%), and analyte-specific limits of detection ranging from 13 to 60 pg/mL for cDCE, TCE, 1,4-dioxane, and PCE. Passive samplers were experimentally evaluated under controlled conditions. PDMS exhibited rapid analyte uptake, higher sorptive capacity, and superior precision (%RSD < 10%) relative to DWR, which accumulated analytes more slowly due to its natural matrix composition. Sampler-specific effective LOD and LOQ values were 0.03-0.69µg/L and 0.10-2.30µg/L, respectively, supporting PDMS selection for upcoming deployment in environmental studies. Currently, field application of passive samplers is planned to assess the spatial and temporal distributions of Cl-VOCs, with headspace GC-PID analysis serving as a complementary, real-time validation tool. This approach provides a practical framework for rapid and scalable monitoring of subsurface chlorinated VOCs using portable instrumentation.

Keywords: Key words: Subsurface chlorinated VOCs, Headspace GC-PID, Tree core analysis, Passive samplers, PDMS tubing, Environmental monitoring.

Poster #12

Evaluating Plant Germination and Contaminant Uptake in 3D-Printed Dredged Sediments

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The U.S. Army Corps of Engineers (USACE) mandate to achieve 70% beneficial use of dredged sediment by 2030 requires innovative strategies to restore capacity in confined disposal facilities (CDFs). This study investigates an Engineering With Nature approach by combining additive manufacturing and phytoremediation to transform non-hazardous CDF dredged sediments into a dual-purpose solution. Novel methods were developed to transform dredged sediments into 3D-printed discs embedded with native upland plant seeds, creating an integrated, easily deployable restoration media.

To evaluate viability and remediation efficacy, two rounds of controlled greenhouse trials were conducted across five candidate species: *Hordeum pusillum* (little barley), *Puccinellia nuttalliana* (Nuttall's alkaligrass), *Panicum virgatum* 'Blackwell' (switchgrass), *Distichlis spicata* (seashore saltgrass), and *Spartina pectinata* 'Red River' (prairie cordgrass). The first trial evaluated baseline germination and growth in unamended dredged material. The subsequent trial assessed plant performance, tolerance, and extraction efficiency in dredged sediment spiked with elevated concentrations of lead, cadmium, and zinc.

Contaminant residuals in the 3D-printed disc sediment matrix, and accumulation in roots, and shoots were quantified using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Phytoremediation potential and physiological partitioning were evaluated through the calculation of Bioconcentration Factors (BCF) and Translocation Factors (TF). Preliminary findings demonstrate species-specific germination resilience and distinct metal partitioning behaviors within the 3D-printed structure. These results provide critical baseline parameters for scaling to field-scale containment testing and validate the viability of seed-embedded, 3D-printed dredged sediment as a dual-purpose solution for sediment repurposing and targeted in situ phytoremediation.

Keywords: Dredge material, phytoremediation, 3D Printing

Poster #13

Synthesis of EOs-loaded nanocarriers and their antibacterial activity against *Erwinia amylovora*

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Fire blight is one of the most destructive diseases causing major apple yield losses. Conventional antibiotics used to manage the bacterial pathogen (*Erwinia amylovora*) raise concerns about the development of antibiotic-resistant bacteria, environmental impacts, and unintended risks to human health. These concerns motivate the development of formulations based on essential oils (EOs) that could reduce reliance on antibiotics. Although EOs are environmentally friendly bactericides, their volatility, limited water dispersibility, and susceptibility to degradation restrict their performance in field application. Using nanocarriers is an effective strategy to enhance the stability and efficacy of EOs. This study aims to determine whether zein- and hydrogel-based nanocarriers can improve the EOs stability and delivery while maintaining activity against bacteria. We are preparing formulations using different synthesis methods and oil-loading levels, as well as characterizing their morphology, surface charge, solubility, encapsulation efficiency, and EOs' release behavior. The antibacterial activity of encapsulated EOs is to be evaluated in vitro against *E. amylovora*. Moreover, these will also be tested in a model system, the formulations will be applied to the surfaces of *Arabidopsis thaliana* leaves infected with Pseudomonas. syringae to investigate their efficacy in vivo. This study evaluates the potential of EOs-loaded nanocarriers for controlling fire blight, and provides potential alternatives to mitigate the reliance on traditional antibiotics for orchard disease management.

