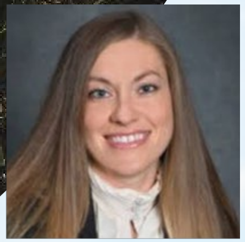
Farming Carbon:

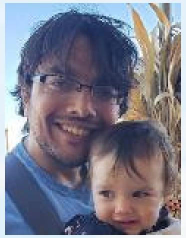
How Plant Roots, Microbial Ecophysiology, and Soil Minerals Shape the Fate and Persistence of Soil Carbon

Jennifer Pett-Ridge

Lawrence Livermore National Lab/
University of California Merced



Kate Zhalnina



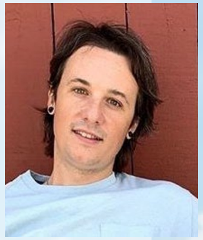
Nameer Baker

Erin Nuccio

Eric Slessarev

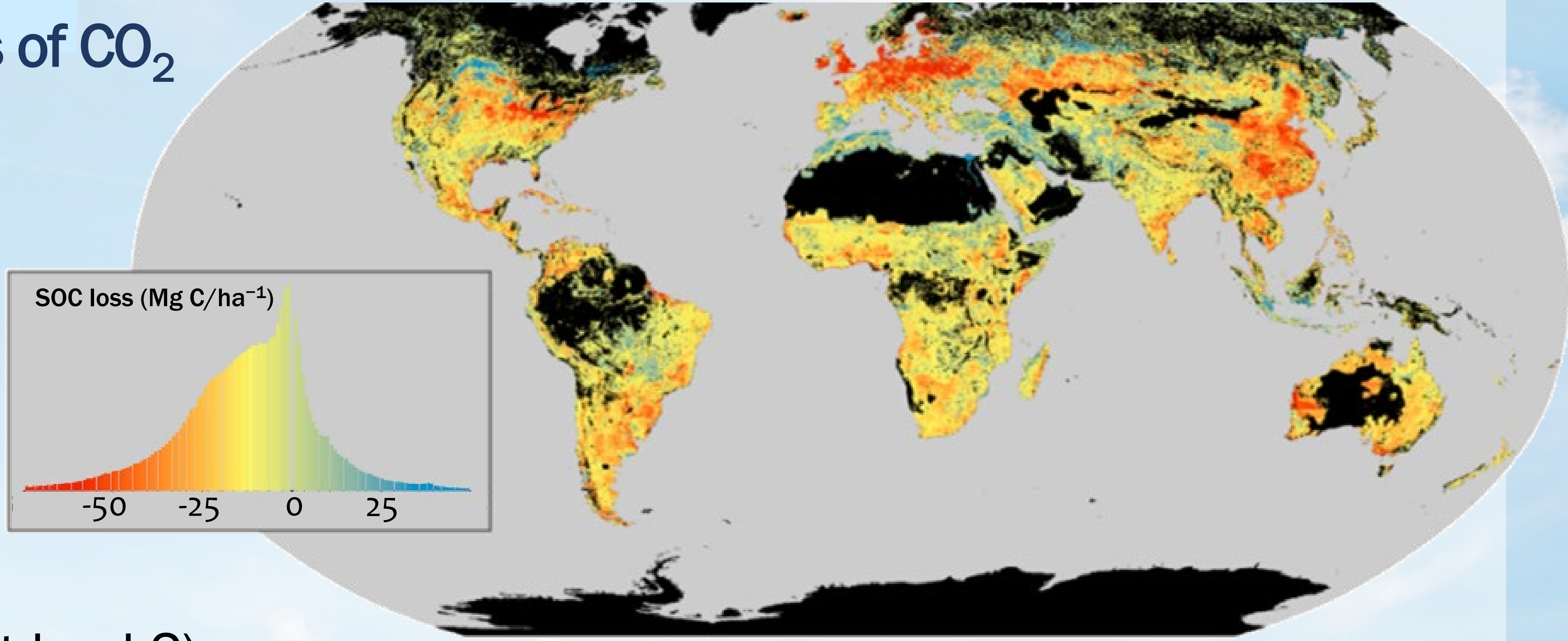
Kat Georgiou

Craig See



Cesar Terrer

The world's agricultural soils have lost at least 487 gigatons of CO_2 (equivalent)



(Can we put it back?)

In the USA alone, an estimated 0.5 - 1 Gt/yr could be sequestered

Sanderman et al. *PNAS* 2017

National analysis: Soil C solutions scorecard

Removal Class	Subclass	Measurability of carbon storage	Removal vs. avoided emissions	Risk of unaccounted GHG emissions	Additionality	Leakage risk	Durability
Soil	Cover cropping	**	**	**	***	**	**
	Deep-rooted perennials	**	**	**	***	*	**
	Tillage reduction	*	**	**	*	**	**
	Organic amendments	*	**	*	*	*	**
	Grazing management	*	**	*	**	**	**

Cover crop rate > 5%

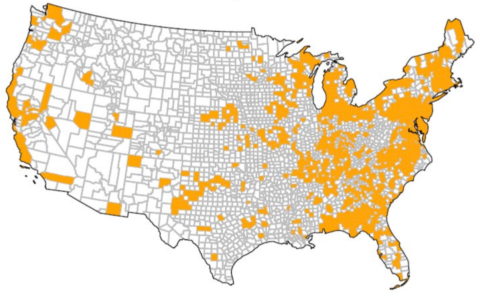


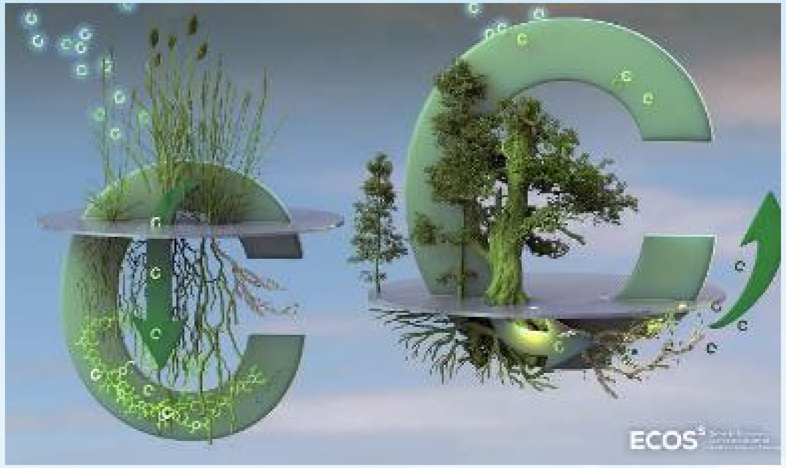
Figure 3-6. Counties where the rate of cover cropping exceeds 5%. *These counties were excluded from our capacity estimates because they exceeded the 5% additionality threshold.*

