Pacific Northwest NATIONAL LABORATORY

PHYTOBIOMES ALLIANCE

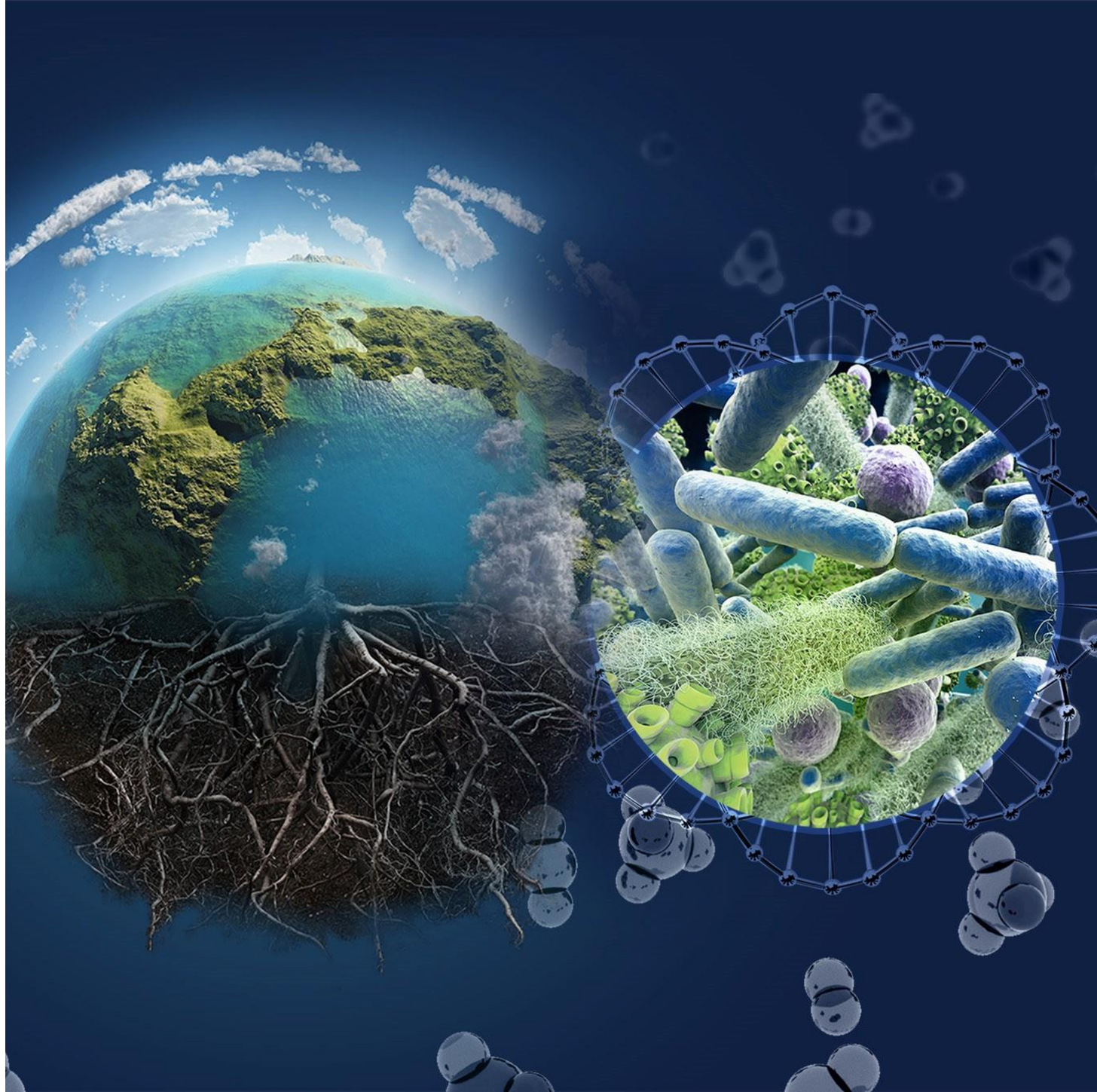
Decoding rhizosphere ecology for soil health

December 18, 2024

Kirsten Hofmockel

Kirsten.hofmockekl@PNNL.gov

@KHofmockel



U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Acknowledgements

This program is supported by the U. S. Department of Energy, Office of Science, through the Genomic Science Program, Office of Biological and Environmental Research, under FWP 70880. A portion of this work was performed in the William R. Wiley Environmental Molecular Sciences Laboratory (EMSL), a national scientific user facility sponsored by Office of Biological and Environmental Research and located at PNNL. PNNL is a multi-program national laboratory operated by Battelle for the DOE under Contract DE-AC05-76RLO 1830.

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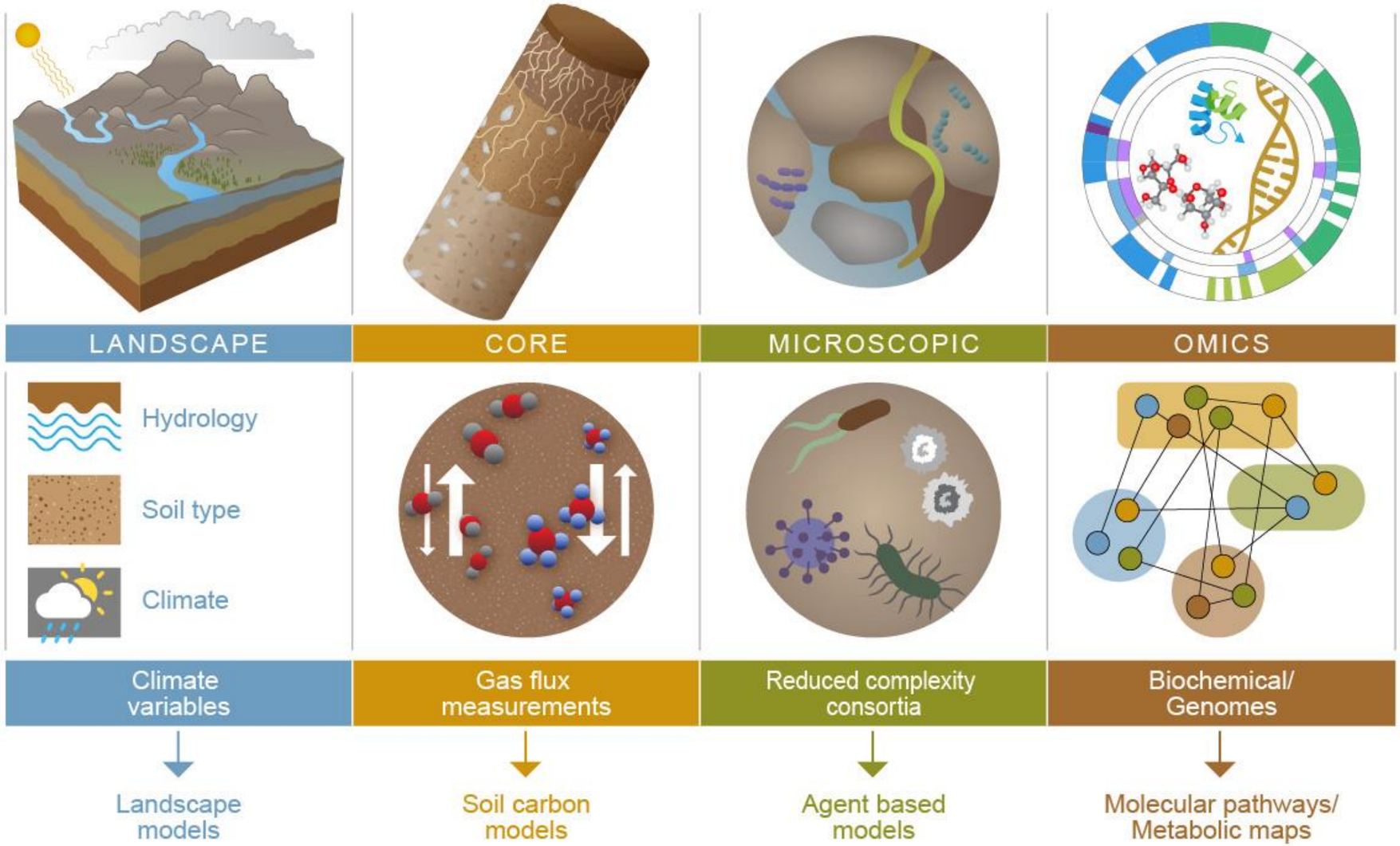
Linking microbial interactions to ecosystem outcomes

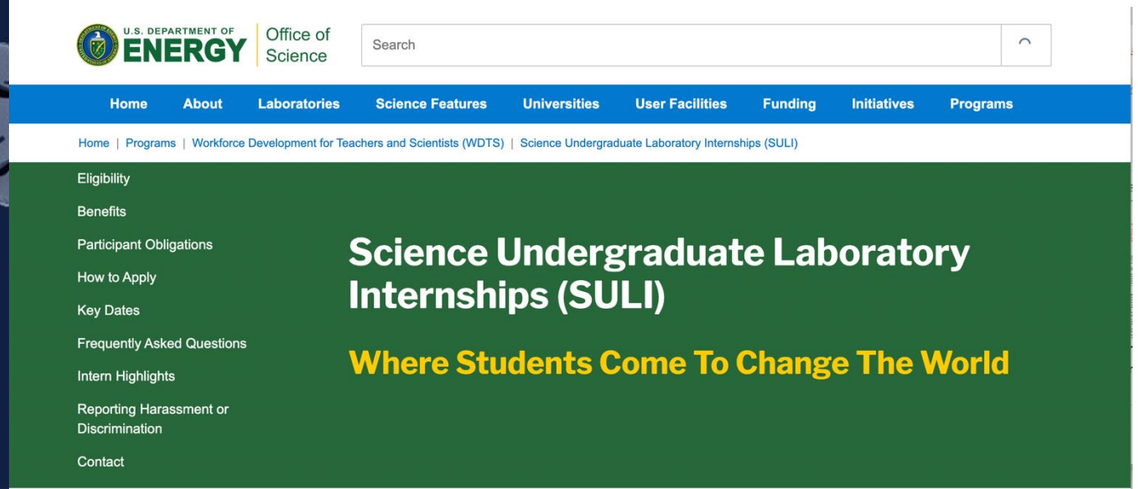


Naylor et al. 2020 ARER

National Lab and University Collaborations

- SULI – Undergrad Internship
- SCGSR – Grad Student Research Fellow
- Post bac, post masters, post doc
- Organize sessions at society meetings

- Collaborate on grants
- Subcontracts
- Sabbaticals
- Joint Appointments



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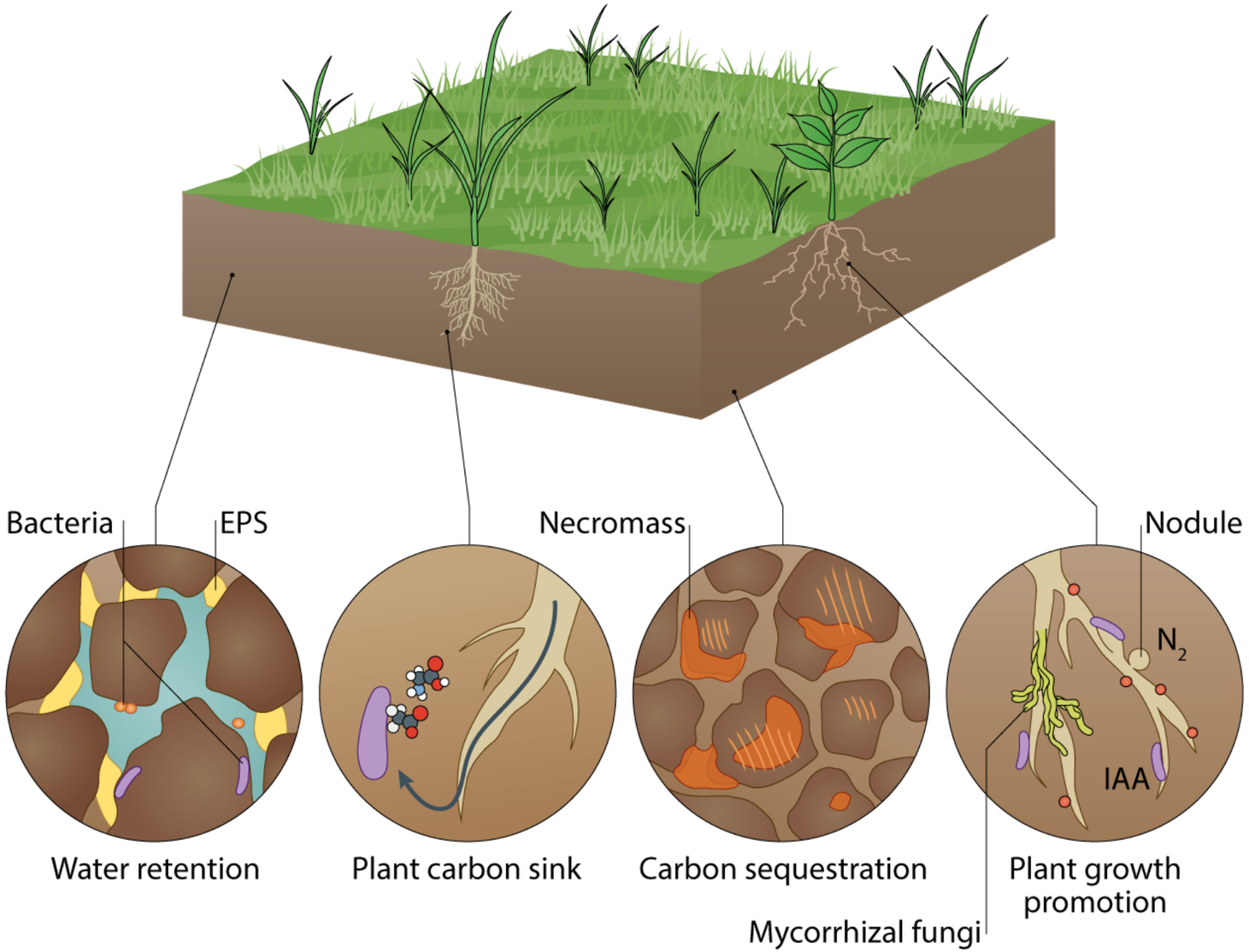
SOIL MICROBIOME SFA @PNNL

- Perspectives rhizosphere ecology
- Coupling field and lab experiments
- Rhizosphere metabo-lipidomics
- Future Research and Opportunities

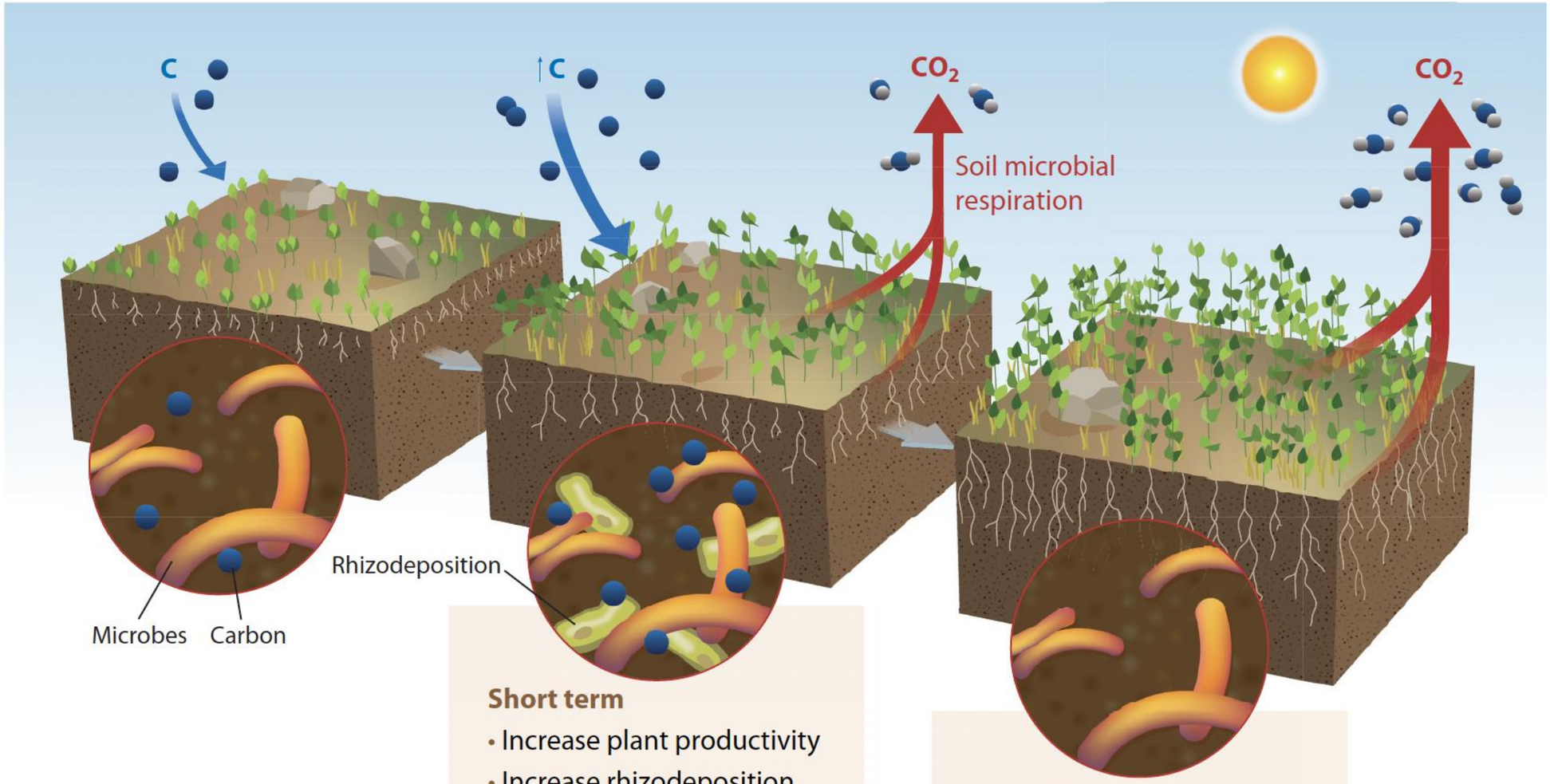
https://www.pnnl.gov/projects/soil-microbiome

