Fungal hyphal networks play a key role in soil microbiome micronutrient acquisition and transport during drought

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Project Goals: PNNL's Soil Microbiome SFA aims to achieve a systems-level understanding of the soil microbiome's phenotypic response to changing moisture. We focus on a multi-scale examination of the molecular and ecological interactions occurring within and between members of microbial consortia. Integrated experiments are designed to confront spatial challenges and inter-kingdom interactions that regulate networks of biochemical reactions. The exchange among bacteria, fungi, viruses and plants are being characterized in the context of microbial metabolism and community function. These experimental data have been used to parametrize individual- and population-based models for predicting interspecies and inter-kingdom interactions. Predictions are tested in lab and field experiments to reveal individual and community microbial phenotypes. Our cross-scale experiments are coordinated together to investigate the influence of moisture on the interkingdom-interactions. Data is captured and shared through an optimized data management pipeline. Knowledge gained will provide fundamental understanding of how soil microbes interact to decompose organic carbon and enable prediction of how biochemical reaction networks shift in response to changing moisture regimes.

Abstract: Increasing evidence suggest that inter-kingdom interactions are critical to microbial resiliency under water and nutrient stress. Within soil microbiomes, fungal constituents are believed to be among the most successful under water and nutrient limited conditions. This is in part due to the filamentous hyphal networks that most soilborne fungi can develop, which permits them to link and exploit discrete substrate pools. Furthermore, widespread fungal interactions with plants and bacteria make fungi integral to all aspects of C, N, P, and S cycling within soil. Nonetheless, the precise mechanisms of how soil fungal communities biosense and access specific nutrient sources under drought remains vastly understudied. Here, we explored the presence and role of fungal hyphal networks in native soil experiencing drought-like conditions, and then we aimed to gain deeper insight into the processes that govern mycelial bridging of nutrient sources within the soil microenvironment.

We built a controlled soil environment (a so-called 'SoilBox')[1], which enables determination of spatial organization and interaction of soil microbial communities using optical and mass spectrometry imaging techniques.[2] Within the SoilBox, we were able to visualize fungal hyphal networks bridging different chitin islands over distances of 27 mm in native soil under limited soil moisture conditions.

Moreover, optical and molecular imaging results showed the rate of chitin island decomposition by the native soil microbial community under different moisture regimes, where degradation of the islands was not significantly altered under dry soil conditions in comparison to soil moisture at field capacity under the timeframe we measured. We then inoculated *Fusarium chlamydosporum* into micromodels that concurrently simulate the porosity and mineralogy of soil. We observed increased hyphal density and fungal thigmotropism around obstacles and through soil-like pore spaces within mineral-doped soil micromodels in comparison to micromodels without minerals. Secondary ion mass spectrometry analysis showed K^+ and Na^+ enrichment and translocation in fungal hyphae grown in mineral-doped channels. The translocation from minerals by fungal hyphae resulted in K^+ speciation, as was observed using X-ray near edge absorption analysis. In comparison, fungal mycelia grown in micromodels without minerals did not exhibit thigmotropic behavior, micronutrient cation translocation, or K^+ speciation. These results provide the first direct evidence of hyphal translocation of micronutrients from a mineral surface under nutrient limiting conditions. Taken together, these studies demonstrate that mycelial acquisition and transport of mineral-derived inorganic nutrients provides fungal communities a survival advantage, where they can access scarce and discrete organic nutrient pools within soil microenvironments and act as nutrient highways during drought.

References

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