Biological controls of soil organic matter and responses to changing moisture conditions

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Journées horticoles et grandes cultures de Saint-Rémi

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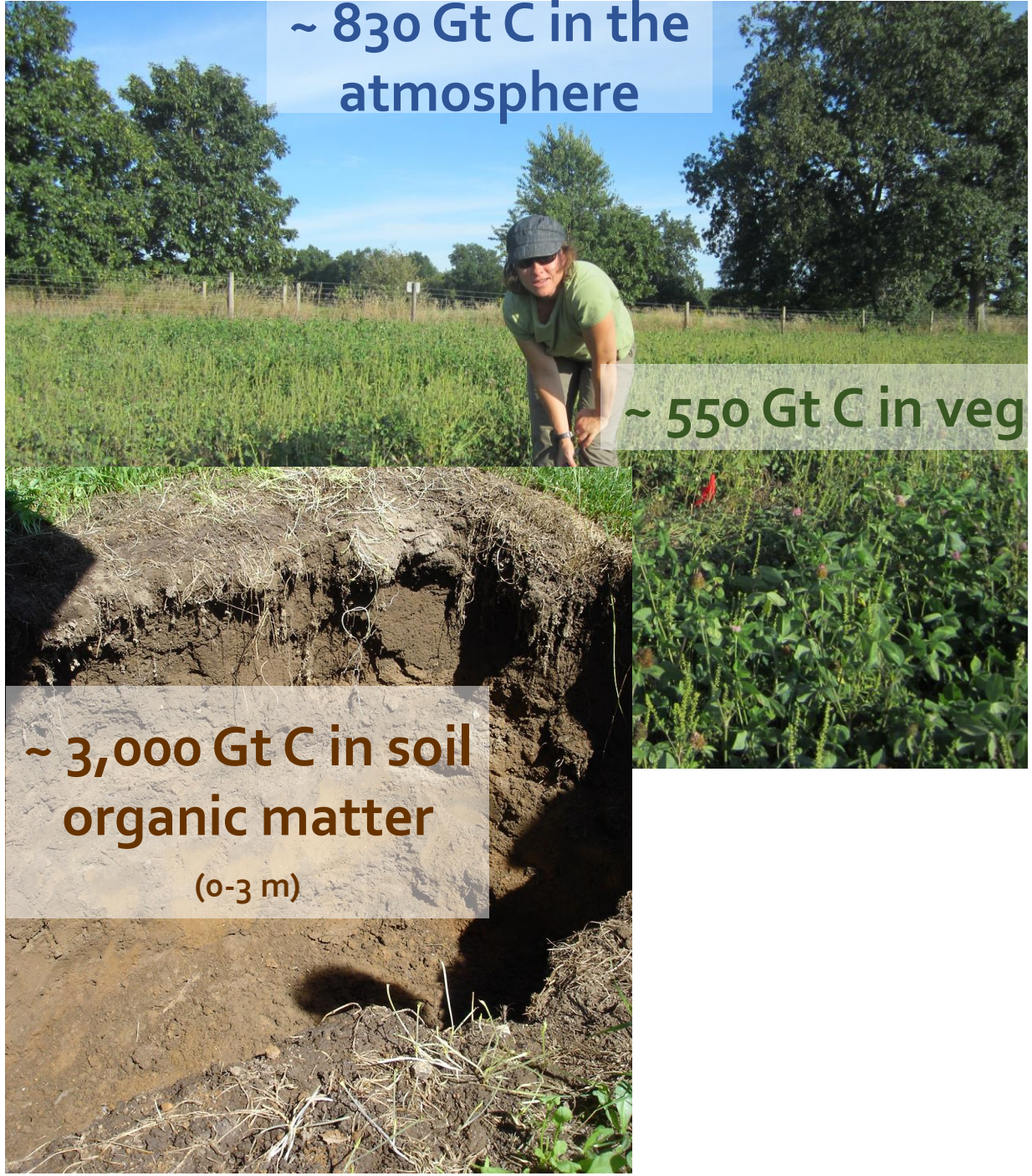
Soil Biogeochemistry and Ecology lab: https://kallenbachcm.wixsite.com/soils

Microbial community

Soil carbon flows

Soil organic matter (SOM)

Soil Biogeochemistry and Ecology lab: https://kallenbachcm.wixsite.com/soils



Sanderman et al., 2017

Where is our Terrestrial Carbon?

SOM Provides Numerous Benefits!

1. Binds particles to form soil aggregates
2. Source of macro and micro nutrients N, P, S, B, metals (Cu, Zn, Mg, Ca, Fe, Mo, Mn)
3. Contributes to soil pH
4. Has a high cation exchange capacity
5. Feeds organisms in the soil

6. Controls transport/ retention of pollutants
7. Enhances water retention
8. Regulates global C cycle
9. Gives soil a darker color (heat adsorption /retention)

Erosion

Biodiversity

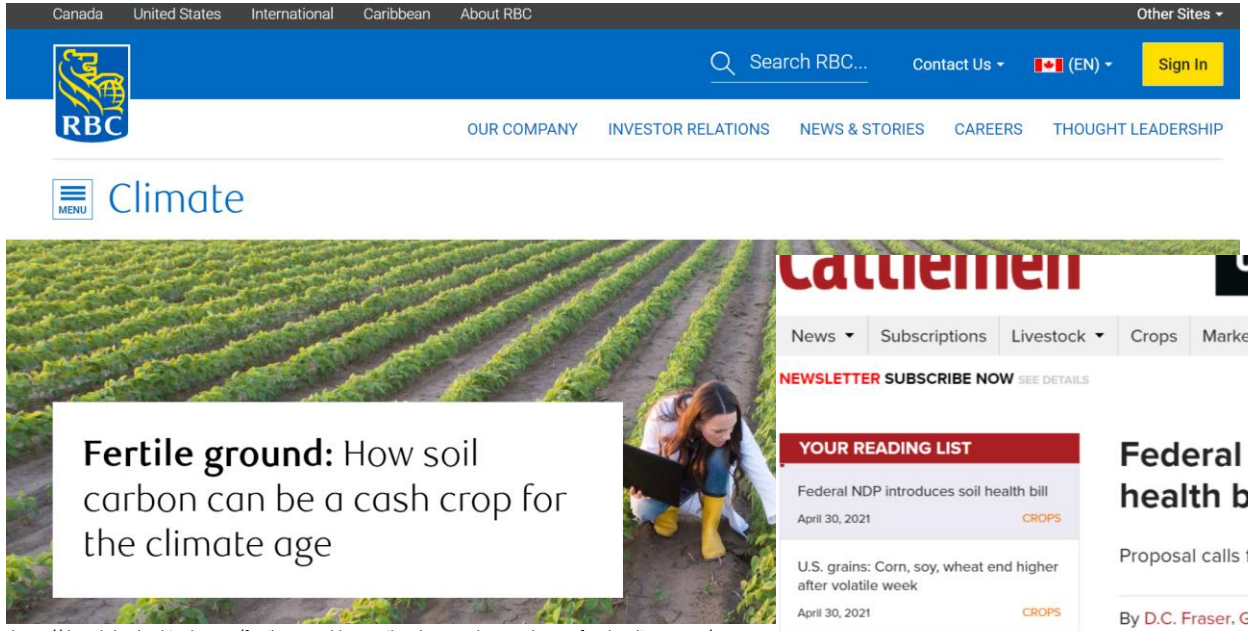
Water quality

Greenhouse gases

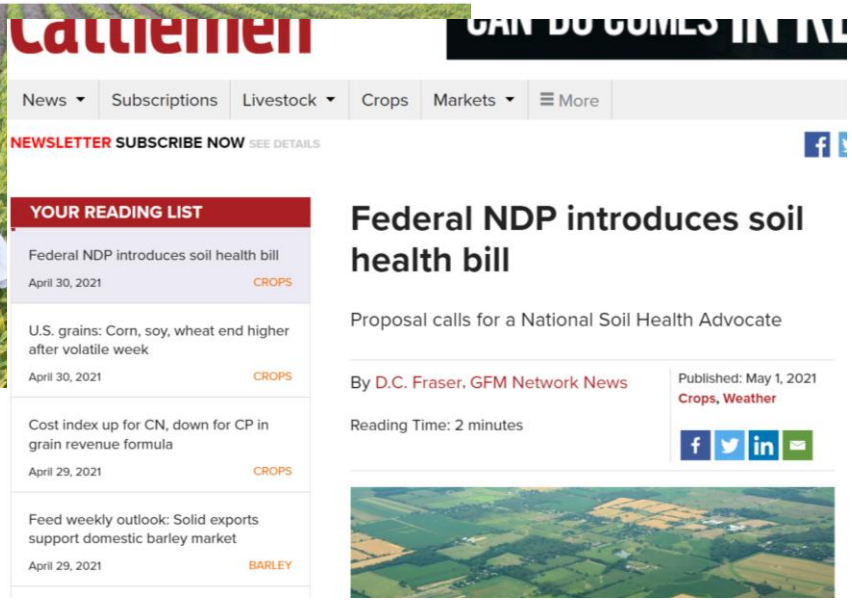
Reduce soil and water pollution

Crop productivity

Soil Carbon in Policies and Markets



https://thoughtleadership.rbc.com/fertile-ground-how-soil-carbon-can-be-a-cash-crop-for-the-climate-age/



https://www.canadiancattlemen.ca/daily/federal-ndp-introduces-soil-health-bill/

https://www.theguardian.com/environment/2023/jul/04/improving-farming-soil-carbon-store-global-heating-target

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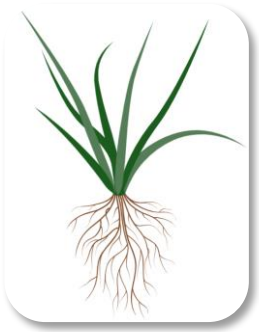
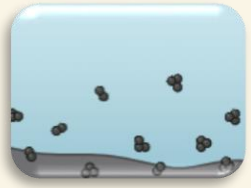
Not all Soil Carbon is the Same

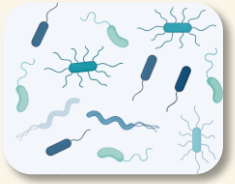


Plant biomass

Total soil carbon



Dissolved organic matter



Microbial/fauna biomass

Particulate organic matter free

Mineral associated organic matter

Increasing residence time
(time carbon stays in the soil)

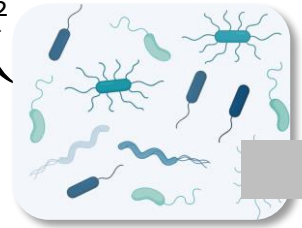
Accumulation of Soil Carbon

Microbial communities
- Cellular chemistry
- Growth (microbial yield)
- Community composition

Plant biomass

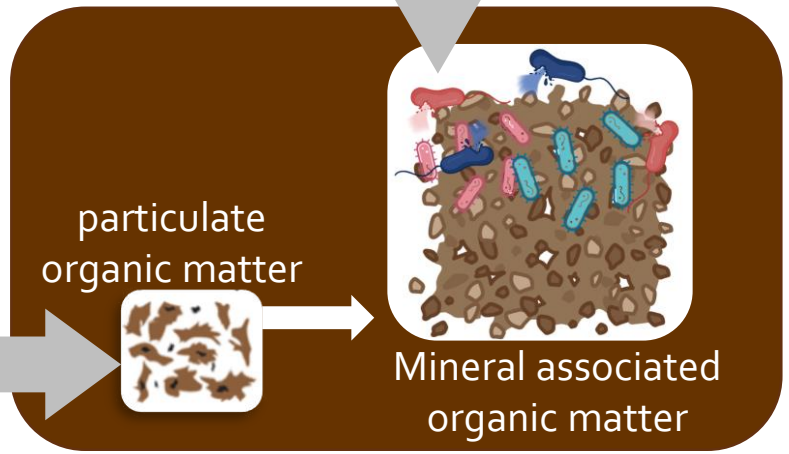
Microbial/fauna biomass

CO_2



Soil organic matter

Exocellular enzymes

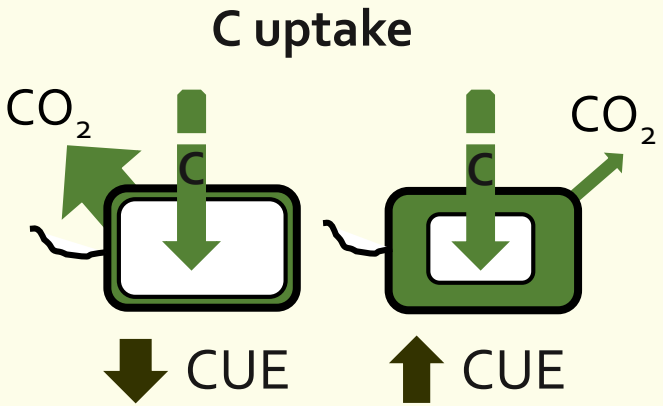


Crop residue,
- Plant productivity (yield)
- Chemistry, quality

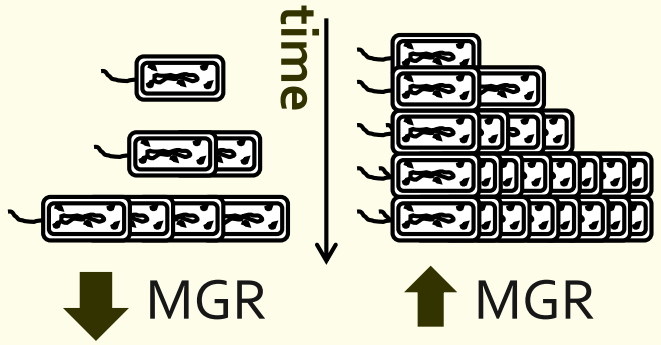
SOM protection (mineralogy, texture, cations, pores, aggregation)

Key Biomass Regulatory Growth Traits

Carbon Use Efficiency (CUE)



Microbial Growth Rate (MGR)



