Fire Impacts on Soil Organic Matter Composition and Microbial Metabolism: A Fourier Transform Mass Spectrometry Approach

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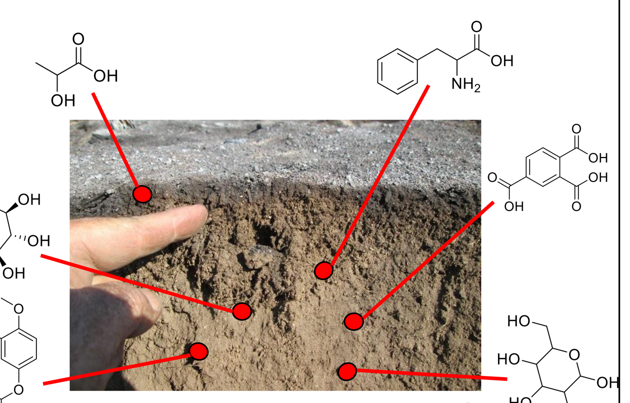
Background

- The length of the global fire-weather season has increased by 27% and events of extreme fire weather has increased by 54% since 1979.[1]
- More frequent and intense fires can alter the composition of soil organic matter (SOM): a complex mixture of thousands of organic molecules that serve as nutrients for plants and microbes.[2]
- Changes in SOM composition could impact nutrient cycling, recolonization of microbial communities, and carbon stabilization.

2020 Cameron Peak Fire, CO[3]



Impacts of fire on soil[4]

Driving question: what is the composition of the fire-impacted SOM, and what compounds are available for microbial consumption?

Objectives

- Identify short-term (one month), post-fire transformations of SOM composition.
- Determine how those shifts in SOM composition impact SOM biodegradability, microbial metabolism, and microbial activity.

Experimental Design

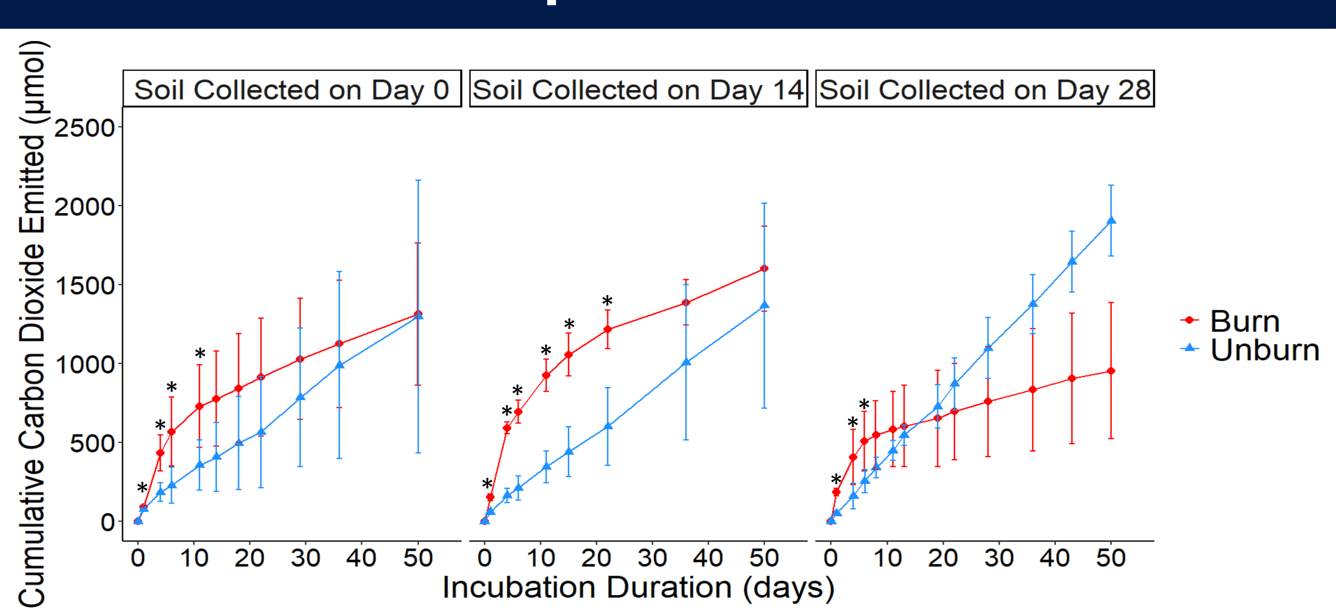
- Pine wood was burned on three steel containers ("pyrocosms") filled with mineral soil to simulate wildfire burn. Three unburned pyrocosms served as the control group.
- Water was added to all pyrocosms after the burns to stimulate microbial activity.
- Soil was sampled to a depth of 0-5 cm immediately after the burns ("Day 0") and three days, seven days, 14 days, and 28 days after the burns.
- Soil organic matter was extracted with water-based extraction.