Research Frontier: Managing Rhizosphere Ecology for beneficial functions



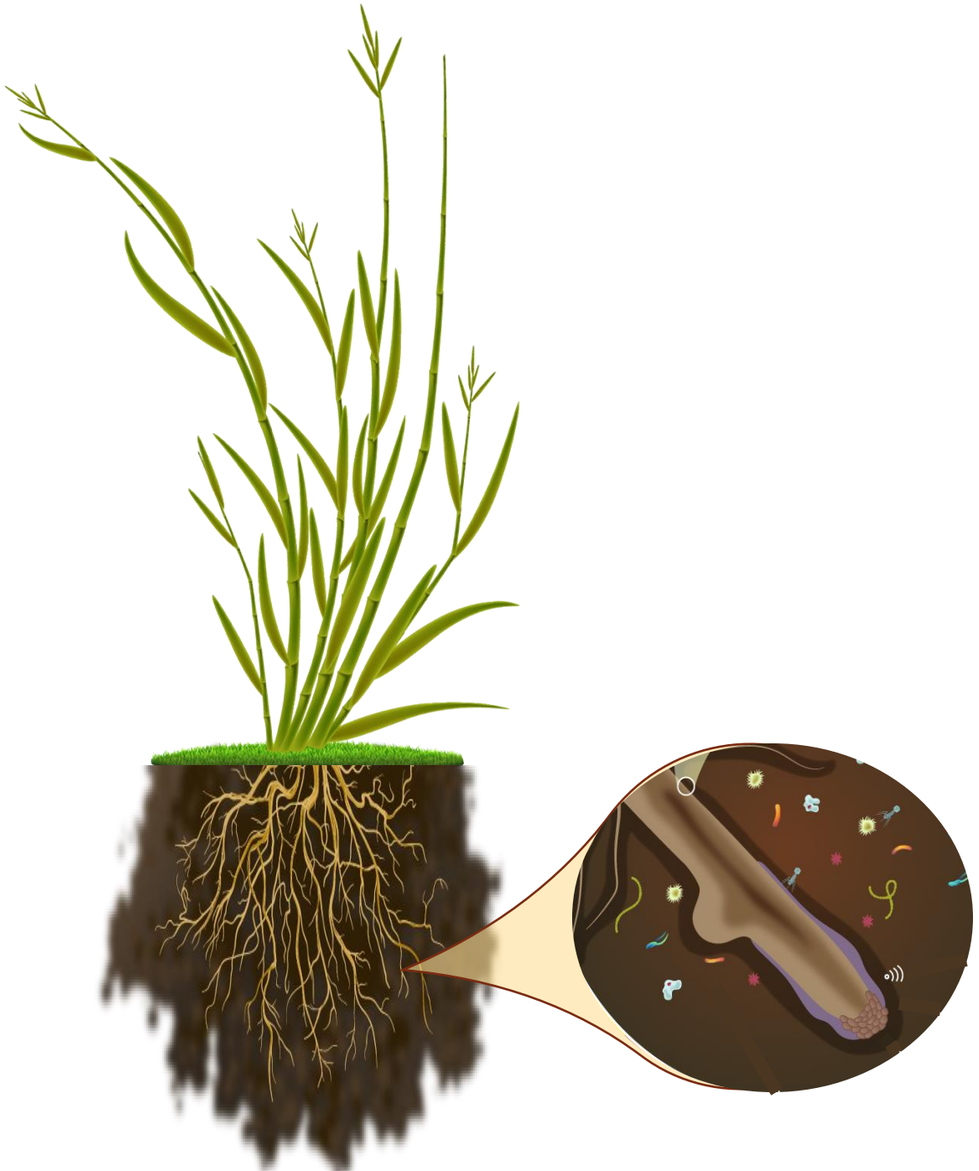
Jansson & Hofmockel. Nature Microbiology Reviews. 2020

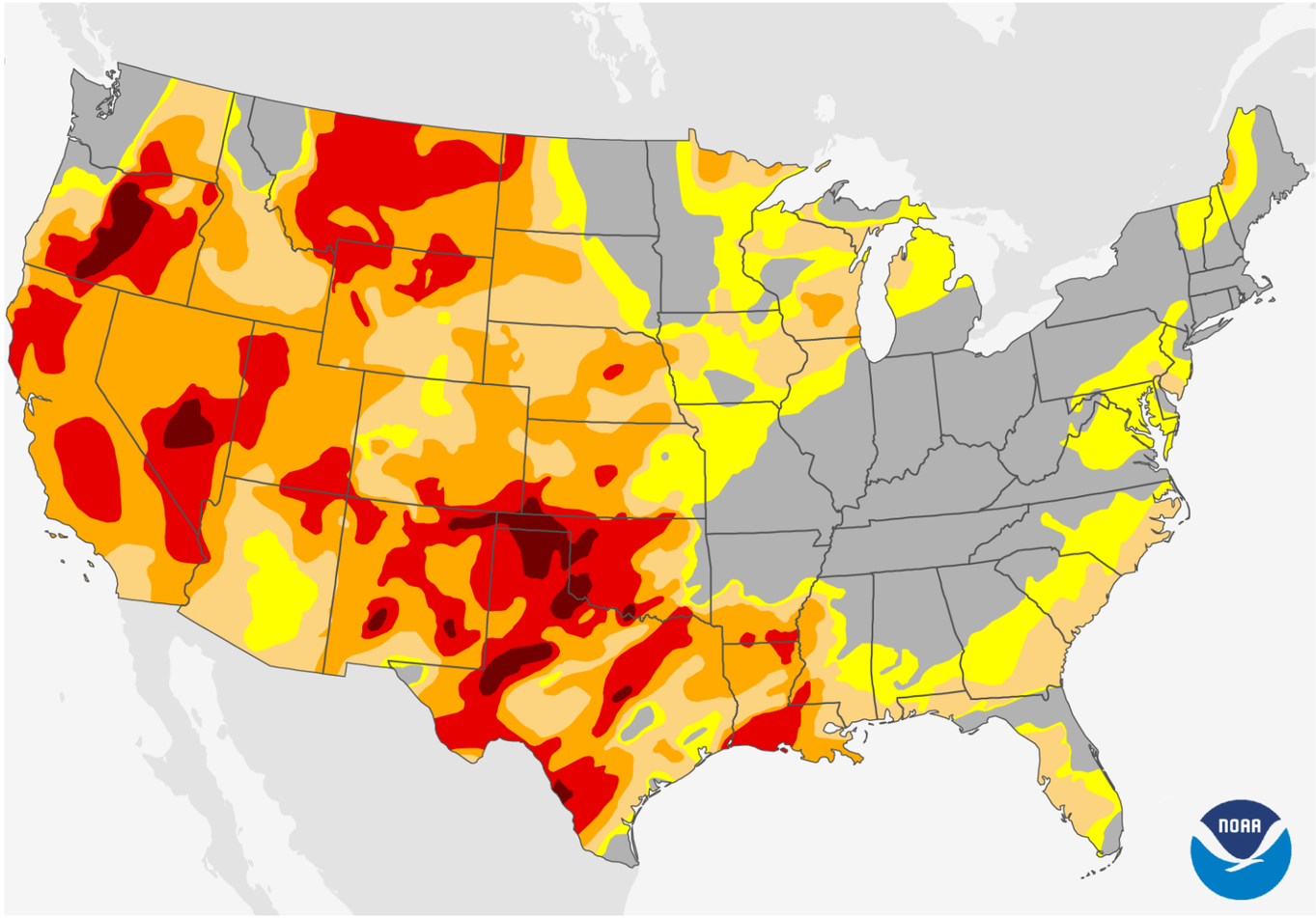
Rhizosphere responses to climate change



Naylor et al. 2020 Annu. Rev. Environ. Resour. 2020. 45:29–59

Drought stress impacts on phytobiome





No Drought | Abnormally Dry | Moderate Drought | Severe Drought | Extreme Drought | Exceptional Drought

Climate.gov
Data: NDMC

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WASHINGTON STATE UNIVERSITY

Steve Norberg

What rhizosphere interactions promote carbon capture?

Amy Zimmerman

Sheryl Bell

Evan Warburton

Sharon Zhao

Regan McDearis

Field Site at the WSU Irrigated Agriculture Research and Extension Center

SOIL MICROBIOME @PNNL

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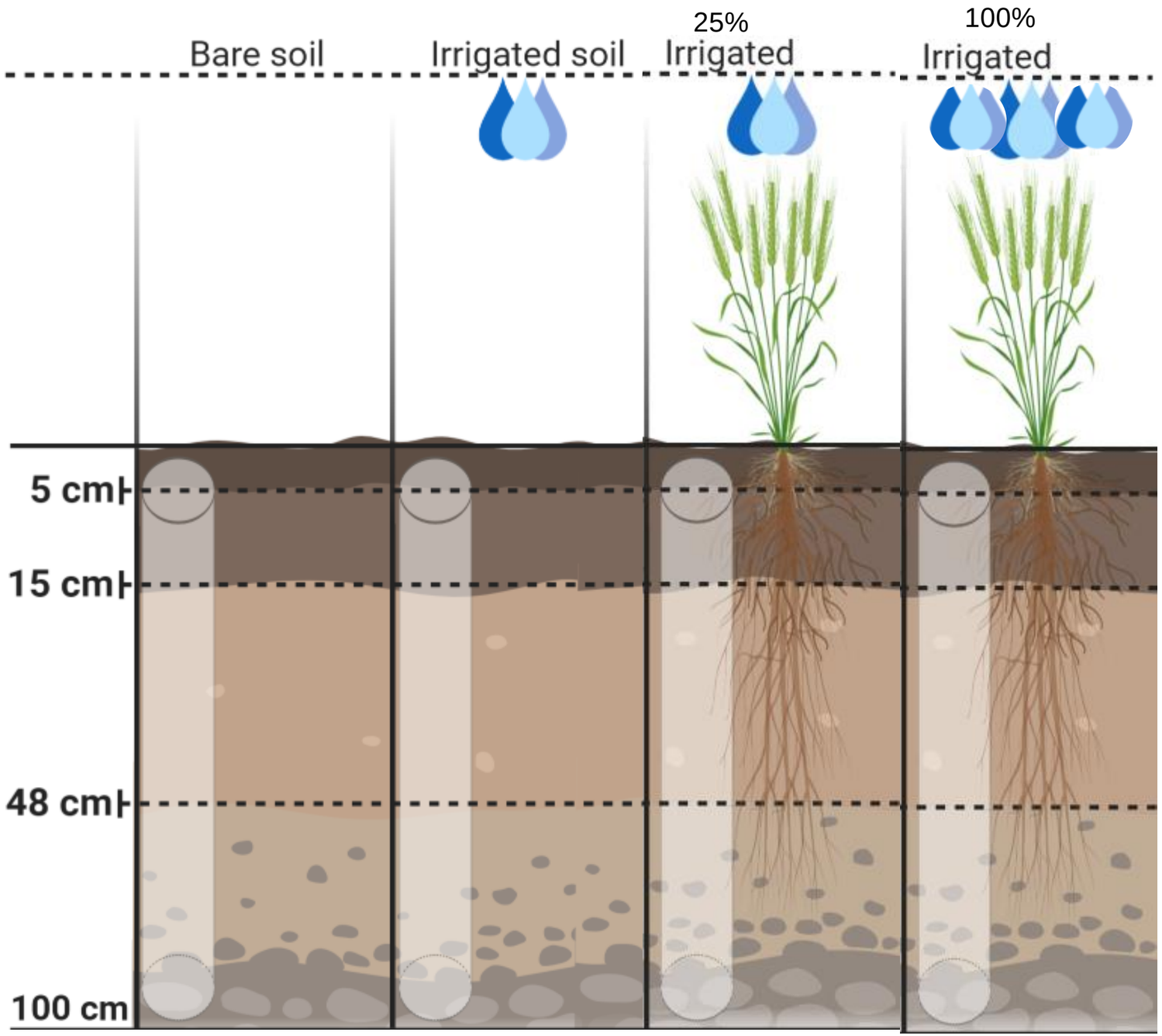
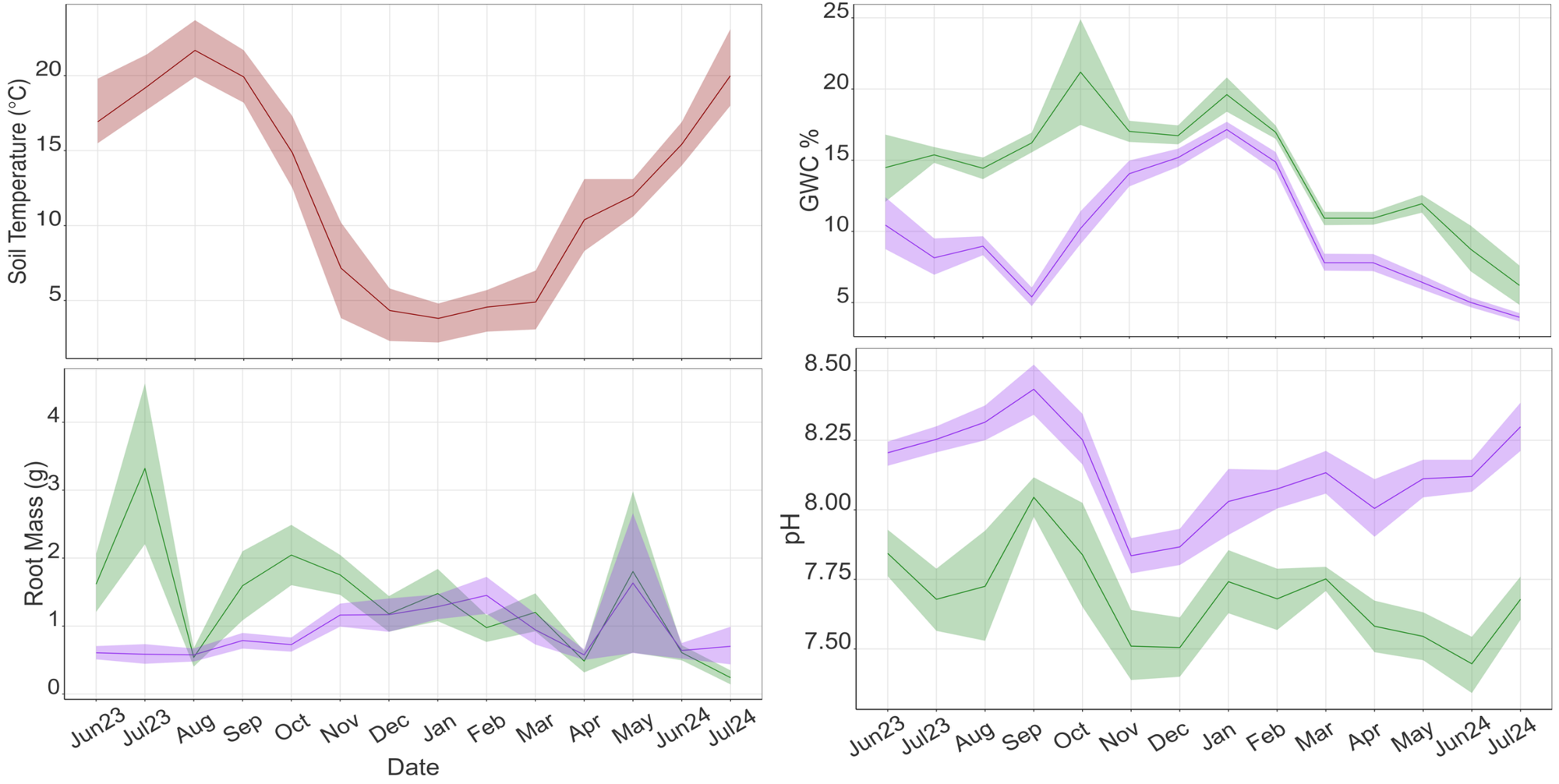
How does water stress change rhizosphere interactions?



