How do microbes transform plant residues into soil organic matter and, why does it matter?

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Soil organic matter

Promotes:

- good soil structure
- aggregate formation and stability

Regulates:

- soil moisture availability
- nutrient cycling
- climate (carbon storage and GHG)

Is a source of:

- nutrients for plants and microbes
- energy (food) for microorganisms

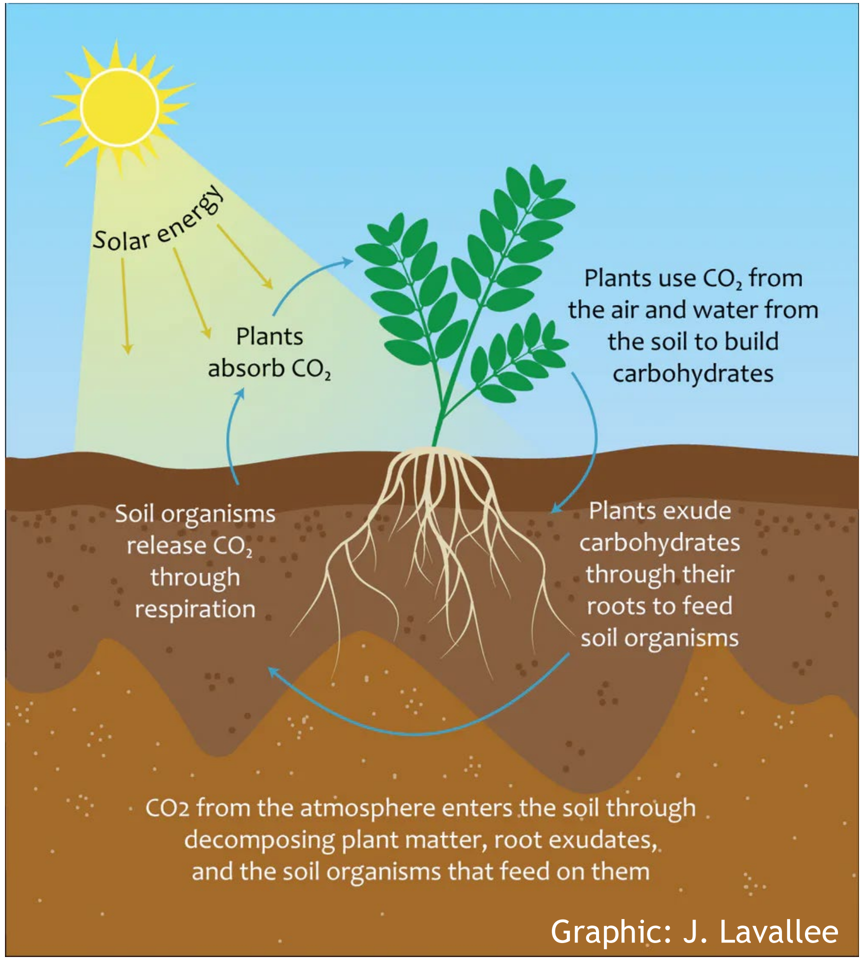
Soil organic matter provides resilience to stress

Soil organic matter supports biota

Soil biota: ecosystem services
Decomposition & cycling of organic matter
Regulation of nutrient availability
Suppression of pests and disease
Maintenance of soil structure & hydrology
Gas exchange and carbon storage
Soil Detoxification
Plant growth control

https://www.quartoknows.com/blog/quartohomes/2015/04/22/sustainable-gardens-and-organic-matter/

Where does soil organic matter come from?



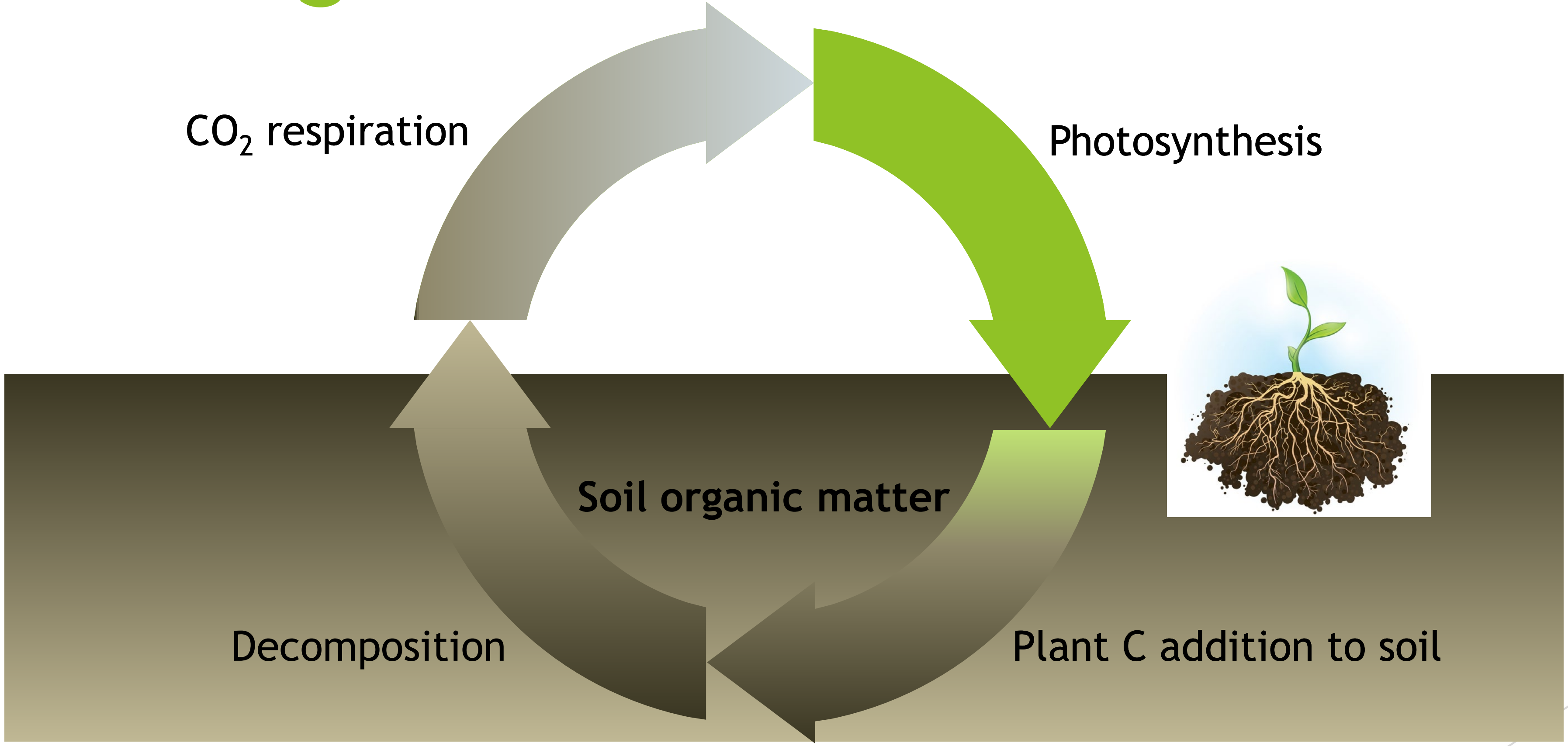
https://theconversation.com/soil-carbon-is-a-valuable-resource-but-all-soil-carbon-is-not-created-equal-129175

In agroecosystems most new C comes from plants (and organic amendments).