* low	* avoided only	* high risk	* relatively low	* high risk	* Less than 10 years
** intermediate	** mixed	** medium risk	** intermediate	** medium risk	** 10 - 100 years
*** high	*** removal only	*** low risk	*** relatively high	*** low risk	*** 1000's of years

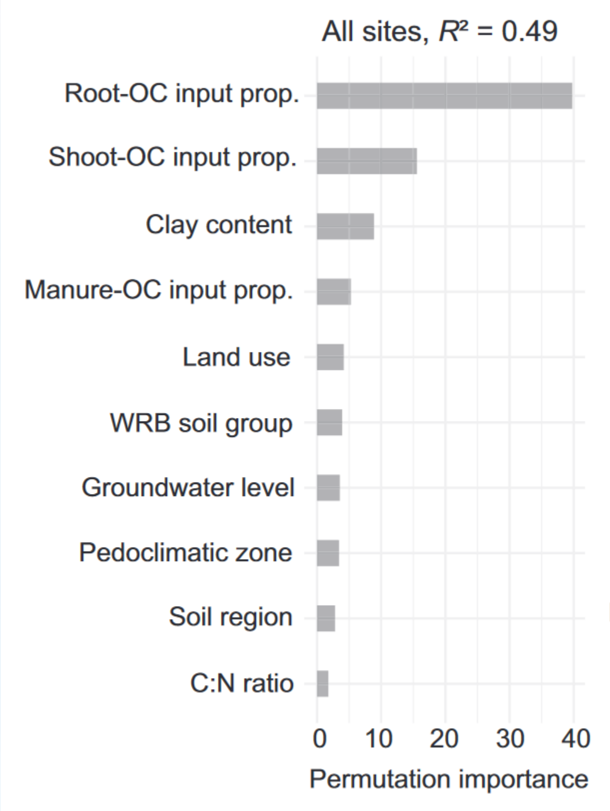
Schmidt et al., *Carbon Negative by 2030: CO_2 removal options for an early corporate buyer*, 2022

Deep roots—an excellent way to put carbon in the ground

- Deep root C appears to persist
- Grasslands have significantly higher soil C residence time than forests/croplands
- "maximizing root biomass input = most straightforward way to increase soil C stocks"