Pyrocosm

Instrumentation

- Infrared CO_2 gas analyzer (IRGA, LICOR)
- 21 T Fourier Transform Ion Cyclotron Resonance Mass Spectrometry (FTICRMS) Negative and positive mode electrospray ionization (ESI)
- Single Quadrupole Gas Chromatography-Mass Spectrometry (GC-MS)

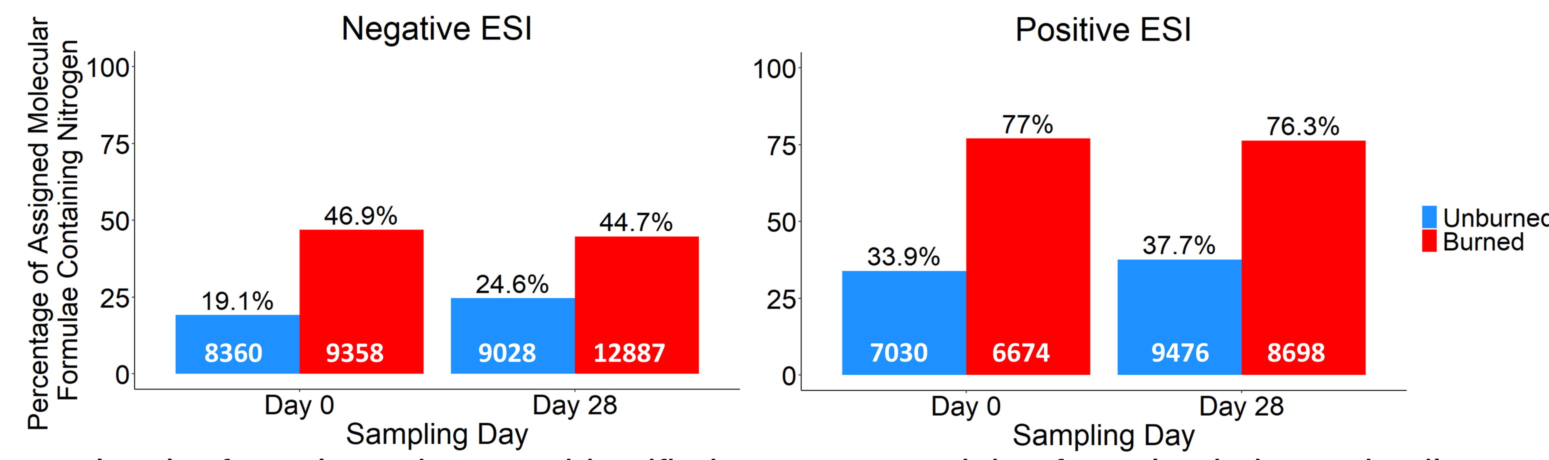
Soil Respiration Results



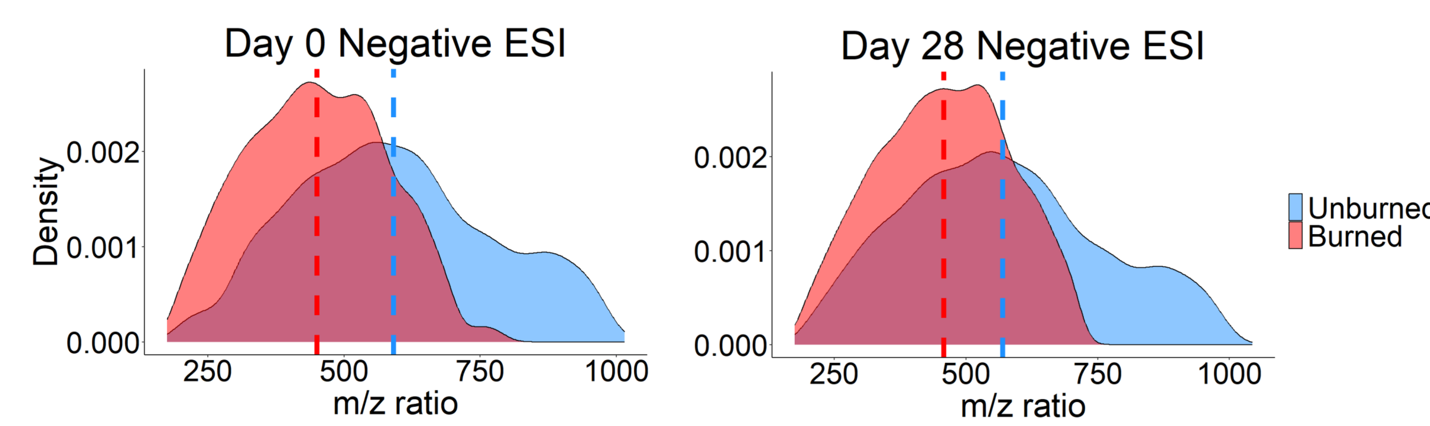
Results from soil incubations measuring CO_2 emitted from burned and unburned soils (n=5, error = standard deviation). Asterisk indicates significant difference between burned and unburned values (t-test, p<0.05)

- Soil CO_2 respiration can serve as a proxy for microbial activity.
- Initially, more CO_2 was emitted from the burned soil samples.
- While degassing could contribute to CO_2 emissions during the first day of incubation, these results suggest that there may be SOM in the burned soils that can be readily metabolized by the remaining microbial communities.