Energy held by carbon ***fuels*** other important processes

(e.g. N, P cycling)

How does plant matter become *soil* organic matter?

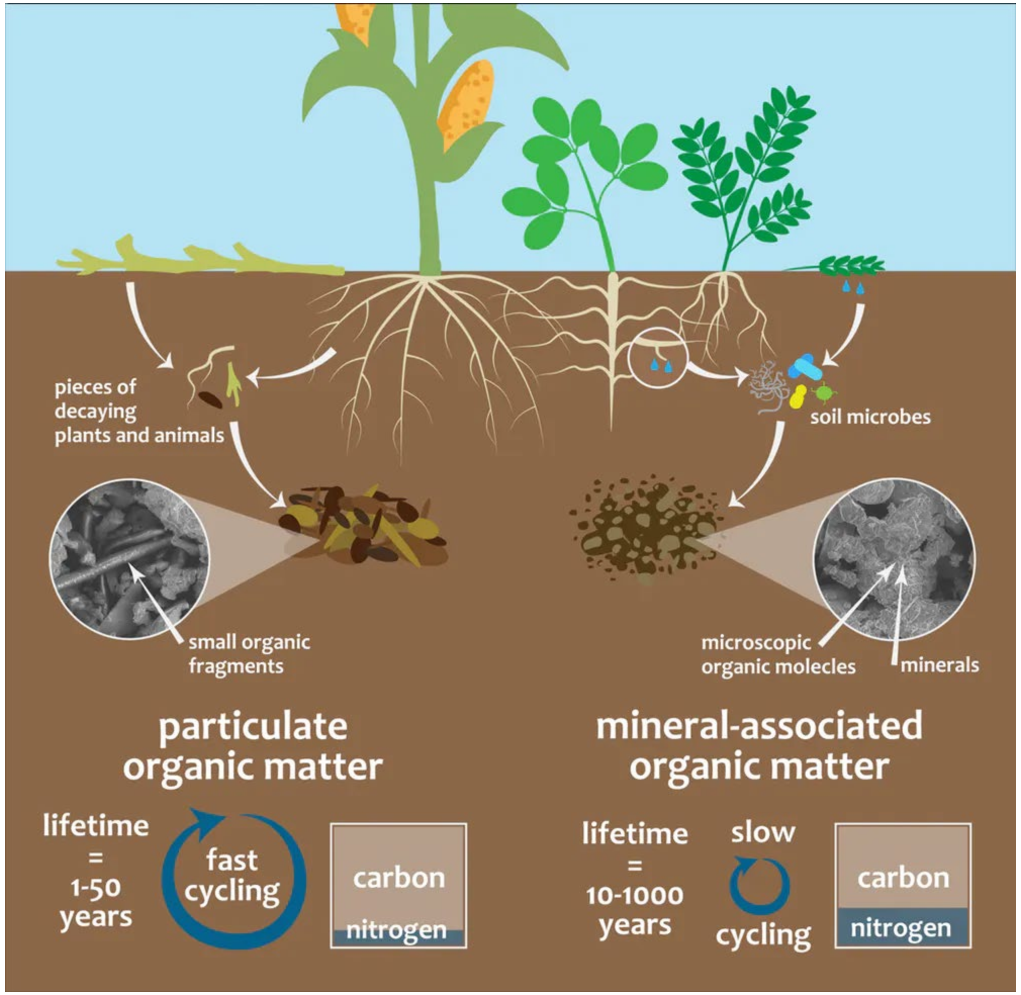


ODE TO ROT (J. Updike 1985)

" 'Let there be rot', and hence bacteria and fungi sprang into existence to dissolve the knot of carbohydrates photosynthesis achieves in plants, in living plants…

…Dead matter else would hold the elements in thrall -- nitrogen, phosphorus..."

Not all soil organic matter is created equally

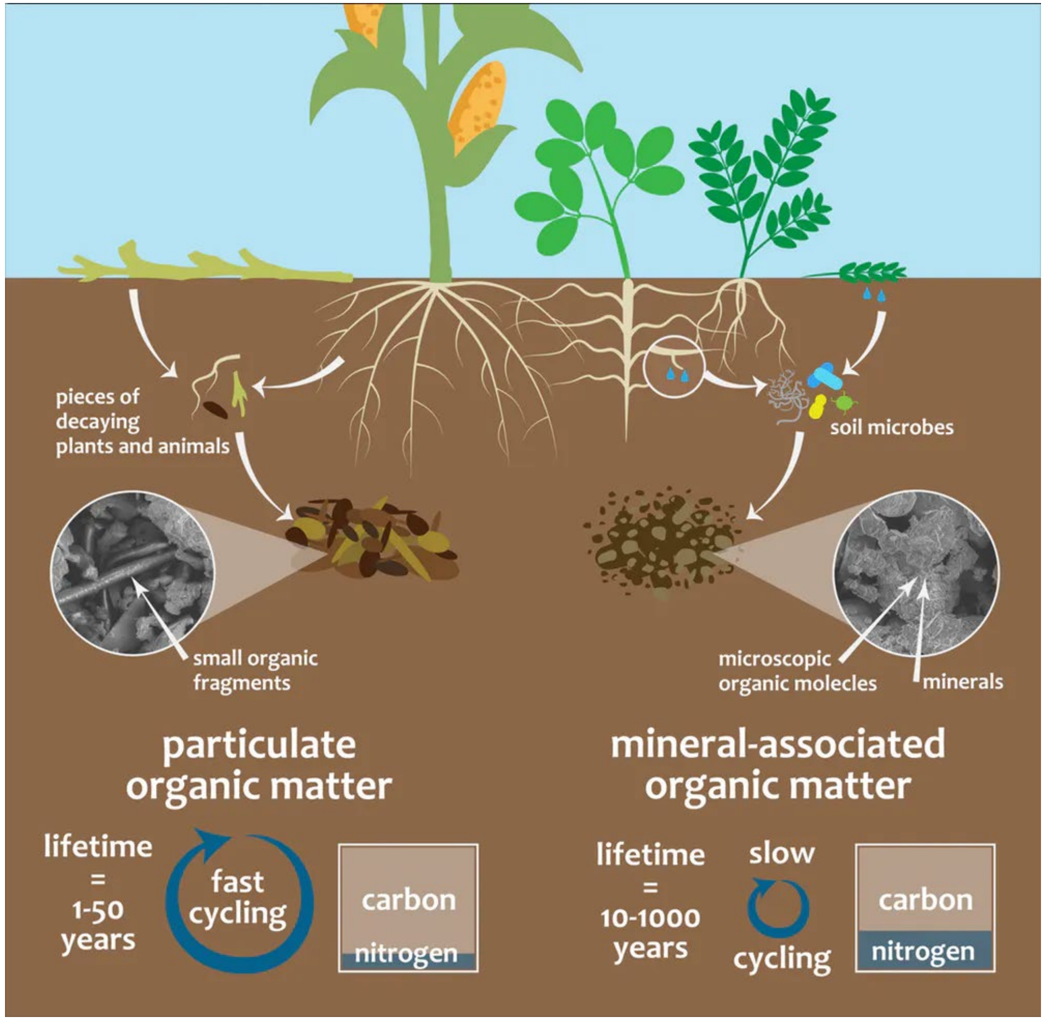


https://www.freepik.com/premium-photo/fertile-loam-soil-suitable-planting-soil-texture_4882973.htm

Graphic: J. Lavallee

https://theconversation.com/soil-carbon-is-a-valuable-resource-but-all-soil-carbon-is-not-created-equal-129175

How is soil organic matter retained?