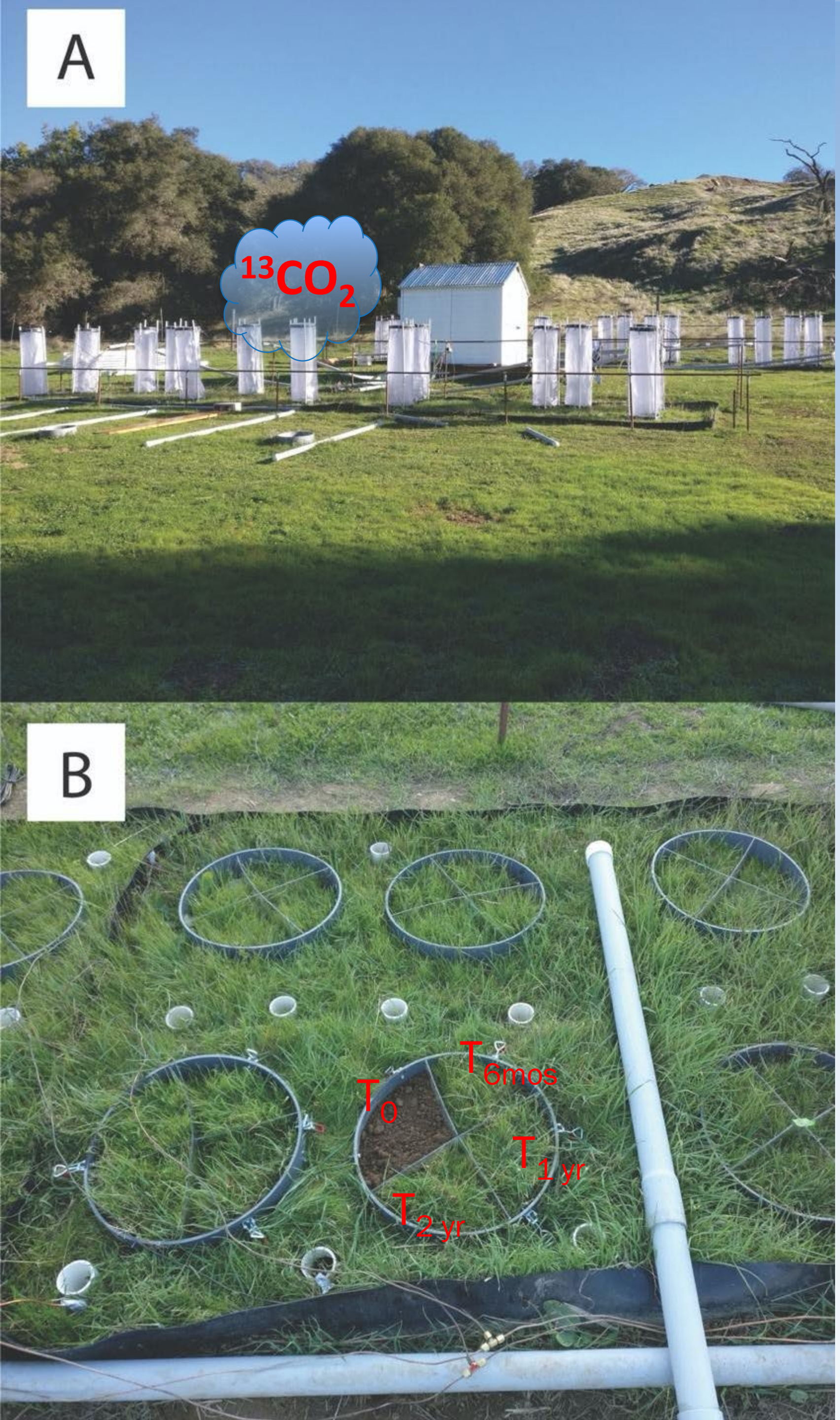
Terrer et al., *Nature*, 2021



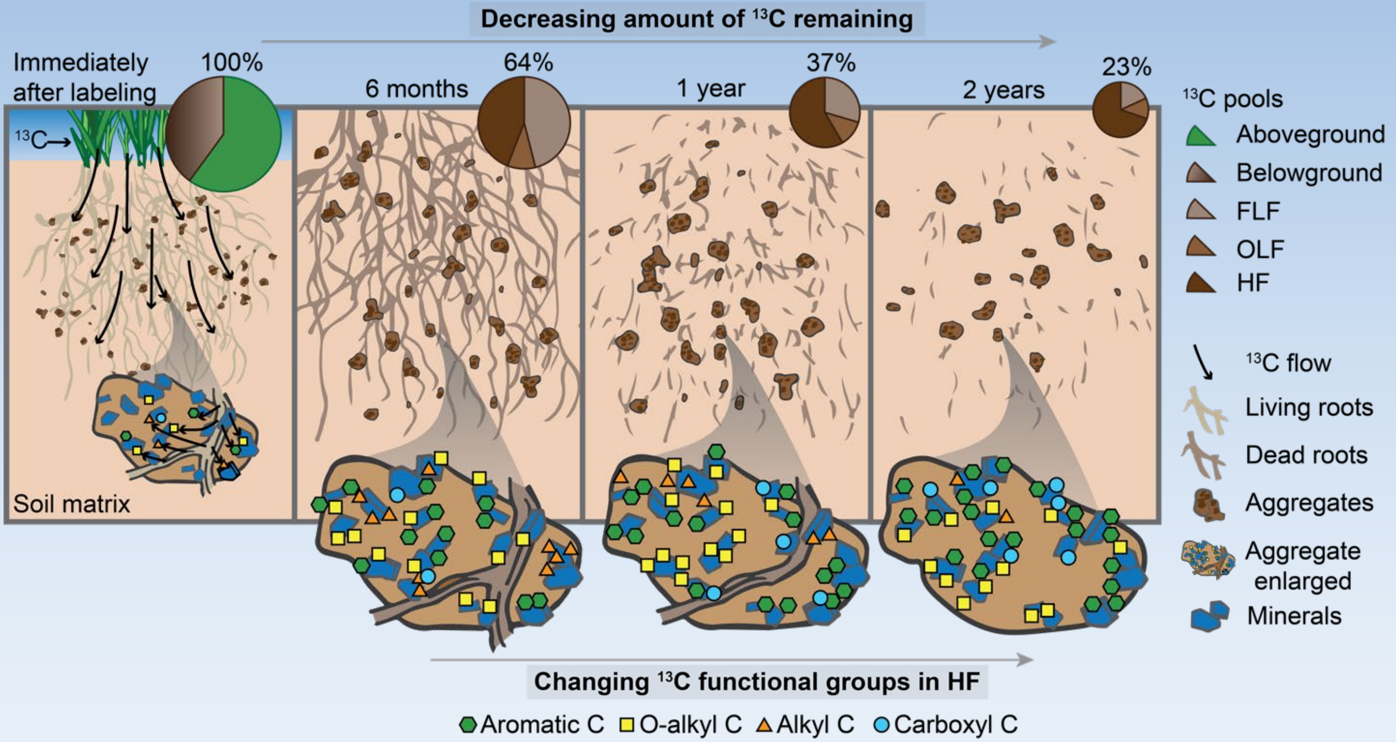
Poeplau et al., *Global Change Biology*, 2021

I. Inputs: effects of roots

Panicum virgatum



Isotope tracing shows the fate & persistence of fresh plant inputs