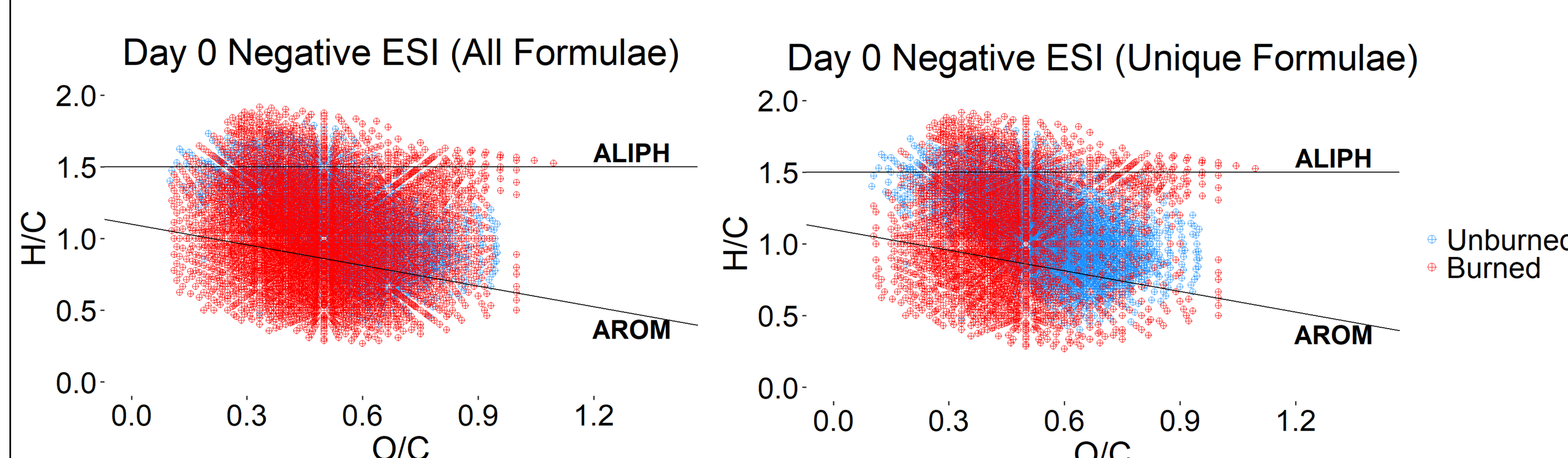
FTICRMS Results



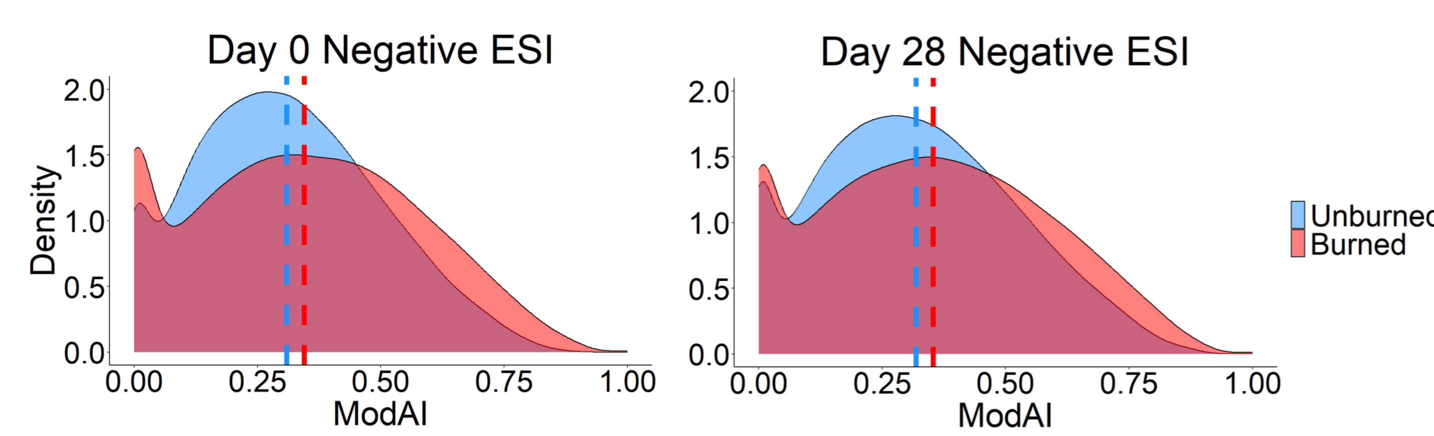
Molecular formula assignment identified more N-containing formulae in burned soil samples, indicating that SOM is enriched in N post-fire. The total assigned molecular formulae are shown in white. Each bar represents one soil-water extract sample analyzed with FTICRMS.



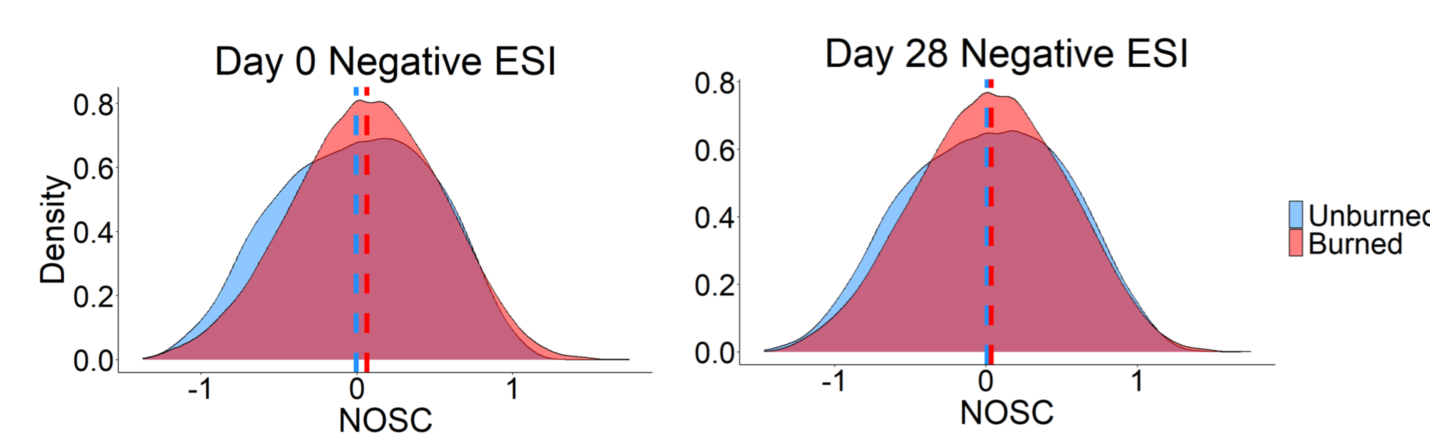
Density plots of m/z ratios of assigned molecular formulae. Dashed lines represent means of the samples. Fire exposure causes a shift to lower m/z ratios for SOM. These density plots (and all following density plots) were made from a total of four soil samples (Day 0 Burned, Day 0 Unburned, Day 28 Burned, Day 28 Unburned)



Van Krevelen plots of **ALL** assigned molecular formulae and **UNIQUE** molecular formulae in burned and unburned soils. Right-hand plot demonstrates that fire shifts SOM composition towards more condensed, reduced, aromatic compounds.