Keywords*: Erwinia amylovora*, bactericides, Essential oils, nanocarrier, in vitro activity

Poster #14

Nickel Hyperaccumulation in Mosses and Leaching Behavior from Rocks in Japanese Serpentine Regions

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Nickel (Ni) is a critical resource for electric vehicle batteries, yet conventional smelting processes pose severe environmental and energetic challenges. Phytomining utilizing hyperaccumulators offers a sustainable, low-environmental-impact alternative for metal recovery from serpentine soils. In Japan, however, only one Ni hyperaccumulator species has been reported previously. This study investigated novel Ni-accumulating plants in serpentine areas along the Kurosegawa Tectonic Zone in Japan. Moss and soil samples were collected from two geographically distinct locations. The moss samples were separated into upper (photosynthetic) and basal sections, acid-digested, and analyzed for Ni concentrations using ICP-AES. Molecular phylogenetic analysis identified the collected moss as belonging to the family Pottiaceae. Chemical analysis revealed that this moss exhibits extraordinary Ni hyperaccumulation, reaching a maximum concentration of 4,460 mg/kg-dry weight (DW) in the basal section. This significantly exceeds the standard hyperaccumulation threshold of 1,000 mg/kg-DW and represents the discovery of only the second native Ni hyperaccumulator in Japan. Furthermore, Ni concentrations were consistently higher in the basal part compared to the upper part (maximum 2,471 mg/kg-DW) across all evaluated samples. At one site, the moss demonstrated a remarkably high bioaccumulation factor of approximately 19, efficiently concentrating Ni from soils with a relatively low total Ni content of 22.1 mg/kg. The preferential accumulation in the basal section suggests a mechanism to immobilize Ni, thereby protecting the active photosynthetic upper tissues. Because the basal section constitutes the vast majority of the plant's biomass (approximately 90%). This spatial distribution of Ni is highly advantageous for metal recovery. The unique ability of this moss to grow directly on serpentine rocks and actively extract Ni highlights its promising potential as a novel biological resource for practical phytomining applications.

Keywords: Nickel, Serpentine, Mosses

Poster #15

Nanofertilizers and Nanobiostimulants to Improve Food Quality and Crop Resilience

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Nanomaterials approaches may improve the food quality and crop resilience, exemplified in different case studies: Iron (Fe) is a crucial micronutrient for plant physiology, playing a key role in various metabolic processes including photosynthesis and respiration. However, Fe deficiency is a common problem in agriculture, often leading to impaired plant growth and reduced crop yields. Conventional Fe supplements can sometimes lead to oxidative stress and to other physiological issues. The use of iron oxide nanoparticles (nFe_3O_4) as a novel approach to control iron release in plants. On the other hand, nanosilica ($nSiO_2$) can be applied to mitigate the effects of salt stress. These studies aim to assess the potential positive effects of different potential nano-based application in term of nutrient supplementation and salt stress mitigation at physiological, and molecular level; evidence was coupled with synchrotron-based observation related Silicon (Si) and Iron (Fe) uptake and translocation within the plant. Physiological and phenotypic parameters were monitored and leaves and roots samples were analyzed using μ-XRF and transcriptional analyses. Results showed that nanometric and ionic Fe did not induce significant morphological changes, $FeCl_3$ treatment was associated with reduced photosynthetic activity, increased stomatal transpiration, and elevated lipid peroxidation, indicating oxidative stress. The use of nFe_3O_4 suggested a more controlled and less stressful method of Fe supplementation in plant cultivation, warranting further investigation into their broader agricultural applications. $nSiO_2$ application reduced lipid peroxidation in plant roots under salt stress, although proline content was unaffected. X-ray fluorescence elemental maps showed a higher silicon accumulation in stems treated with Na_2SiO_3, suggesting a greater Si translocation in ionic form. The reduced $nSiO_2$ translocation results in a differential gene expression regulation. These findings suggest that utilization of nanofertilization and nanobiostimulation offer promising strategies to enhance plant resilience, providing more sustainable solution to address the challenges posed by increasing soil nutrient limitation and abiotic stress mitigation in agricultural practices.