Particulate organic matter (POM):

- protected within aggregates

Mineral-associated organic matter (MAOM):

- protected by binding with clay minerals

Graphic: J. Lavallee

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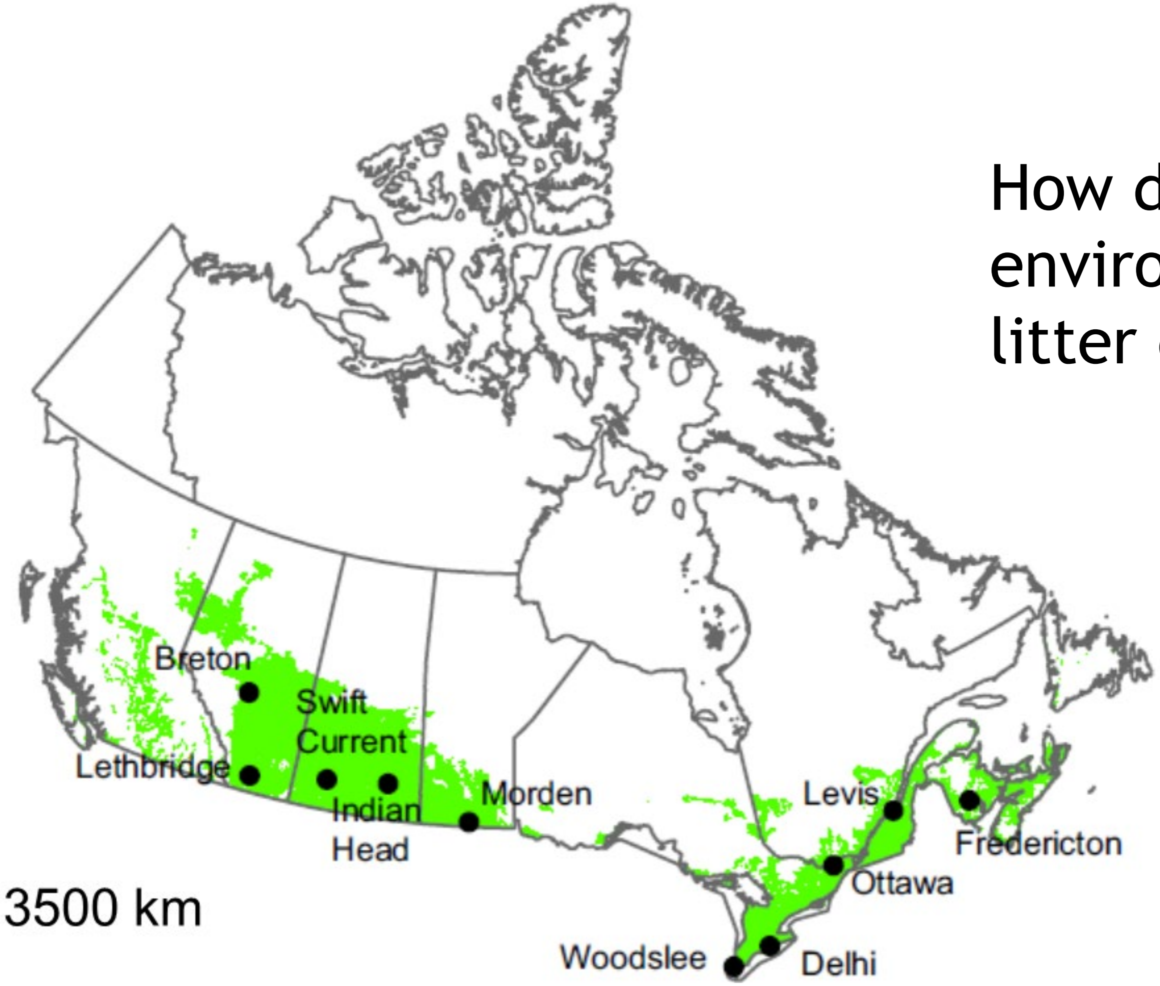
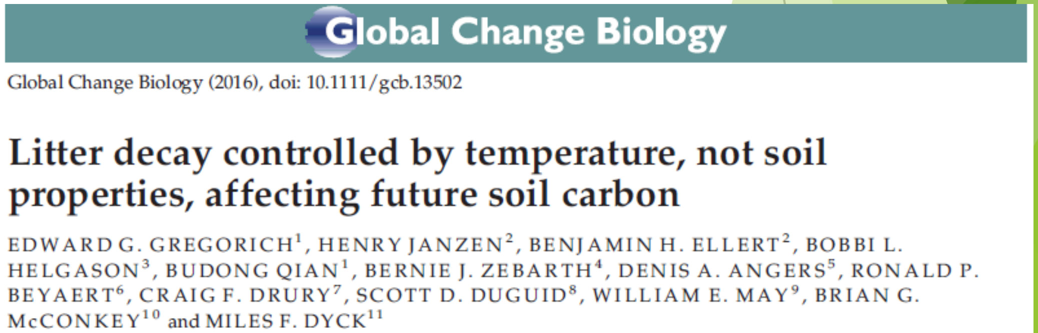
Crop residue decomposition – what controls it?



How do soil properties and environmental conditions affect litter decomposition?


Global Change Biology

Global Change Biology (2016), doi: 10.1111/gcb.13502

Litter decay controlled by temperature, not soil properties, affecting future soil carbon

