

Introduction

- Wildfires are an increasingly significant driver of soil degradation and environmental pollution in California, causing long-term damage to soil structure, chemistry, and biological properties.
- Pyrogenic stress can increase bulk density, induce hydrophobicity, disrupt nutrient cycling, and suppress microbial function, limiting post-fire ecosystem recovery.
- This project was inspired by observing the impacts of the Eaton Fire in California in 2025. The impacted land appeared barren even months after the fire was extinguished.
- This led me to an important question: If the soil is damaged, how can ecosystems and communities recover?
- I became interested in:
 - Soil degradation as a hidden form of pollution
 - Long-term recovery challenges after wildfire
 - Developing practical, accessible restoration solutions
- This project investigated wildfire-induced soil stress by comparing burned and unburned soils across key physical, chemical, and biological indicators, including bulk density, NPK, pH, hydrophobicity, infiltration, and CO₂ respiration. Rainfall simulation tests assessed erosion risk, runoff behavior, total dissolved solids, and potential contaminants.
- In Phase 2, bioremediation strategies including compost, biochar, mulch-based hydroseeding, and an integrated Soil Restoration Kit were tested over 16 weeks. A biodegradable soil blanket was also designed for surface stabilization.
- Results show integrated treatments improved soil health, reduced erosion, and supported vegetation recovery, demonstrating a scalable, community-accessible approach to post-fire restoration.

Hypothesis

- Wildfire degrades soil by increasing compaction and hydrophobicity, reducing nutrient availability, and suppressing microbial activity.
- A combined bioremediation approach will restore soil health more effectively than single treatment.

Research Question

- How do wildfires affect soil’s physical, chemical, and biological properties including soil health, nutrients, water retention, microbial activity, and which bioremediation strategy can we use to most effectively restore soil function, reduce erosion, and support vegetation recovery?

Methods

Phase 1 Soil Impact Analysis

Experimental Conditions and Variables:

- Wildfire ash soil
- Wildfire mixed soil (0–12 in)
- Garden soil (unburned, control)

Tests conducted:

- Bulk density
- NPK nutrient analysis
- pH
- Hydrophobicity
- Water infiltration
- CO₂ respiration

Rainfall simulation measuring runoff, sediment loss, and TDS

Phase 2: Bioremediation Treatments

Experimental Conditions and Variables:

- Compost
- Biochar
- Mulch based hydroseeding
- Bioindicator plants: Mustard and Sunflowers
- Combined restoration kit
- Burlap based biodegradable blanket with restoration kit for slope stabilization

Monitored over 16 week with Phase 1 tests repeated each week



Left - Photo taken by Finalist of Wildfire landscape after Eaton Canyon Fire, 2025
Right - Photo taken by parent of Finalist showing finalist collecting soil samples from the Eaton Canyon fire site near Los Angeles, 2025