Keywords: nanofertilizers, biostimulation, crop resilience, transcriptomics, synchrotron-based analyses

Poster #16

Phytoremediation Strategies for the Detoxification of Explosive Compounds

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Use of explosive compounds such as 2,4,6-trinitrotoluene (TNT) and hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and newer insensitive munitions such as 2,4-dinitroanisole (DNAN) causes environmental pollution. Clean-up of these compounds is of high priority to the US Department of Defense. Highly phytotoxic, TNT and DNAN remain tightly bound to the organic material in the soil, hindering the use of plant-based approaches for remediation. In contrast, RDX is highly mobile in the soil column, and containment and remediation strategies for these compounds are urgently needed. Plants detoxify TNT via direct conjugation to glutathione or reduction-initiated glycosylation, and these conjugates are ultimately sequestered in root cell walls. Our biochemical and genetic studies on TNT using *Arabidopsis thaliana* as our model species have revealed response mechanisms and modes of toxicity, for example through the activity of monodehydroascorbate reductase (MDHAR6). Through expression of a *Drosophila melanogaster* glutathione transferase, we successfully enhanced TNT glutathionylation within Arabidopsis, allowing characterization of this detoxification pathway in planta. Alongside identifying new metabolic derivatives of TNT, we confirmed the importance of gamma-glutamyl transpeptidase activity in initiating TNT-glutathione conjugate metabolism and confirmed TNT-metabolite compartmentalization within Arabidopsis root tissue. These results provide *in planta* evidence for glucosyl- and malonyl-conjugate compartmentalization and importance in TNT metabolism and sequestration, while also demonstrating the versatility of a benchtop non-aqueous fractionation technique for investigating compartmentalization of plant metabolism. Funded by the US Strategic Environmental Research and Development Program and UK Biotechnology and Biological Sciences Research Council, we will present findings on these in planta detoxification routes and demonstrate how this technology can be successfully transferred into remediation-applicable species and tested in-the-field.

Keywords: Phytoremediation, Organic, Pollutant, Explosives, Detoxification, Metabolite Sequestration

Poster #17

Phytotechnologies for Soils Contaminated with Pyrite Ashes: Preliminary Results from a Case Study in Central Italy

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The legacy of the industrial boom is reflected in the presence of numerous contaminated sites surrounding now-abandoned factories. A preliminary study was conducted to assess the applicability of phytotechnologies to restore a polluted site in Central Italy, where a factory producing sulphuric acid generated pyrite ash containing Arsenic, lead and zinc as byproduct, which was used as backfill material.

The preliminary study included three main activities. First, a survey of spontaneous vegetation was carried out to identify naturally occurring species and to quantify the potential toxic elements (PTEs) in the biomass of the most abundant tree species. Second, phytotoxicity tests were performed on three substrates with different contamination levels, following the ISO 11269 protocol for germination and growth assays *(Lepidium sativum* and *Avena sativa*). Third, controlled-condition experiments on phytoextraction and phytostabilisation were conducted using two herbaceous species: *Cannabis sativa* and *Pteris vittata*, selected for their known tolerance and different responses to PTEs. Over two months, plants were tested using the same contaminated substrates of phytotoxicity tests. Germination, growth and eco-physiological parameters were monitored, and pollutant concentrations were analyzed in both soil and plant biomass at the end of the experiment.

Although the study is still ongoing, preliminary findings indicate that none of the tested substrates prevent plant growth; however, they do inhibit plant development, particularly in dicotyledonous species. *P. vittata* adapted well to the contaminated substrates and even showed improved growth compared to the control, suggesting a possible hormesis effect. *C. sativa* was more sensitive but remained capable of germinating and growing even in highly contaminated soil. A second phase will involve an in-situ pilot study to validate these promising results under field conditions and to inform a recovery plan for the site. This research will also provide indications useful for similar polluted sites across Italy.

Keywords: Cannabis sativa, plant physiology monitoring, *Pteris vittata*, phytoextraction, phytostabilisation

Poster #18

Pilot-Scale Bioaugmented Phytoremediation to Treat 1,4-Dioxane-Contaminated Groundwater

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Background/Objectives. 1,4-Dioxane (dioxane) is a probable carcinogen and a persistent groundwater pollutant, often found co-occurring with chlorinated solvents (e.g., trichloroethylene, dichloroethylene, and trichloroethane). Because of dioxane's high mobility in groundwater, dioxane plumes tend to be large and dilute. Proposed EPA risk guidelines for dioxane in drinking water are as low as 0.35 ug/L. Reaching this low clean-up guideline through remediation has proven difficult and costly. Utilizing aggressive pump-and-treat and ex situ technologies, such as advanced oxidation (AO), for dilute dioxane plumes is often prohibitively expensive. Monitored natural attenuation (MNA) is a low-cost alternative; however, it can struggle to reach stringent cleanup concentrations.