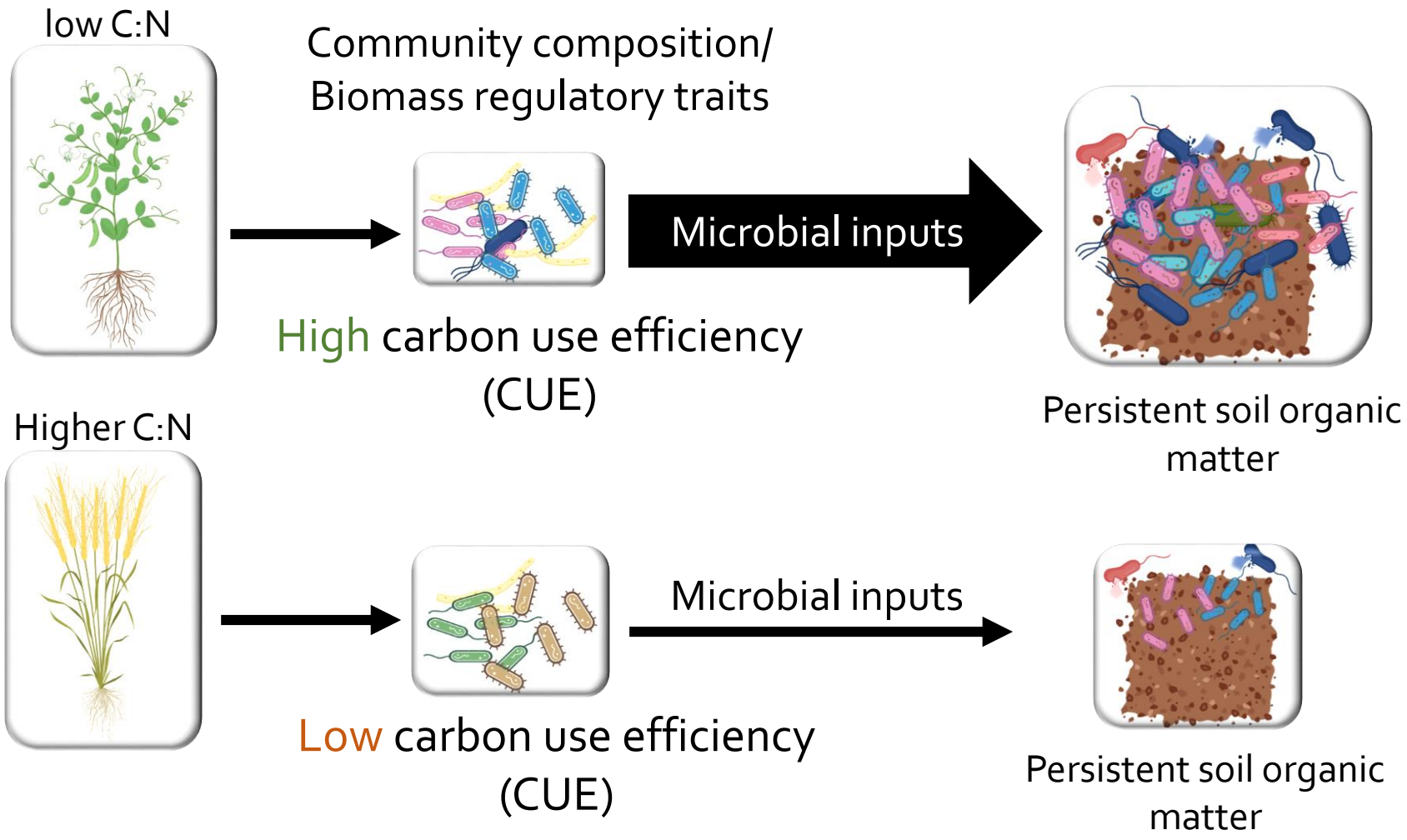
Vary across fields and climate and among species (genetics)

Growth efficiency

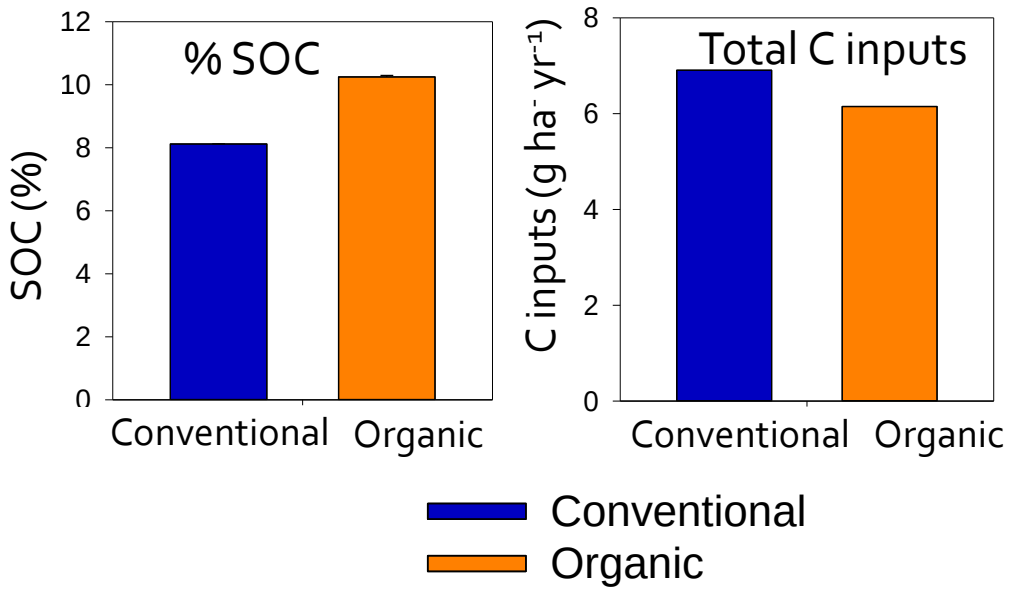
Growth rates

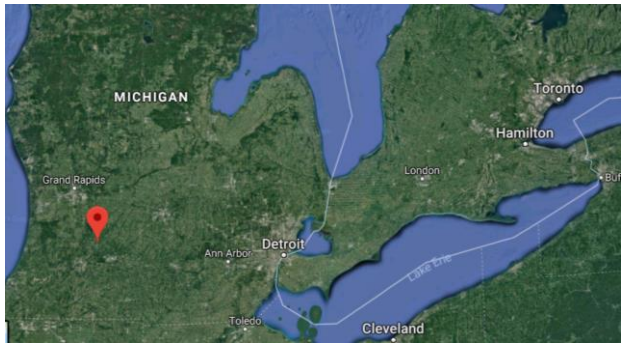
Higher quality plant input (low C:N)
Frequent C inputs

Plant Quality Influences Microbial Growth and SOM



Kellogg Biological Station LTER, SW Michigan





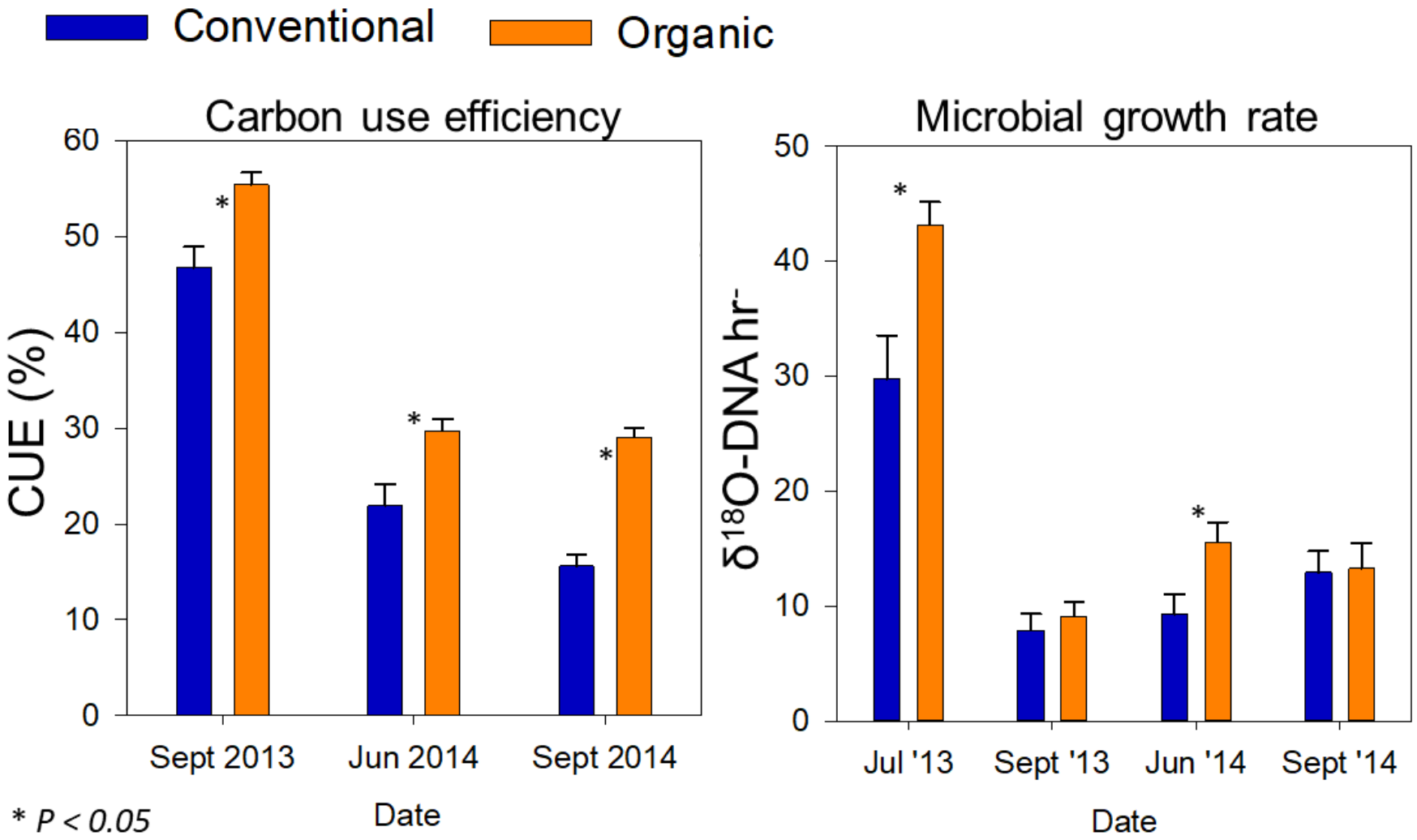
Conventional: corn-soy-wheat rotation

Organic: corn-**rye**-soy-wheat-**clover**

Cover crops: Increase input diversity, frequency, quality (C:N<30)

Hypothesis: Differences in management alter microbial growth and C allocation with consequences to stable soil C

Microbial community carbon use efficiency and growth rate is higher in organic



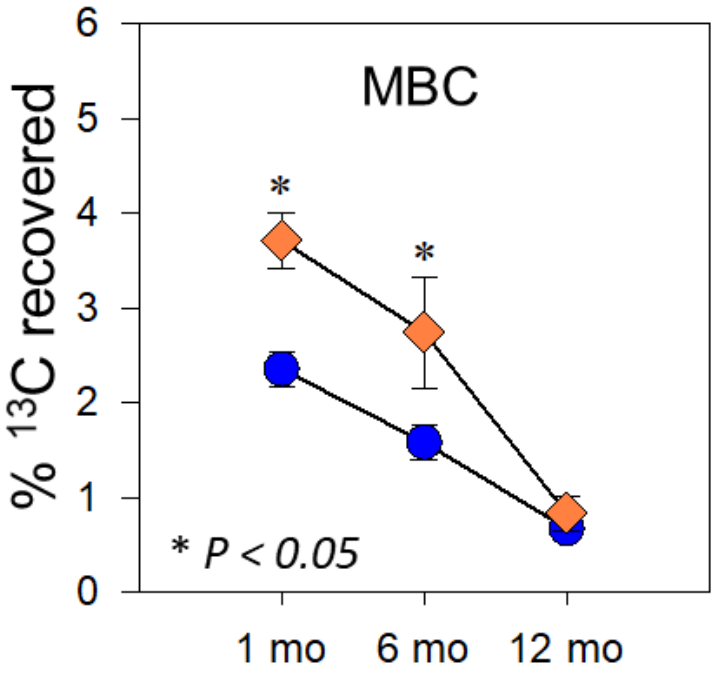
Kallenbach et al., SBB 2015

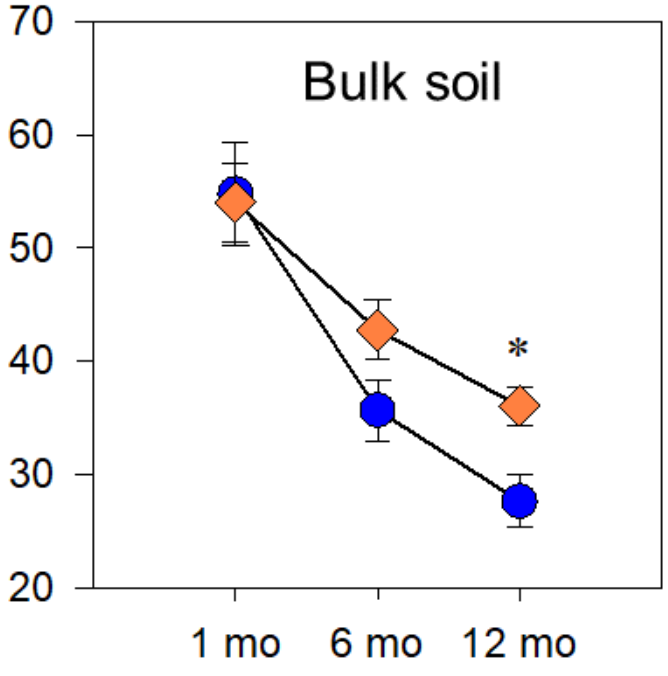
Organic system stores more new carbon

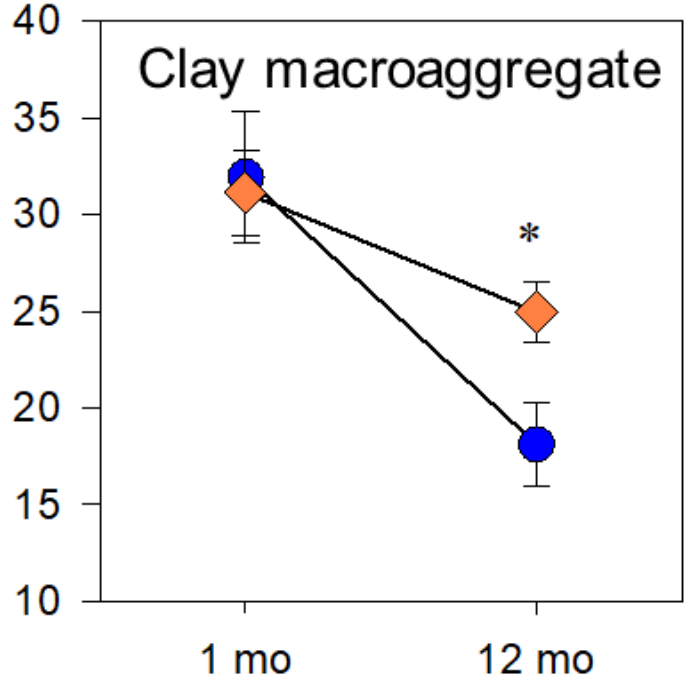
Conventional
Organic

More new C recovered in microbial biomass (MBC) in organic

Over time: More new C recovered in stable fraction of SOM

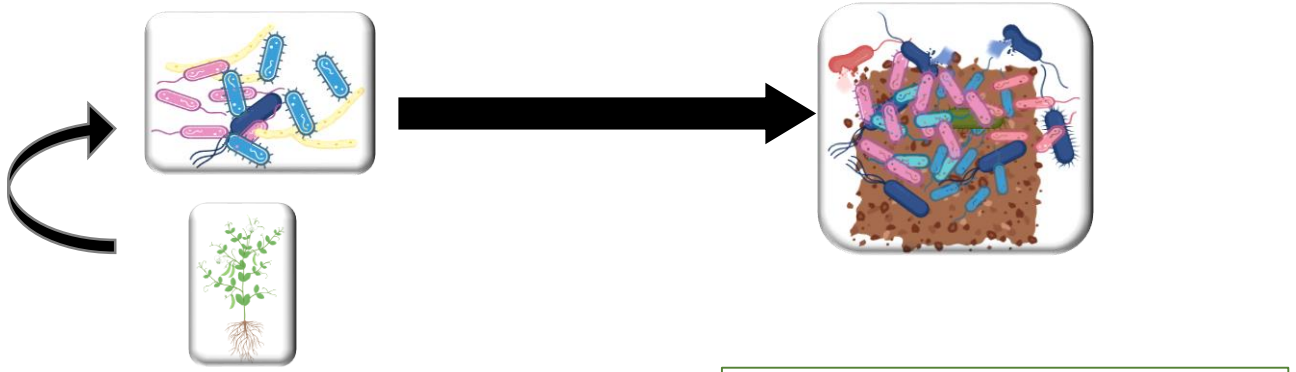






Kallenbach et al., SBB 2015

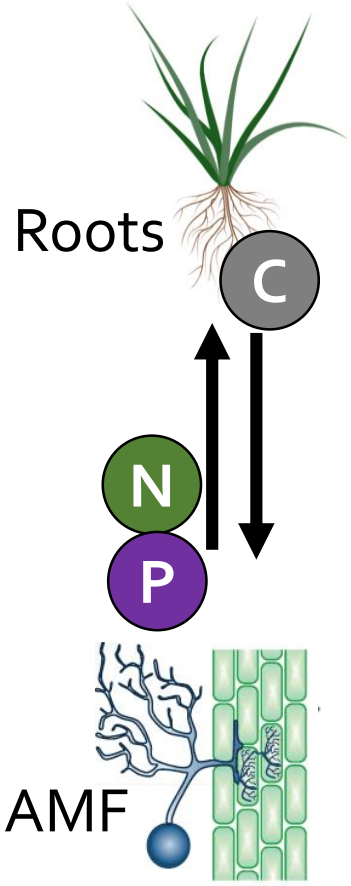
Manage agricultural systems for higher C accumulation via growth traits