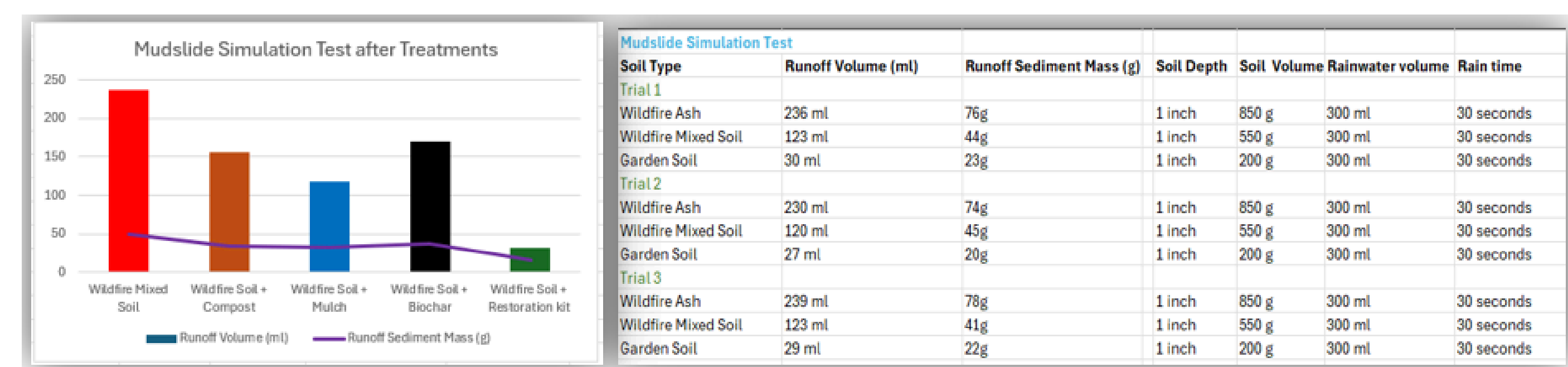
Rebuilding Pyrogenic Soils

Evaluating Stress Impacts and Bioremediation Viability for Ecosystem Recovery

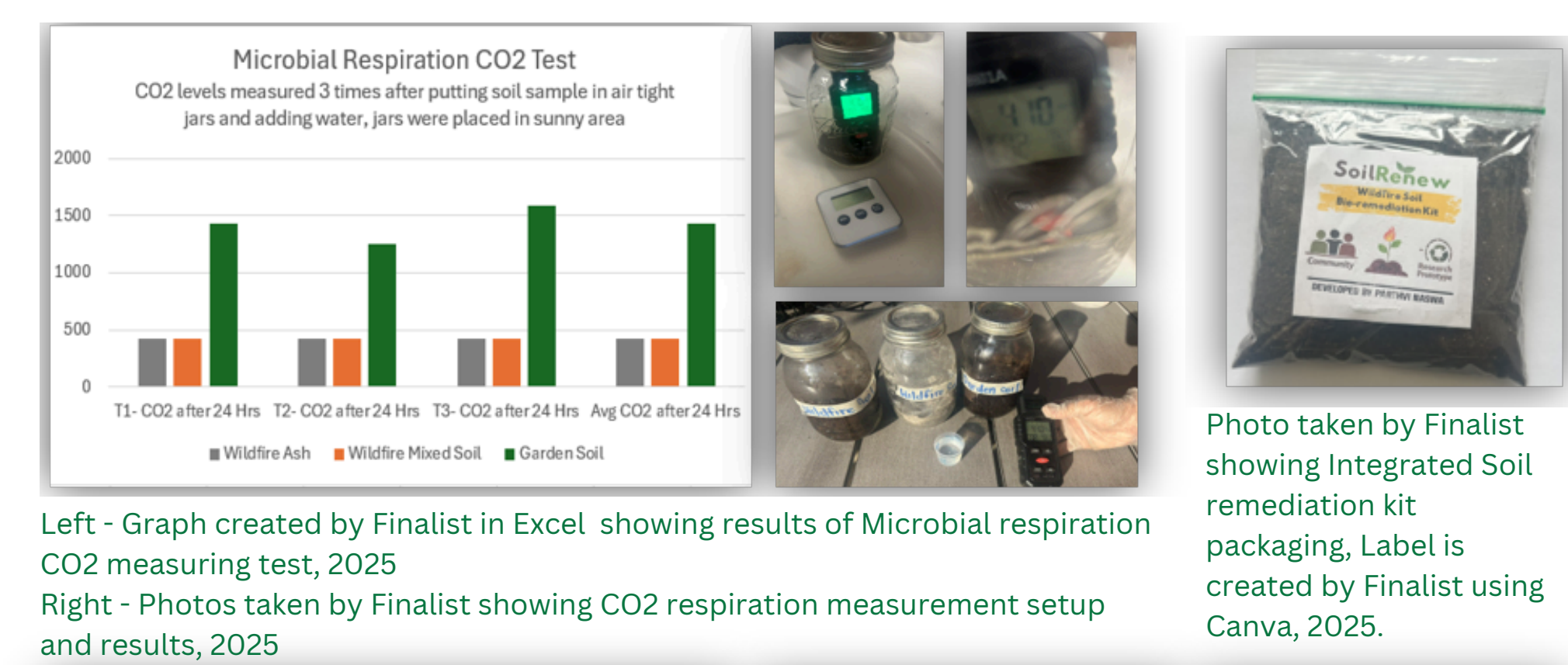
EXPERIMENTAL DESIGN & PROCESS

Phase 1 Soil Impact Analysis

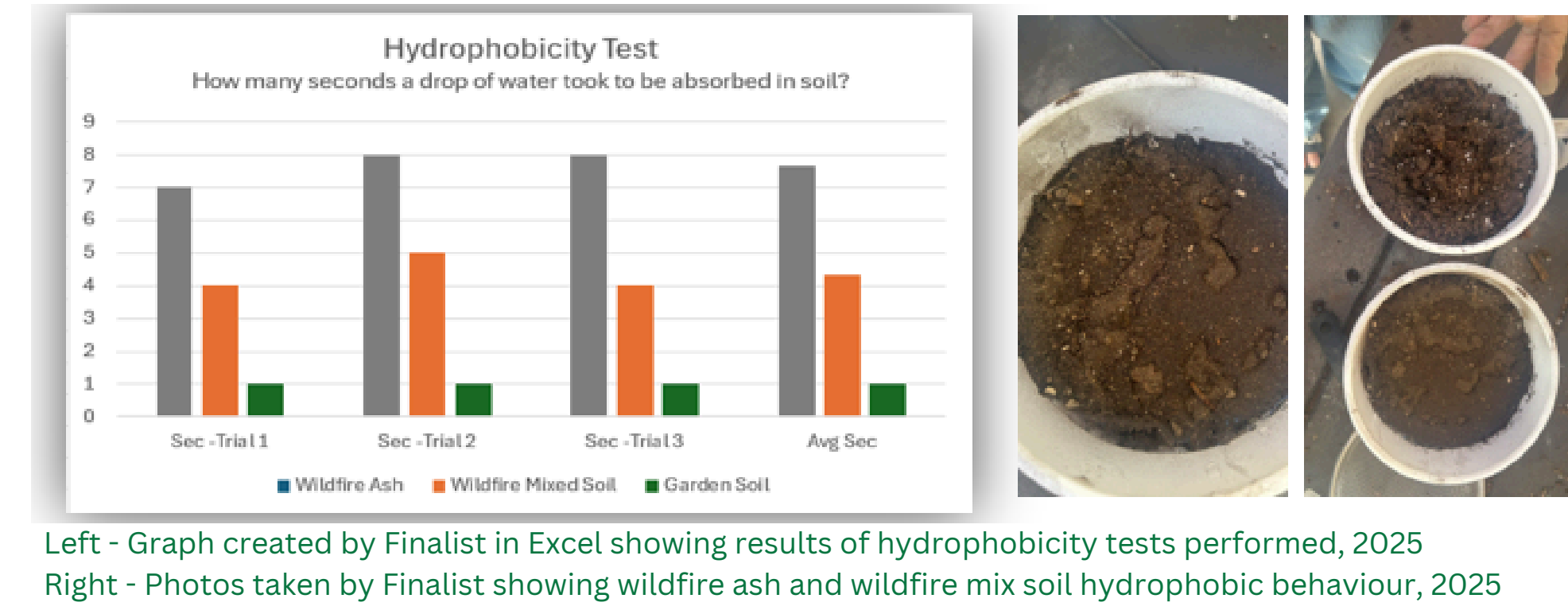
- Soil samples were independently collected from wildfire-affected areas, handled using basic safety and contamination control procedures and categorized into surface ash-rich soil and mixed soil from the top 12 inches. Unburned garden soil was used as a control. All samples were air-dried, standardized, and tested under consistent conditions.
- Soil health was evaluated using multiple physical, chemical, and biological indicators. Bulk density was calculated by measuring the mass-to-volume ratio of soil samples to assess compaction. Nutrient availability (NPK) and pH were measured using standardized soil testing procedures. Hydrophobicity was assessed using water drop penetration time (WDPT), and water infiltration rates were measured by recording the time required for a fixed volume of water to infiltrate the soil, along with simulated rainfall tests to evaluate runoff, sediment loss, and erosion potential. Microbial activity was estimated through CO₂ respiration by measuring CO₂ accumulation in sealed containers over time.
- Each test was repeated multiple times to ensure consistency and reliability.