Our current work aims to demonstrate that phytoremediation using hybrid poplar and willow trees bioaugmented with dioxane-degrading microbes provides a reliable, cost-effective solution for treating 1,4-dioxane and chlorinated solvent co-contaminants. We have previously shown that bioaugmenting the poplar rhizosphere with dioxane-degrading bacteria accelerated 1,4-dioxane treatment to ~1 ug/L. Additionally, we identified *Rhodococcus ruber* 219, a metabolic dioxane degrader, as a strong candidate for field bioaugmentation. With the addition of B-vitamins, this strain can sustain degradation at dilute dioxane concentrations (<100 µg/L) and break down dioxane to below health advisory levels (<0.35 µg/L).

Approach/Activities. Since 2023, we have operated a pilot-scale bioaugmented phytoremediation demonstration at the former Twin Cities Army Ammunition Plant (TCAAP) in Arden Hills, MN. TCAAP has an abundance of 1,4-dioxane (<100 µg/L) and trichloroethylene (<1 mg/L) in groundwater, which has spread off-site and contaminated drinking water wells in nearby New Brighton, MN. To demonstrate the technology, we installed forty Phyto Attached Growth Reactors (PhAGRs®), developed by Ecolotree, Inc. To facilitate complete dioxane treatment, all PhAGRs were bioaugmented with R. ruber 219. TCAAP groundwater was applied to the PhAGRs via subsurface drip emitters. Ultrasonic water level sensors controlled the pumping from groundwater reservoirs and between PhAGR rows. The system was operated in series, with the effluent from each row transferred via in-line pumps as influent to the next row.

Results/Lessons Learned. We report data collected during 2024-2026 from our pilot-scale demonstration installed at TCAAP. The system maintained sustained effluent concentrations of

1,4-dioxane below 1 µg/L, with levels as low as 0.5 µg/L. Dioxane-metabolite analyses from the PhAGR effluent, as well as dioxane analyses in tree tissue samples, suggest that most of the dioxane loss occurs through biodegradation in the PhAGR reactors. Additionally, chlorinated solvent co-contaminants were effectively removed to below detection limits. Moreover, tree transpiration successfully ran the system to dryness, resulting in zero liquid effluent discharge. Based on quantitative PCR results, we also report sustained *R. ruber* 219 populations for up to seven weeks without rebioaugmentation. Overall, this research demonstrates that bioaugmented phytoremediation is a promising strategy for treating dilute dioxane-contaminated groundwater to meet health advisory concentrations.

Keywords: 1,4 Dioxane, Bioaugmentation, Phytoforensics

Poster #19

Septic Wastewater Treatment Results Using PhAGR at PanelView RV Park, Hermiston OR.

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PhAGR® (Phyto-attached Growth Reactor) concept processes wastewater pollutants by intimate contact with roots covered by active microbes. The result reliably realized is a legally permitted water discharge.

What is different? In conventional wastewater cleanup, the organic carbon in wastewater is the primary carbon energy source for microbes. At tertiary treatment levels required by regulations, there is little remaining carbon to achieve tighter concentrations of BOD_5, ammonia-nitrogen, and E. Coli. Leaf chlorophyll creates sugars and proteins that travel down phloem into the rhizosphere providing nutrients for a large diverse microbe population. The root carbon is the primary microbe food; the pollutant organic matter (measured as BOD_5) is a minor food source, so pollutants are co-metabolized.

Post-septic tank wastewater is dosed into aerobic PhAGR Bags growing roots throughout porous perlite. As water drains, void spaces fill with atmospheric oxygen as the electron acceptor. Aerated effluent drains by gravity into a basalt rock filled 30-inch-deep lined basin planted with willow. This basin comes anoxic and the nitrate nitrogen reduces to nitrogen gas. Ammonia-N, COD organics, nitrate-N and E. Coli mass ais microbially reduced to regulated discharge standards. Effective E. Coli removal was unexpected. Tree growth exceeded twelve feet in one season; the trees are biannually pollarded and harvested; the root functions never stop. Electrical energy required for PhAGR was 96% less than conventional mechanical treatment technology.

Each of 49 RV parking slots has a 120 square foot photo voltaic panel. The RV Park system is net zero energy due in part to low energy required for the PhAGR. The PhAGR inverts the carbon footprint for water treatment.