Variability is the signature of soil ecology

Sheryl Bell

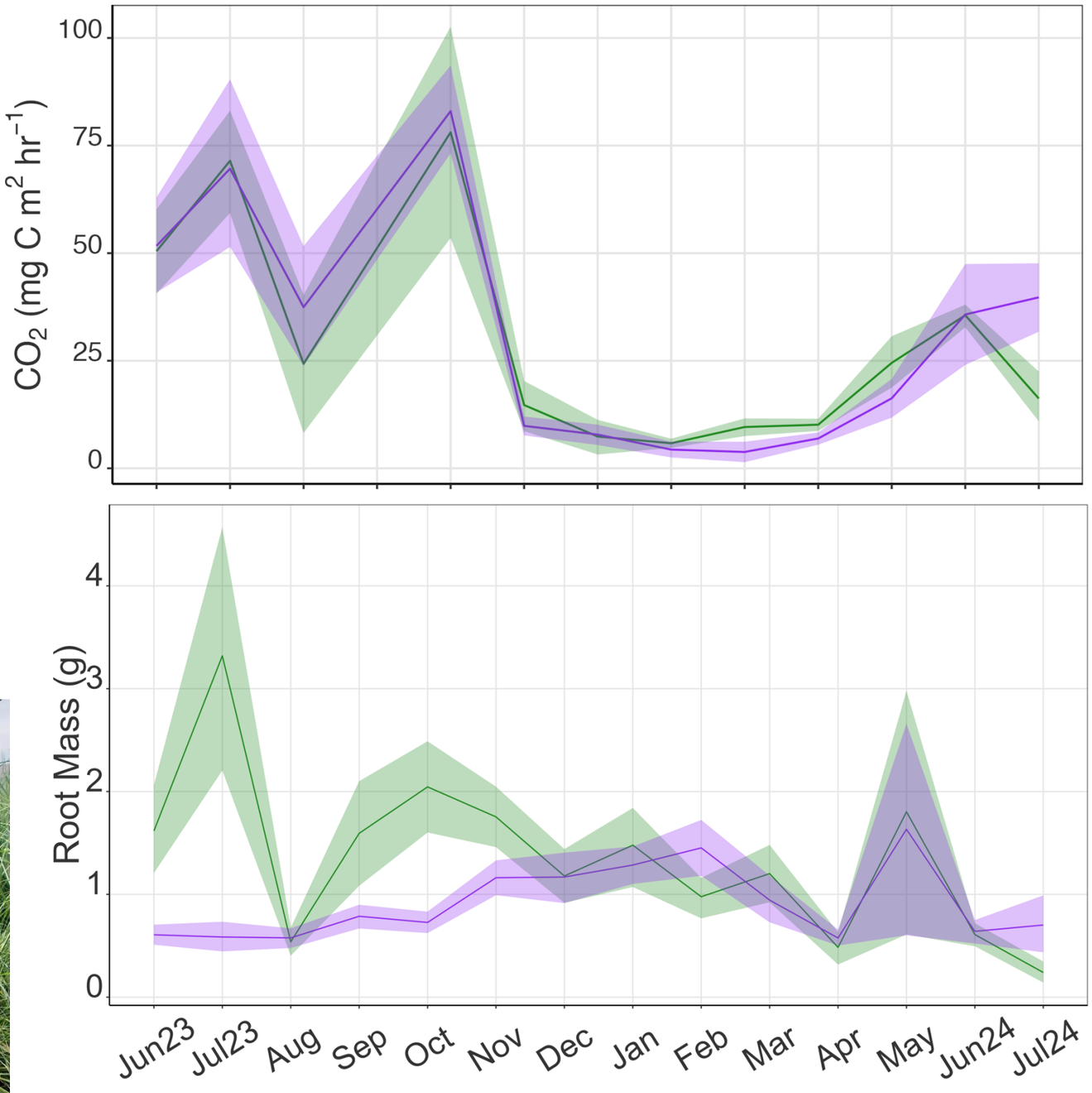


Bell et al. in prep

In-situ soil respiration reflects root dynamics

Sharon Zhao

Kali Cornwall



Substrate-induced respiration reflects potential microbial contributions to soil respiration

Sheryl Bell

Evan Warburton

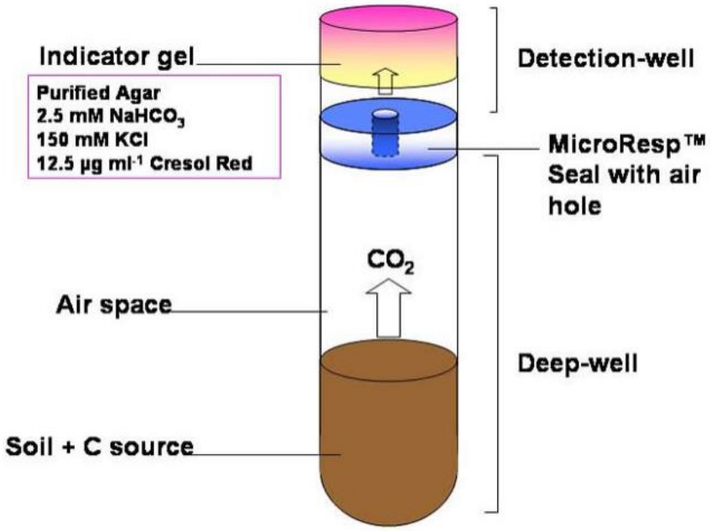
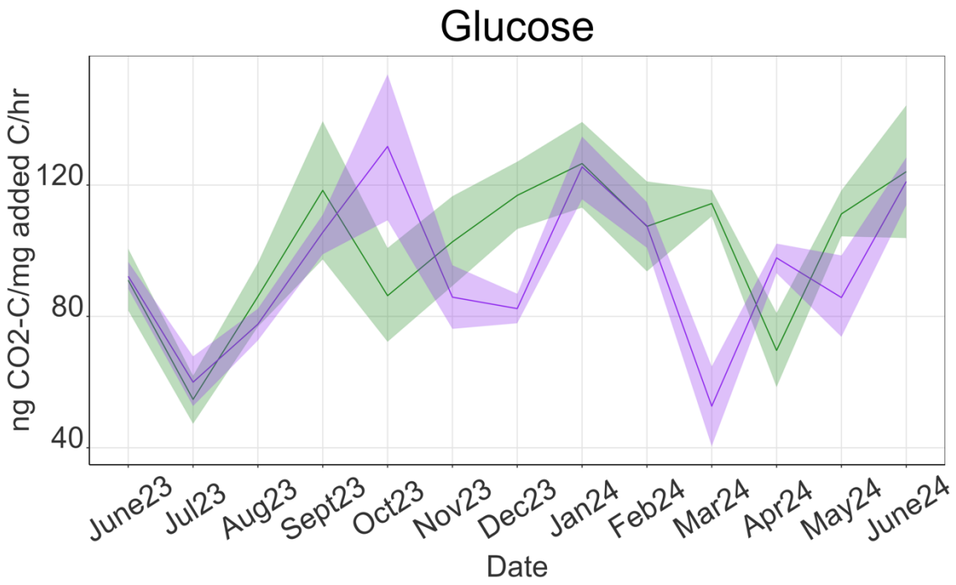


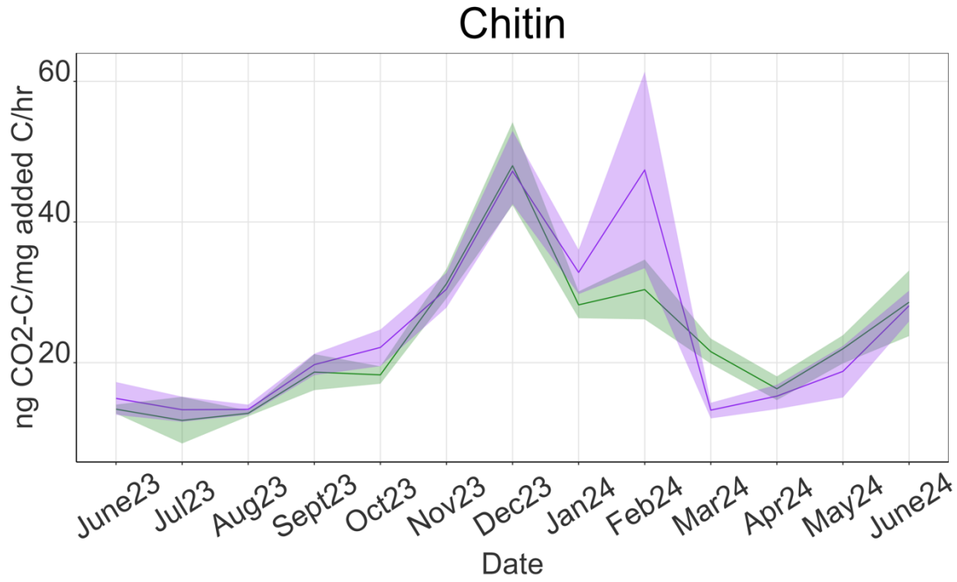
Image: Microresp.com/science

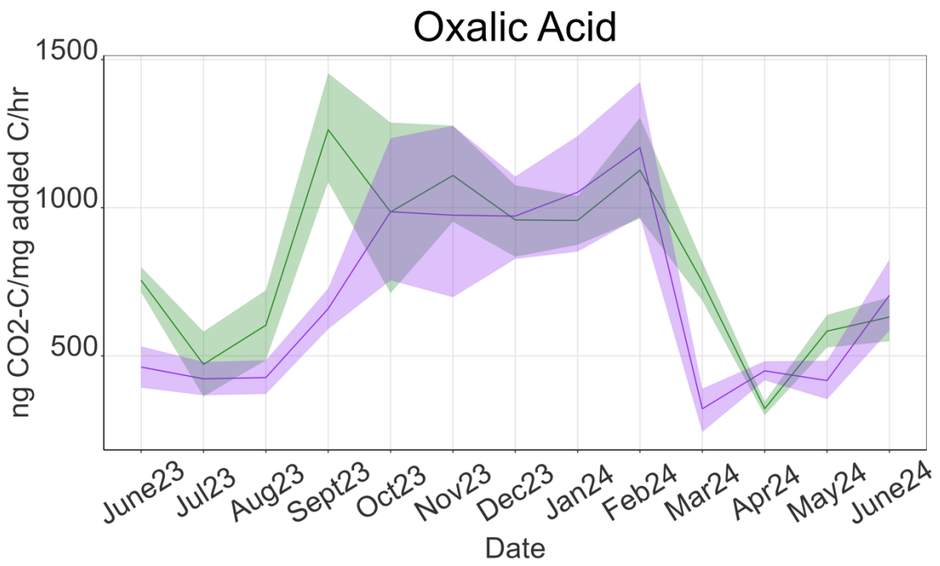
- 8 Carbohydrates
- 5 Carboxylic Acids
- 4 Complex Polymers
- 2 Amines
- 6 Amino Acids
- 1 Signaling Molecule
- 1 Plant Wax Ester
- 1 Fatty Acid Ester
- 1 Protein
- 2 Phenols

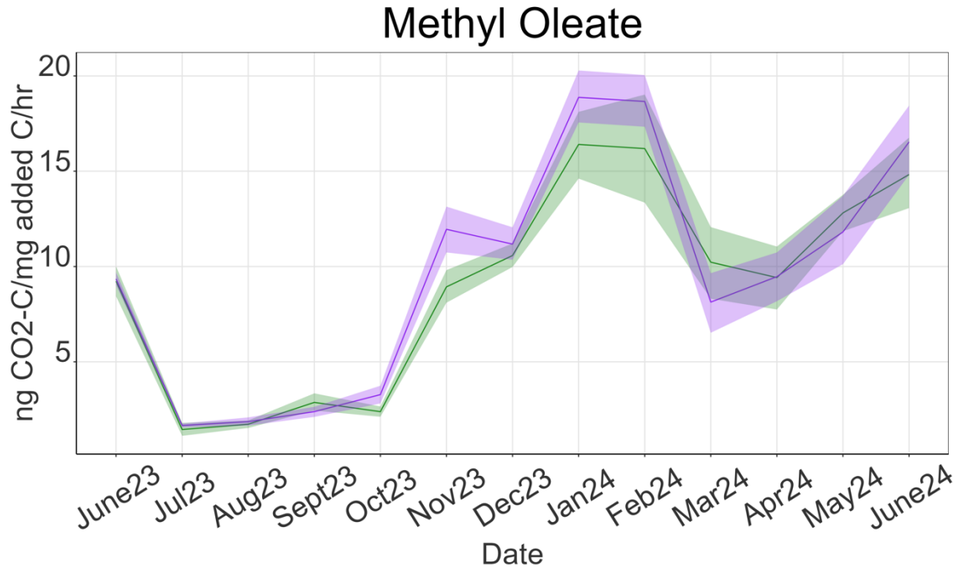
Bell et al. in prep

Microbial respiration potential reflects substrate complexity









Treatment — 100% FWC — 25% FWC

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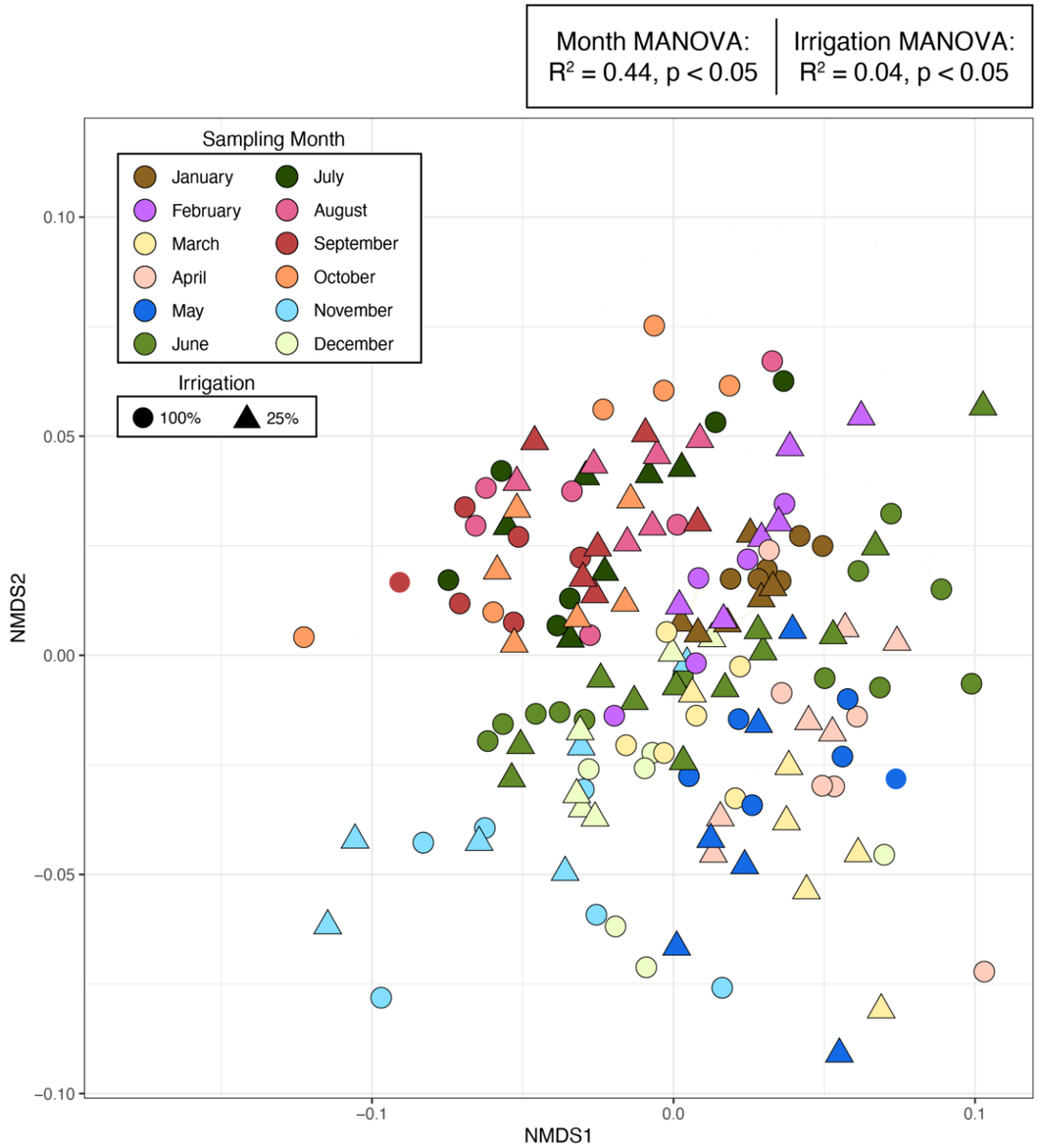
Josué Rodriguez-Ramoz