Left - Graph created in Excel by Finalist showing results of mudslide simulation tests at 16th week after treatment indicating runoff water and sediment loss comparisons, 2025. Right - Data Table created by Finalistn Excel showing collected mudslide simulation test data for 3 trials, 2025



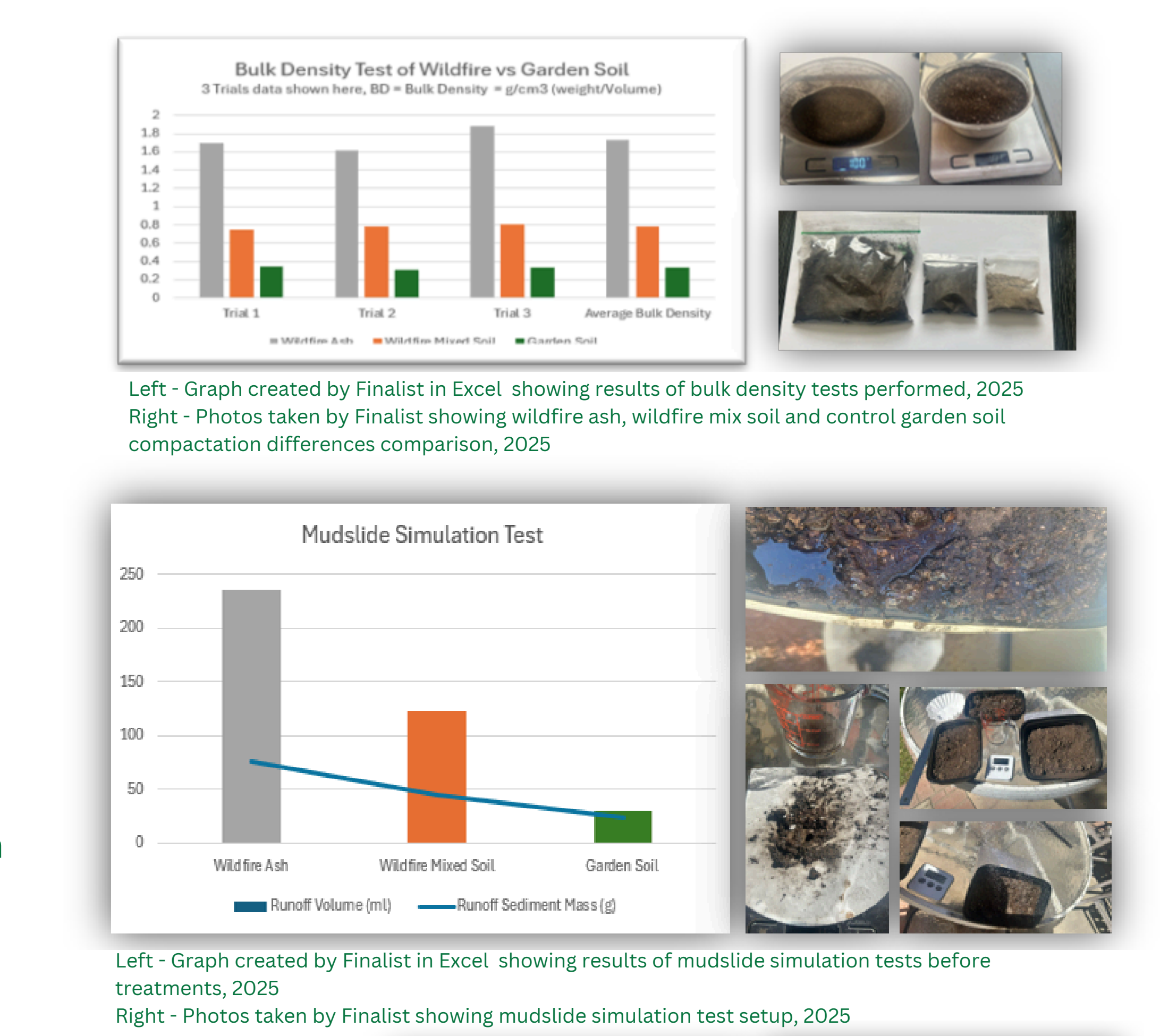
Top Left - Graph created by Finalist in Excel showing plant growth at 16th week after treatments, 2025
Right and Bottom - Photos taken by Finalist showing seeds being planted, various treatments being added and plant growth over research period, 2025



Left - Graph created by Finalist in Excel showing results of hydrophobicity tests performed, 2025
Right - Photos taken by Finalist showing wildfire ash and wildfire mix soil hydrophobic behaviour, 2025



Left - Photo taken by Finalist showing difference in volume of Garden Soil, Wildfire Mix Soil, Wildfire Ash. All Soil samples are measured as ~ 50 grams weight but due to soil being compact, there is difference in volume, 2025.
Photos taken by Finalist showing use of bioblanket for slope stabilization and erosion control, 2025.