DATA Source: PanelView RV Park, Hermiston OR. (Oregon DEQ permit #103258) first permitted PhAGR® operating since December 2020.

Keywords: Wastewater, Septic, PhAGR, poplar, regulated

Poster #20

Uptake and Translocation of Per- and Polyfluoroalkyl Substances by Woody and Herbaceous Plants in Field-Relevant Soil to Evaluate Phytoremediation

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Per- and polyfluoroalkyl substances (PFAS) are a class of synthetic chemicals widely used in various consumer and industrial products due to their amphiphilicity and elevated chemical and thermal stability. However, their persistence and widespread presence in the environment have raised public health concerns. Here, greenhouse experiments were performed to evaluate PFAS uptake, translocation, and phytoremediation potential in various plants grown in field-collected contaminated soil. Two woody plants (poplar and willow) and three herbaceous plants (fescue, sedge, and bluejoint) were cultivated in PFAS-contaminated soil collected from a contaminated airport site. During cultivation, plant growth and health were weekly monitored, including soil moisture, plant height, and chlorophyll levels. After 20 weeks of exposure, we compared the total biomass production over the whole growth period between the control and treatment groups of each plant species. PFAS accumulation in plant roots, stems, and leaves, and the concentration reduction in soil were evaluated and will be presented. PFAS levels in various plant tissues and data on highly variable PFAS distribution in leaves, stems, and roots will be shared. The results are expected to provide key design parameters for species selection, biomass yield, and the development of phytoremediation strategies on PFAS-contaminated soils.

Keywords: Per- and polyfluoroalkyl substances, phytoremediation, bioaccumulation, contaminated soil, field-relevant

Poster #21

Uptake Mechanisms of PFOA in Genetic Model plant *N. tabacum*

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Per- and polyfluoroalkyl substances (PFAS) are synthetic organic chemicals which have been widely used in commercial and industrial products since the 1950s. PFAS are extremely stable and resistant to biophysiochemical degradation and mineralization in the environment, causing them to be ubiquitous and of global concern. This study involves investigating the mechanisms that the genetic model plant *N. tabacum* uses for the uptake of perfluorooctanoic acid (PFOA). We hypothesized that tobacco plants utilize both passive and active channel proteins, such as aquaporins and ion channels, to translocate PFAS throughout a plant. It was determined that the chemical inhibition of the targeted uptake mechanisms resulted in up to 95.9% reduction in root PFOA uptake. Overall plant PFOA concentrations were also shown to be reduced in some cases. Time- and concentration-dependent studies were performed to evaluate uptake kinetics. By evaluating the specific proteins that plants utilize for PFAS uptake, phytoremediation techniques for targeting PFAS could be optimized. Phytoremediation as a means to reduce PFAS contamination in the environment is an apt solution that has not been properly explored. The information gained from this study will provide a basis for molecular techniques that would target specific plant proteins via genetic enhancement of plants for PFAS uptake.`

Keywords: PFAS, Biochemistry, Phytoremediation

Poster #22

Water In, Water Out: Designing Phytoremediation into the Full Site Water Cycle

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Traditional remediation frameworks define success through contaminant removal and regulatory closure. For many brownfield and landfill sites, that bar is too low. A site can be "cleaned up" and still have degraded soils, impaired hydrology, and contaminant pathways that stay active under the right conditions. Closure isn't recovery.

Part of the problem is how water gets managed. At most landfill and brownfield sites, it's handled in pieces -- leachate collected here, stormwater routed there, groundwater monitored at the fence line. This presentation argues that managing those pieces together, through phytoremediation and ecological design working as a connected system, produces better long-term outcomes than treating each pathway separately.

Two projects show how. At the BASF landfill in Rensselaer, New York, a phytoremediation cap and constructed wetland system were designed together to address landfill leachate and groundwater as connected problems. The phyto cap reduces infiltration and pulls contaminants through vegetative uptake, while a stormwater wetland systems reduces the burden on the cap and provided needed ecological uplift. At Heron Pond Park in Denver, a former brownfield, stormwater, groundwater, and ecological restoration were integrated into the park design to create a fully functioning system.

Across both sites, the logic is the same: evapotranspiration, water collection and management, and canopy cover are ecological variables as much as they are phyto variables. With the full hydrologic picture in mind, integrated systems reduces contamination at the source, intercept migration, and feed wetland systems that provide treatment and ecological function at the same time.