PHYTOBIOMES ALLIANCE

Seasonality explains variation in microbial respiration



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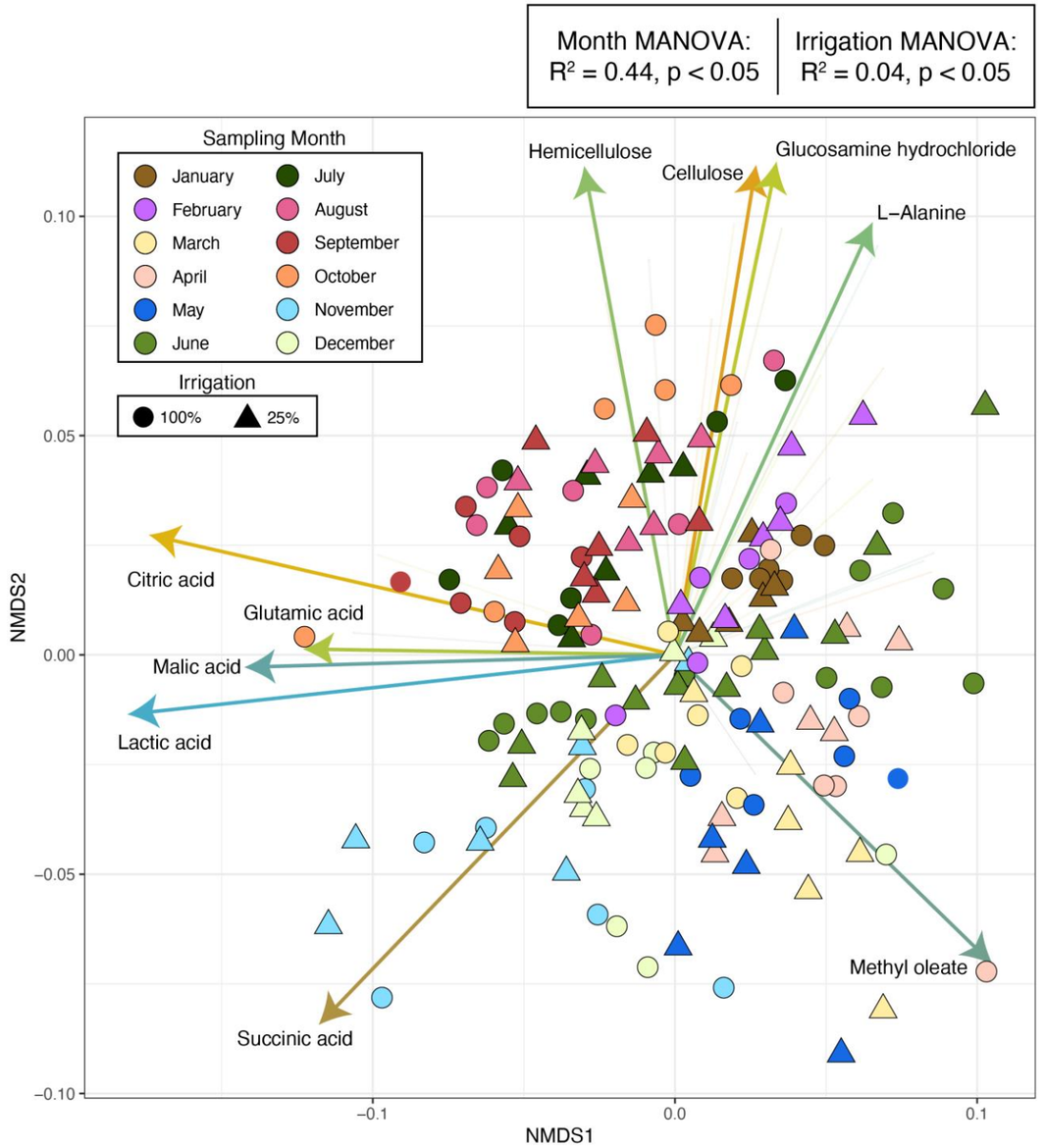
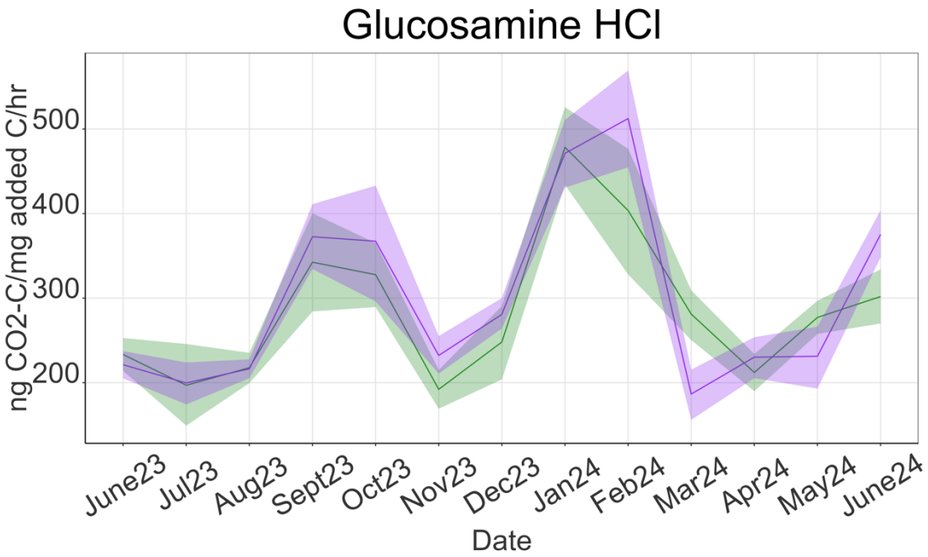
Josué Rodriguez-Ramoz

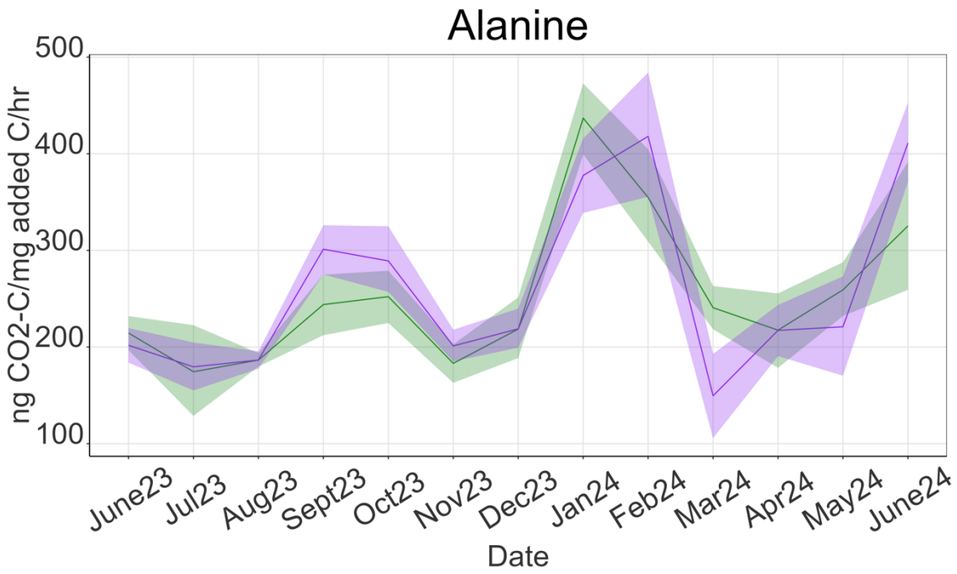
PHYTOBIOMES ALLIANCE

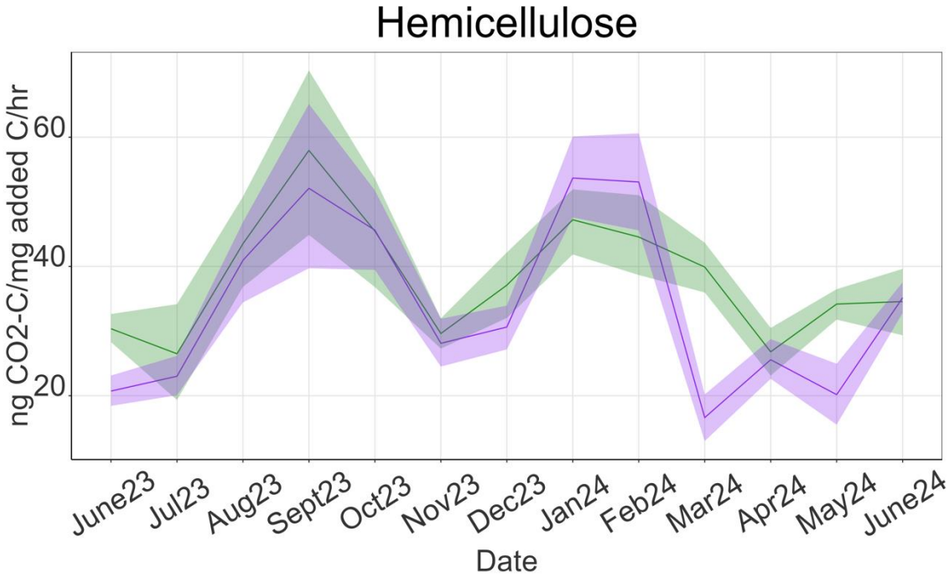
Representative exudate compounds explain seasonal variation in microbial respiration

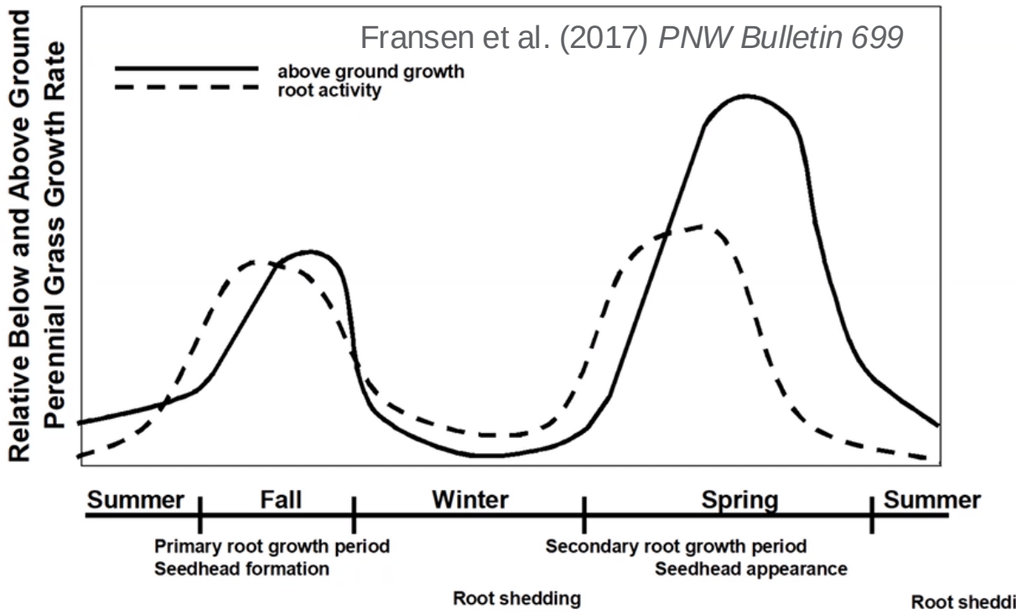


Seasonality of microbial respiration reflects root dynamics







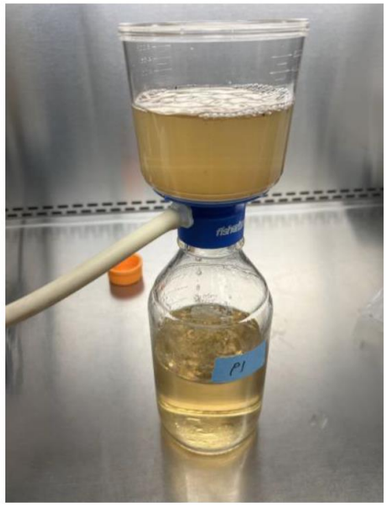


Treatment — 100% FWC — 25% FWC

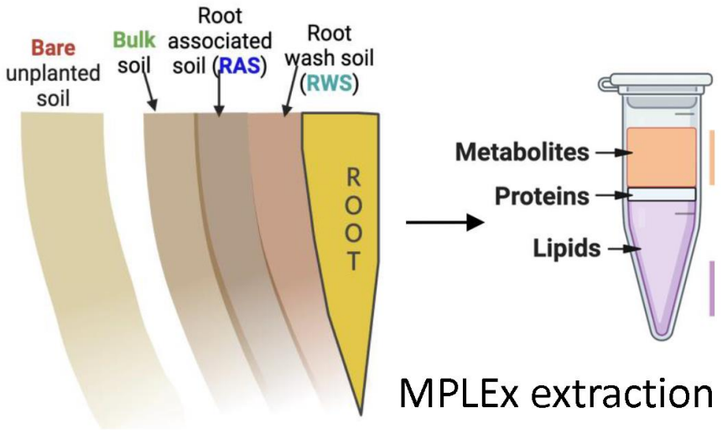
Molecular characterization of rhizodeposition in perennial plants