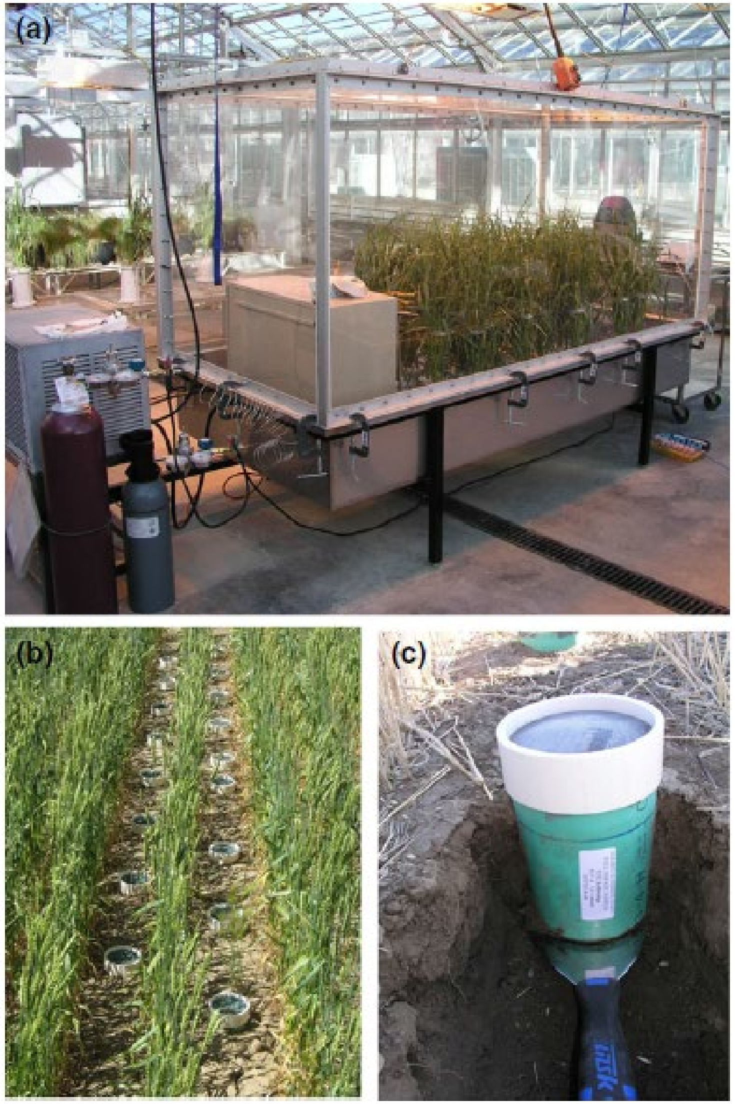
EDWARD G. GREGORICH[1], HENRY JANZEN[2], BENJAMIN H. ELLERT[2], BOBBI L. HELGASON[3], BUDONG QIAN[1], BERNIE J. ZEBARTH[4], DENIS A. ANGERS[5], RONALD P. BEYAERT[6], CRAIG F. DRURY[7], SCOTT D. DUGUID[8], WILLIAM E. MAY[9], BRIAN G. McCONKEY[10] and MILES F. DYCK[11]

Crop residue decomposition

Table 1 Soil classification, texture, organic carbon concentration and pH at the 10 experimental sites

Site	Soil classification (WRB)	Sand (%)	Clay (%)	Organic C (%)	pH	Mean annual air temperature (°C)	Mean annual precipitation (mm)
Fredericton, NB	Humic Podzol	53	9	1.70	6.2	6.6	1157
Levis, QC	Mollic, Umbric, Calcic Gleysol	60	15	2.23	5.0	5.6	1231
Ottawa, ON	Cambisol, Eutric Cambisol	67	12	1.79	6.2	7.4	926
Delhi, ON	Albic Luvisol, Haplic Luvisol	85	6	0.84	6.5	8.9	970
Woodslee, ON	Mollic, Umbric, Calcic Gleysol	41	27	2.88	7.1	10.0	875
Morden, MB	Chernozem	32	36	2.86	6.3	4.1	533
Indian Head, SK	Chernozem	10	48	2.06	7.8	2.5	431
Swift Current, SK	Kastanozem (Aridic)	33	29	1.17	6.0	4.2	397
Lethbridge, AB	Kastanozem (Haplic)	53	23	1.52	7.7	6.5	467
Breton, AB	Albic Luvisol, Gleyed Luvisol	36	22	1.66	5.8	3.5	506

Crop residue decomposition

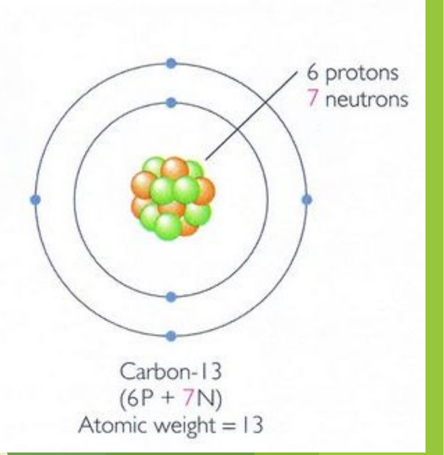


Barley grown in a chamber with a tracer ($^{13}CO_2$)

- Harvested, chopped, mixed with soil
- ^{12}C residues added annually (no tracer)