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Keywords: ecological design, landfill cap, nature-based solutions, stormwater

Poster #23

Leaf-Waste-Derived Lignin Carbon Dots as Sustainable UV-Protective Foliar Coatings for Climate-Resilient Agriculture

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Climate change is increasing environmental stresses that threaten crop productivity, including exposure to ultraviolet (UV) radiation. Here, we developed lignin-derived carbon dots (LCDs) from Norway maple (*Acer platanoides*) leaf waste as sustainable, plant-compatible foliar coatings for UV protection and light management. Lignin was extracted from leaf litter and converted by hydrothermal treatment at 200 °C (pLCD-200) and 350 °C (fLCD-350). Both materials showed strong UV absorption; pLCD-200 converted absorbed UV into visible wavelengths within the photosynthetically active radiation range, whereas fLCD- 350 exhibited greater photostability and near-infrared emission. Under prolonged natural sunlight, pLCD-200 showed gradual fluorescence decay with increased UV absorbance, while fLCD-350 remained optically stable and exhibited photo-brightening. Formulation of fLCD- 350 with biodegradable sodium alginate produced a sprayable foliar film that retained strong leaf-surface fluorescence for at least 10 days outdoors, indicating durable adhesion and persistence. Foliar application to soybean at 300 and 600 mg L^{-1} caused no adverse effects on chlorophyll content, photosystem I activity, plant growth, or biomass. Treated plants also showed higher photosystem II quantum yield (Phi2) and reduced nonregulated energy dissipation, consistent with improved light-use efficiency without photoinhibition. By converting abundant leaf waste into a durable, biodegradable UV-protective nanomaterial, this approach integrates circular bioeconomy principles with crop photoprotection and offers a promising strategy for climate-resilient agriculture under variable and high-radiation field environments associated with climate change.

Poster #24

Accumulation and Translocation of Emerging Contaminants and Their Transformation Products in Broccoli Microgreens Irrigated with Treated Wastewater

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Irrigation with treated wastewater (TWW) is an important water-conservation strategy, but the contaminants present in TWW can affect crop growth and contribute to the accumulation of heavy metals and emerging contaminants (ECs). Chemical changes during wastewater treatment, storage, and plant growth may also generate transformation products. In this study, wastewater samples were collected from a treatment plant in the northeastern United States. To evaluate a worst-case exposure scenario, broccoli (*Brassica oleracea* var. italica) microgreens were grown hydroponically in TWW effluent, with Hoagland nutrient solution used as the control. Plant growth and the uptake of organic and inorganic chemicals were evaluated using liquid chromatography-high-resolution mass spectrometry (LC-HRMS) and inductively coupled plasma-optical emission spectrometry (ICP-OES). Targeted analysis detected and quantified 23 chemicals, including pharmaceuticals, industrial chemicals, and pesticides. Twelve chemicals were detected in plant tissues, of which eight were translocated to the edible shoots. Non-targeted analysis (NTA) detected 153 chemicals in wastewater, including 46 that were also detected in plant roots or shoots. Molecular networking identified clusters of contaminants and related transformation products based on their mass spectrometric data. The elemental analysis showed negligible concentrations of heavy metals in wastewater and plant tissues. Essential nutrient concentrations in wastewater were comparable to those in Hoagland solution, resulting in similar plant growth. The accumulation of organic ECs and transformation products in edible tissues raises potential food-safety concerns. The ability of many targeted, non-targeted contaminants and their transformation products to accumulate in microgreens highlights the need for further investigation. These findings demonstrate that treated wastewater can support microgreen growth but requires comprehensive chemical monitoring and risk assessment before its use in food production.

Keywords: Emerging contaminants, Wastewater reuse, LC-HRMS, Non-targeted analysis, Transformation Products

Poster #25

Assessing the Efficacy of Cellulose Macrofibers Soil Amendment in Reducing Heavy Metal Bioavailability and Accumulation in Lettuce Grown in Two Different Soils

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Heavy metal contamination of agricultural soils poses serious risks to food safety and crop productivity. While metal-based nanomaterials can reduce heavy metal uptake in crops, their potential long-term phytotoxicity remains a concern. Cellulose macrofibers (CMF), fabricated by nitro-oxidation of waste jute biomass (*Corchorus olitorius*), offer a biodegradable alternative with demonstrated efficacy in removing heavy metals from water. This study investigates whether incorporating CMF into contaminated soil can similarly reduce heavy metal bioavailability and plant uptake.