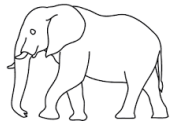
- Potential explanation for higher C accumulation under relatively fewer C inputs
- Alternative strategy for managing agricultural soil C under C-limited conditions


Caitlyn Horsch, MSc
Pedro Antunes, Algoma University

Arbuscular mycorrhizal fungal (AMF) Community Impacts on Soil Carbon



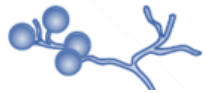
AMF Family Traits



Gigasporaceae

- Low hyphal turnover
- Low growth rates
- Later sporulation
- Larger and fewer spores

Glomeraceae



- High hyphal turnover
- High growth rates
- Earlier sporulation
- Smaller and more spores

Chaudhary et al 2022, Trends Ecol. & Evol; Treseder et al 2018, J Ecol; Chagnon et al 2013, Trends Plant Sci; Hart and Reader 2002, New Phytol

AMF Trait Community Impacts on Soil Carbon

How do communities that differ in their traits influence:

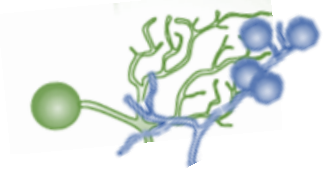
1. AMF carbon input to soil?

2. The fate of AMF carbon after deposition?

Gigasporaceae

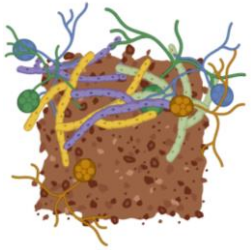
Glomeraceae

Mixed (Glom & Giga)