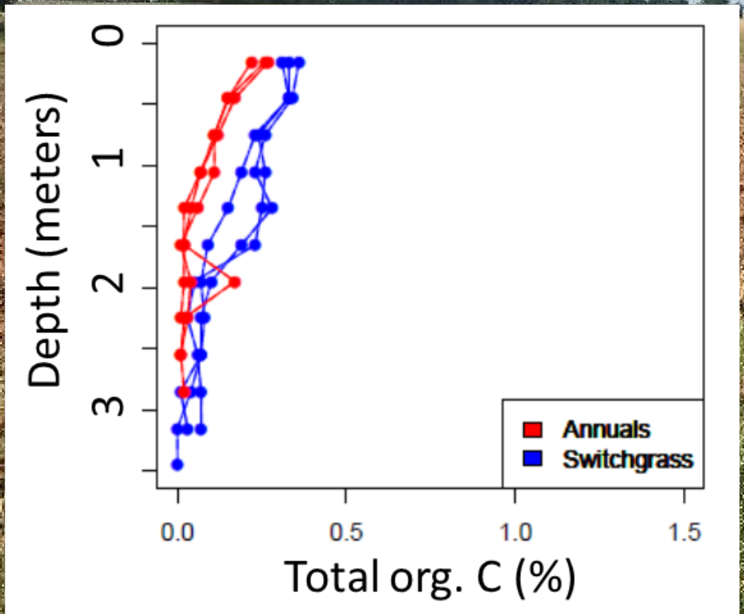


- Root exudate carbon became mineral-associated *very* quickly
- After 2 years, 23% of initial C input remained, but the total C pool size stayed the same

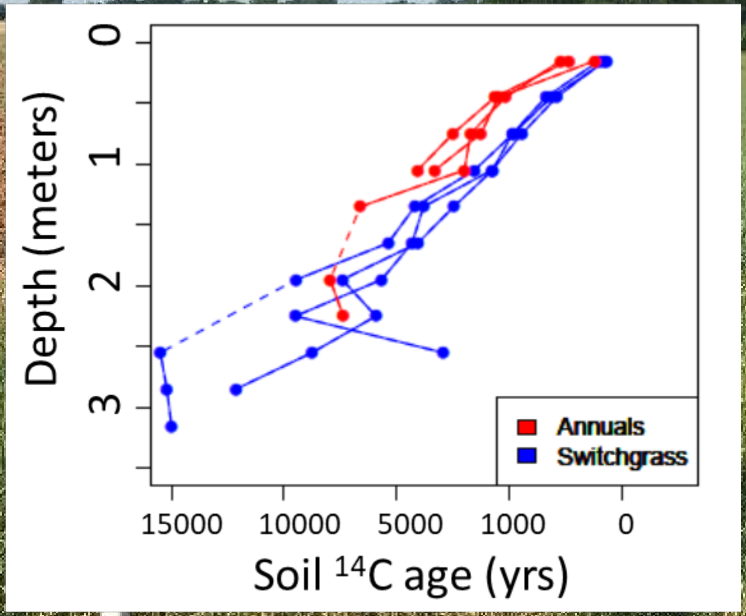
Fossum et al., *Soil Bio & Biochem* 2022