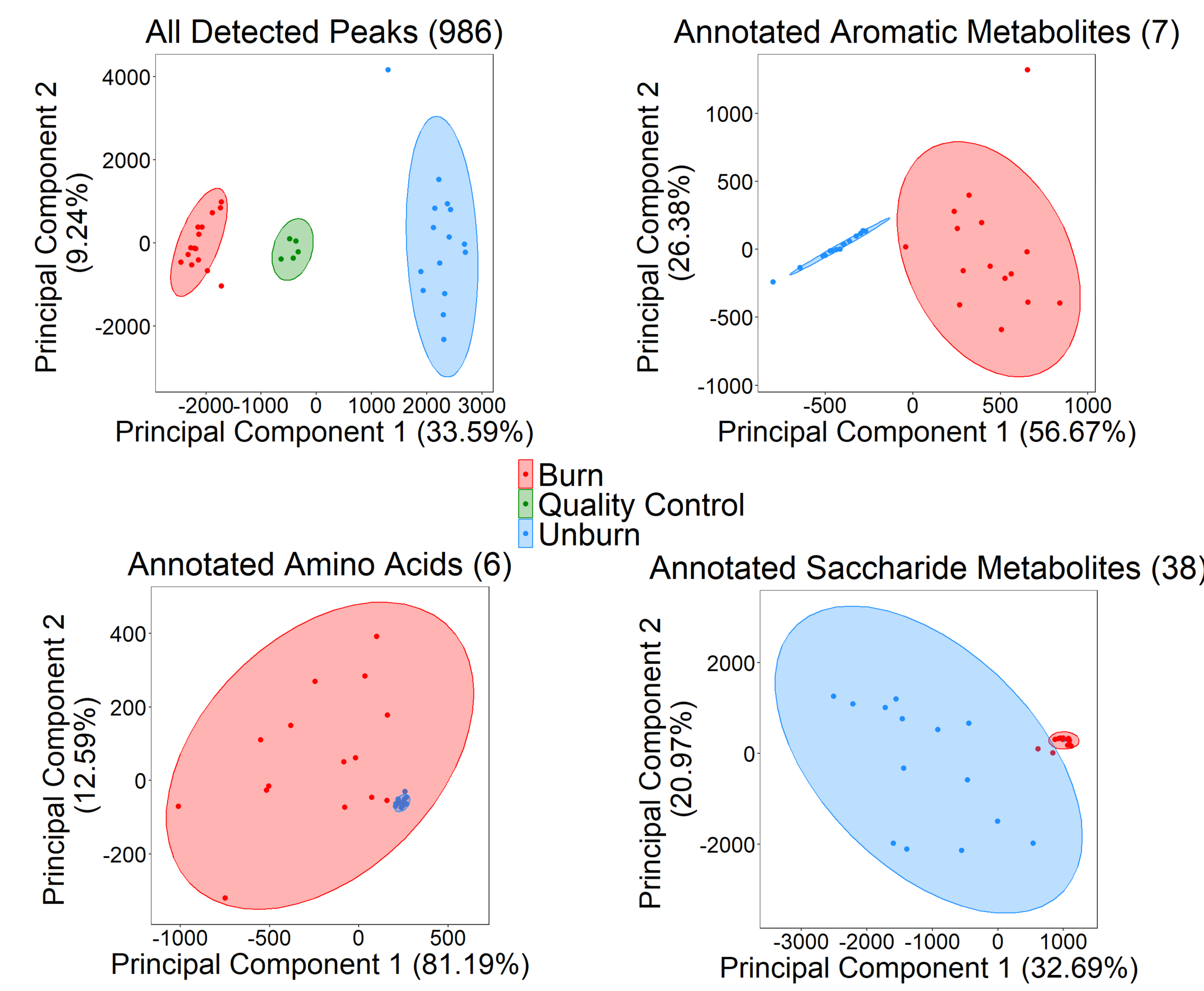
Density plots of modified aromaticity index (ModAI) show shift towards higher ModAI values in burned samples, indicating greater aromatic content in post-fire SOM.[5]



Density plots of nominal oxidation state of carbon (NOSC).[6] As NOSC increases, less energy is required to oxidize organic matter.[6] The distributions of NOSC values are comparable between burned and unburned SOM. This suggests that, thermodynamically, the biodegradability of burned SOM is similar to that of unburned SOM.