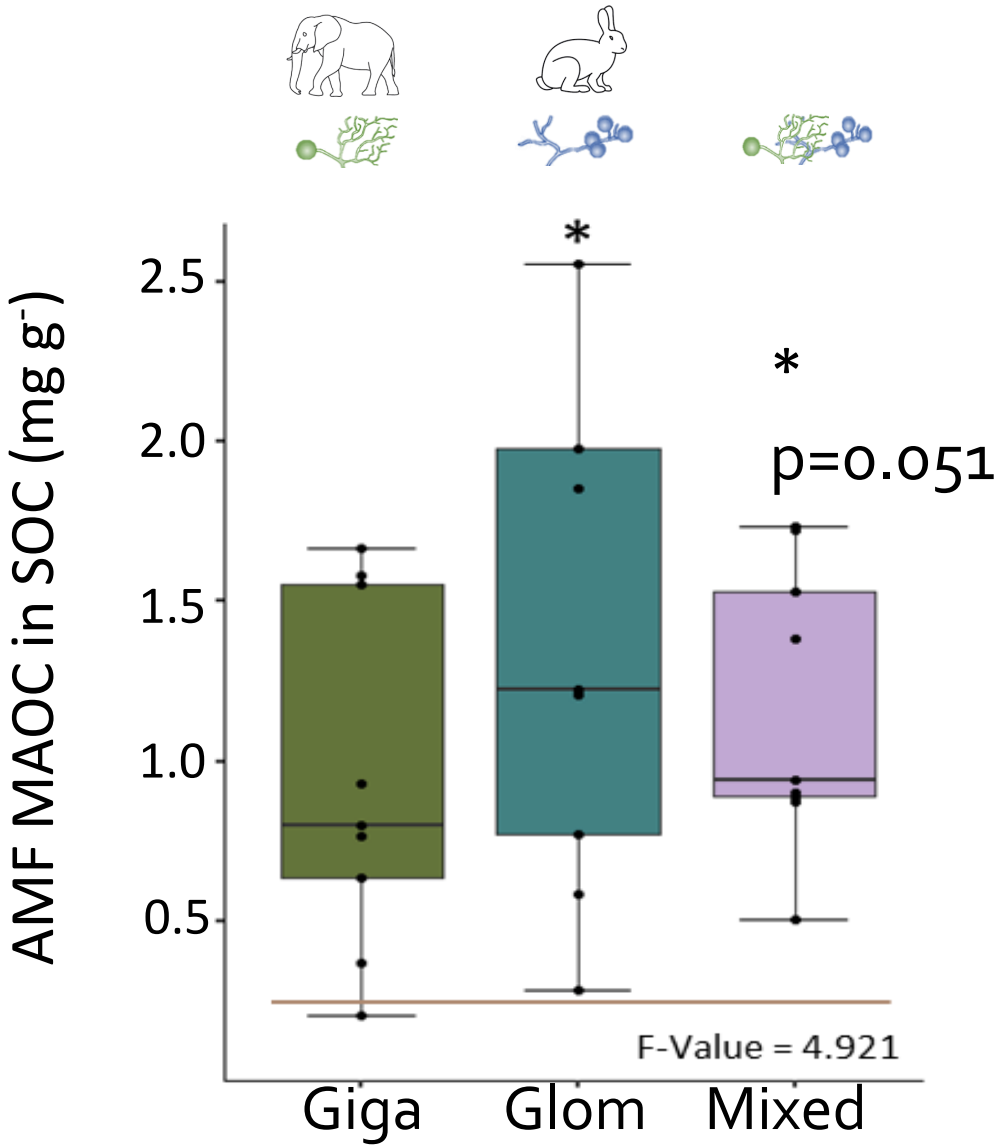


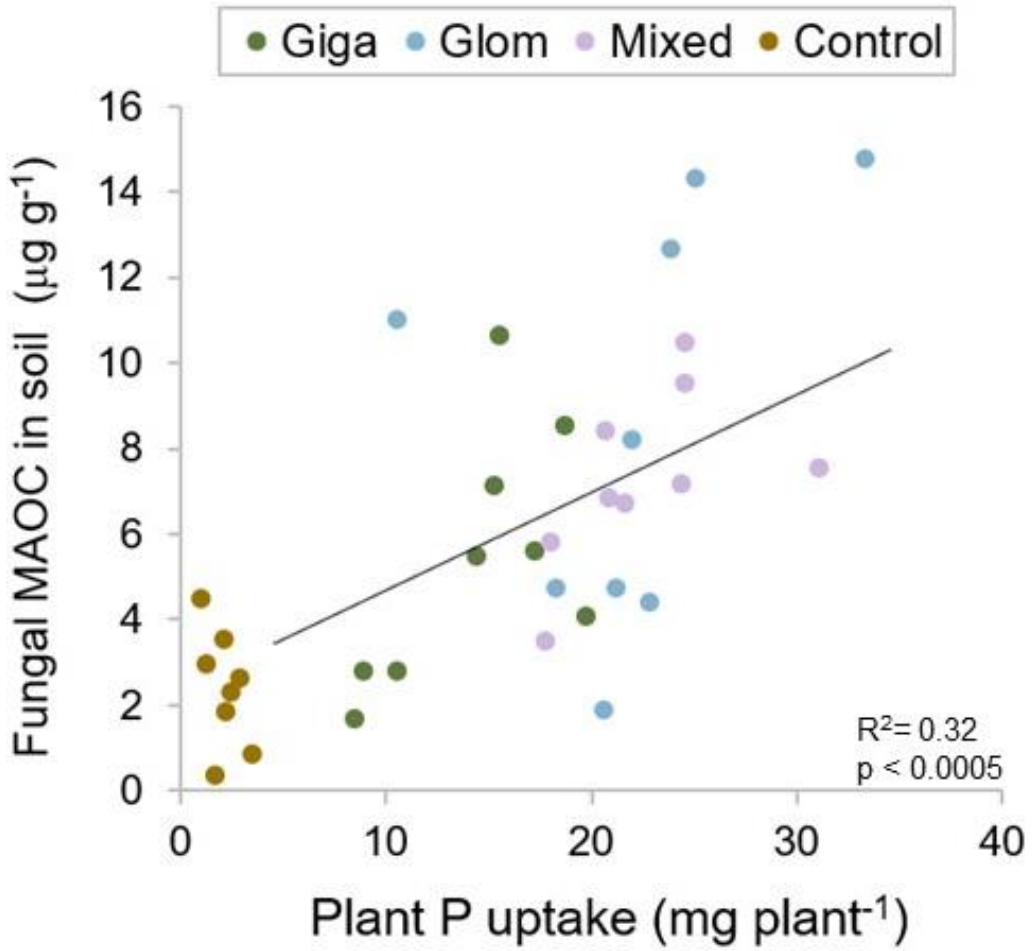
MAOC

Mineral-associated organic C



AMF communities differ in contribution to MAOC



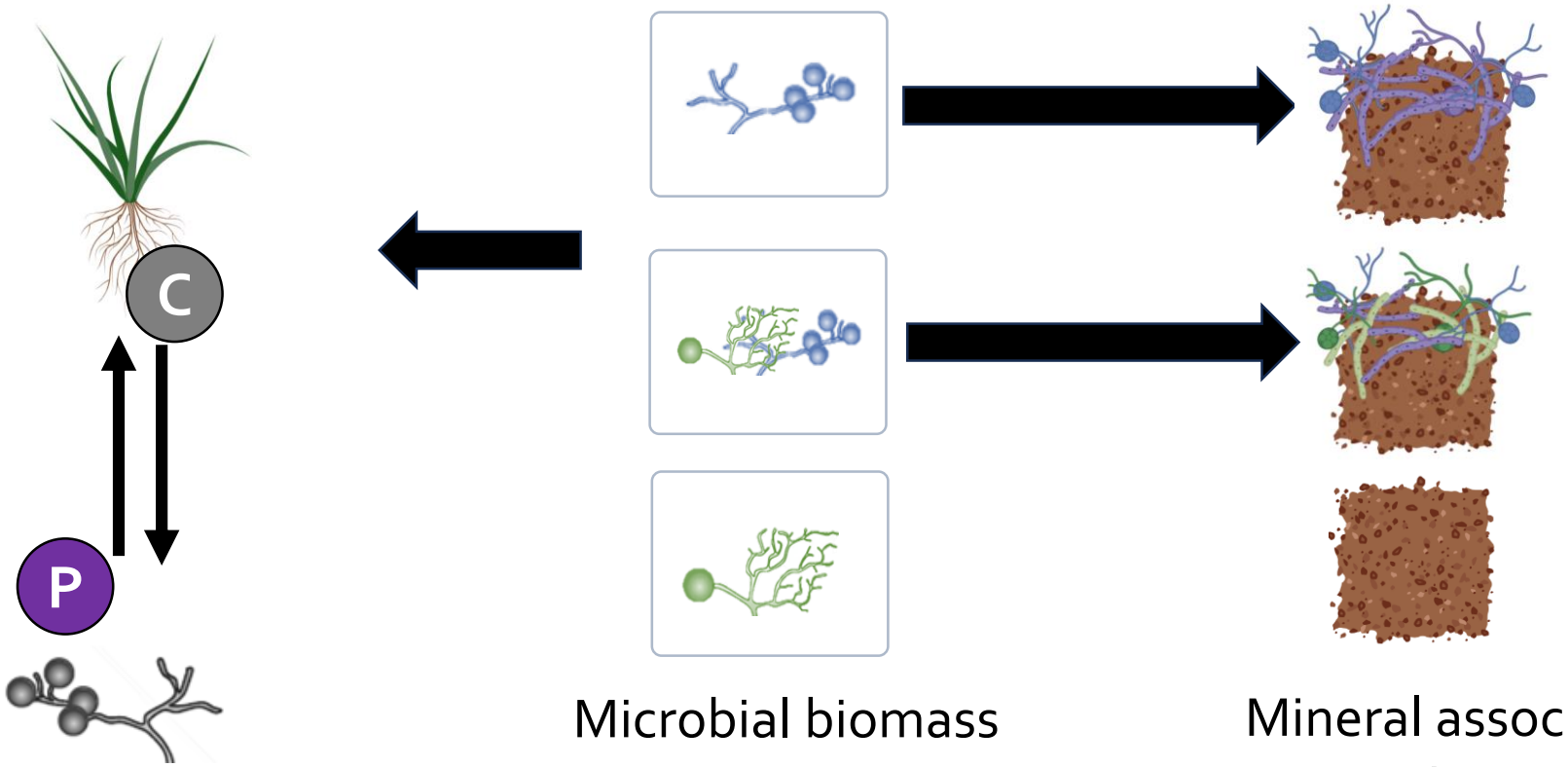


Horsch et al., 2023 *New Phytologist*

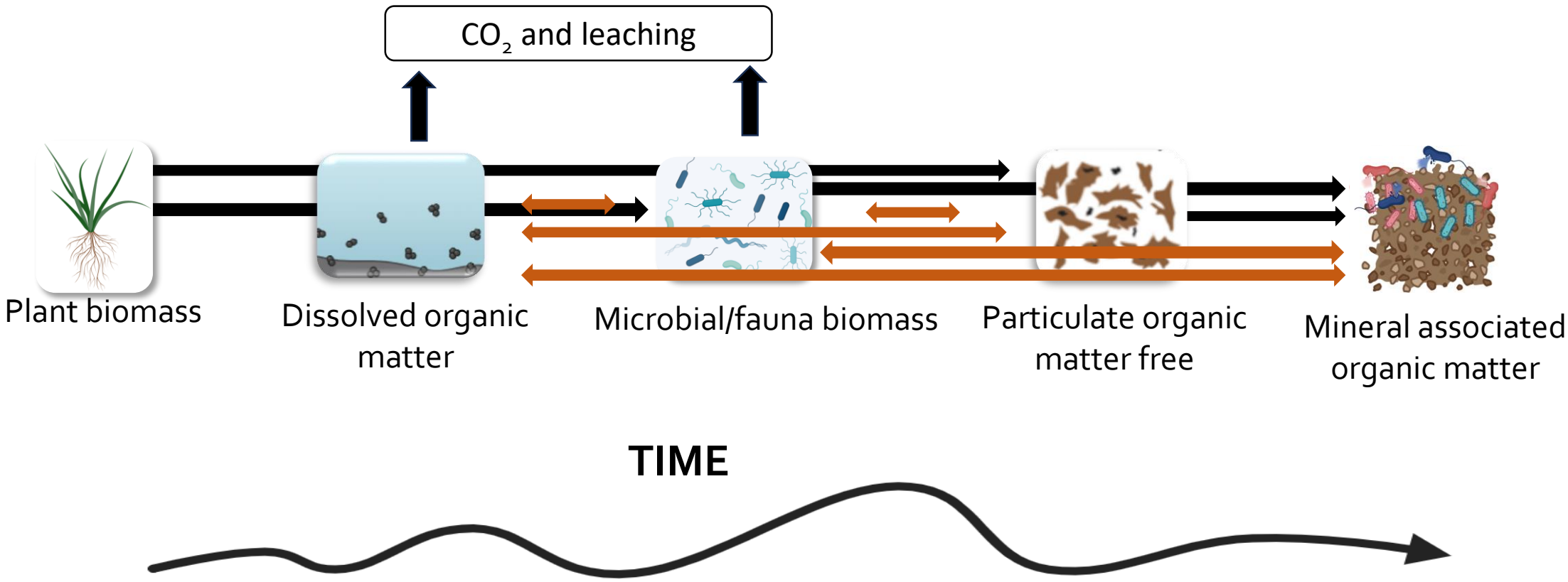
Horsch et al., 2023 Mycorrhizae

In Summary

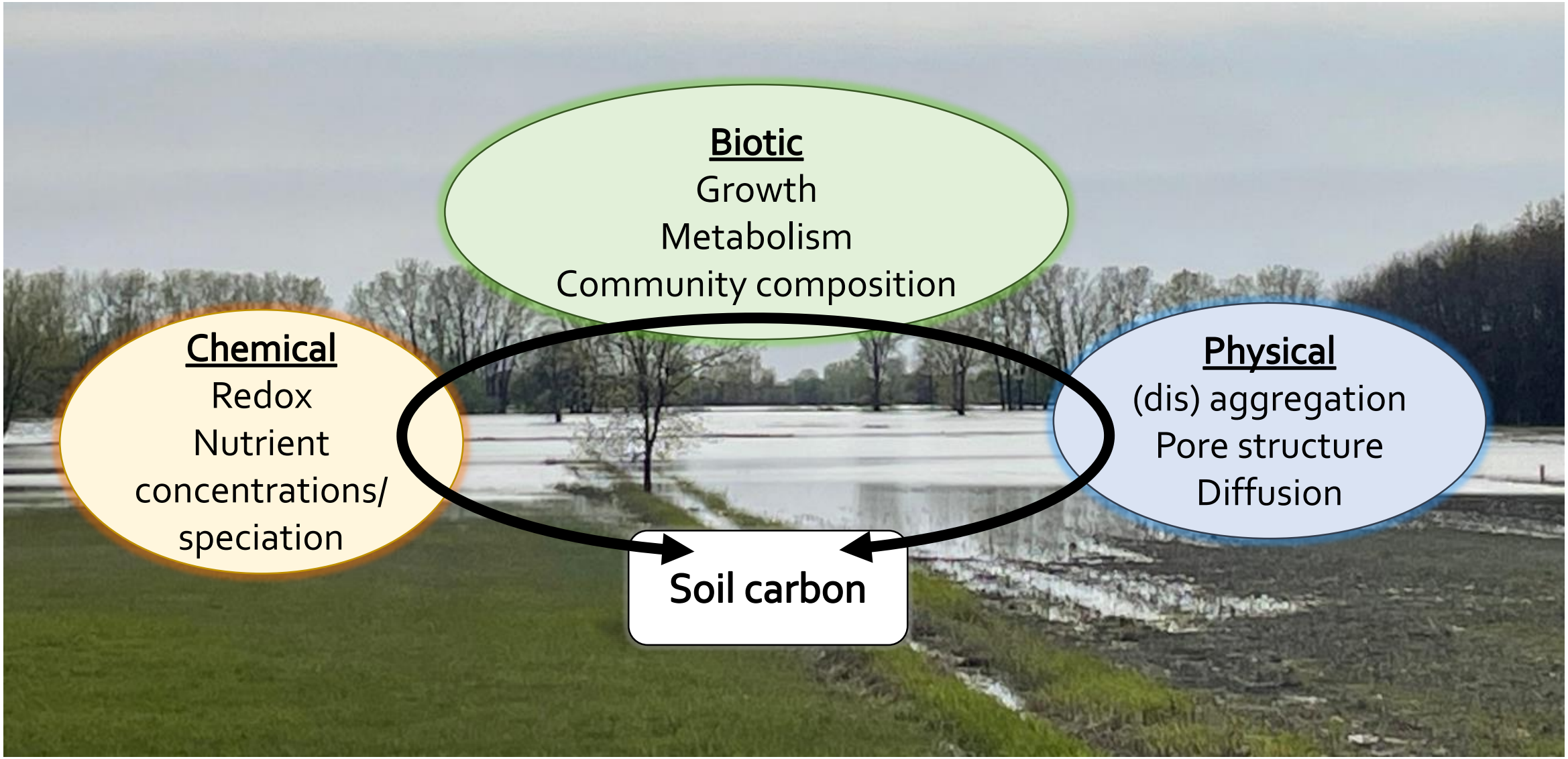
AMF Input to persistent SOM (MAOC) is Community Dependent and related to P uptake



Soil Carbon Pools are Constantly Exchanging



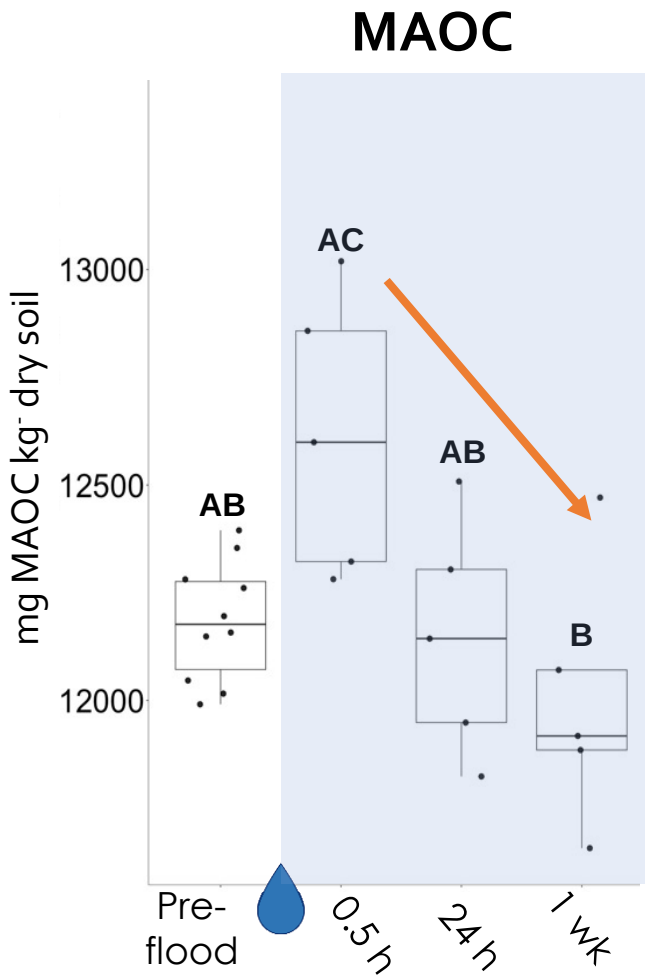
Flooding is a Massive Disturbance to Soil

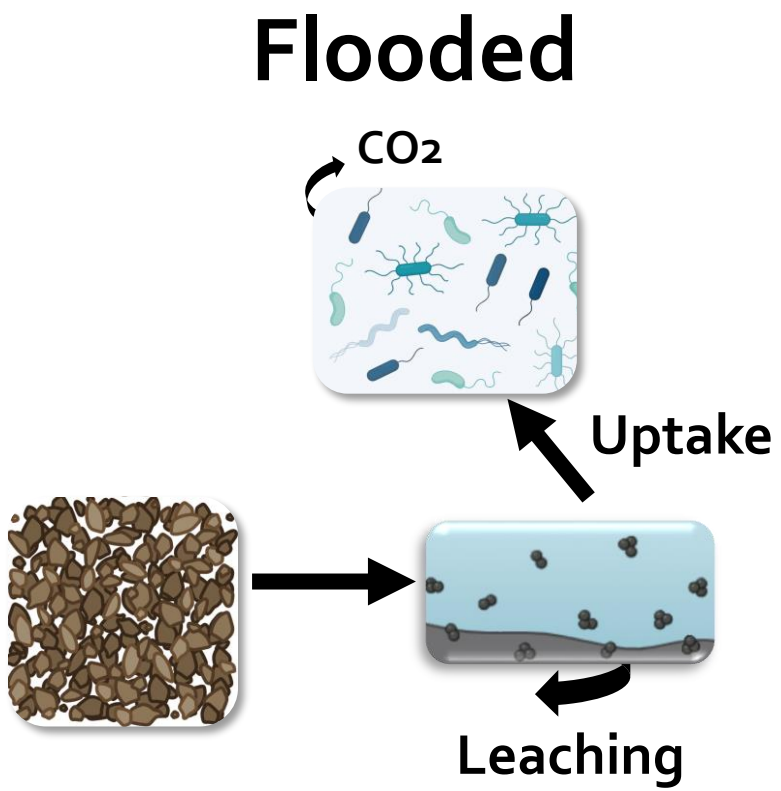


How does Flooding Affect the Fate of Soil Carbon

Hannah Lieberman
PhD Candidate

Mineral-associated organic C is sensitive to flooding



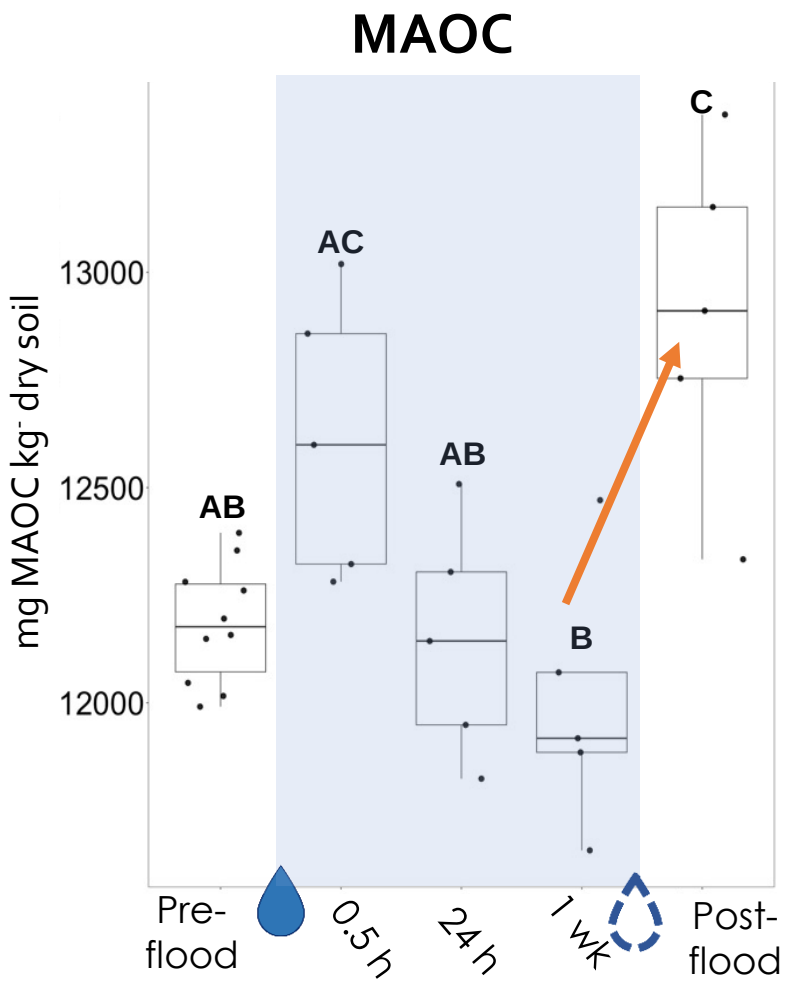


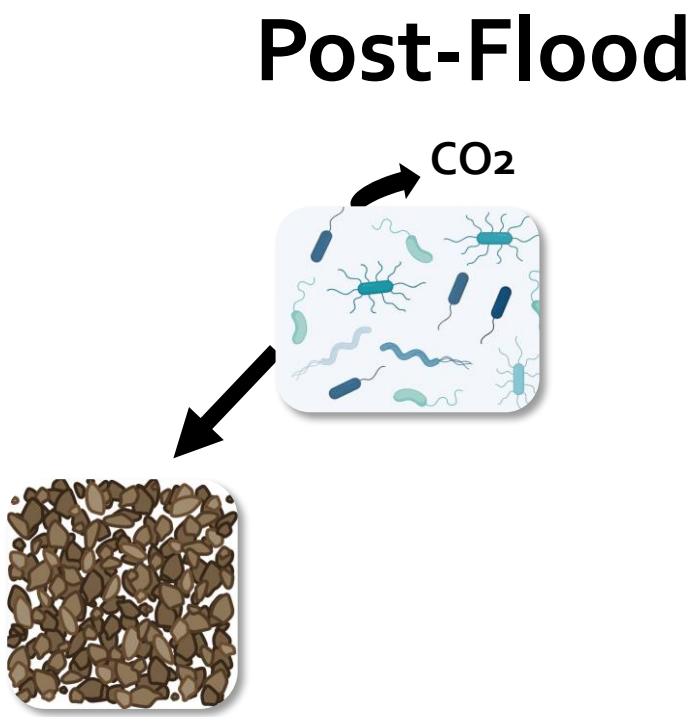
Lieberman et al., 2023 *Biogeochemistry*

How does Flooding Affect the Fate of Soil Carbon

Hannah Lieberman
PhD Candidate

Mineral-associated organic C increases post flood





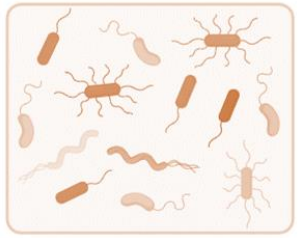
Lieberman et al., 2023 *Biogeochemistry*