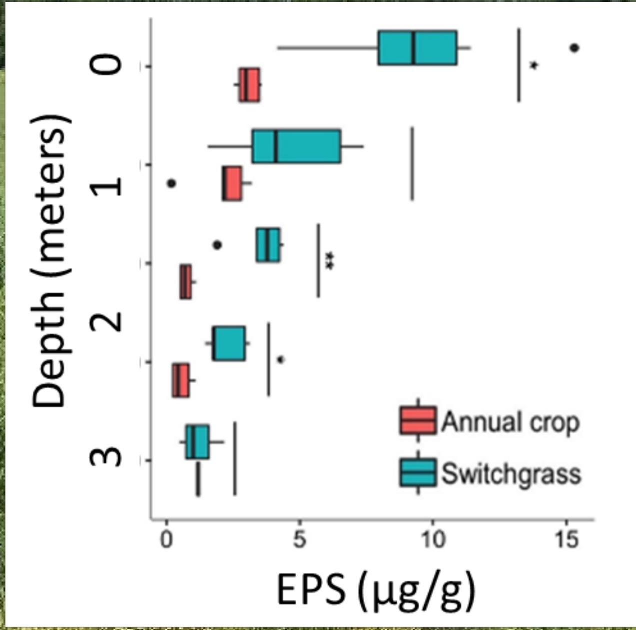
Shallow-Rooted Annuals vs. Deep-Rooted Perennials

10 years, twice as much soil carbon



Slessarev et al. *GCB Bioenergy*, 2020



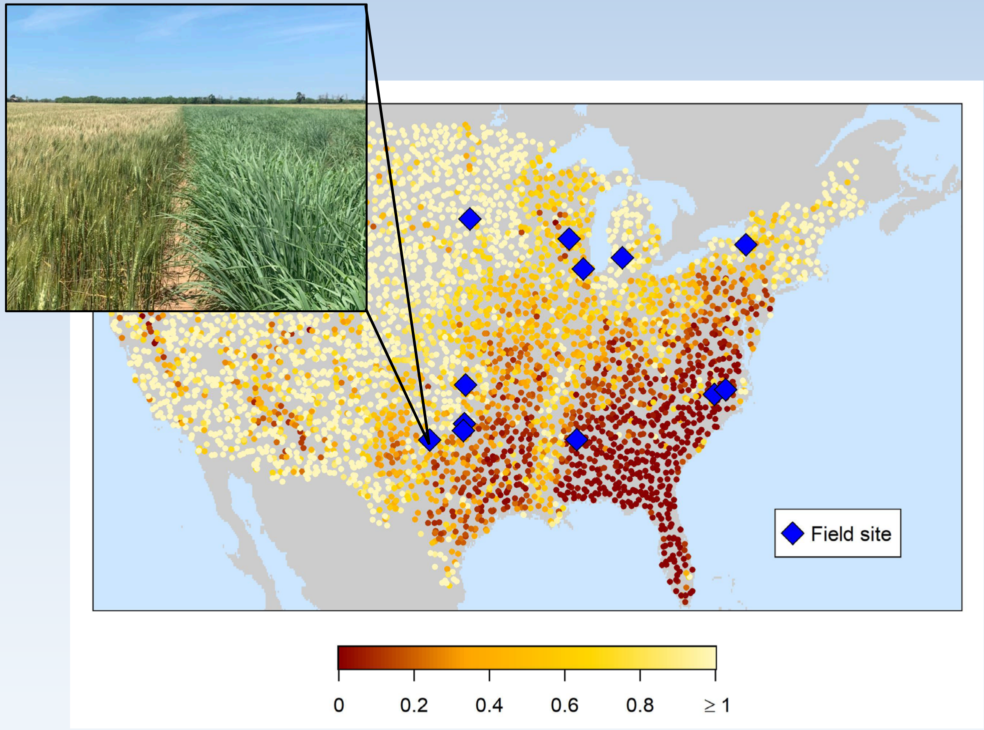


Sher et al. *Soil Bio & Biochem, 2020*

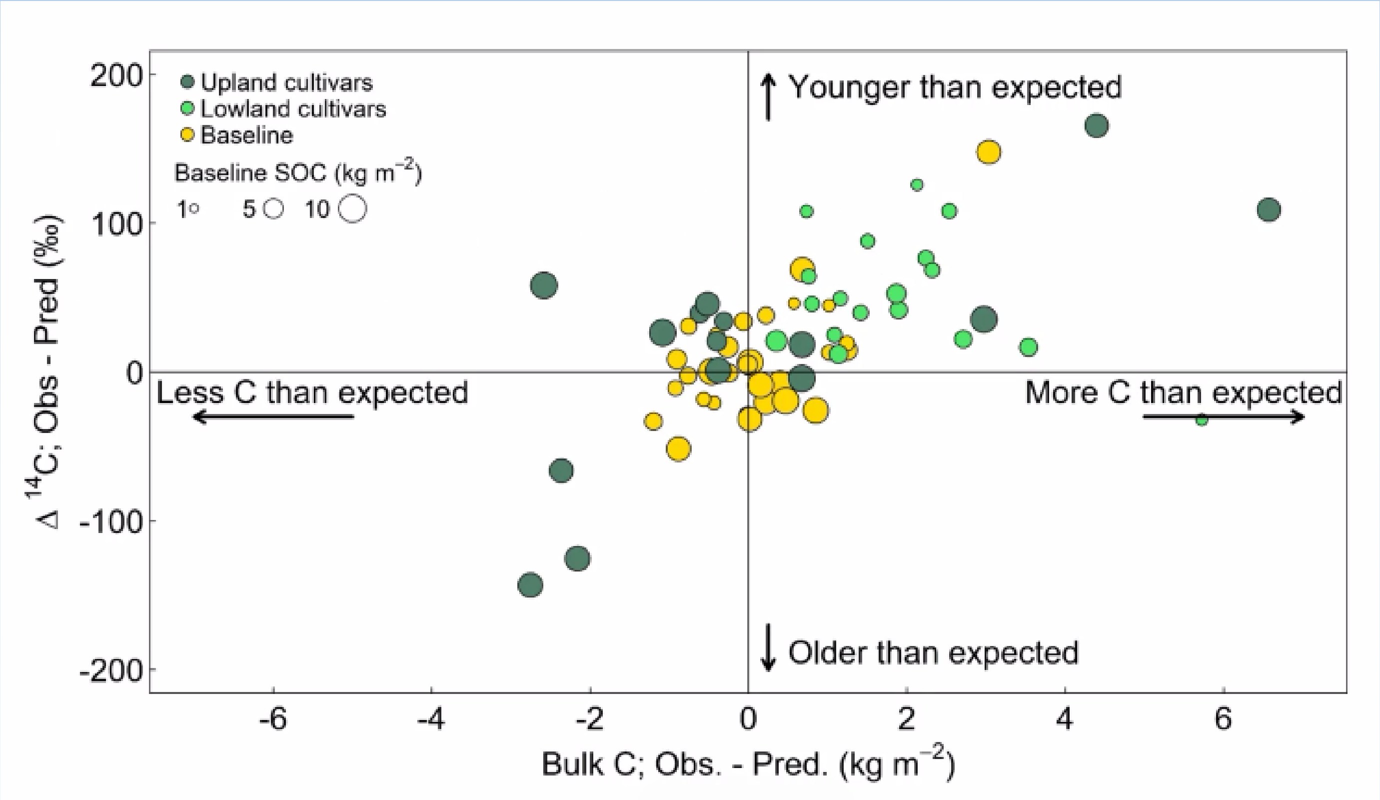
Roots & microbial biofilms 'EPS' lead to increased soil aggregation