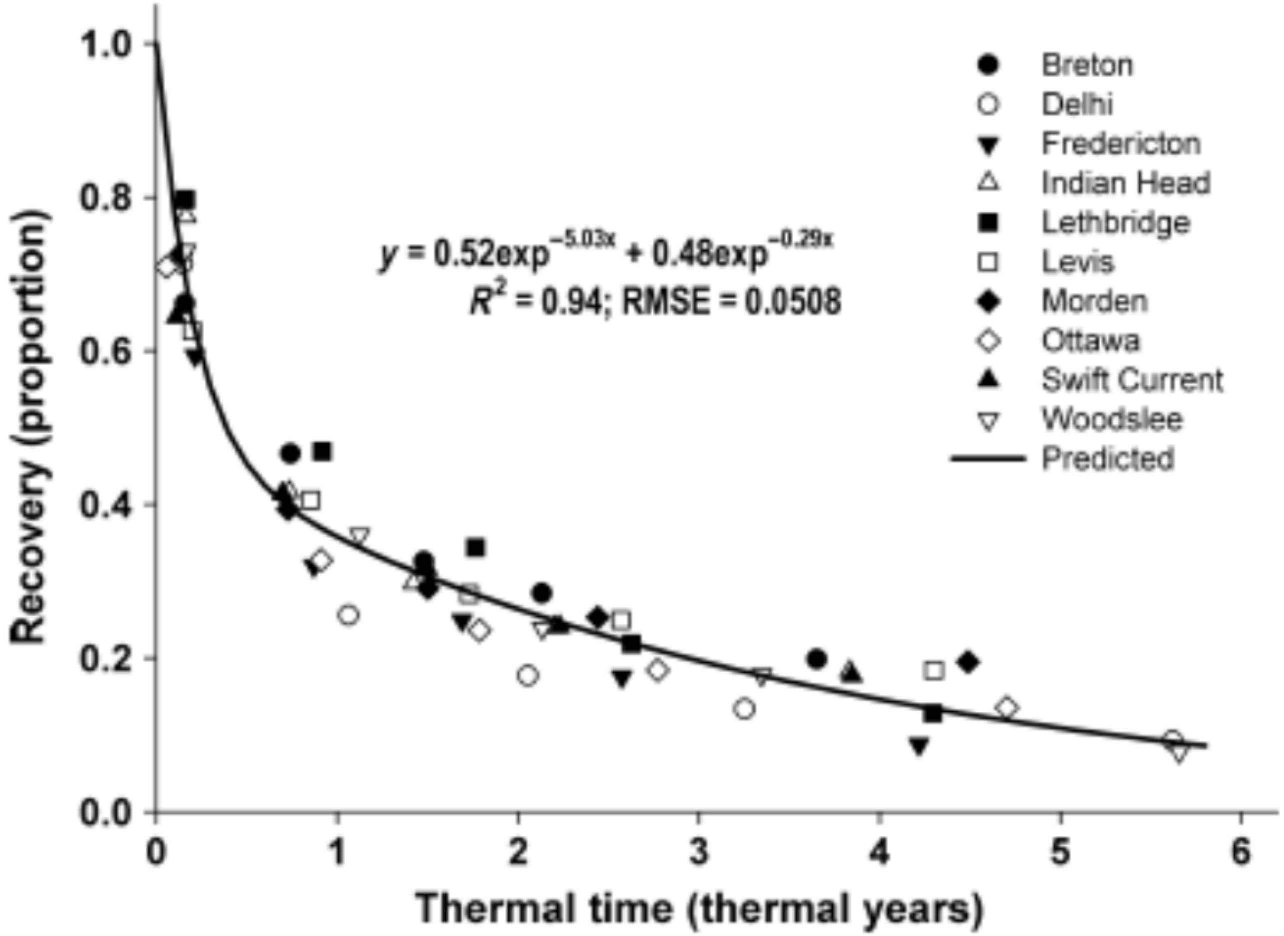
10 atom% ^{13}C

- Sampled after 6mo, 1, 2, 3, 5 years



https://deskarati.com/wp-content/uploads/2015/07/Carbon-Isotopes.jpg

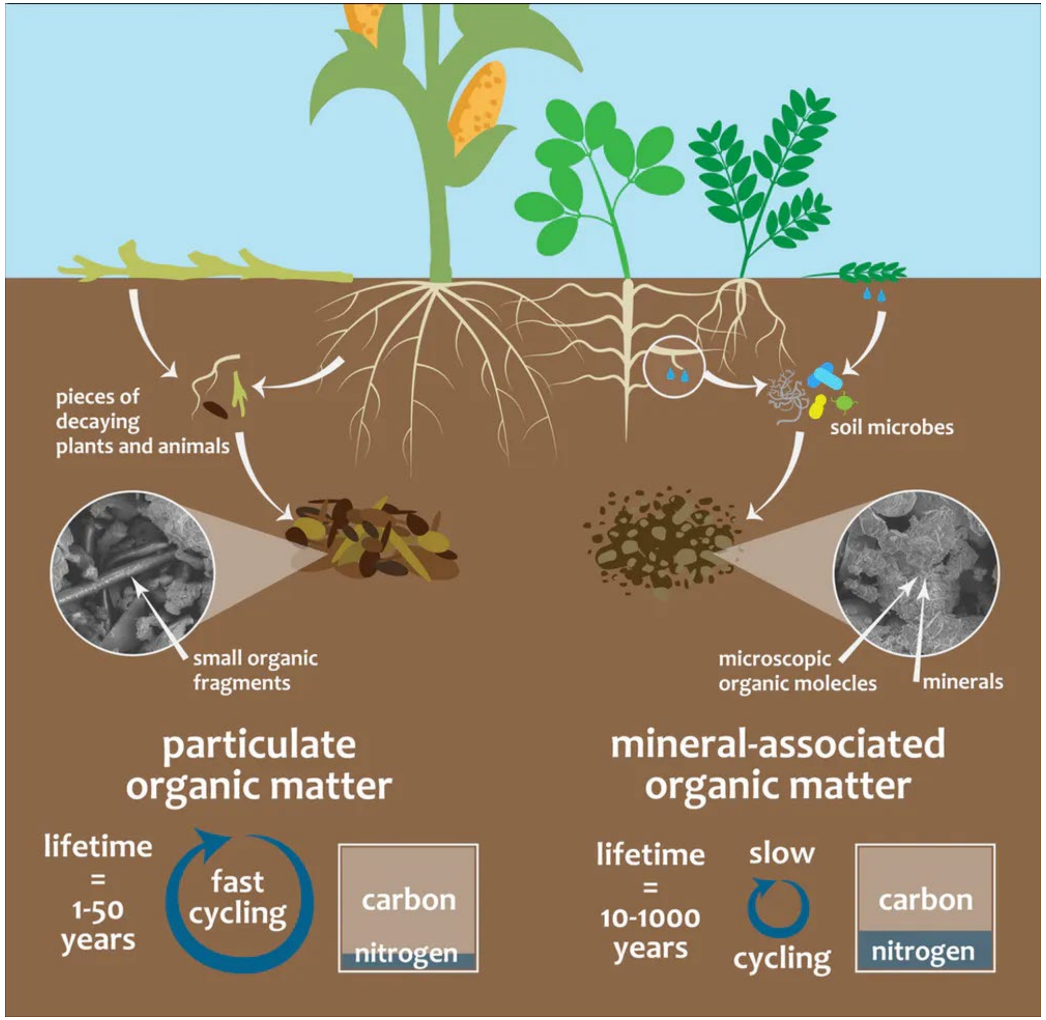
Crop residue decomposition: primarily controlled by temperature



Temperature
("thermal time")

- Cumulative growing degree days above zero

What about residue C stabilization?



Where did the ^{13}C from the barley end up

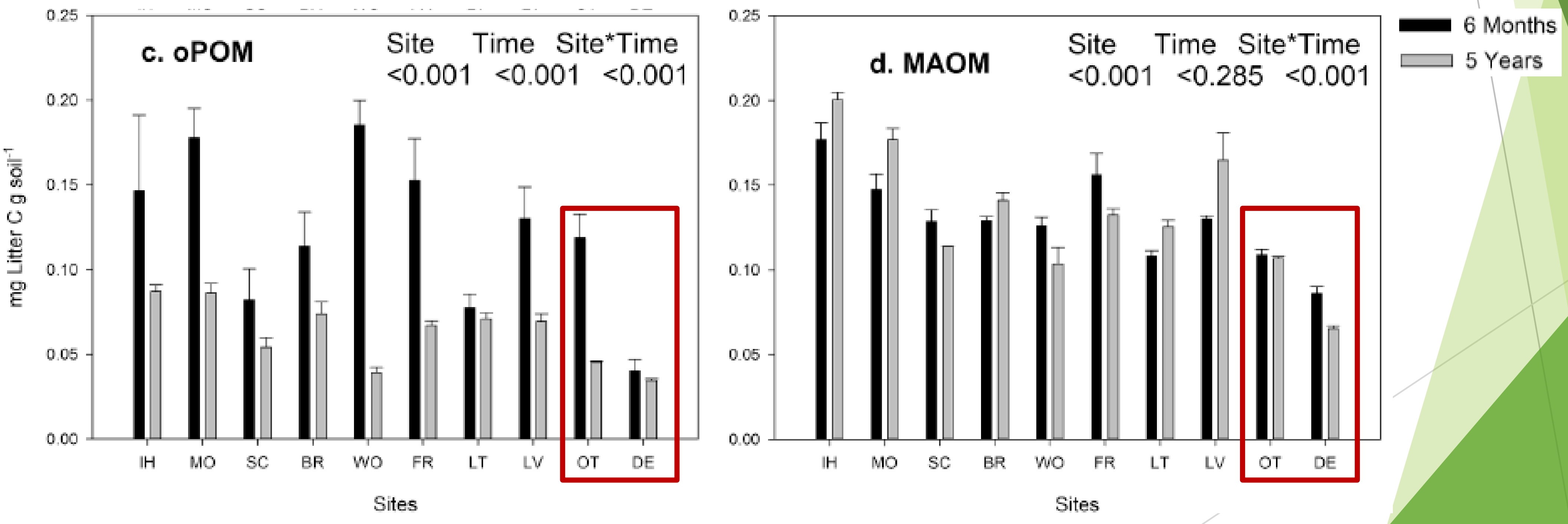
- after 6 months?
- after 5 years?

Graphic: J. Lavallee

https://theconversation.com/soil-carbon-is-a-valuable-resource-but-all-soil-carbon-is-not-created-equal-129175

What about residue C stabilization?

At 6 months, a lot of residue was POM; by 5 years residue C remained as MAOM.