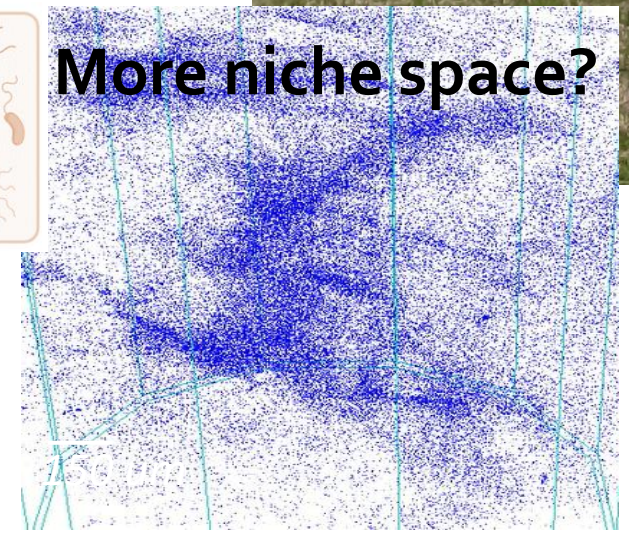
How does the Microbial Community Change over a Flood Event

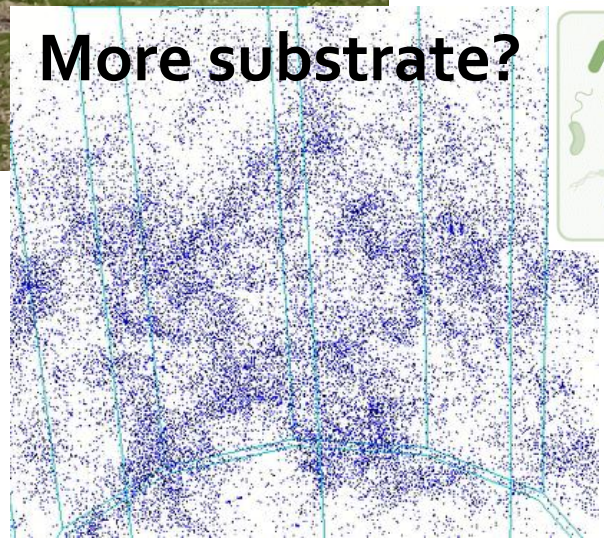
Rachael Harman-Denhoed, MSc

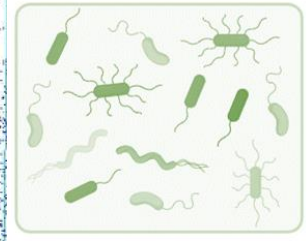
Intact cores

Homogenized (sieved) cores







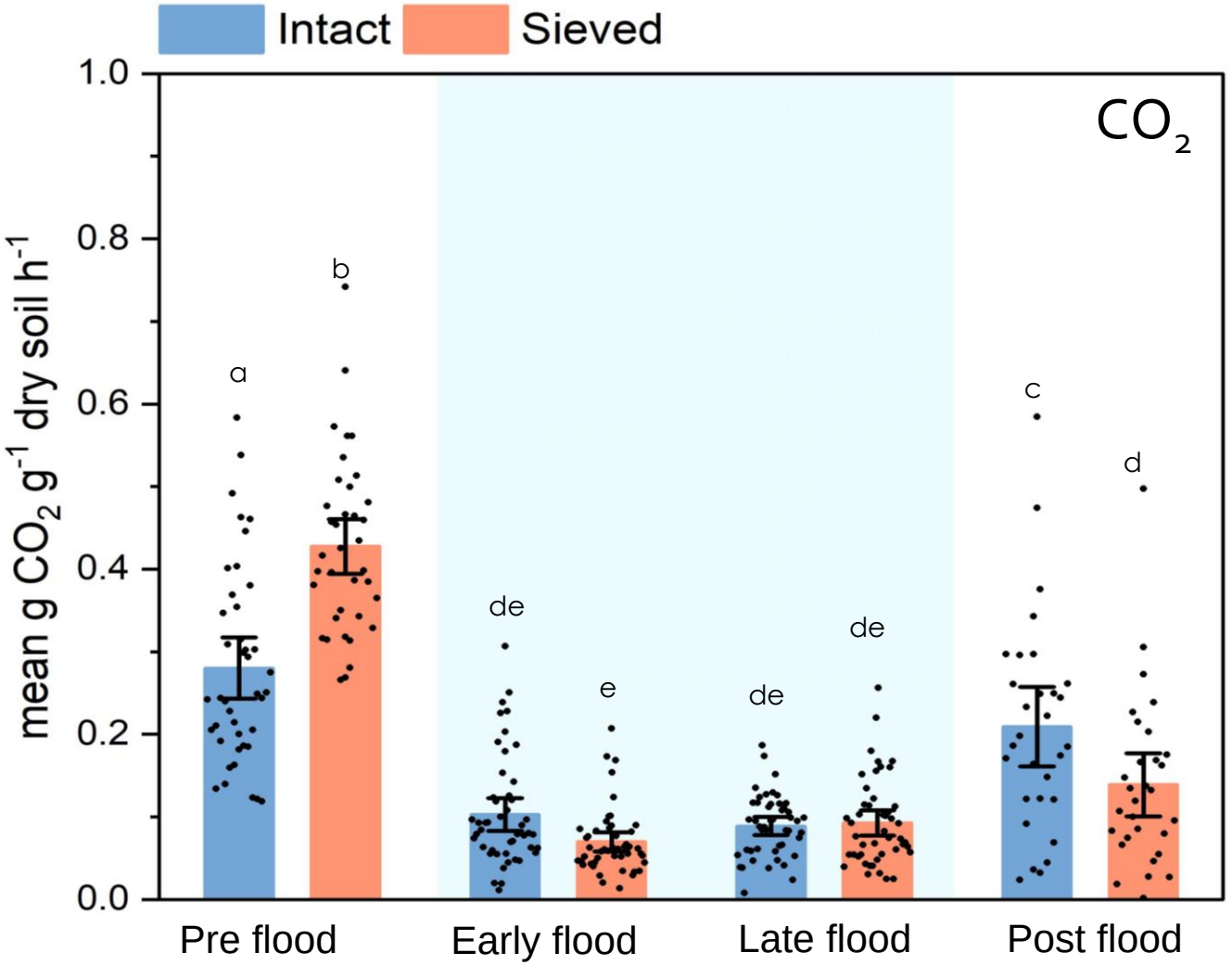


Micro x-ray computed tomography- 1 cm core diameter

Flooded for three weeks

Soil structure affects CO_2

Rachael Harman-Denhoed, MSc



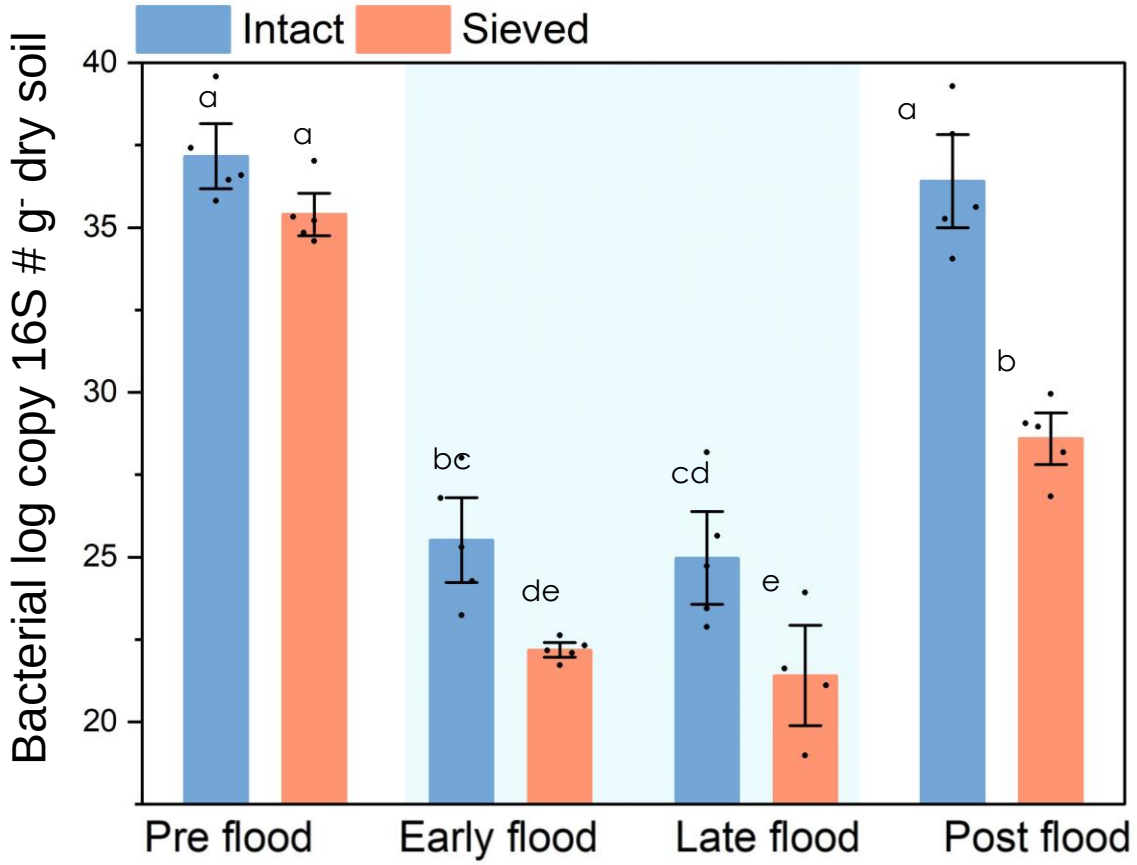
Time: p <0.0001

Structure: p <0.01

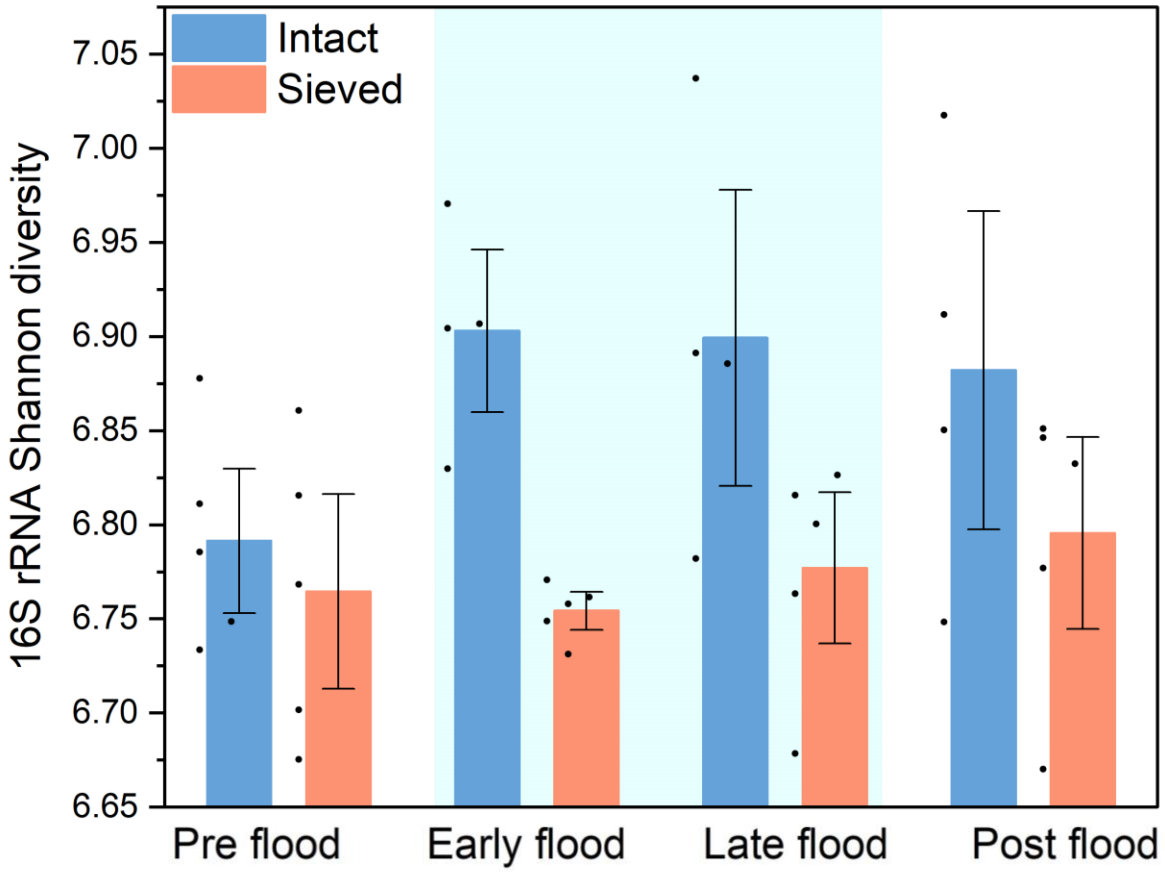
Bacteria abundance and diversity recover more in intact cores

Rachael Harman-Denhoed, MSc

Bacterial abundances



Bacterial diversity

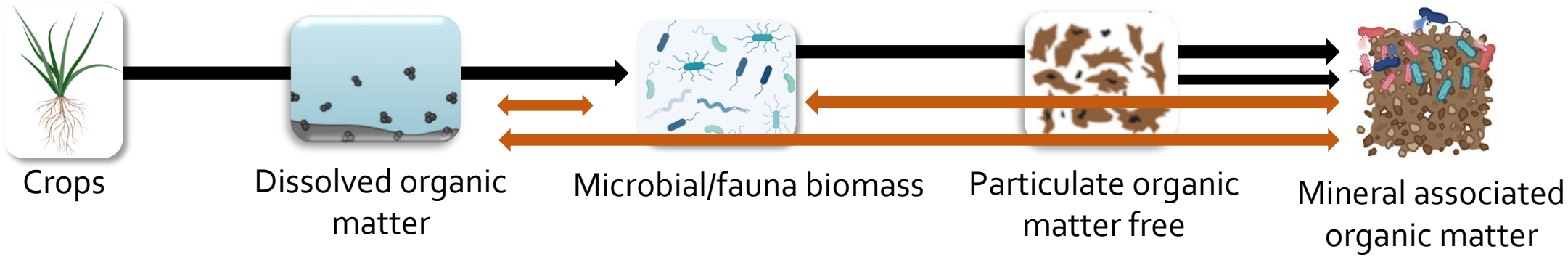


Time: p <0.0001
Structure: p <0.0001

Time: not sig.
Structure: p <0.001

In Summary

- **Microbial community growth and composition can affect soil C accumulation**
- **But…MAOC is quite active during a flood event**
- **Soil structure affects microbial community ability to be active and recover from flooding**



Does increasing **crop diversity** attenuate the responses of soil carbon and microbial communities to changes in **precipitation**?

Fonds de recherche Nature et technologies Québec

Réseau québécois de recherche en agriculture durable

RQRAD

Québec is expected to experience drier summers and wetter autumns and springs

Does increasing **crop diversity** attenuate the responses of soil carbon and microbial communities to changes in **precipitation**?

Diversity and Precipitation Treatment (DART) plots at McGill University

Increasing Species Diversity

1 species	1 species	2 species	3 species	3 species	3 species	4 species
Legume (dry bean)	Small cereal (Spring wheat)	Dry bean Wheat	Dry bean Ryegrass White clover	Wheat Ryegrass White clover	Kernza (perennial wheat) Birdsfoot White clover	Dry bean Wheat Ryegrass White clover

- 30% Reduced Precipitation

Ambient Precipitation

+ 30% Increased Precipitation

*Full factorial of crop diversity and precipitation treatments: 4 replicates, no-till, fertilized

Getting started!