Burneyville, OK

Ability to add deep C depends on soil type and initial C stocks



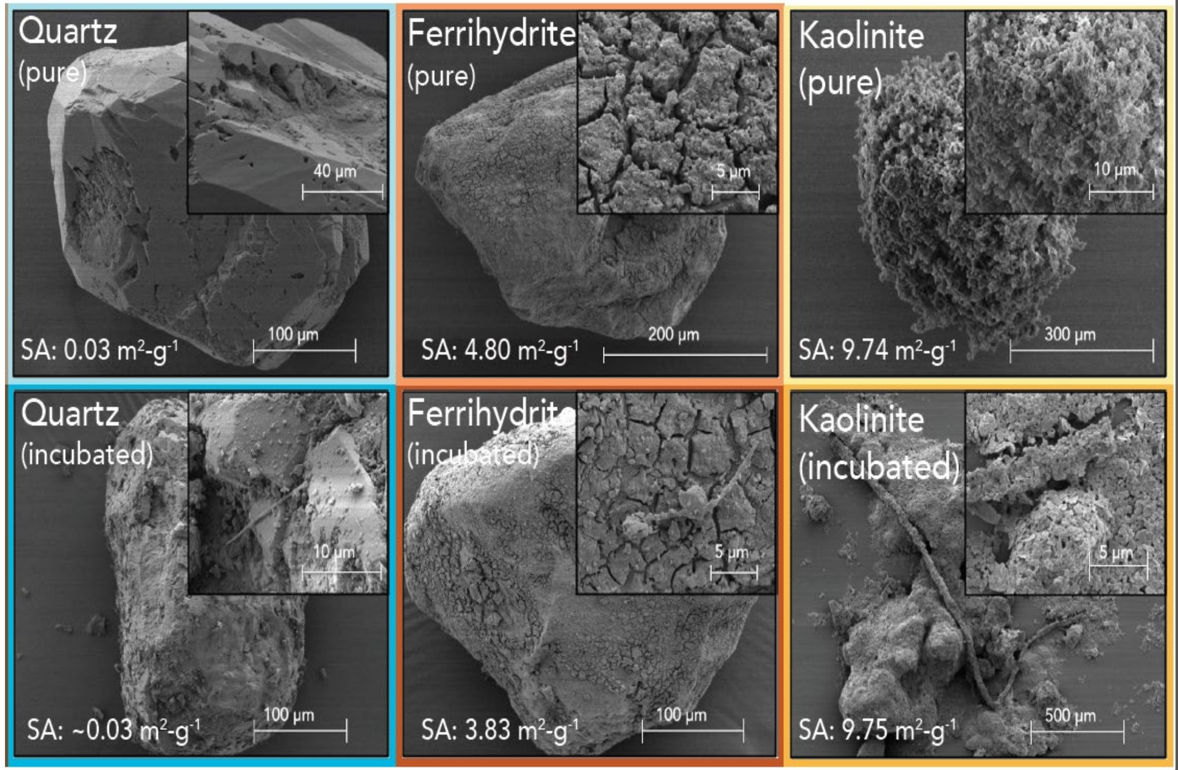
Less -> More Weathered Soil



- Accrual of new C was most apparent in <u>marginal soils</u> with low initial C

Slessarev et al. *in prep.*

II. Soil Minerals

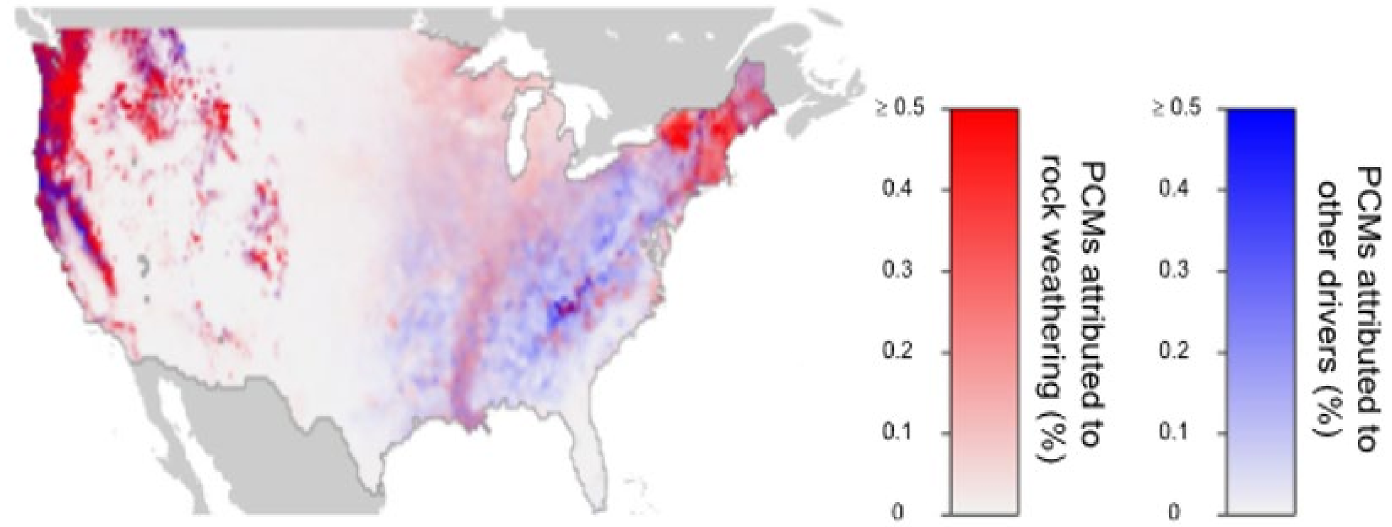


Neurath et al. *ES&T*, 2021; Whitman et al. *Env. Microbiology*, 2018

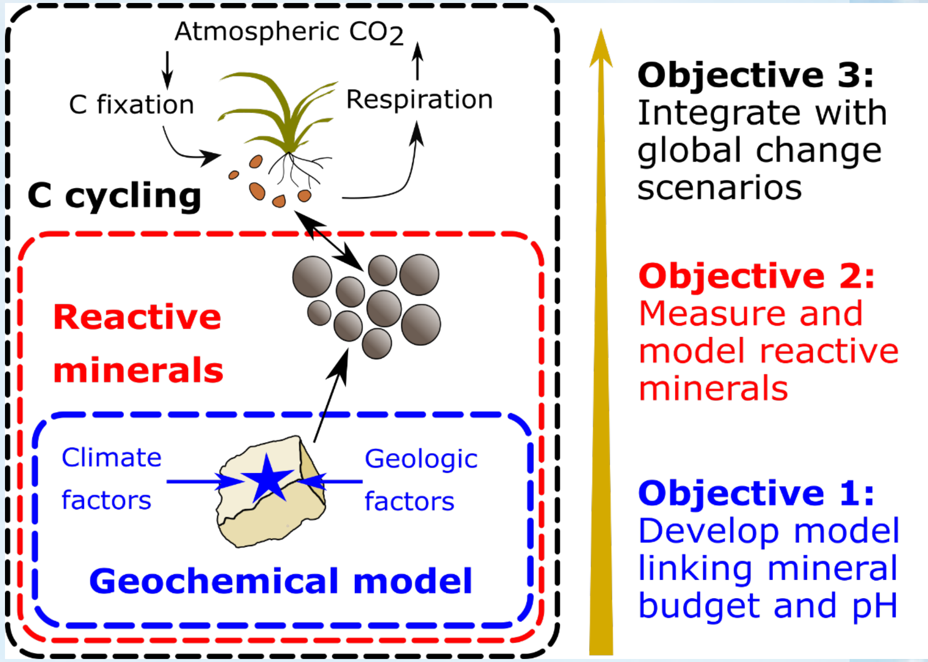
If we could get it out of the atmosphere and park it in soils, that would be ideal....

~(W. Schlesinger, SSSA mtg 10/17)

Where to park the carbon?



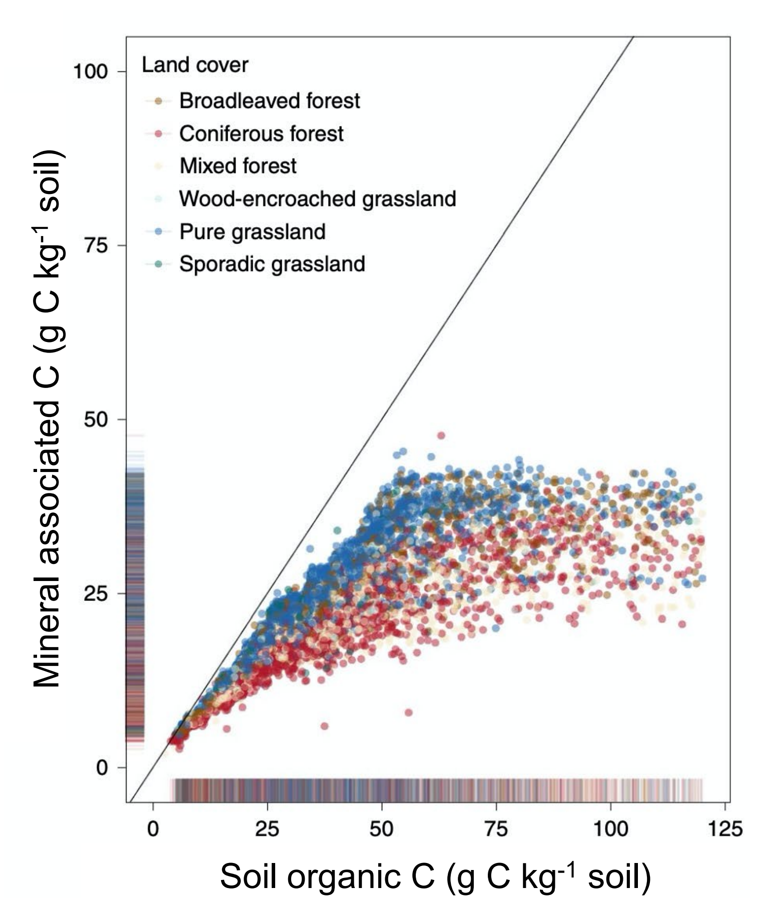
Slessarev et al. *Biogeochemistry Letters,* 2021