Sneha Couvillion

Metabo-lipidomics provides molecular resolution

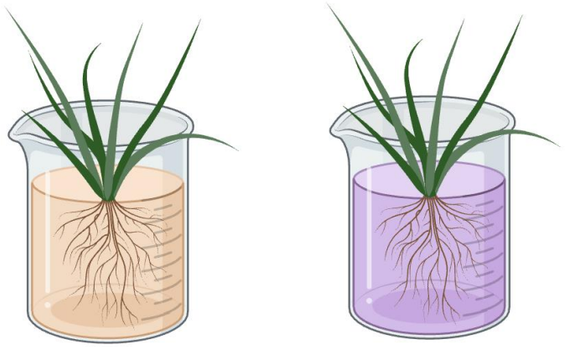


SOIL



MPLEx extraction

ROOT EXUDATES



Aqueous Chloroform

Metabolomics

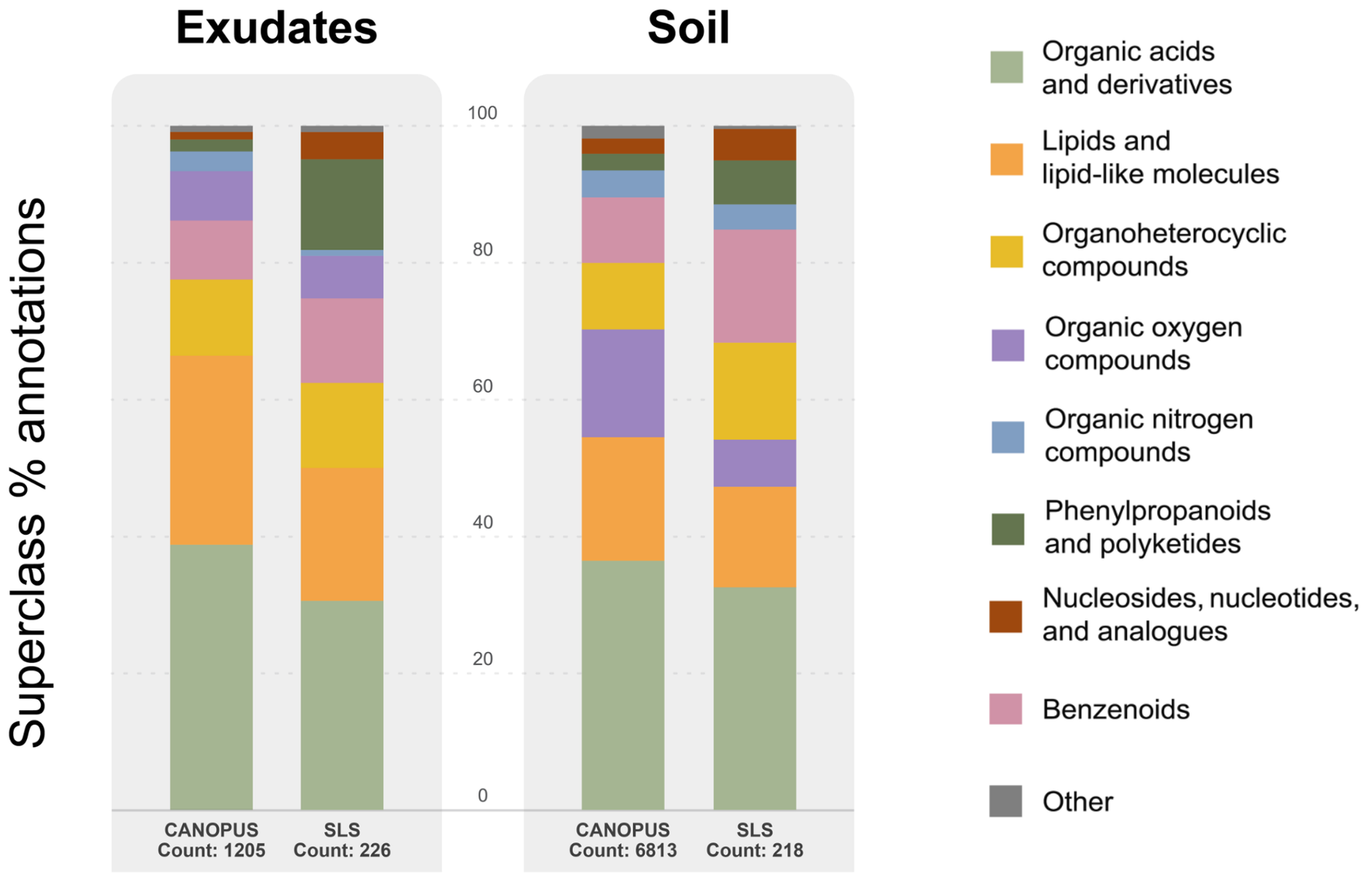
Lipidomics

LC-MS/MS METABO-LIPIDOMICS

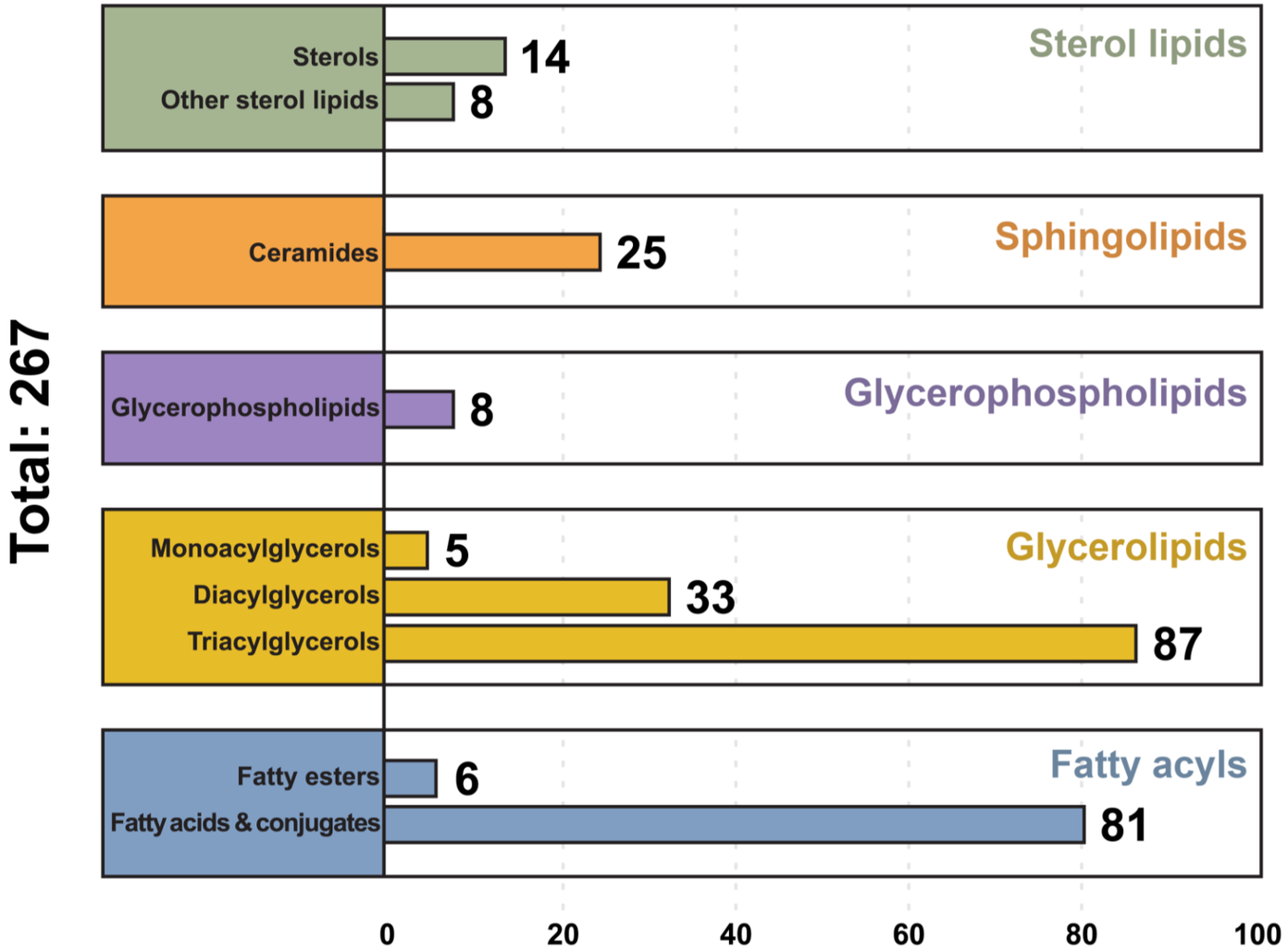
Tackling the Unknowns: Enhancing Metabolite Annotation and Classification

Isabella Yang

Dylan Hermosillo



Discovery of Diverse Lipids in Root Exudates

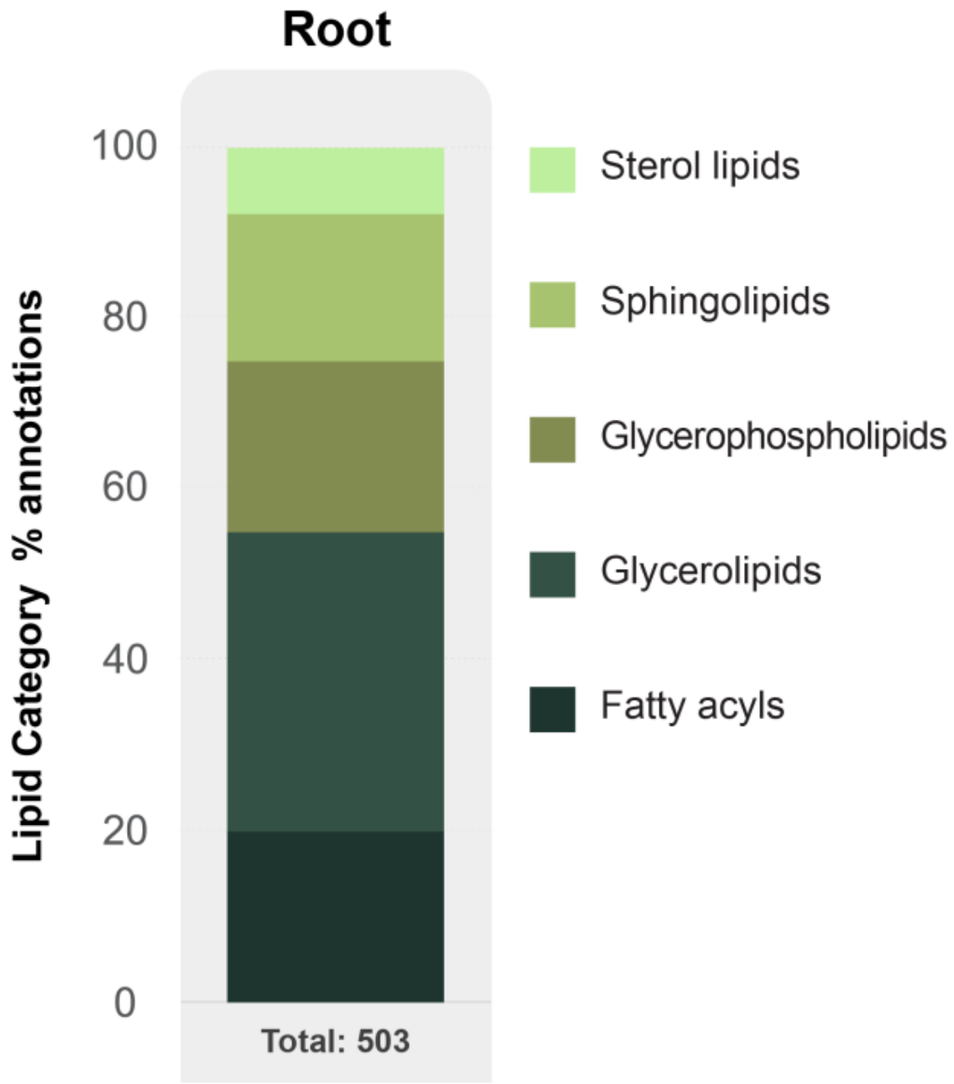


Root exudates contain substantial levels of triacylglycerols (~19 µg/g fresh root per min)

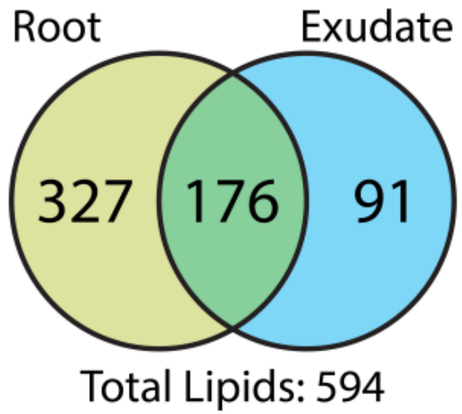
Couvillion et al. (2024). BioRxiv

Root tissue and exudate lipid profiles differ

A

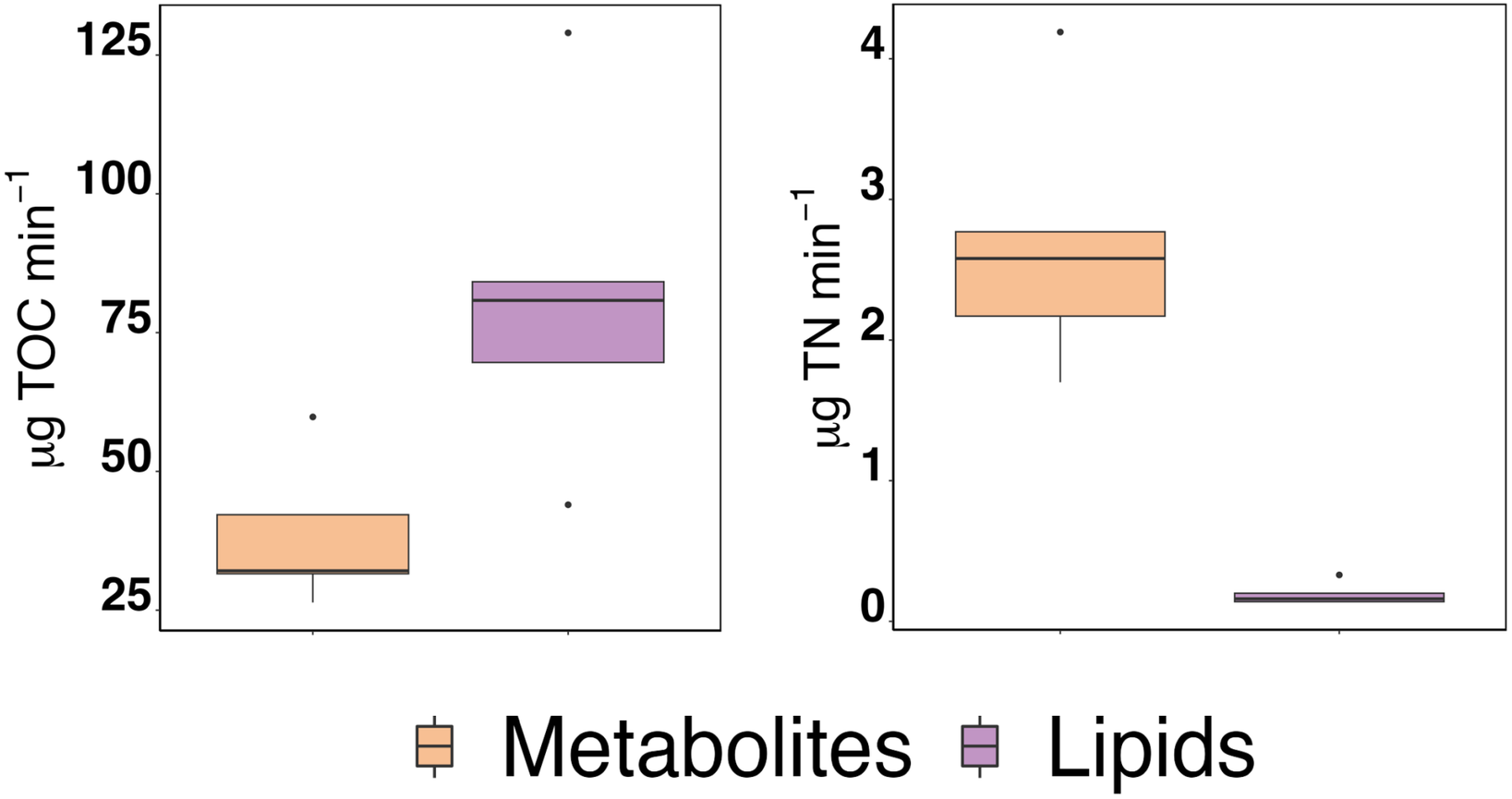


B



Couvillion et al. (2024). BioRxiv

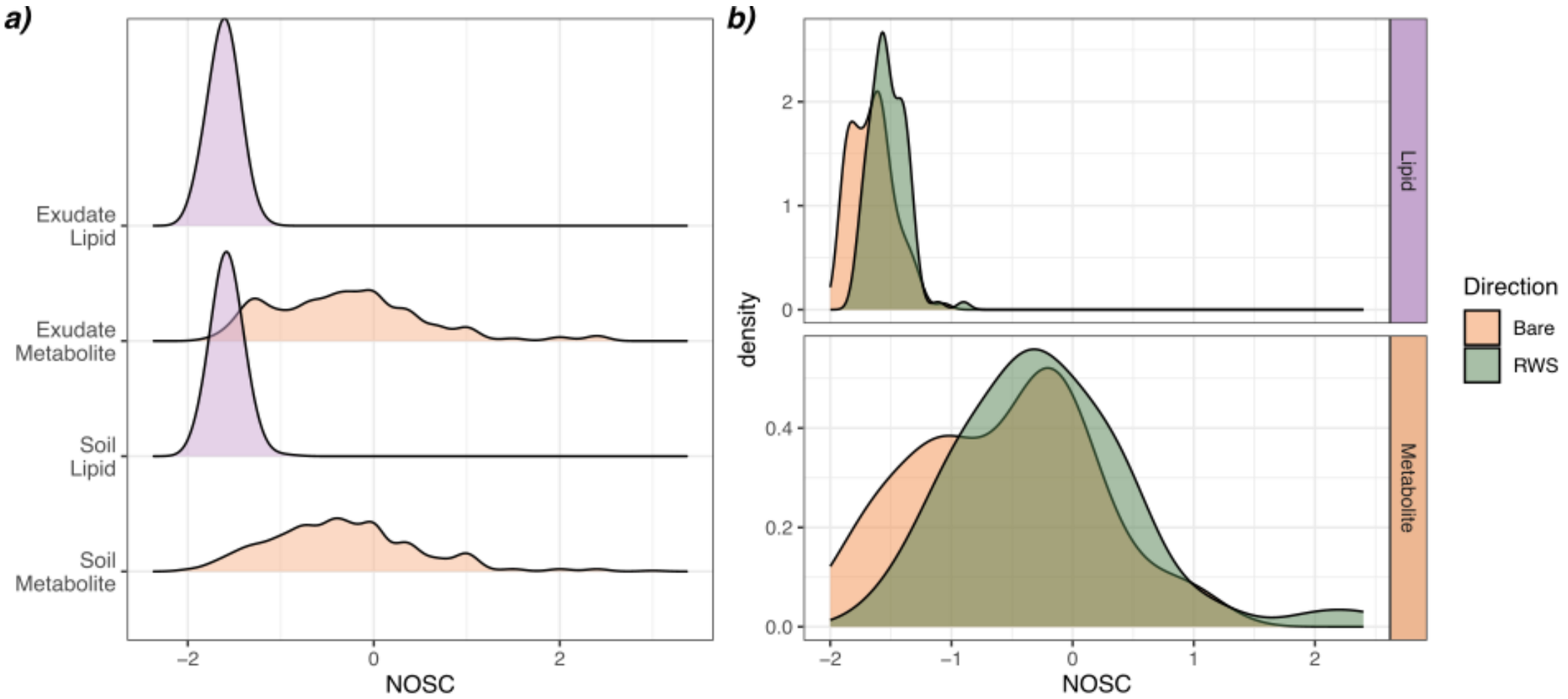
Exudate metabolites and lipids contribute to soil carbon