Reducing and increasing precipitation with rainout shelter and irrigation

Intermediate perennial wheat (Kernza™)

Gas sampling for N model

Soil sampling to 1 m for pesticides, organic matter, nutrients and microbial community

Fonds de recherche Nature et technologies Québec

Thank you for listening!

Project Collaborators

McGill: Philippe Seguin; Christian von Sperber; Valerio Hoyos-Villegas; Grant Clark

Algoma University: Pedro Antunes; Cathy Fahey

Agriculture Agri-Food Canada: Mary-Cathrine Leewis

Regeneration Canada: Antonious Petros

Soil Biogeochemistry and Ecology lab

McGill Sustainability Systems Initiative

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CREATE Climate-Smart Soils

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NSERC CRSNG

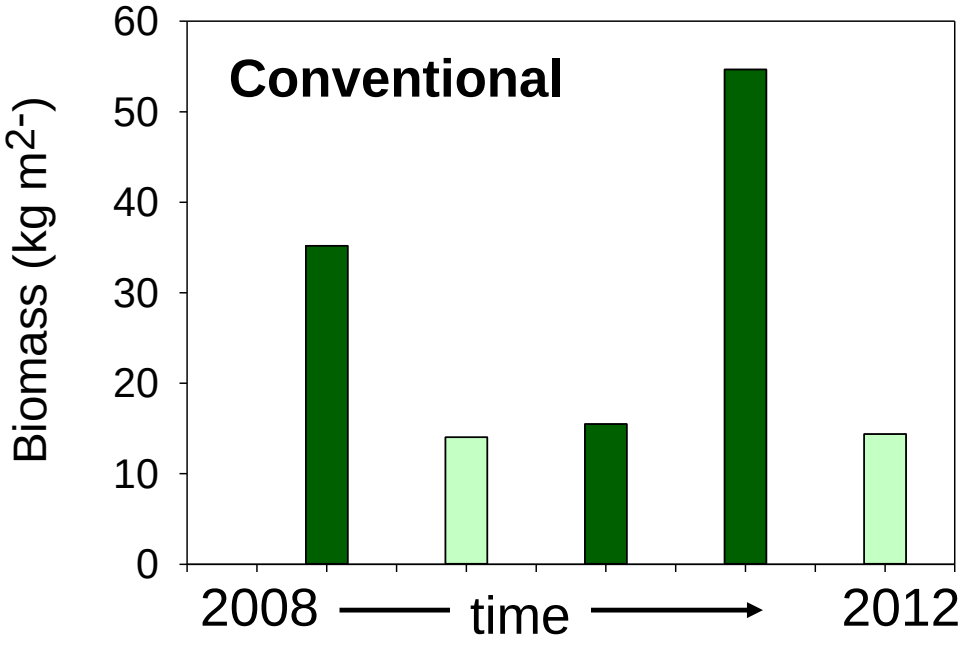
Agriculture, Pêcheries et Alimentation Québec

Case study

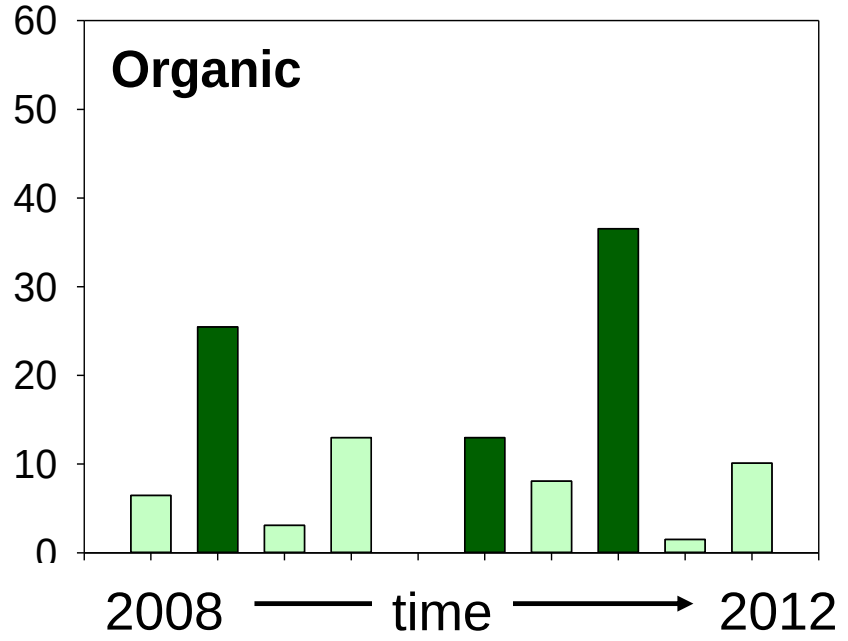
Timing and quality of inputs differ

Biomass CN <35

Biomass CN >35



Total biomass: 134 kg m^{2-}
Soil carbon: 0.91 %

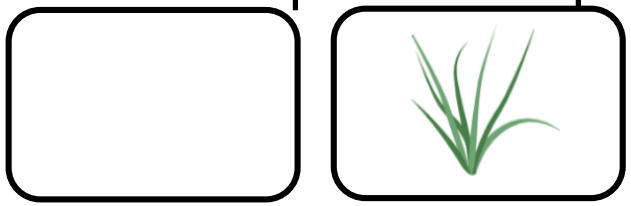


Total biomass: 117 kg m^{2-}
Soil carbon 1.13 %

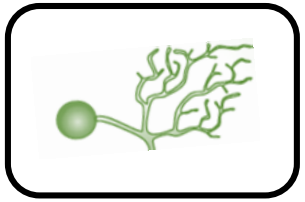
SO: http://lter.kbs.msu.edu/datatables

Experimental AMF Trait-based Communities

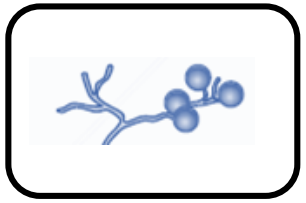
Controls- No plant and plant



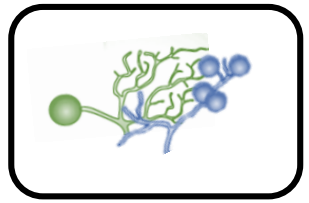
Gigasporaceae



Glomeraceae

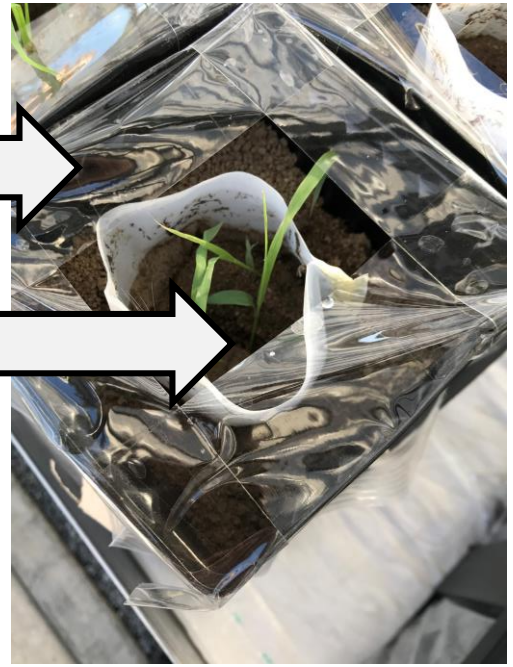


Mixed (Glom & Giga)



Hyphal Compartment

Root Compartment



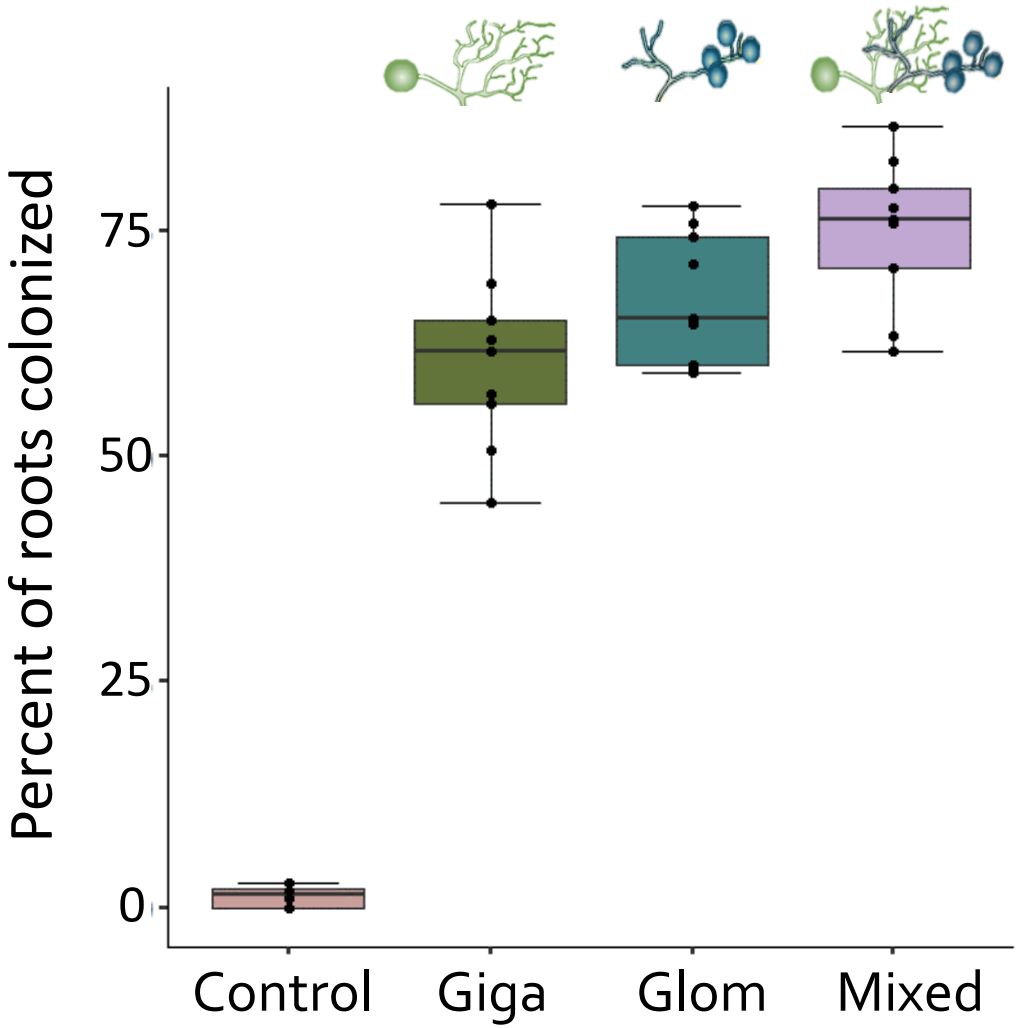
- 9 replicates, sudan grass
- Pots had sterilized sand/soil mix with an added AMF-free microbial wash

AMF Mock Communities

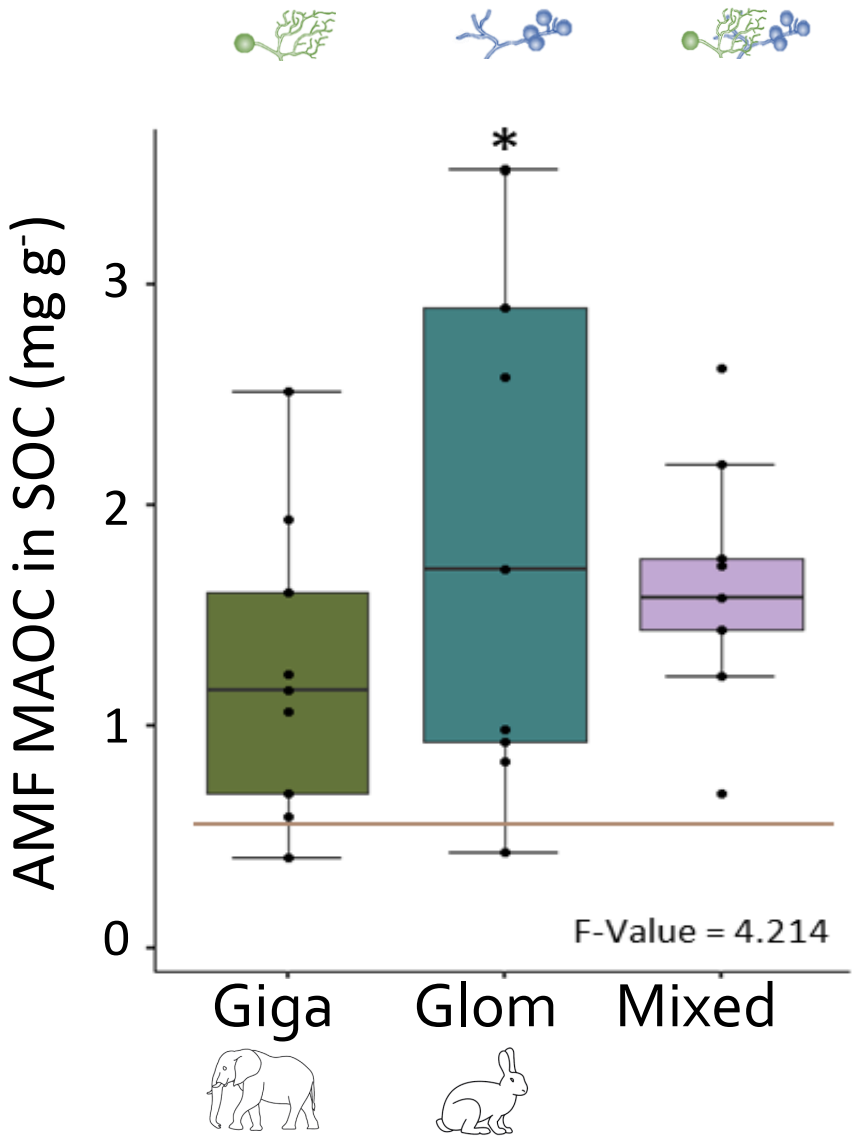
Family	Isolates	Associated traits[1,2,3,4]
Gigasporaceae 	*Cetraspora pellucida*	Lower hyphal turnover
	Dentiscutata heterogama	Lower growth rate
	Gigaspora margarita	Later sporulation
	Racocetra fulgida	Larger and fewer spores
	Scutellospora calospora	More extra-radical hyphae
Glomeraceae / *Claroideoglomeraceae** 	*Claroideoglomus etunicatum*	Higher hyphal turnover
	Funneliformis mosseae	Higher growth rates
	Rhizophagus clarus	Earlier sporulation
	Rhizophagus intraradices	Smaller and more spores
	Septoglomus deserticola	More root-internal hyphae and nutrient exchange structures

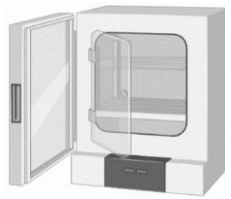
[1]Chaudhary et al., 2022; [2]Treseder et al., 2018; [3]Chagnon et al., 2013; [4]Hart and Reader, 2002