We hypothesized that CMF would reduce the bioavailable contaminant fraction by binding metals to carboxylate ions on the cellulose surface, thereby limiting accumulation and improving plant growth.

Two soil types were spiked with sodium arsenate, cadmium chloride, and lead nitrate to achieve individual contamination levels of 50 ppm arsenic (As), 50 ppm cadmium (Cd), and 200 ppm lead (Pb), plus a mixed treatment (As & Cd: 10 ppm; Pb: 40 ppm). CMF was incorporated at 1% dry weight, and soils were equilibrated for one week at 60% water-holding capacity. Three-week-old lettuce (*Lactuca sativa*) seedlings were transplanted and grown for six weeks. Plant tissues were analyzed for total metal accumulation.

Soil amendment with CMF reduced arsenic, cadmium, and lead accumulation in shoots by 8, 40, and 55%, respectively, in one soil, but not the other. CMF's mechanism of action is being investigated through biochemical and molecular studies of plant samples and physicochemical characterization of soil samples collected at transplanting and harvest.

This work explores a novel, biodegradable strategy for heavy metal immobilization in agricultural soils, with implications for sustainable remediation and food safety.

Keywords: Cellulose Microfibers, heavy metals, lettuce, food safety

Poster #26

Assessing Portable X-Ray Fluorescence for Metal Quantification of Serpentine Soils and *Streptanthus polygaloides*

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Streptanthus polygaloides, a nickel (Ni) hyperaccumulator within the Brassicaceae family, is endemic to the Sierra Nevada foothills of California. It grows on serpentine soils characterized by elevated metal concentrations, poor nutrient availability, and low calcium to magnesium ratios. For phytoremediation and phytoming research to progress it is important to accurately quantify metal concentrations in hyperaccumulator plant tissues and the soils they grow in. Currently, Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) is one of a few standard metal quantification methods. However, ICP-OES requires sample transport, and destruction in the case of plants, and can be costly and time-consuming. Portable X-Ray Fluorescence (pXRF) is an alternative rapid and nondestructive method which has potential for reducing the cost, logistical complexity, and time often involved in hyperaccumulator research. This study sought to examine the relative accuracy of pXRF in quantifying Ni, Zn, and Cu concentrations in serpentine soil samples and *Streptanthus polygaloides* tissues. All samples were analyzed using pXRF and ICP-OES techniques. The relationship between pXRF and ICP-OES metal concentrations was then assessed for both matrices using linear regression and bland altman analysis. The results indicated a strong correlation between methods for Ni concentrations of both matrices after drying: soil (R^2 = 0.9229 and Pearson correlation value of 0.9606) and plant tissue (R^2 = 0.8044 and Pearson correlation value of Pearson correlation value of 0.8969). Zinc and Cu exhibited moderate to low correlation overall. This study demonstrates that, although further fine-tuning is needed, pXRF has much potential to reduce costs and time of metal quantification in the phytoremediation and phytoming research field.

Keywords: pXRF, hyperaccumulator, *Streptanthus polygaloides*, serpentine soil

Poster #27

Microbial Dynamics in Petroleum Contaminated Soil remediated with Biochar, Bioactivators, and Plants

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Microbial communities play a key role in the degradation of organic pollutants in contaminated soils. Bioaugmentation, based on the introduction of specific microbial strains or consortia, is a promising strategy to enhance biodegradation processes. However, its effectiveness depends on the survival and activity of the introduced microorganisms. In this context, biochar, owing to its high surface area and porous structure, can provide favorable microhabitats for microbial colonization and support microbial activity, thereby potentially improving the performance of bioaugmentation-based soil remediation.