Sheryl Bell

Couvillion et al. (2024). BioRxiv

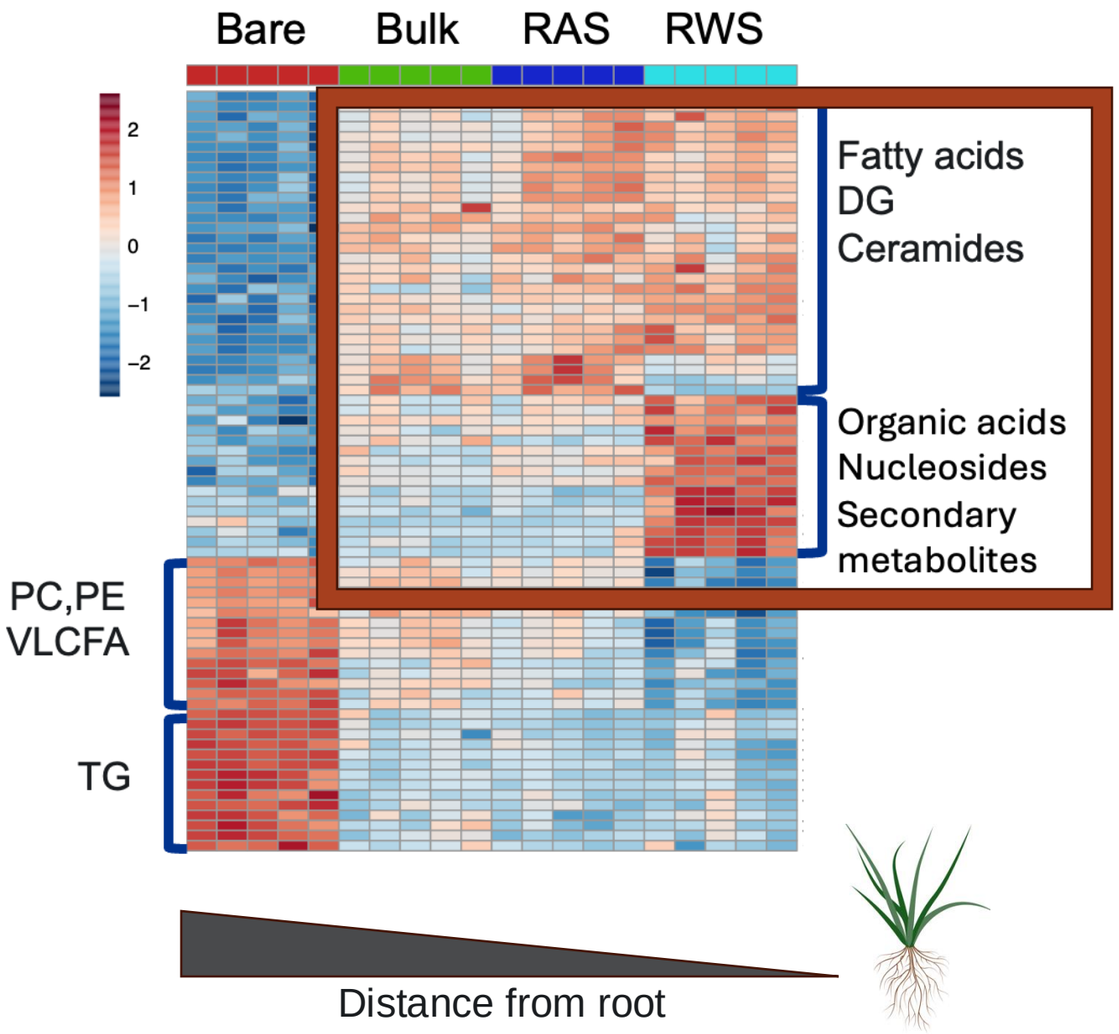
Exudates may contribute to persistent soil organic matter

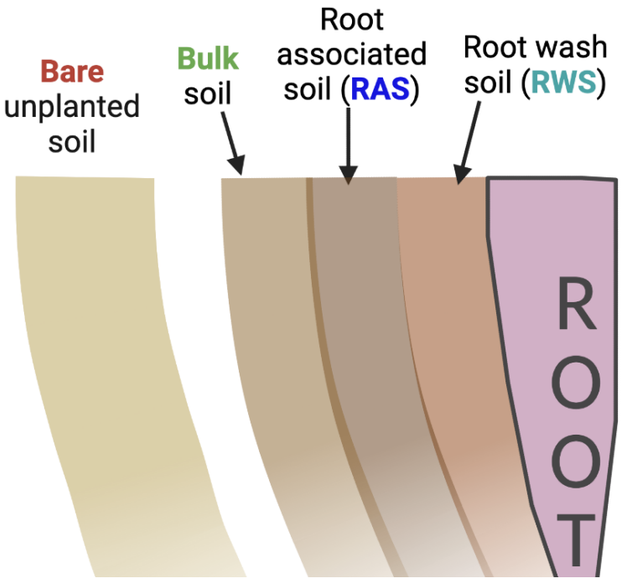


Nominal oxidation state of C (NOSC)

Couvillion et al. (2024). BioRxiv

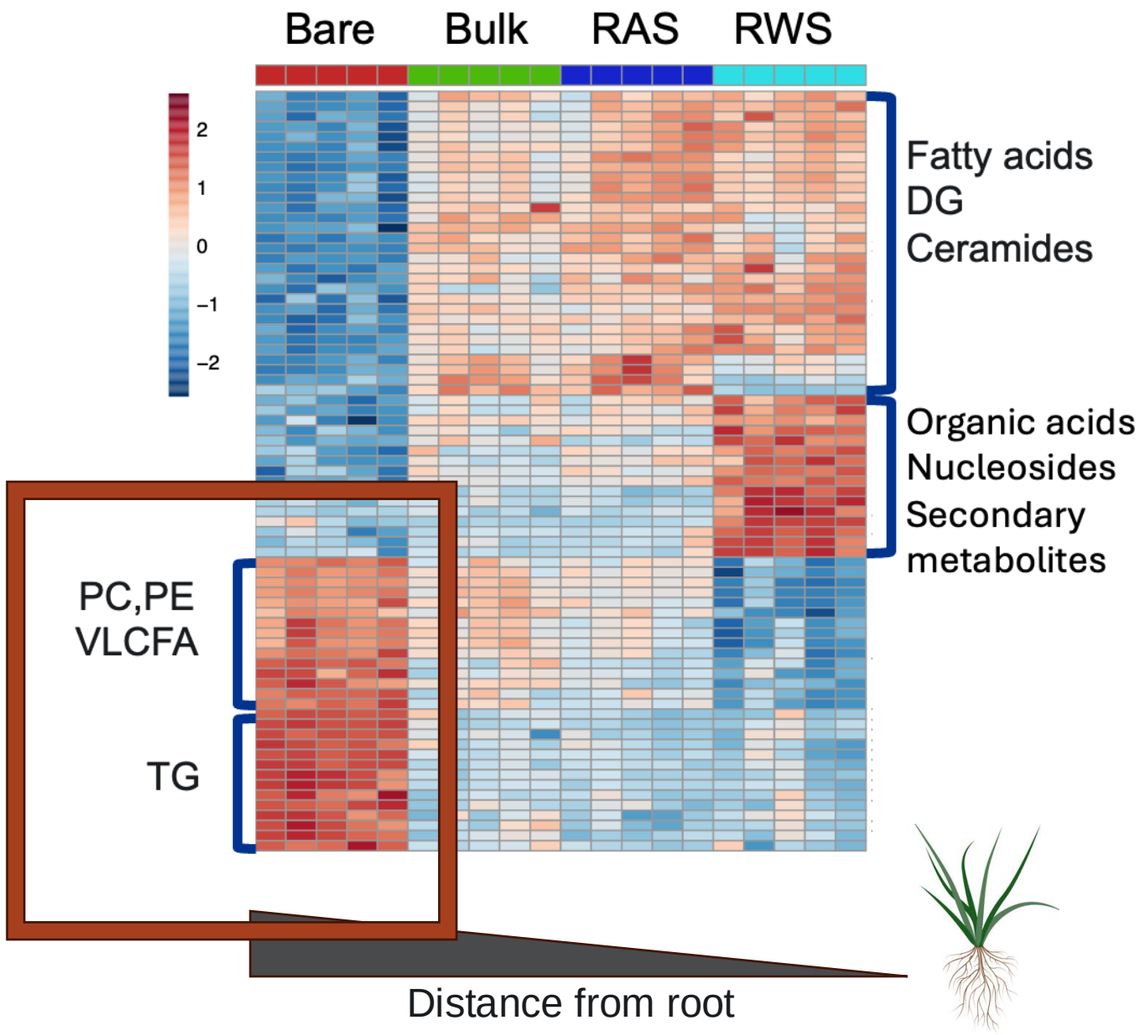
Metabo-lipidomics reveals rhizodeposition gradient



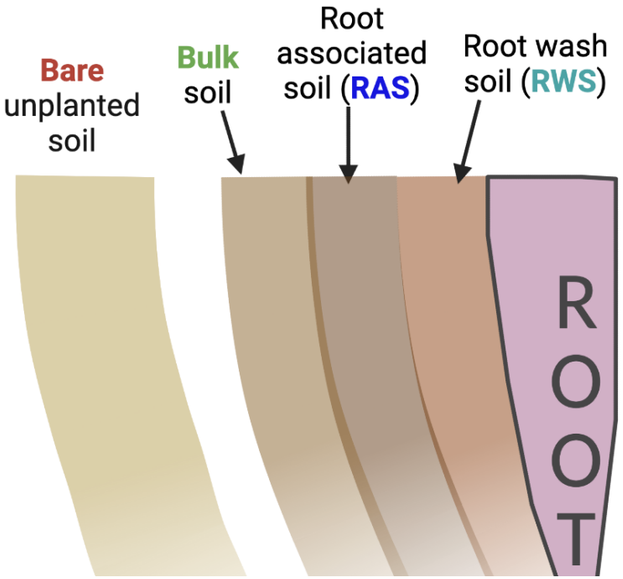


Couvillion et al. (2024). BioRxiv

Metabo-lipidomics reveals rhizodeposition gradient



Microbial phospholipids
Triacylglycerols

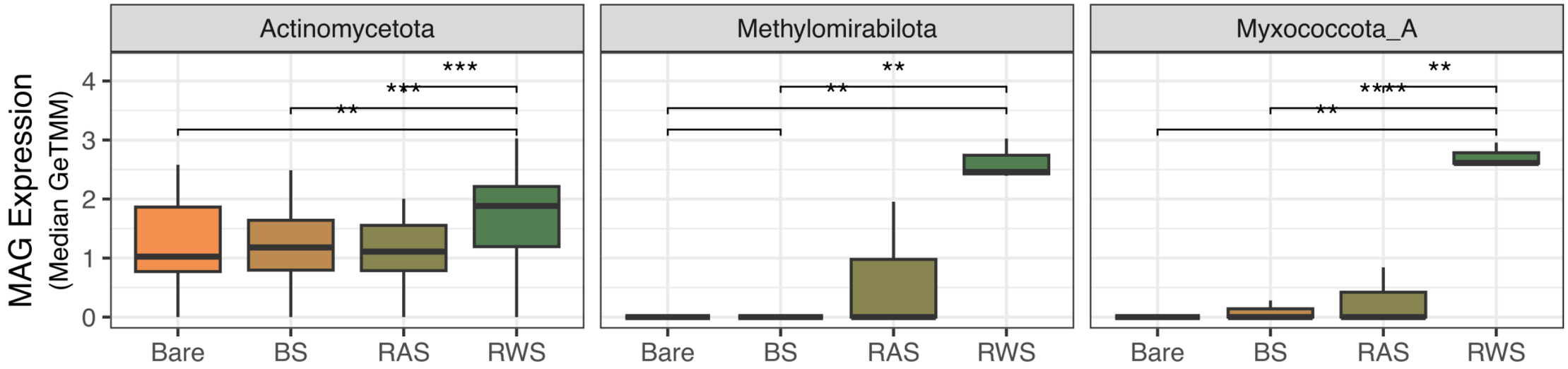


Couvillion et al. (2024). BioRxiv

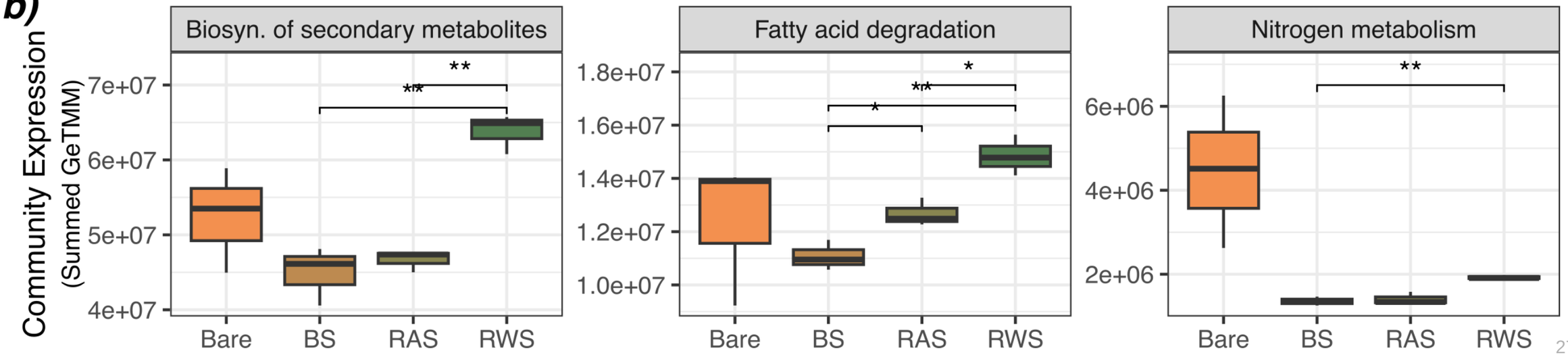
Rhizodeposition gradient reflected in microbial phylogenetic and functional responses

Bob Danczak

a)



b)