AMF Root Colonization was Successful

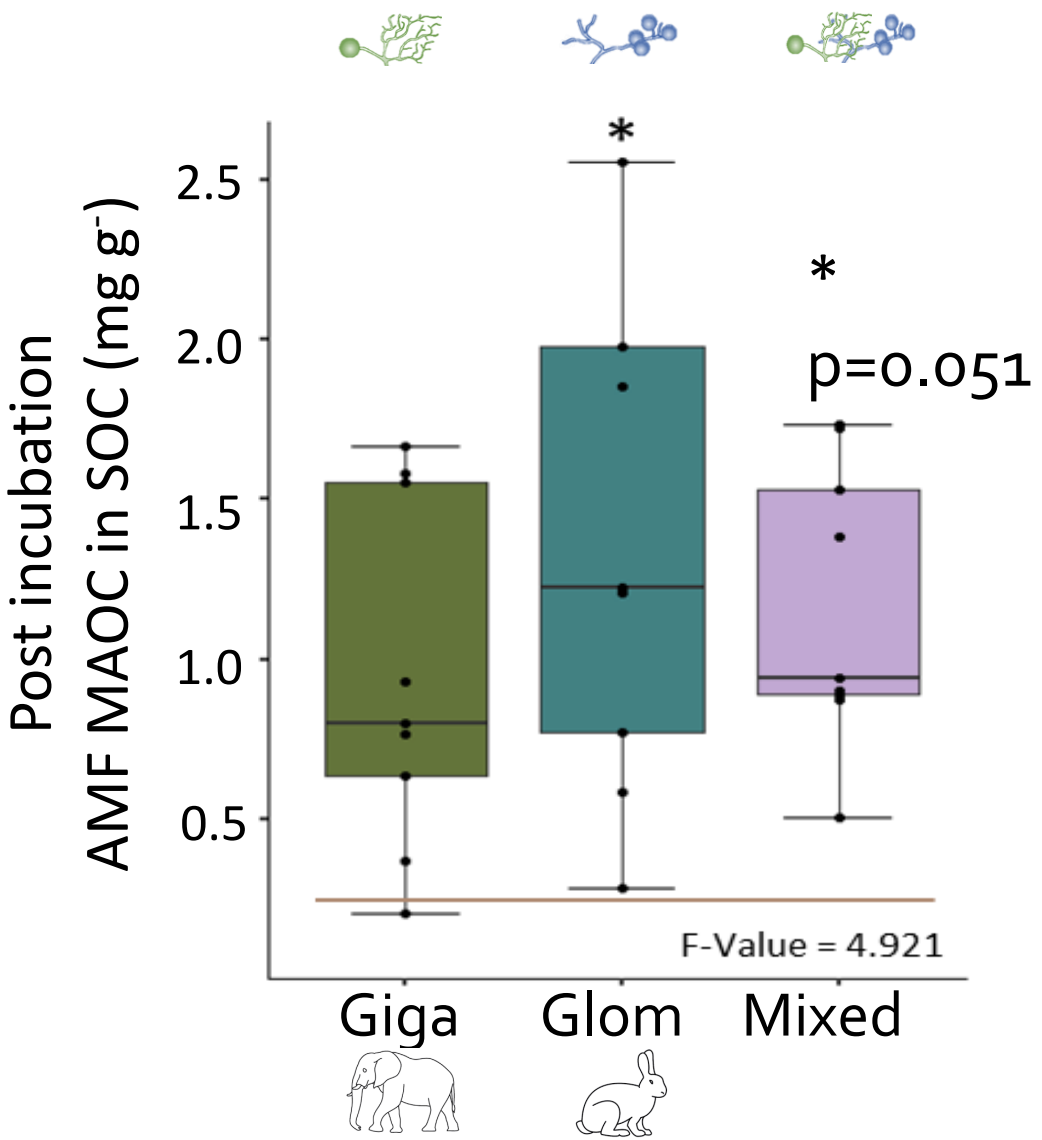


AMF Communities Differ in Contribution to MAOC



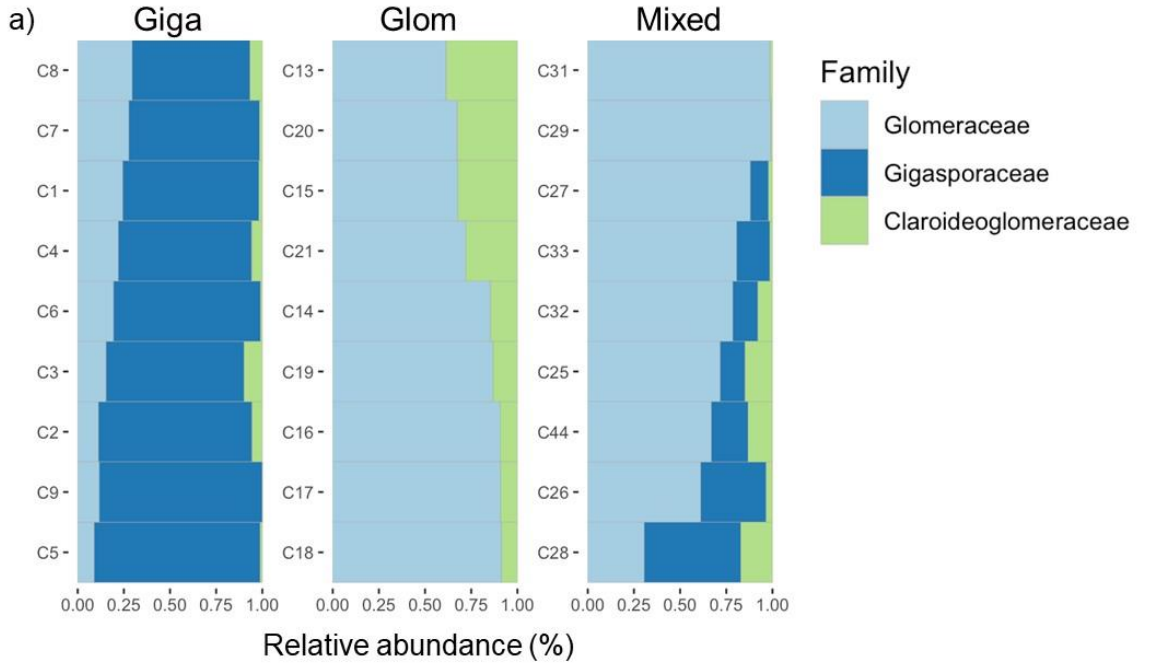


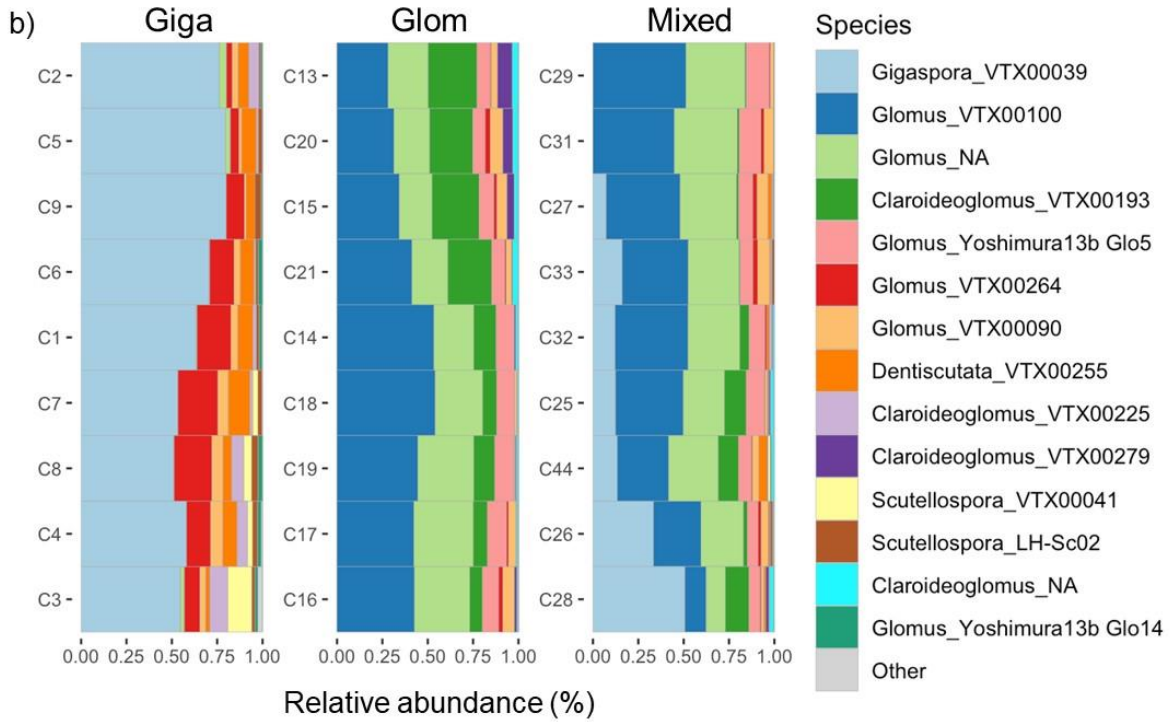
Incubated for one month



Horsch et al., 2023 *New Phytologist*

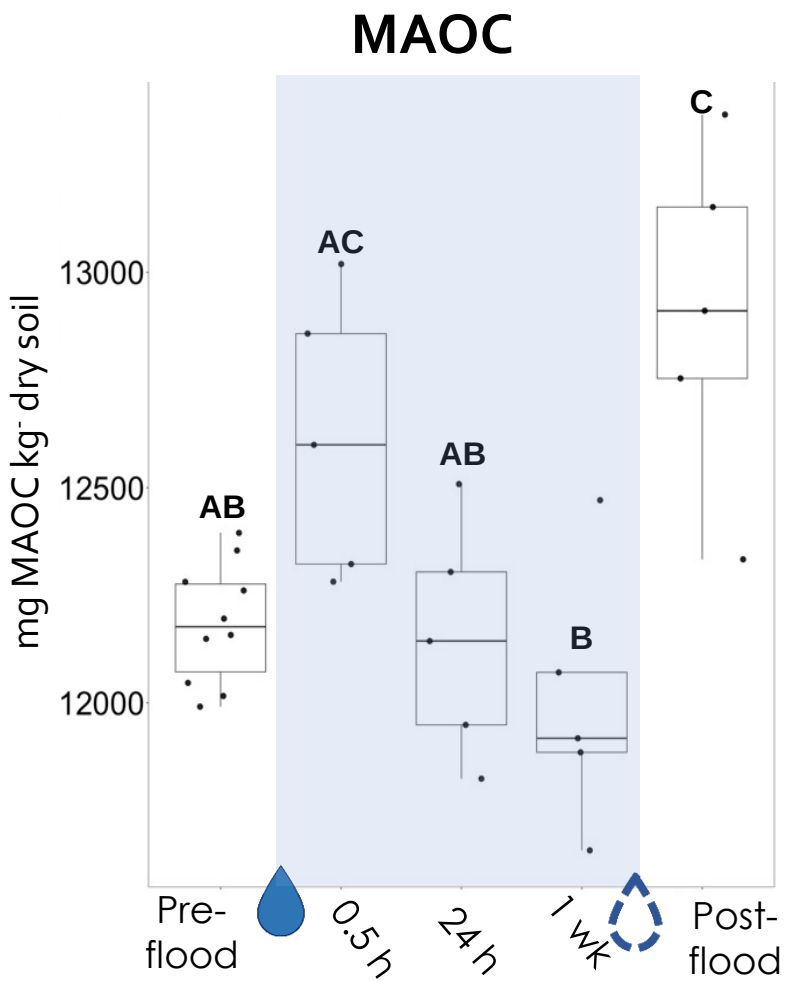
- We extracted root genomic DNA
- The SSU rRNA was amplified for each sample using the WANDA-AML2 primer set
- Illumina MiSeq PE300 sequencing at Génome Québec (Montréal, Québec, Canada)