Haddix et al. 2020 Geoderma

Organic matter supports soil biota

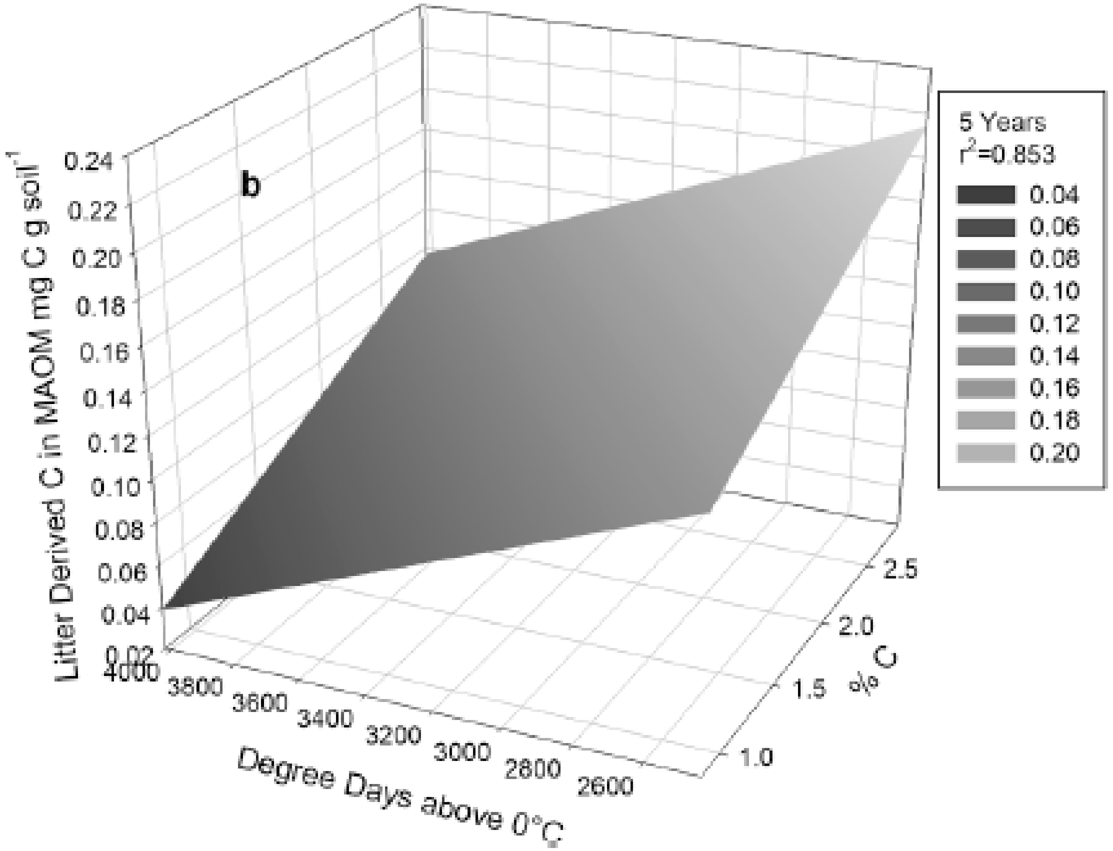


Fig. 4. Graph of best fit model parameters for litter-derived C formation (a; 6 months) and persistence (b; 5 years) in the mineral-associated organic matter (MAOM) fraction.

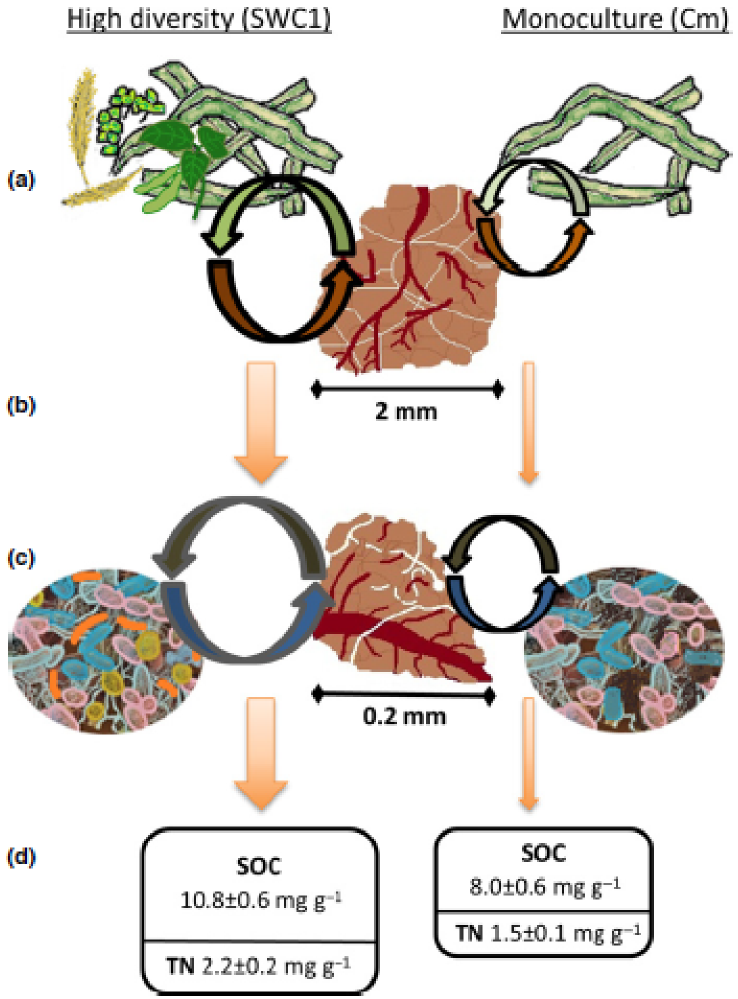
After 5 years, ^{13}C oPOM and MAOM best predicted by:

- •degree days above 0°C
- •soil organic C (%) at time 0

Haddix et al. 2020 Geoderma

How does crop diversity affect SOM?

Crop rotation provides a
"balanced diet"
= improved fertility?



Tiemann et al. 2015 Ecology Letters

How does crop diversity affect SOM?

Long-term cereal monoculture vs. diverse rotations

AAFC New Rotation Experiment (Swift Current est. 1987)

continuous wheat vs. wheat-canola-wheat-pea (n=3)




AAFC Totten Rotation Experiment (Harrow est. 2001)

continuous corn vs. corn-soybean-winter wheat (n=4)

Dr. Jennifer Town
AAFC, Saskatoon RDC

How does crop diversity affect microbial communities?