Slessarev et al. *in prep.*

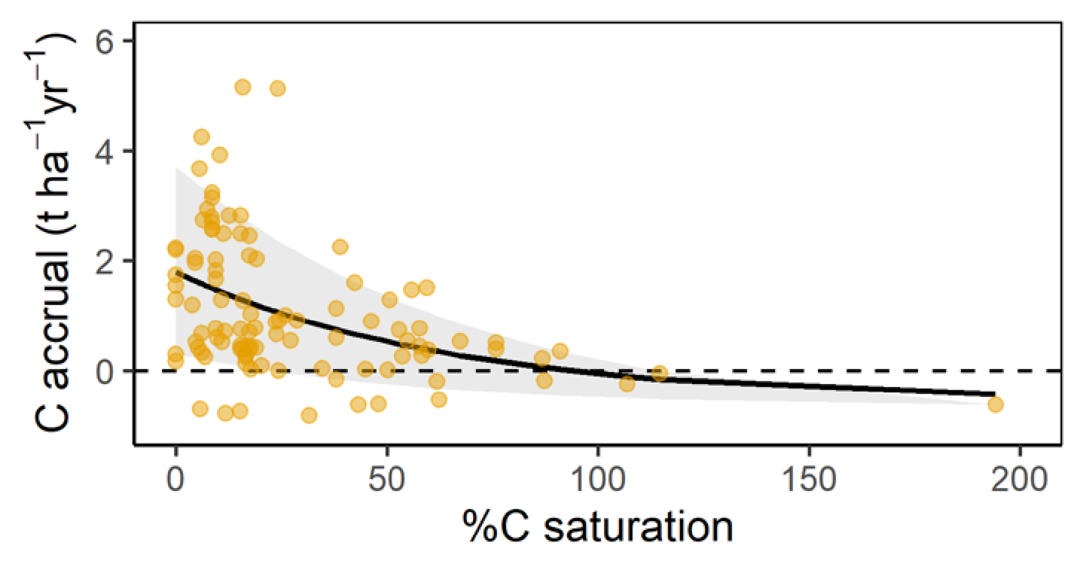
Mineralogical C capacity in practice

186 soil profiles and model-predicted values across Europe



Cotrufo et al. *Nat. Geosci,* 2019

Global synthesis of C accrual studies from 103 soil profiles

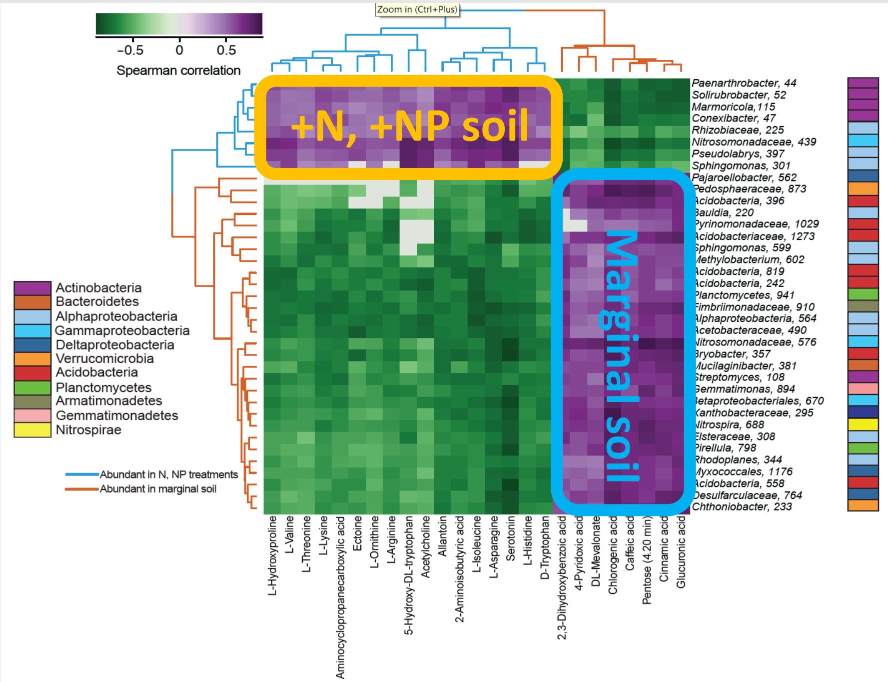


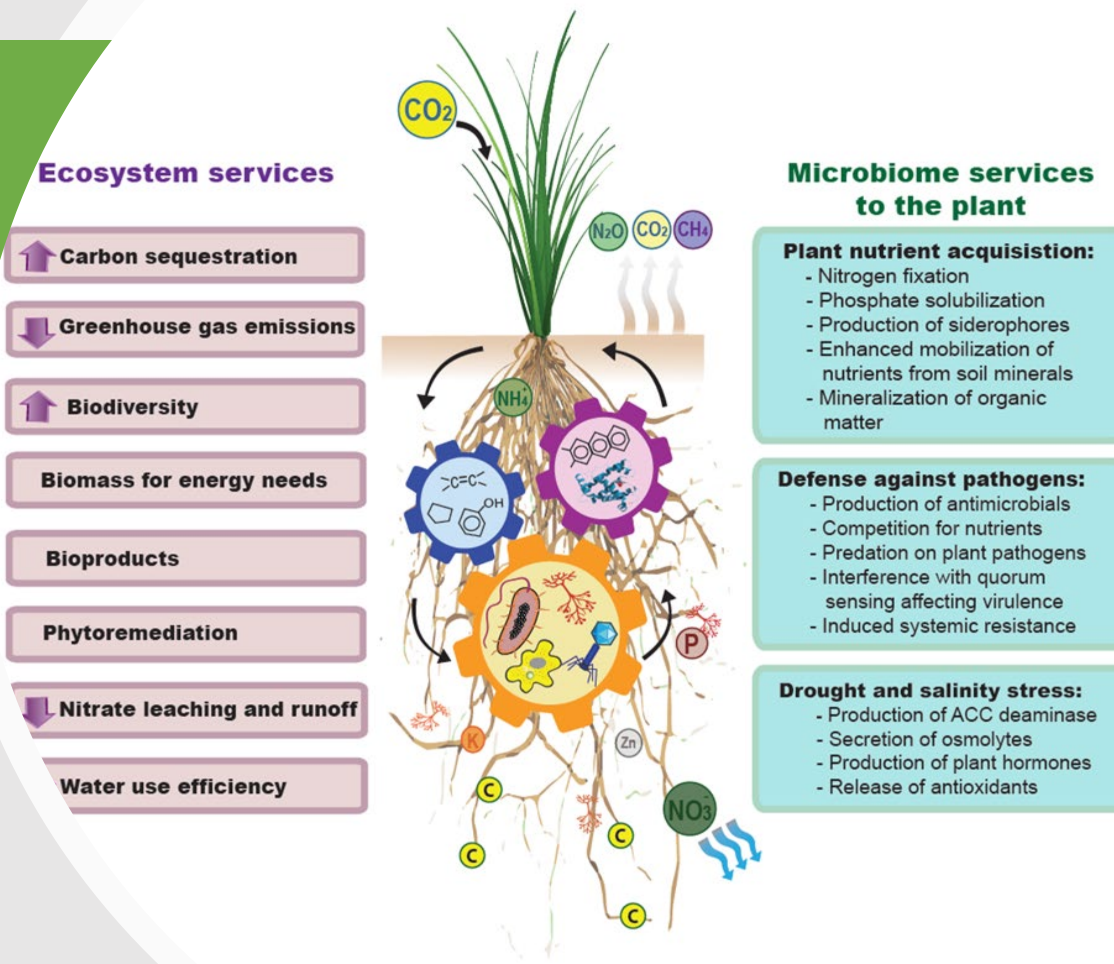
Accrual rates were ~3x higher in soils at 10% saturation than at 50% saturation.