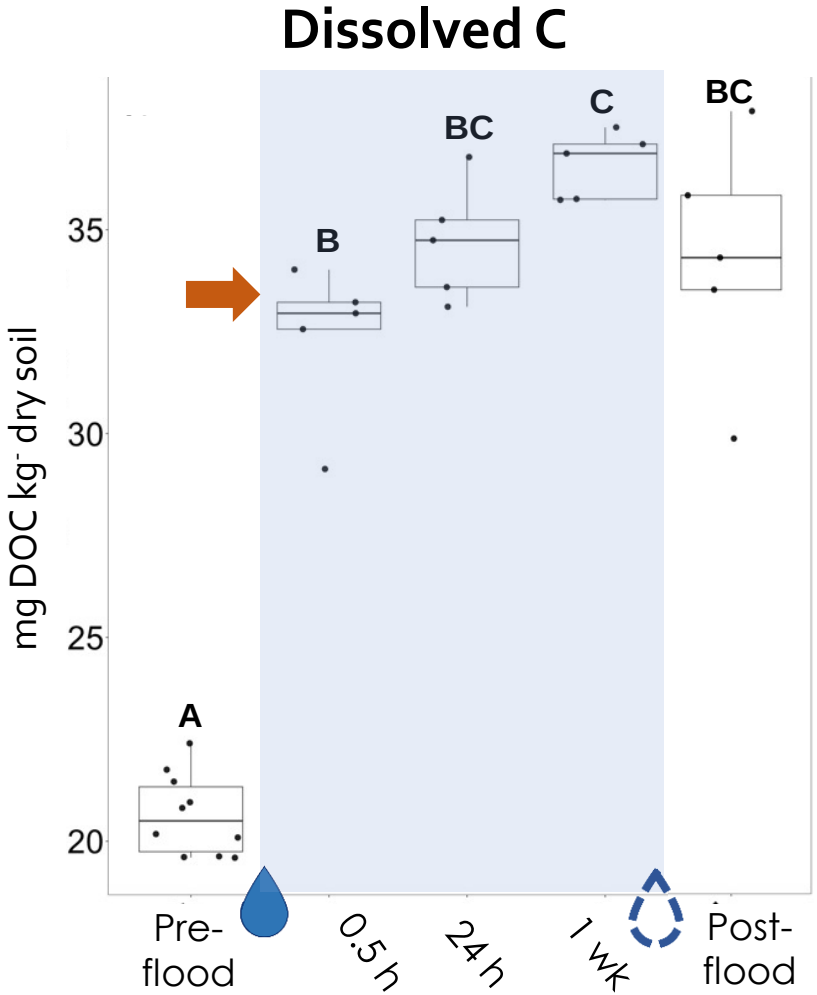


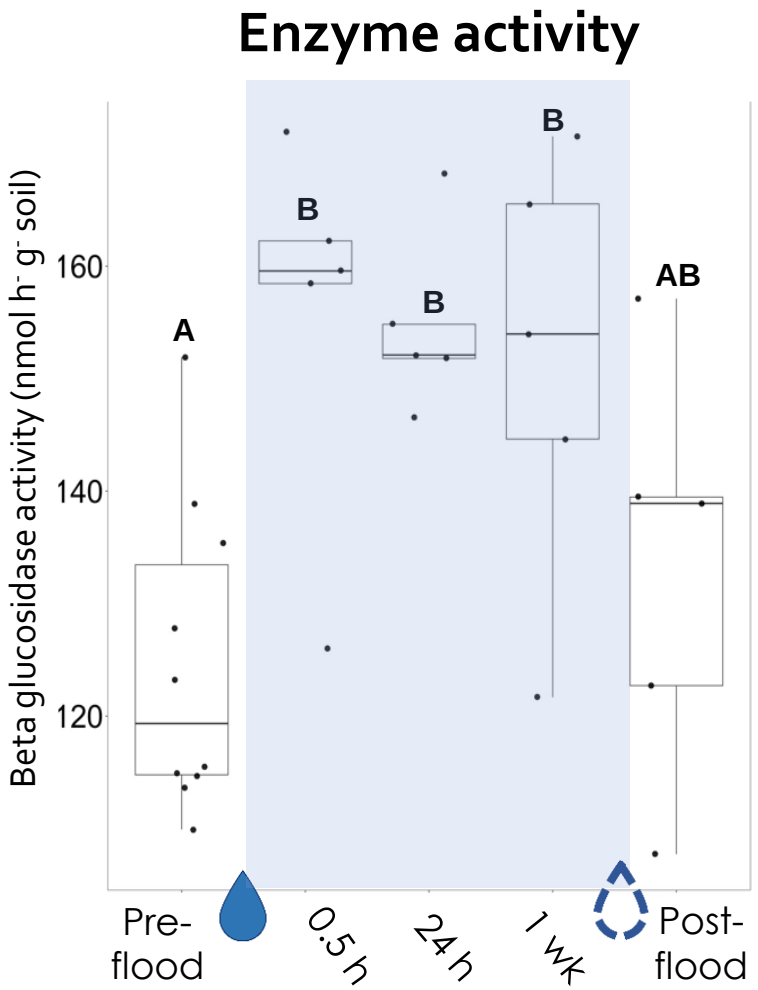


Mineral-associated organic C is sensitive to flooding

Hannah Lieberman
PhD Candidate





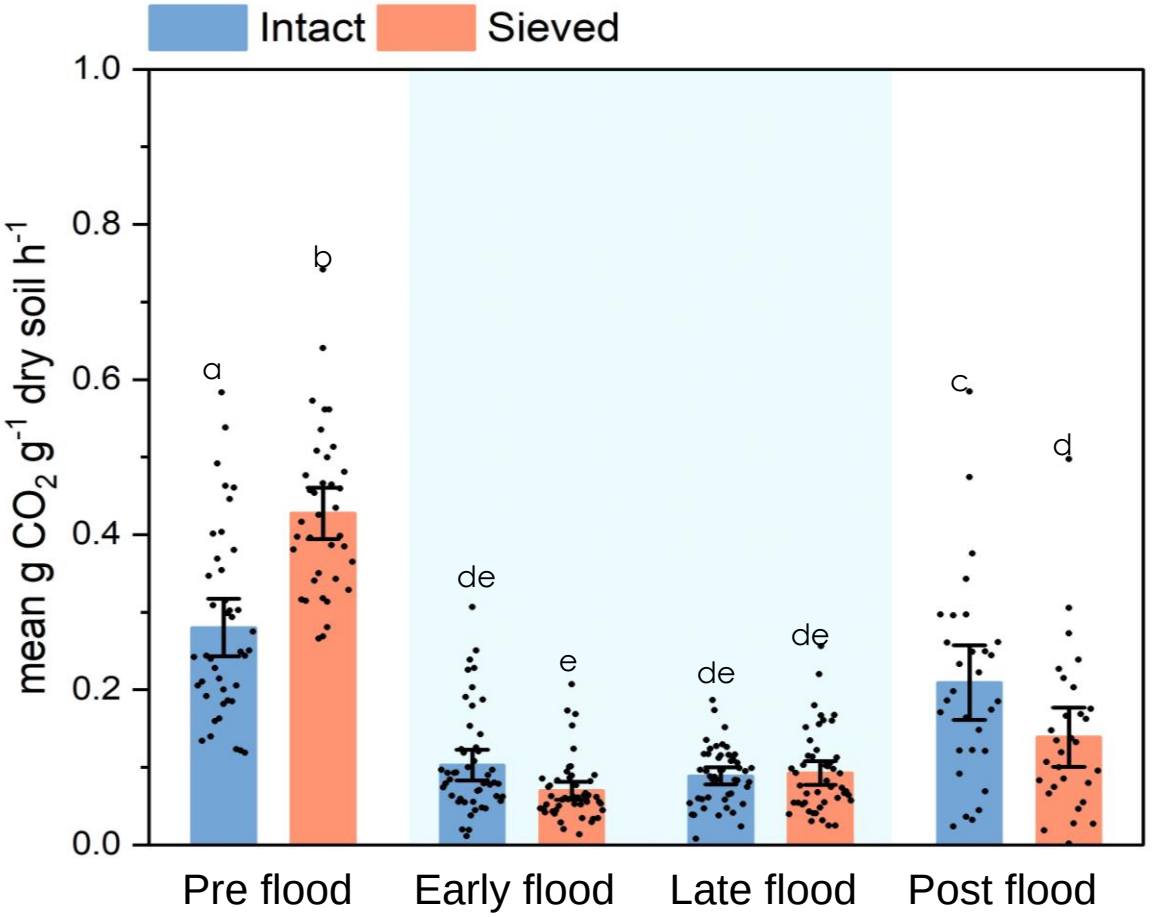


Lieberman et al., 2023 *Biogeochemistry*

Soil structure affects CO_2 but not DOC

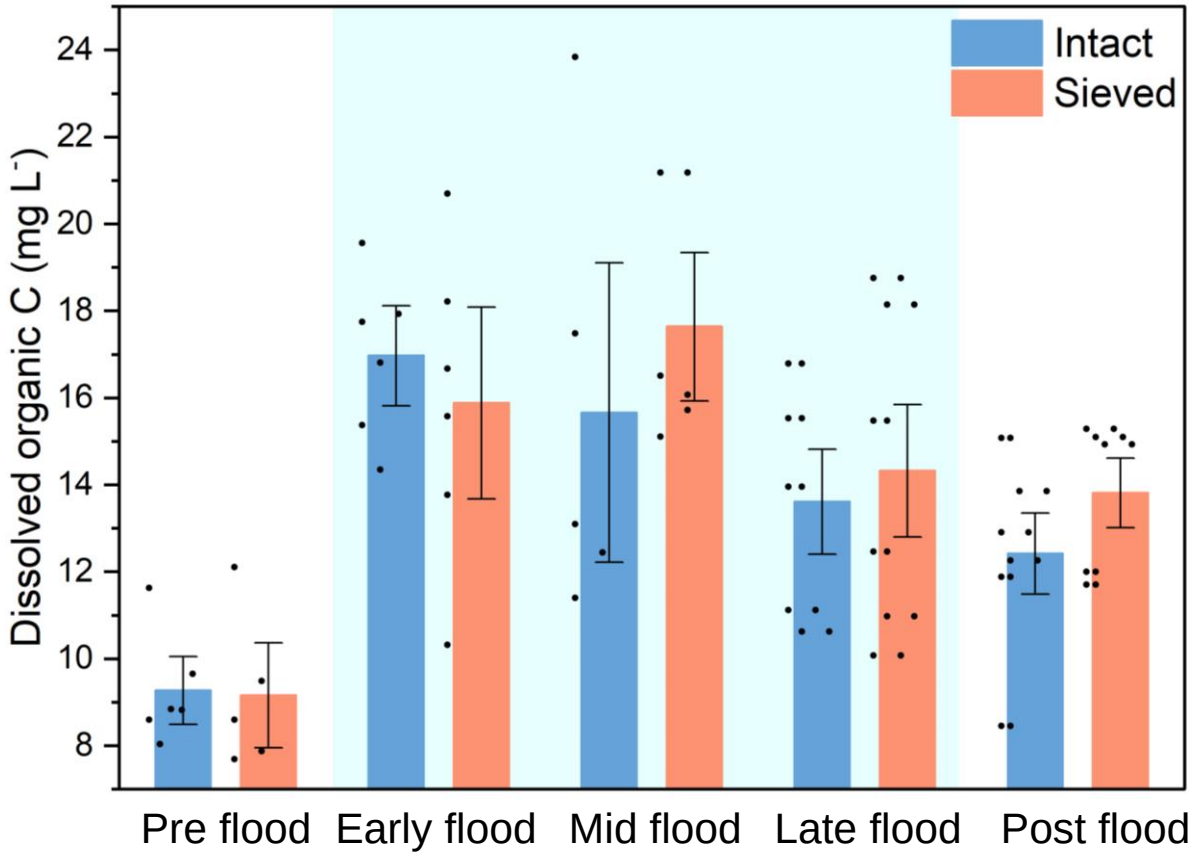
Rachael Harman-Denhoed, MSc

CO_2



Time: p <0.0001
Structure: p <0.01

Dissolved organic C

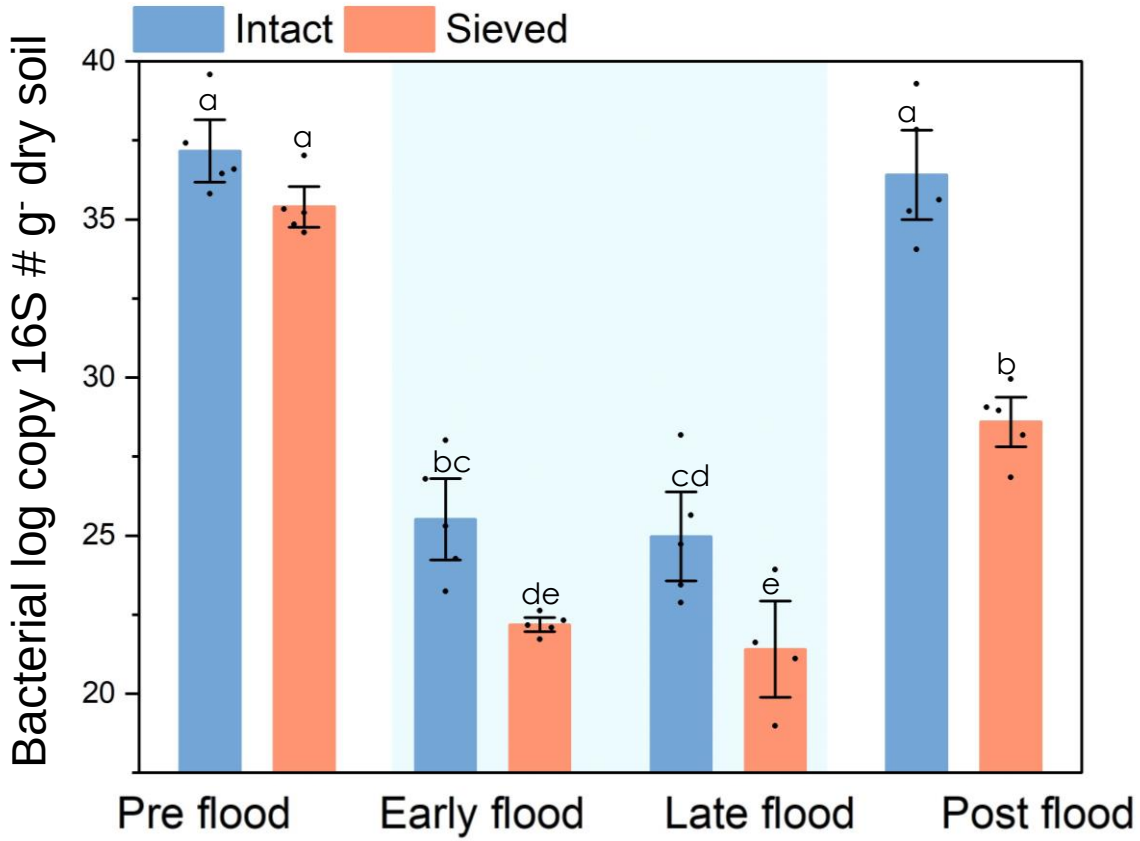


Time: p <0.0001
Structure: ns

Bacteria and fungal populations recover more in intact cores

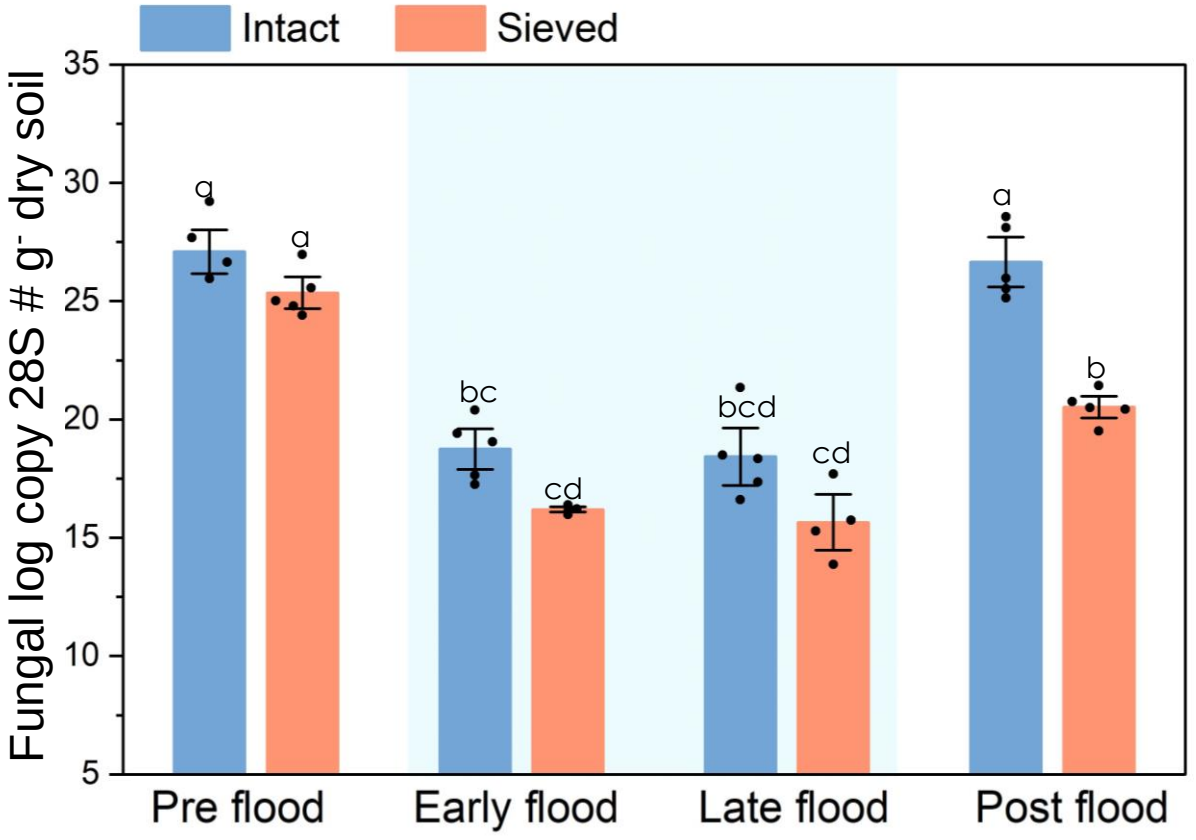
Rachael Harman-Denhoed, MSc

Bacterial abundances



Time: p <0.0001
Structure: p <0.0001

Fungal abundances



Time: p <0.0001
Structure: p <0.0001