Location	Stage	Date
Harrow, ON	Early Vegetative (EV) Anthesis (AN) Post-harvest (PH)	June 21 August 3 December 5
Swift Current, SK	Early Vegetative Anthesis Post-harvest	June 6 July 20 September 12

Organic Matter Characterization

- Lignin (lignin phenols)
- Amino sugars
- Available C (CO_2 respiration; 38d)

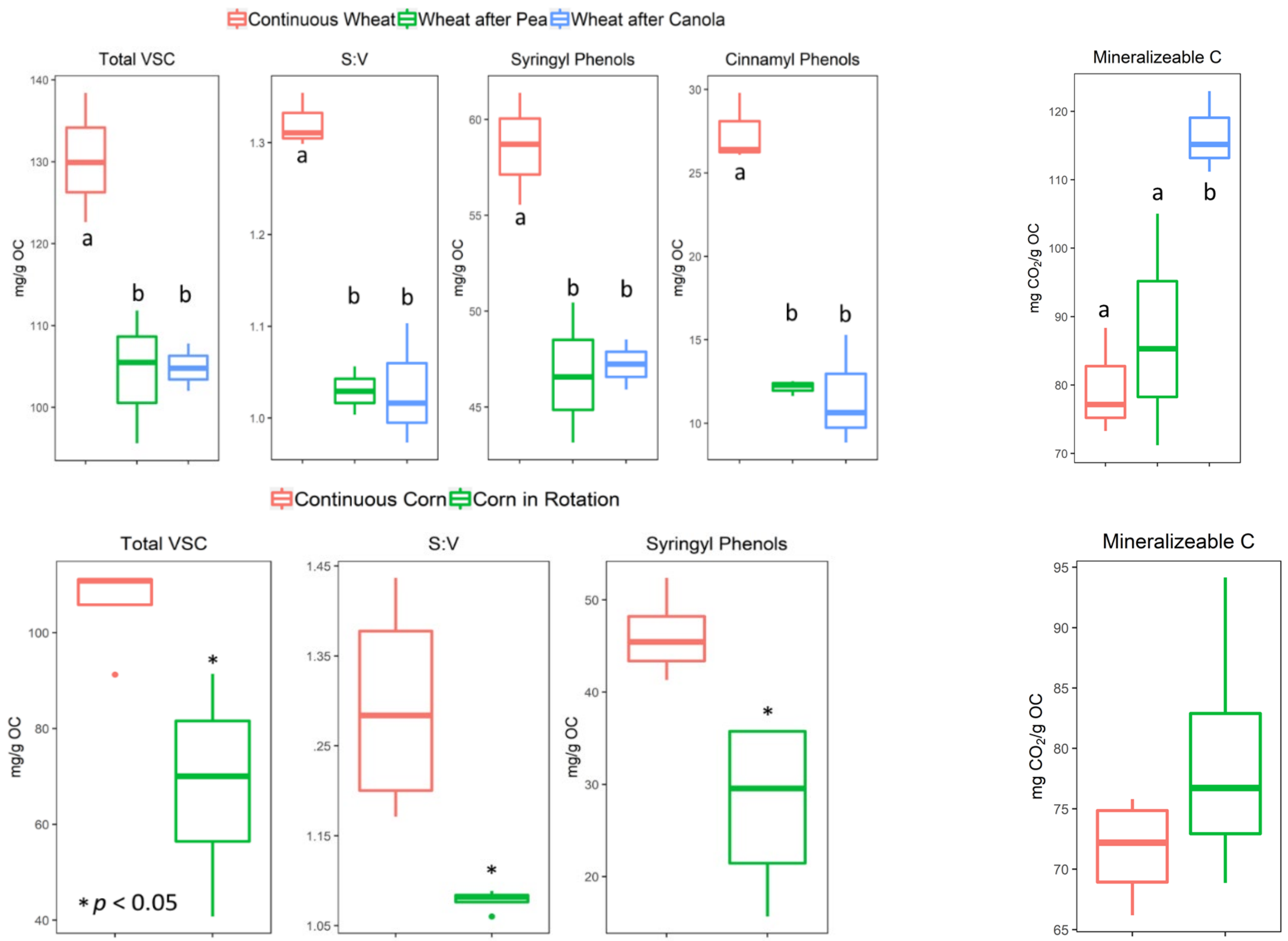
Biogeochemistry

- PO_4, NO_3, total N, total and organic C
- Microbial enzyme activities

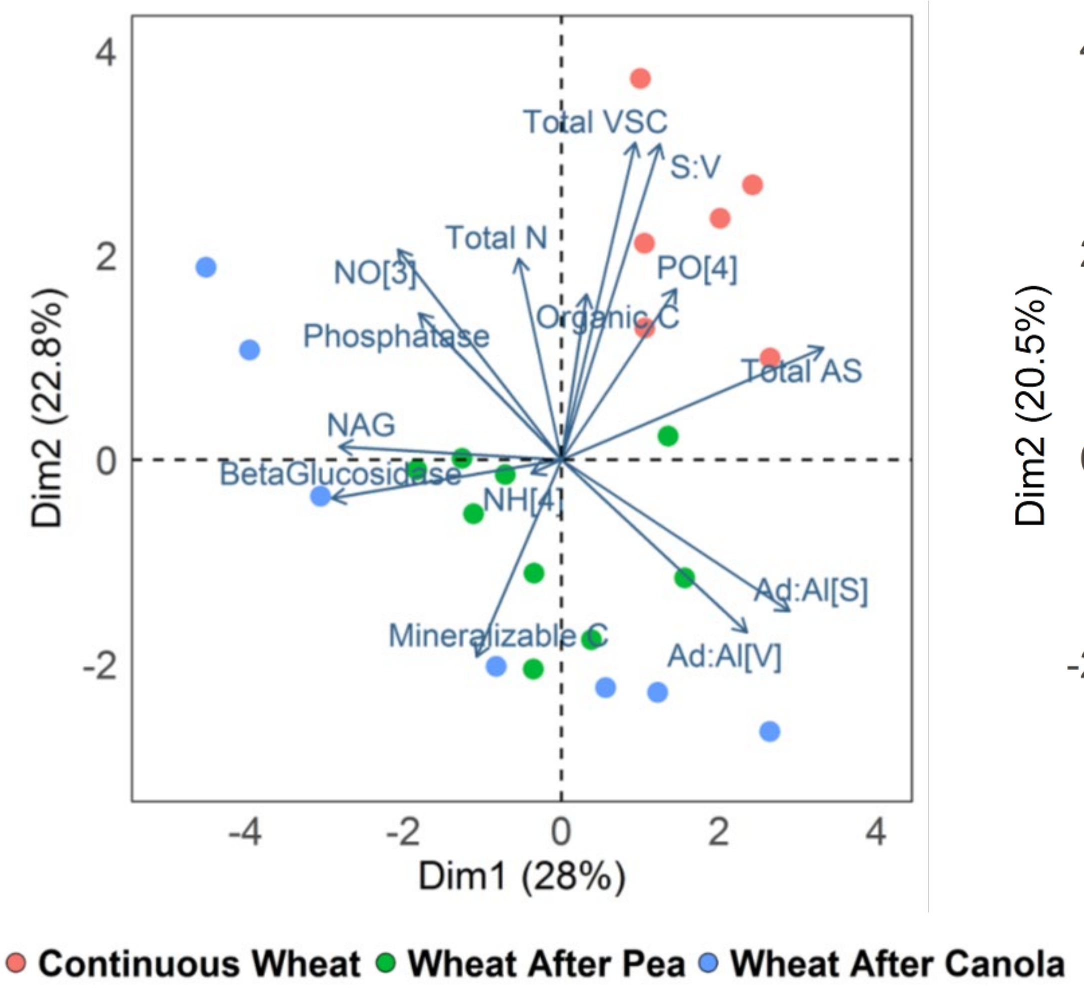
Microbial community characterization

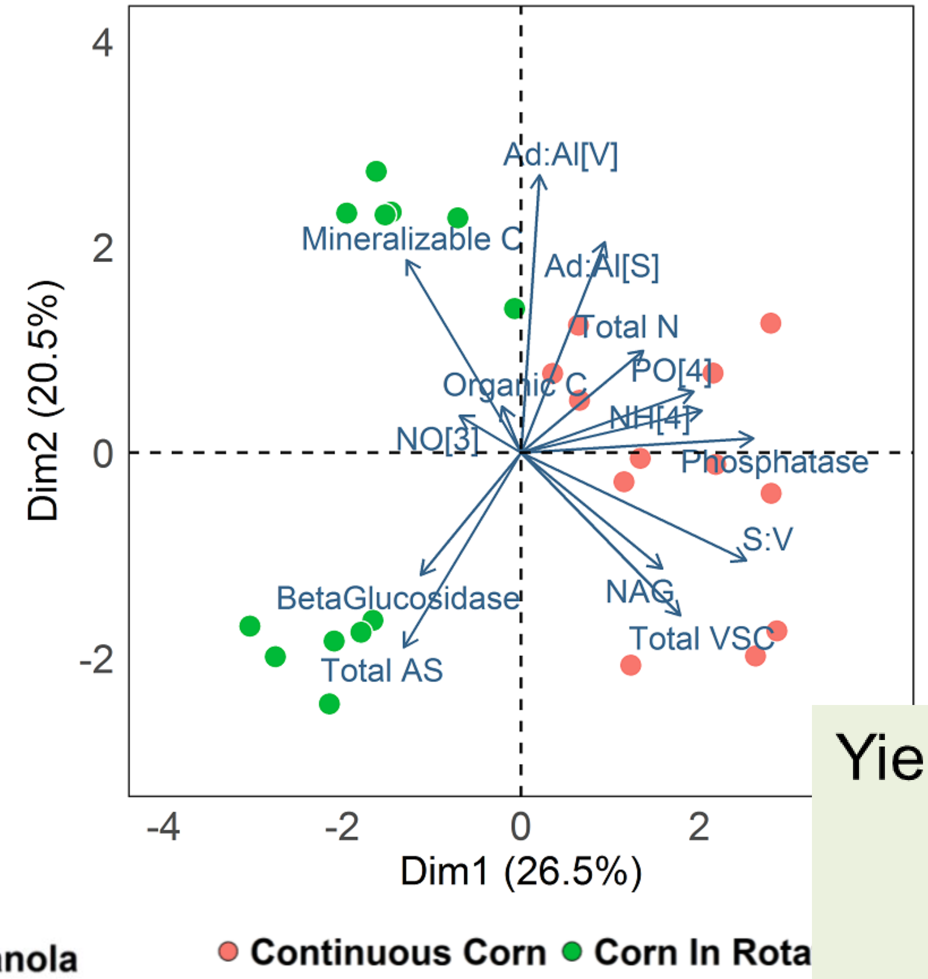