EXPERIMENTAL DESIGN & PROCESS

Phase 2 Wildfire Soil Bioremediation

Techniques and their viability

- Wildfire-affected soil was divided into treatment groups and amended using different bioremediation strategies.
- Mustard and sunflower seeds were chosen for their high resilient nature, fast growing quality and phytoremediation properties.
- All treatments were maintained under identical conditions, including soil volume, watering schedule, and light exposure.
- Over a 16-week period, plant growth and soil recovery were monitored.

Data collected included plant height and overall plant health. Soil properties were periodically reassessed using the same indicators from Phase 1 to evaluate changes in compaction, nutrient availability, hydrophobicity, water infiltration, and microbial activity.

Rebuilding Soil Structure and Nutrient Cycling

- Several organic amendments, compost, biochar, mulch and crushed dried leaf litter were applied to burned soil to restore organic matter lost during wildfire.
- These treatments were selected for their accessibility and suitability for community-scale use.
- Ultimately, a combined soil restoration solution kit integrating compost, biochar, leaf-based mulch and seeds was tested to address multiple post-fire soil limitations simultaneously. This integrated approach restored physical structure, nutrient availability, water behavior, and biological activity more effectively than individual treatments alone.
- The following changes were observed in the soil:
 - Reduction in bulk density
 - Recovery of nutrient balance including nitrogen and potassium
 - Increased microbial activity and CO₂ respiration
 - Improved water infiltration
 - Improved plant growth
- These treatments demonstrated that low-cost, locally available materials can significantly improve post-fire soil health.
- A bio blanket made from biodegradable burlap and soil restoration kit as a layer was also developed to be used for slope stabilization and erosion control.

Results - Phase 1 Impact of Wildfire on Soil Health

- Bulk Density: Wildfire soils showed significantly higher bulk density than garden soil, indicating compaction and reduced pore space.
- NPK & pH: Surface ash showed elevated potassium, while mixed wildfire soils showed reduced nitrogen and nutrient imbalance.
- Hydrophobicity & Infiltration: Wildfire soils exhibited delayed water infiltration and higher water drop penetration times, confirming strong hydrophobicity.
- CO₂ Respiration: Lower CO₂ levels in wildfire soils indicated reduced microbial activity.
- Runoff & Erosion: Rainfall simulation showed increased runoff and sediment loss in wildfire soils compared to control.

Results - Phase 2 Bioremediation Effects

- Compost: Increased nutrient levels and microbial activity (higher CO₂).
- Biochar: Improved moisture retention and stabilized soil structure.
- Mulch/Hydroseeding: Reduced surface drying and improved infiltration.
- Combined Kit: Showed the greatest improvement across all indicators, including:
 - Lower bulk density, Reduced hydrophobicity
 - Increased microbial activity, Higher plant growth (mustard & sunflower)

Data Trends & Analysis

Results were consistent across trials with minor variability due to soil heterogeneity. Comparative analysis showed combined treatments outperformed individual treatments across multiple indicators. Overall trends support improved soil function through integrated remediation.

Real World Application and Community Impact

Community gardens and backyards: Enables residents to restore soil and grow plants after wildfire events.
Fire-impacted neighborhoods: Reduces erosion, runoff, and mudslide risks.
Parks and open spaces: Supports faster vegetation re-establishment without heavy machinery and chemical usage.
Educational tool: Demonstrates soil recovery using accessible materials.
This project proposes a simple, scalable soil restoration solution that can be deployed in wildfire-affected communities without any specialized equipment.

Future Work and Limitations

Future Work

- Test the solution performance under different soil types and burn severities.
- Monitor long-term soil recovery over multiple growing seasons.
- Evaluate erosion reduction during rainfall.
- Expand solution design for large-scale landscape applications.
- Compare community-deployed solutions with professional restoration methods.

Limitations

- Study conducted at small scale under controlled conditions.
- Seasonal variability and long-term effects were not fully captured.
- Microbial activity was estimated using CO₂ respiration rather than detailed microbial or DNA analysis.

Innovation & Advancement

- Developed a combined Soil Restoration Kit that addresses physical, chemical, and biological soil damage simultaneously.
- Designed a biodegradable soil blanket to reduce erosion and improve surface stability.
- Unlike many large-scale restoration methods, this approach is low-cost, accessible, scalable for community and backyard use

References

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