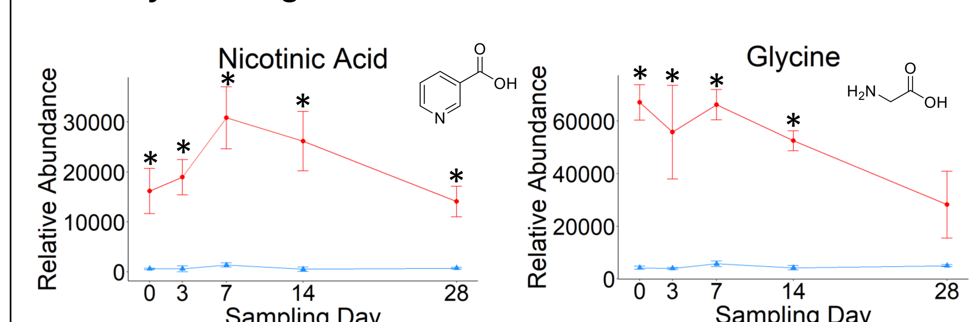
GC-MS Results

FTICRMS can detect molecules over a specific m/z range (~175 to 1050 m/z), missing low molecular weight metabolites such as organic acids, saccharides, and amino acids which may be relevant to microbial metabolism.
GC-MS can be used to target that specific pool of SOM molecules.



Principal component analysis (PCA) plots of untargeted GC-MS dataset. Each plot features 30 samples. Number of annotated metabolites is in parenthesis in each plot title. Peak areas of detected peaks were Pareto scaled and plotted.

Metabolomic profiles of burned and unburned soils are distinct (Upper Left). Burned and unburned samples cluster separately for annotated aromatic metabolites (Upper Right), amino acids (Lower Left), and saccharides (Lower Right). The presence of annotated saccharides indicates that there may be readily-biodegradable SOM in burned soil.

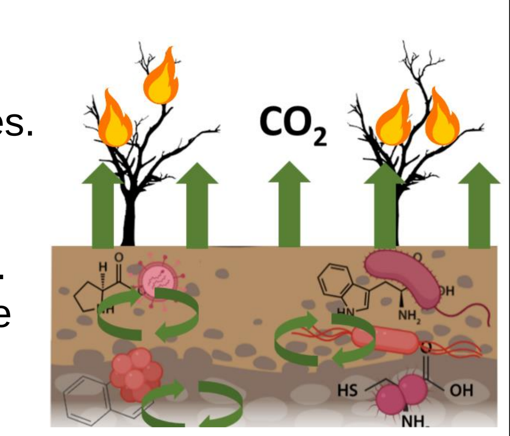


Asterisk indicates significant difference between burned and unburned values (t-test, p<0.05). n=3. Error = standard deviation

Amino acid abundances were greater in burned soils as well as aromatic metabolite abundances which agrees with more aromatic, lower molecular weight molecules observed with FTICRMS.

Conclusions and Implications

- Fire-impacted SOM has lower m/z ratios, more nitrogen content, and is more aromatic.
- Burned and unburned SOM have similar NOSC values.
- Annotated amino acids and aromatic metabolites are more abundant in burned soils.
- Annotated saccharides were detected in burned soils.
- Overall, these results show that readily-biodegradable SOM may be present after burning which may influence post-fire soil nutrient cycling and carbon stabilization in post-fire environments.



Acknowledgements

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1). Jones, M. W. et al. Global and Regional Trends and Drivers of Fire Under Climate Change. *Reviews of Geophysics* **2022, 60 (3)** 2). González-Pérez , J. A. et al. The effect of fire on soil organic matter—a review. *Environment International* **2004, 30 (6), 855-870.** 3). Image courtesy of campoutcolorado.com 4). Image courtesy of US Forest Service 5). Koch, B. P.; Dittmar, T. From mass to structure: an aromaticity index for high-resolution mass data of natural organic matter. *Rapid Communications in Mass Spectrometry* **2016, 30 (1), 250-250.** 6). (1) Larowe, D. E.; Van Cappellen, P. Degradation of natural organic matter: A thermodynamic analysis. *Geochimica et Cosmochimica Acta* **2011, 75 (8), 2030-2042.**