Georgiou et al., *Nat. Comms.* In review

III. Microbiome Effects

- By managing plant exudates, we can also manage the root microbiome
- Plant exudates also affect broader ecosystem processes—e.g. accumulation of soil C





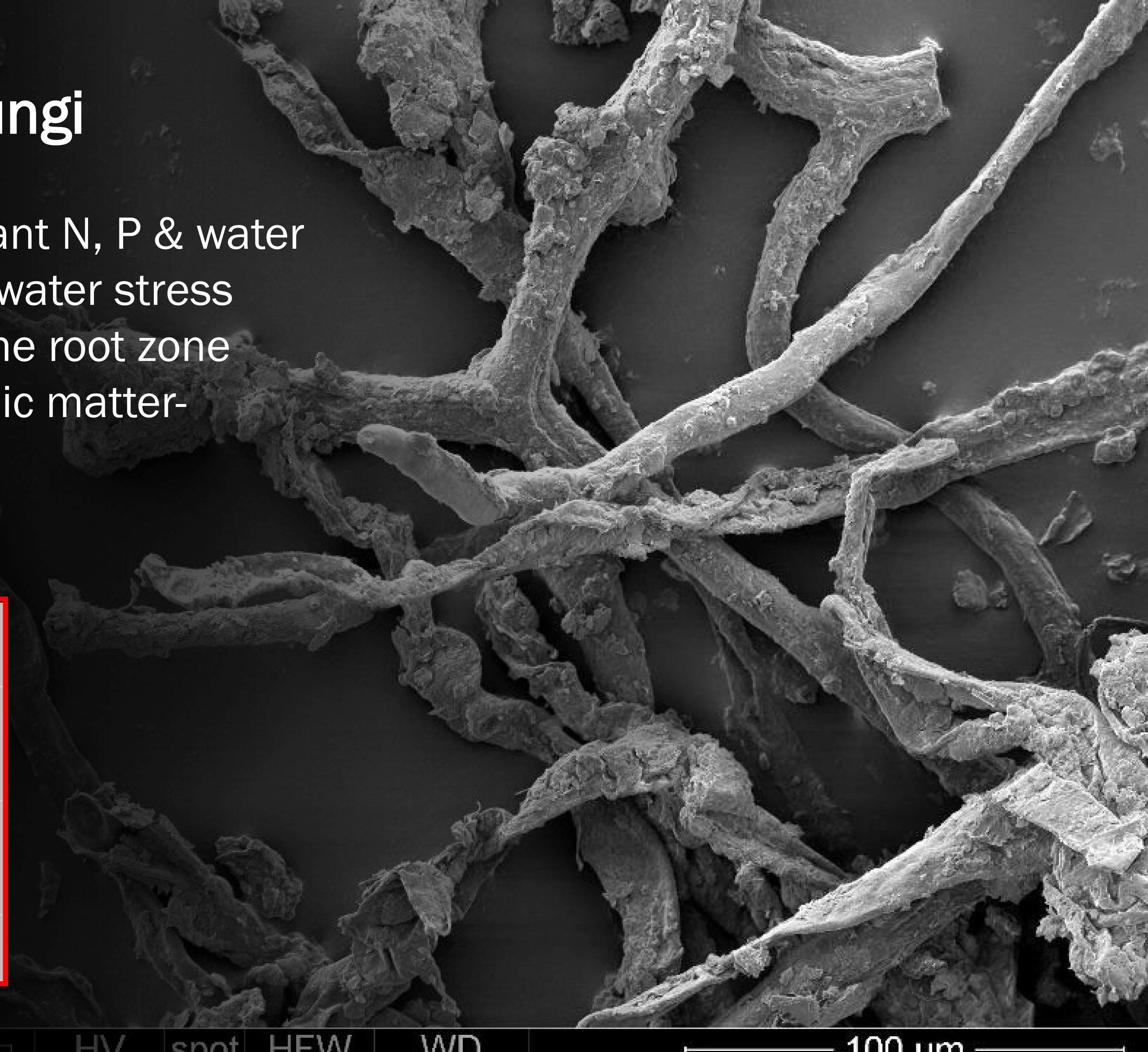
Zhalnina et al. 2021 *Phytobiomes*

Arbuscular mycorrhizal fungi

--provide significant amount of plant N, P & water
--can ‘rescue’ rhizo-biome during water stress
--transport plant-fixed C outside the root zone
--key mechanism leading to organic matter-mineral interactions

Density in soil	Global Mean
Total hyphae (cm cm^{-3})	**102,000** (100-1,255,400)
AMF only (cm cm^{-3})	**2,000** (100-15,000)
Fine roots (cm cm^{-3})*	**6.8**

See et al. *Global Change Biology* 2022



Opportunities:

- Deep rooted plants, particularly perennials, can have a net positive impact on SOC → **engineer for deep, robust root systems**
- We need to measure the geographic patterns of biophysical constraints and mineral capacity → **include dynamic minerology in our SOC models**
- Rhizodeposits (extracellular polysaccharides, “EPS”) play an important role in promoting soil aggregation/carbon persistence → **engineer for EPS production**
- Beneficial fungi transport N, P and water to the plant host, and fungal hyphae transport C to mineral surfaces → **select for enhanced mycorrhizal symbioses**

U.S. DEPARTMENT OF ENERGY
Office of Science

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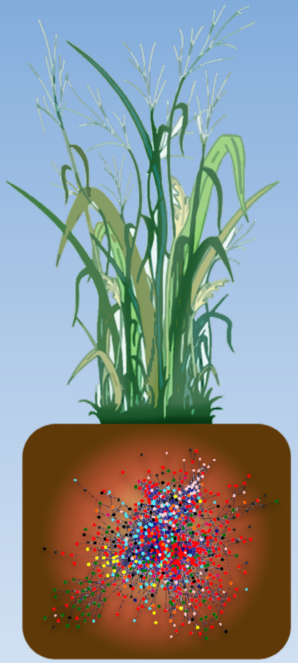
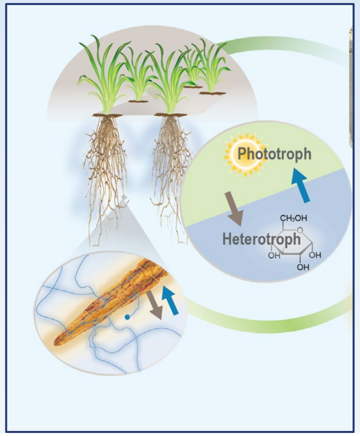


BER Sustainable Switchgrass Project

LLNL Soil Microbiome SFA



LLNL µBiospheres SFA

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Anticipating the threat and preparing DOE for the next major phase of climate mitigation technology

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