Impact of Drought on Root Exudates and Rhizosphere Microbial Metabolism

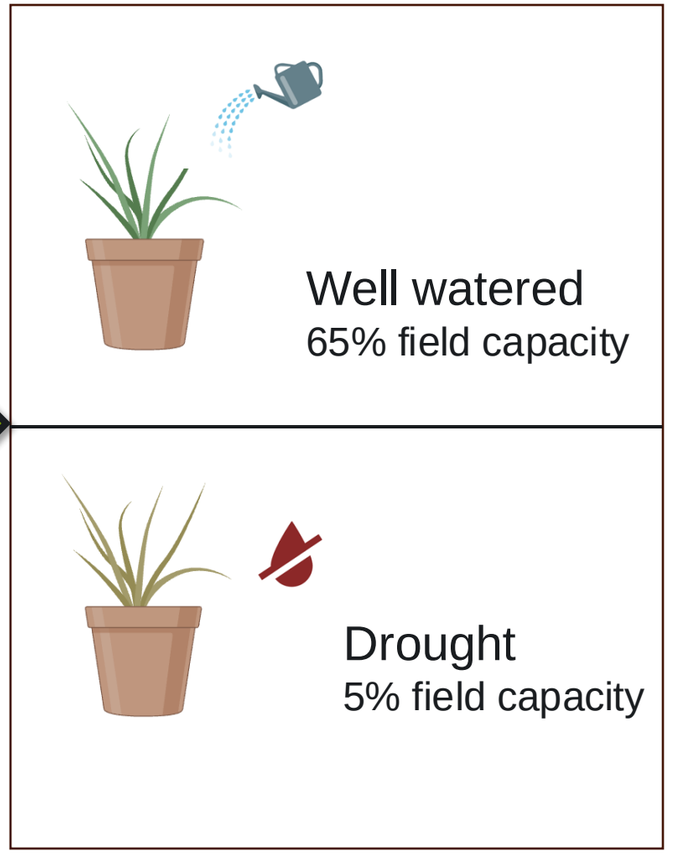
Evan Warburton

FIELD

Othello, WA

LAB

Acclimated 8 weeks

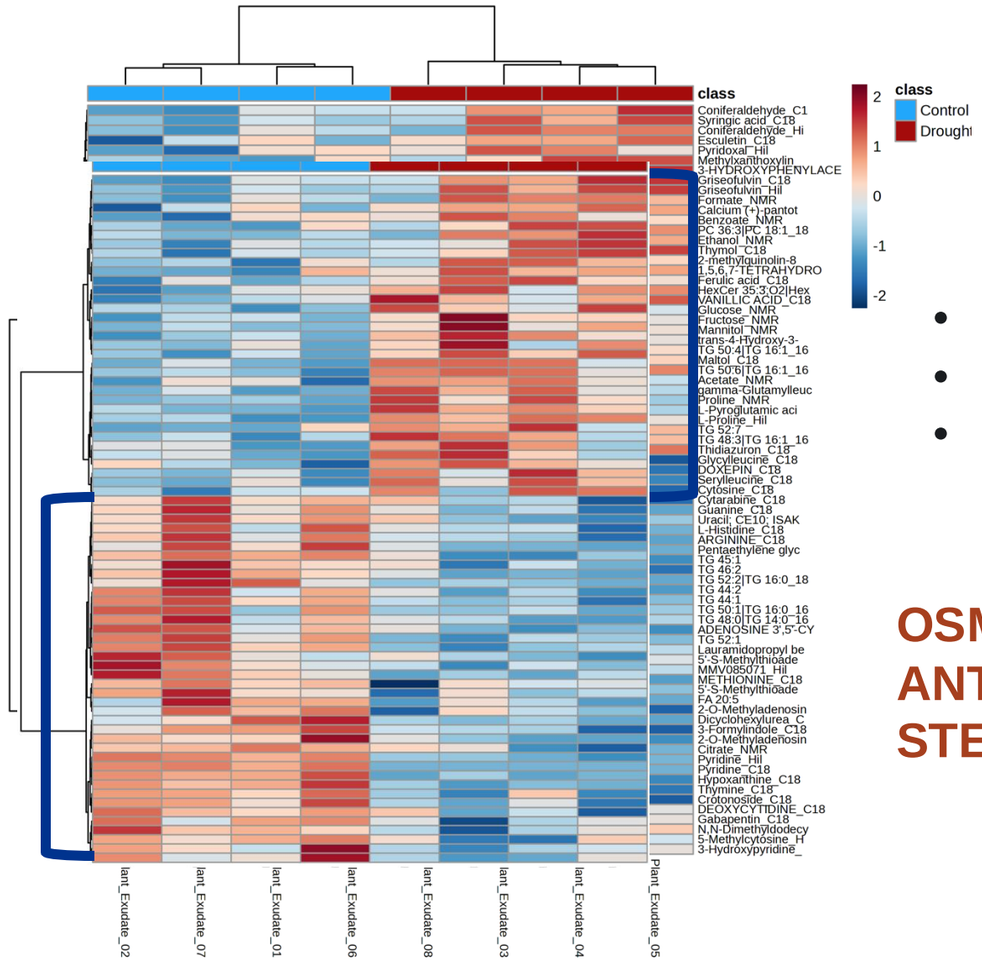


70 days

Couvillion et al. in prep

Drought alters root exudate metabolite and lipid composition

CONTROL **DROUGHT**



GROWTH
MAINTENANCE
SECONDARY METABOLISM

- Nucleosides
- Amino acids and derivatives
- Secondary metabolites
- Triacylglycerols with lower unsaturation

- Sugars
- Phenolic compounds
- Triacylglycerols with higher unsaturation

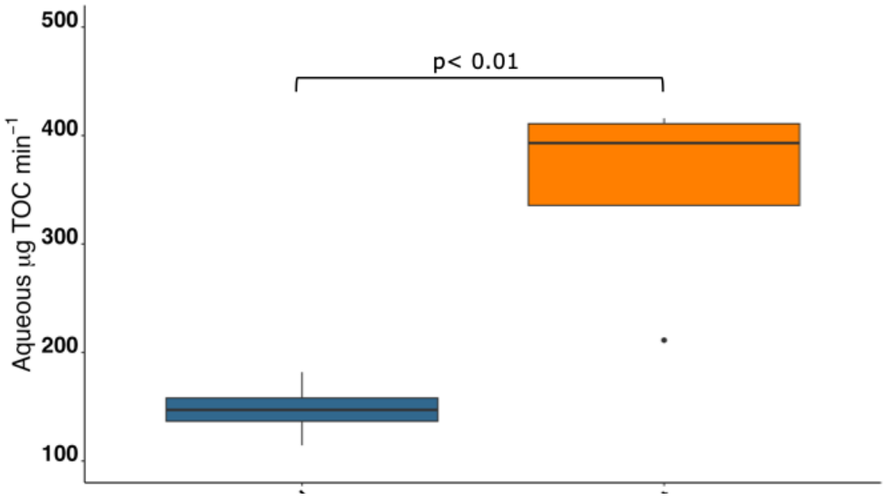
OSMOPROTECTANTS
ANTIOXIDANTS
STESS SIGNALLING

Couvillion et al. in prep

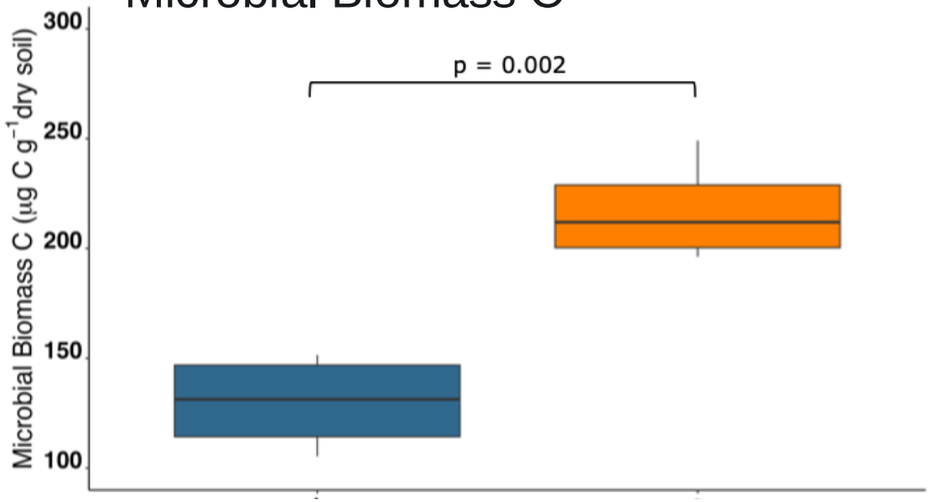
Drought increases C in hydrophilic root exudates and soil microbial biomass

Control Drought

Root Exudates



Microbial Biomass C

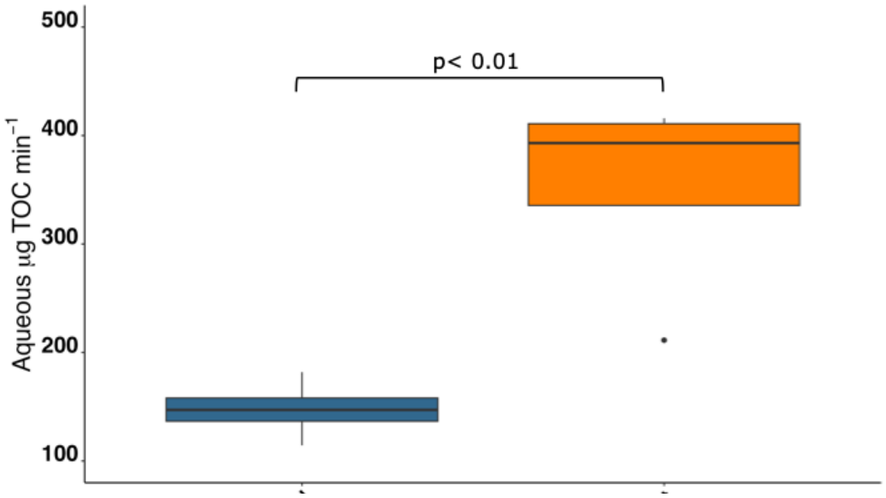


Couvillion et al. in prep

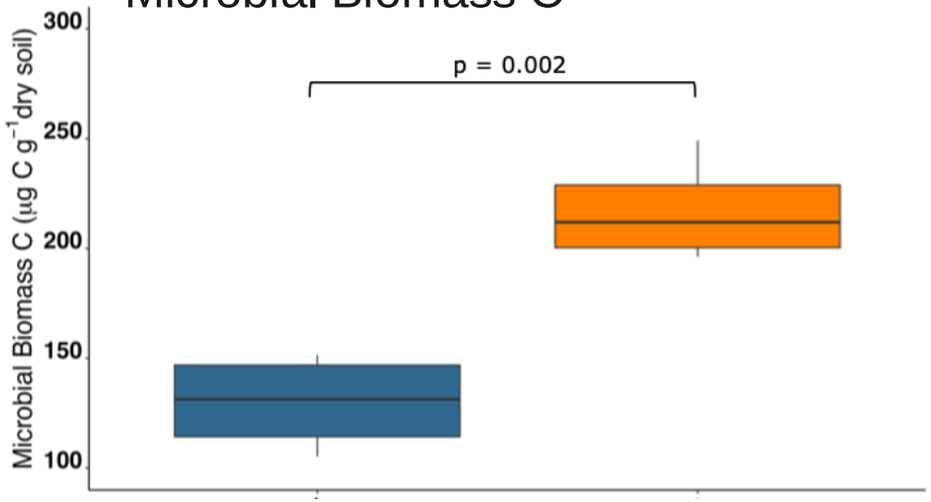
Drought increases C in hydrophilic root exudates and soil microbial biomass