This study evaluated the remediation potential toward petroleum hydrocarbons (PHs) of different soil treatments biochar (SB) and biochar combined with bioactivators (SBB) in the presence or absence of plants (P) over a 9-month period. At multiple time points, we monitored PH concentrations and characterized the microbial community in terms of total abundance, taxonomic composition, and diversity. Marked differences in microbial community structure were detected among treatments and across sampling times. After nine months, the combined addition of biochar and bioactivators promoted the enrichment of specific bacterial groups. In the SBBP treatment, richness (ASV number) increased from the initial to the final sampling, while Simpson and Shannon diversity indices decreased, indicating community restructuring. Overall, microbial community composition shifted substantially from the start to the end of the experiment in all conditions, as confirmed by PCoA analyses showing that both time and treatment type shaped community assembly. Microbial co-occurrence networks were also constructed to explore potential interactions among taxa throughout the experiment. Concurrently, PH concentrations decreased across all treatments, reaching up to 90% removal in soils amended with both biochar and bioactivators. Despite severe PH contamination, the affected agricultural soil maintained a vital and abundant microbial community. The most effective remediation strategy was the combined use of biochar and bioactivators.

Keywords: bioremediation, petroleum hydrocarbons, microbial consortium, biochar

Poster #28

X-rays for Life, Environmental, Agricultural, and Plant Sciences (XLEAP): A New Beamline Under Construction at the Cornell High Energy Synchrotron Source

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A new microprobe beamline called XLEAP (X-rays for Life, Environmental, Agricultural, and Plant Sciences) is under construction at the Cornell High Energy Synchrotron Source (CHESS). This mid-scale research infrastructure award (USNSF-2330043) began in April 2024, and the facility is planned to open for user operations in 2028. During construction, graduate students and faculty from the University of Texas at El Paso are collaborating with CHESS staff and Cornell faculty on pilot experiments that develop future capabilities and workflows for XLEAP.

The science priorities for XLEAP, driven by workshops and conferences in 2020-2023, include (1) fundamental mechanisms in plant sciences, such as micronutrient uptake, transport, and storage; (2) how plants respond to external stimuli such as nanoparticles, pathogens, and environmental stresses; (3) mechanisms of elemental cycling at the root-soil interface and in soil; and (4) mechanisms of elemental uptake and cycling in aquatic flora, seaweeds, algae, and other organisms. Moving forward, the XLEAP science program will incorporate plant interactions with critical elements, and metals in nutrition and food safety.

XLEAP will offer spatially resolved x-ray fluorescence microscopy (2D mapping, 3D computed tomography, and 3D confocal imaging), x-ray absorption spectroscopy, and x-ray diffraction, with tunable spatial resolution from >100 µm to 1 µm, energies ranging from 3-80 keV, and high-flux or high-energy-resolution modes. XLEAP will also offer users complementary optical microscopy, plant growth, and sample preparation facilities, as well as the potential for in-situ x-ray measurements with custom plant growth environments directly on the beamline. We will illustrate the planned experimental modes, report on ongoing pilot experiments, and describe new possibilities for flexible access to accommodate experiments with longer time scales.

Keywords: phenotyping, x-rays, synchrotron, metals, microscopy

Poster #29

Engineering Copper- and Sulfur- Based Nanomaterials for Improved Foliar Delivery and Plant Physiological Responses

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Copper- and sulfur-based nanomaterials offer promising opportunities to improve nutrient delivery, enhance plant growth, and increase crop resilience. However, their agricultural performance depends strongly on physicochemical properties that regulate nutrient release, plant uptake, and biological responses. This study investigates how nanoscale properties and surface engineering influence the interactions of Cu- and S-based nanomaterials with tomato and soybean. Nanoparticles with different organic surface coatings were synthesized and evaluated for their dissolution behavior, foliar uptake, spatial distribution, and physiological effects in tomato and soybean. Nanomaterial release was investigated, while foliar absorption and redistribution were assessed through localized leaf application. Plant responses were further evaluated through photosynthetic pigments and carbohydrate accumulation.

Results demonstrated that surface chemistry and solution composition significantly influenced nutrient release from nanoparticles, while organic coatings regulated foliar uptake and spatial distribution within leaves. Selected surface-modified CuS formulations increased chlorophyll a content and soluble sugar accumulation in soybean. Additionally, sulfur nanoparticles alleviated cadmium stress through combined soil geochemical and plant physiological mechanisms. Nanoscale sulfur reduced soil Cd bioavailability by up to 32%, decreased Cd accumulation in soybean pods by 23%, and increased shoot biomass by 62%, accompanied by improved antioxidant responses. Collectively, these findings demonstrate the potential of engineering Cu- and S-based nanomaterials to improve nutrient delivery, enhance plant physiological performance, and mitigate environmental stress for sustainable agriculture.

Keywords: Nano-enabled agriculture; Cu- and S-based nanoparticles; Plant nutrient uptake; Stress resilience; Cd contamination