Control Drought

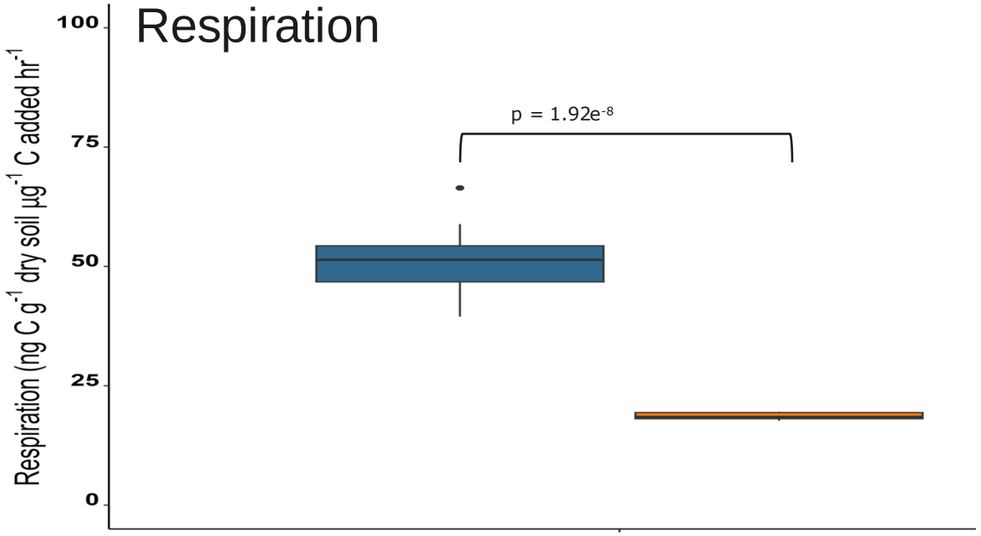
Root Exudates



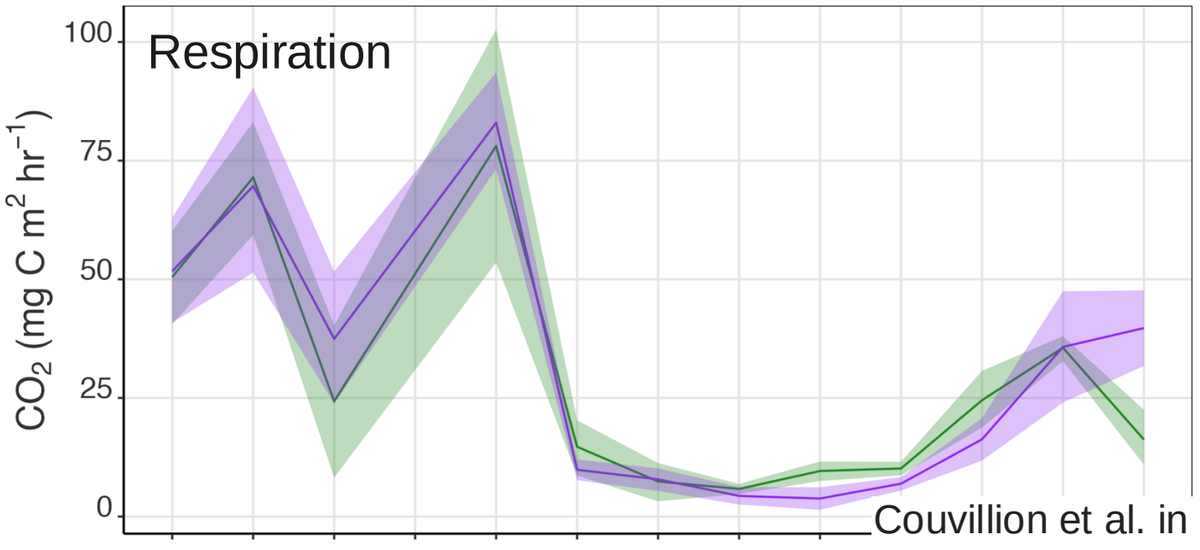
Microbial Biomass C



Respiration

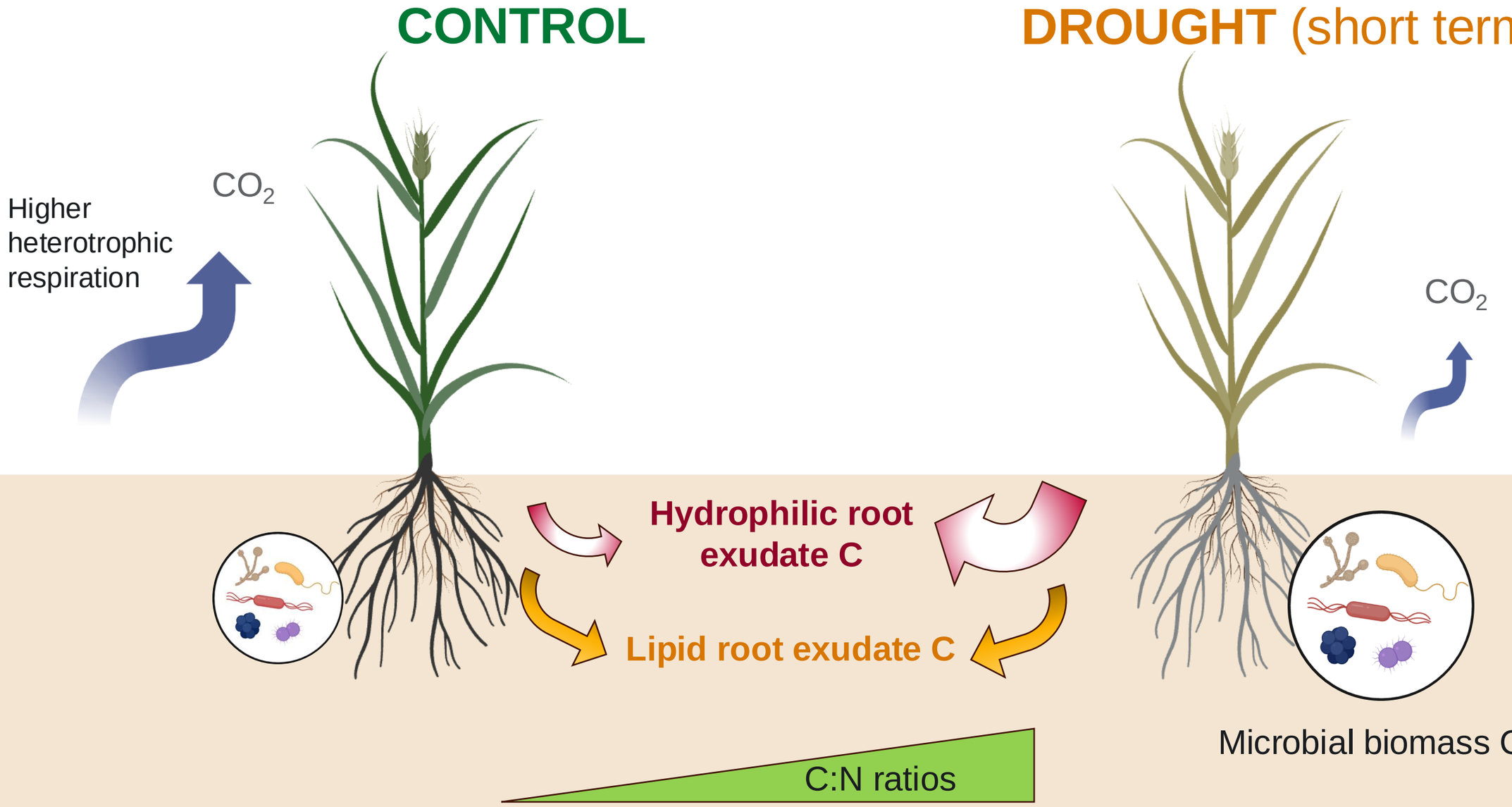


Respiration



Couvillion et al. in prep

Molecular interactions inform ecosystem outcomes



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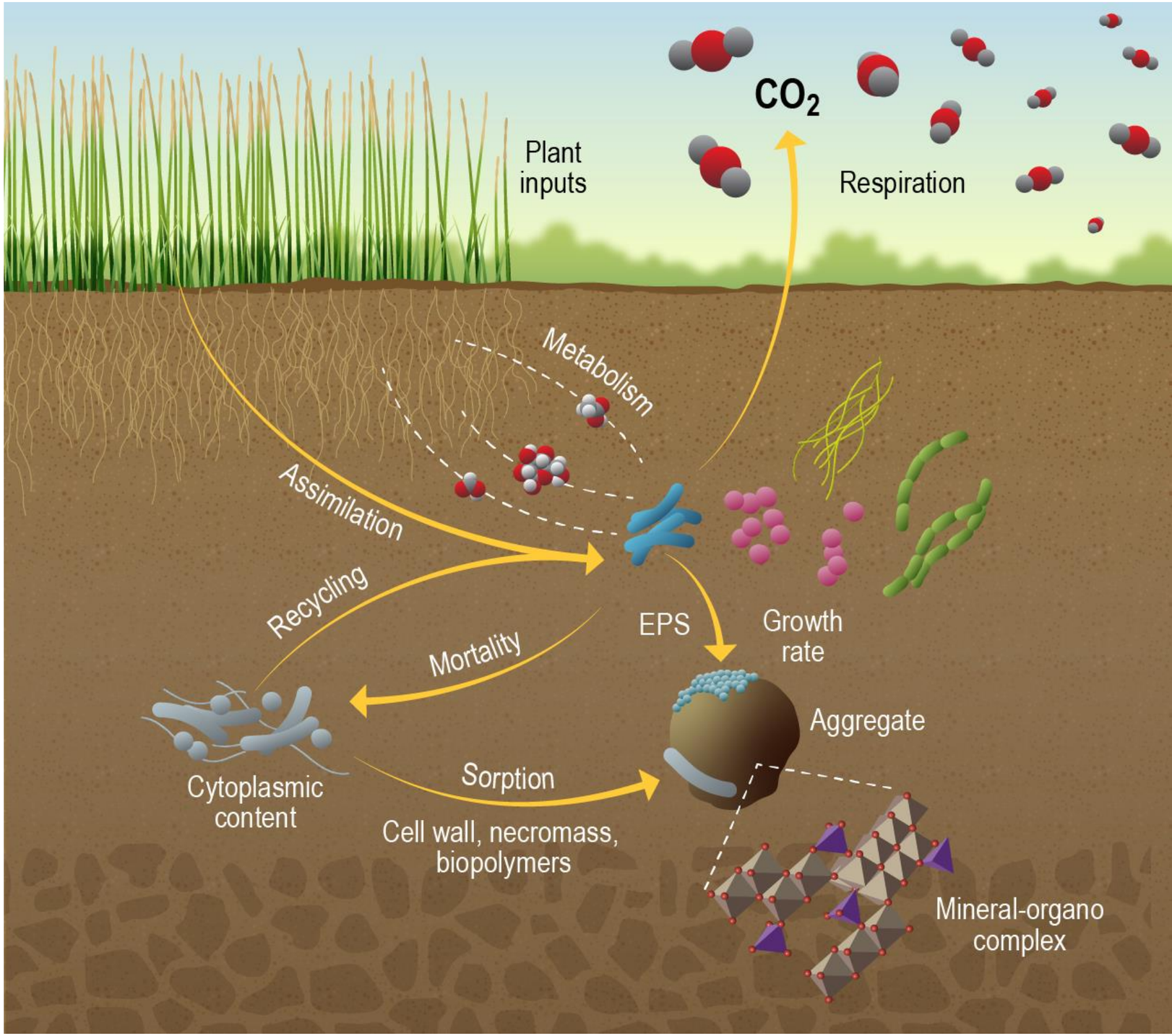
Kaitlin Rempfert

Do lipids and metabolites persist in the soil?



Rempfert et. al, 2024

^{13}C tracing of microbial necromass persistence

2 Site | **2 Crop** | **2 Treatment**

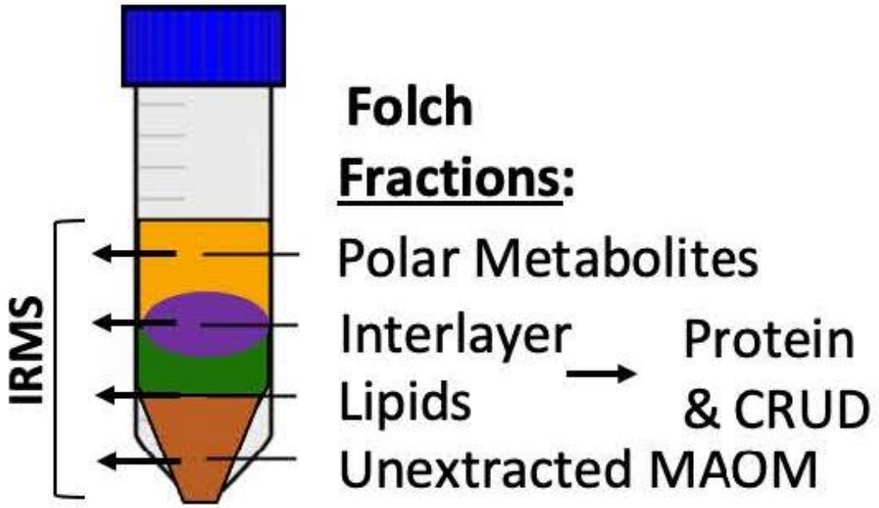
Silty | Sandy | Corn | Switchgrass | ^{13}C-Glucose | NA-Glucose

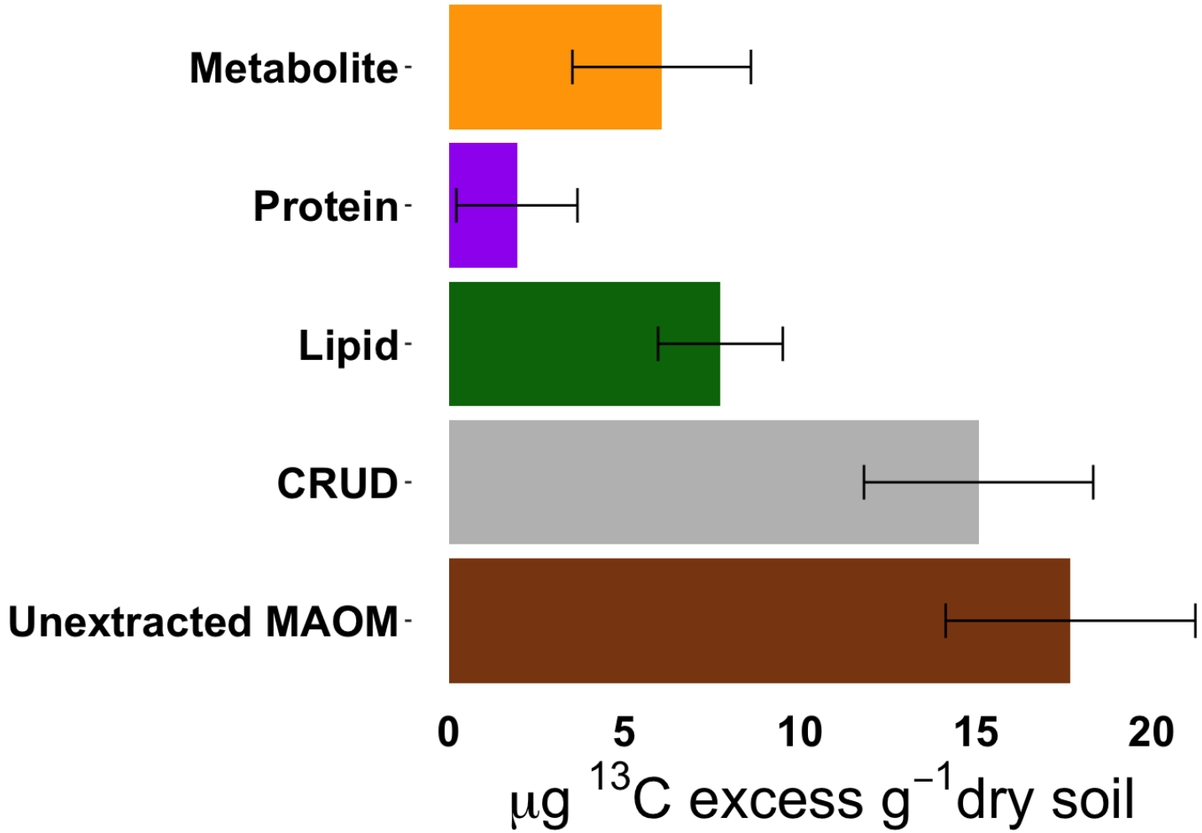
What is the influence of mineralogy on microbial necromass retention?

Do bioenergy cropping systems favor C accumulation?

What microbial residues form durable carbon?

Lipids and metabolites persist after 1 year





Rempfert et. al, 2024

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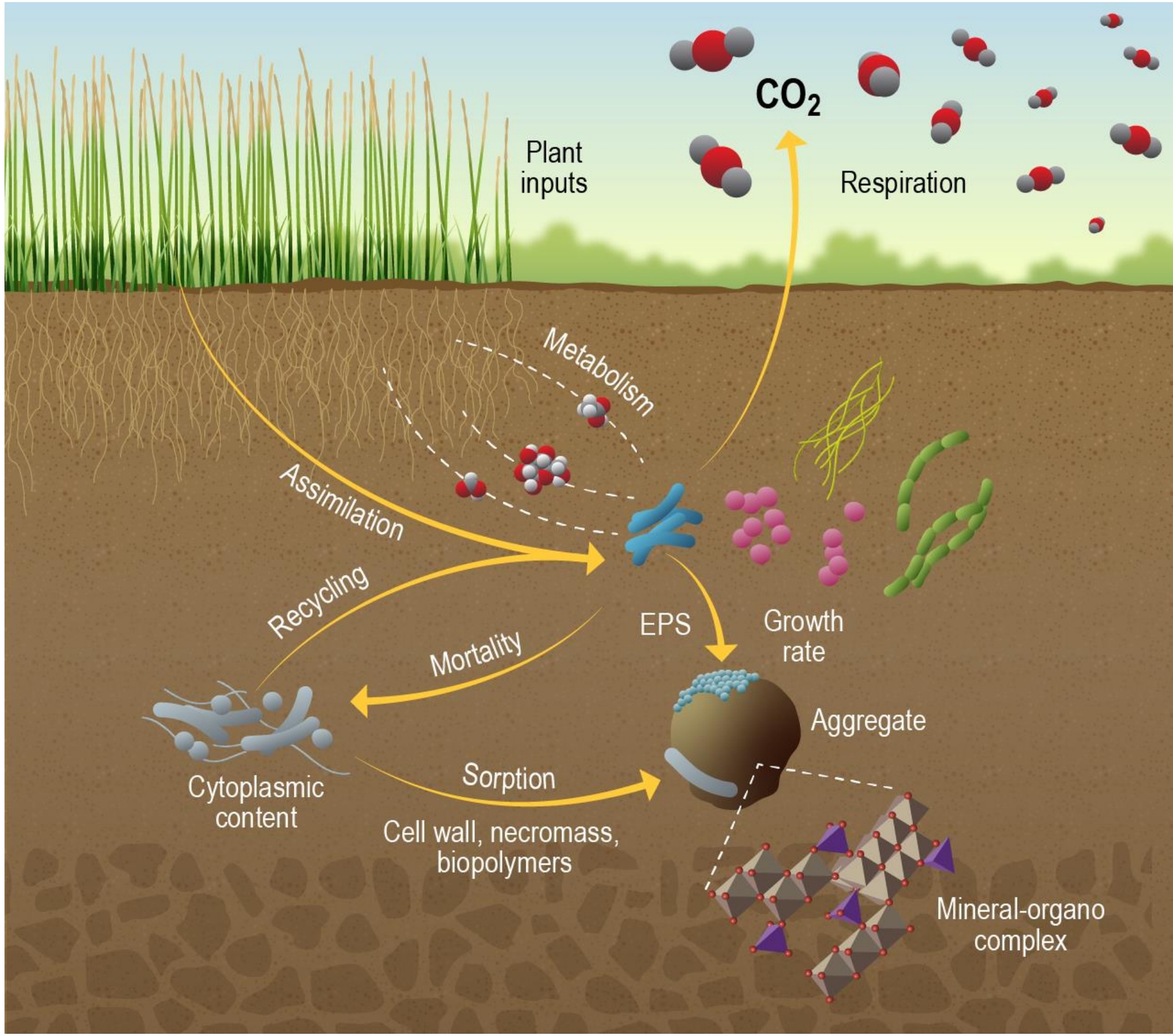
Kaitlin Rempfert

What Pathways Support Soil Health and Carbon Capture?



Rempfert et. al, 2024

Concluding thoughts

- Soil respiration reflects seasonal variation in root biomass and associated exudate dynamics
  - Seasonal dynamics in respiration potential varies with exudate chemistry
  - Strong evidence that respiration potential reflects plant phenology

- Metabo-lipidomics is an important frontier
  - Diverse lipids and metabolites are exuded from mature, field-grown, perennial grass
  - Lipids and metabolites can contribute to enhancing soil carbon accumulation
  - Microbial metabolism is tied to exudate chemistry

- Short term drought (70 days) alters root exudate metabolite and lipid composition
  - Drought increases C content of root exudates- in the form of specific hydrophilic molecules
  - Drought increased microbial biomass carbon and decreased basal soil respiration

Ongoing work…..

- Influence of plant phenology on soil ecology – above v belowground growth
- Drought effects on exudate chemistry and plant-microbe interactions
- Exudate effects on bacterial- fungal – viral ecology
- Translating science between lab and field to discover governing mechanisms
- Identification of field-relevant reactions and phenotypes that alter soil carbon storage and cycling

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PHYTOBIOMES
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Thank you