- DNA sequencing
- Phospholipid fatty acids

Crop rotation affected SOM quality



Diverse crop rotations resulted in different soil *functioning*



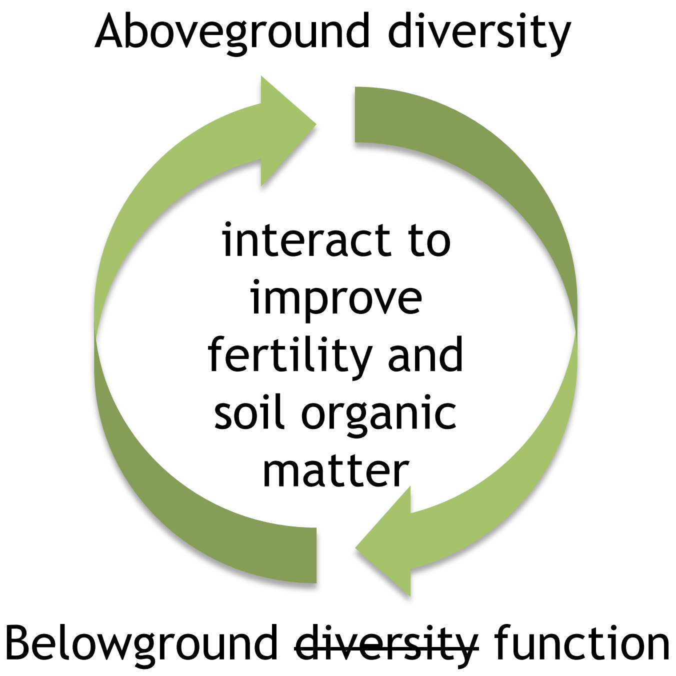


Yield boost:

Corn: +36%

Wheat: +20%

Diverse crop rotations in both systems resulted in different soil *function*



Plant matter quality is important for fertility

Diverse crop rotations improve system resilience to adverse conditions

Bowles et al. 2020 doi.org/10.1016/j.oneear.2020.02.007

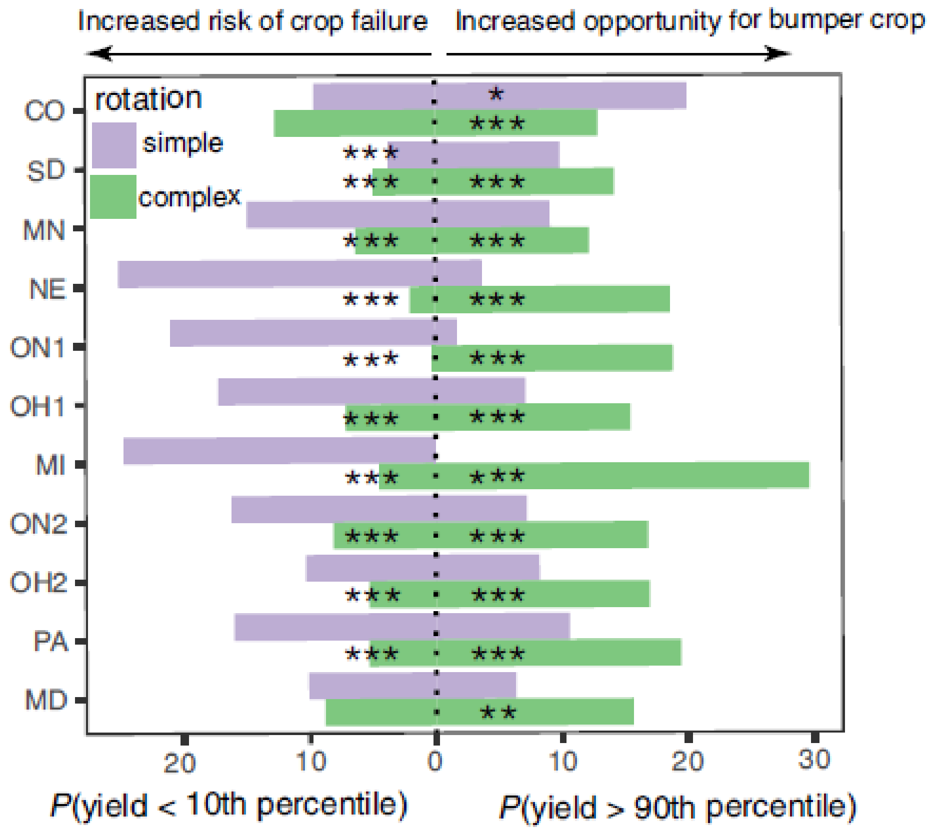


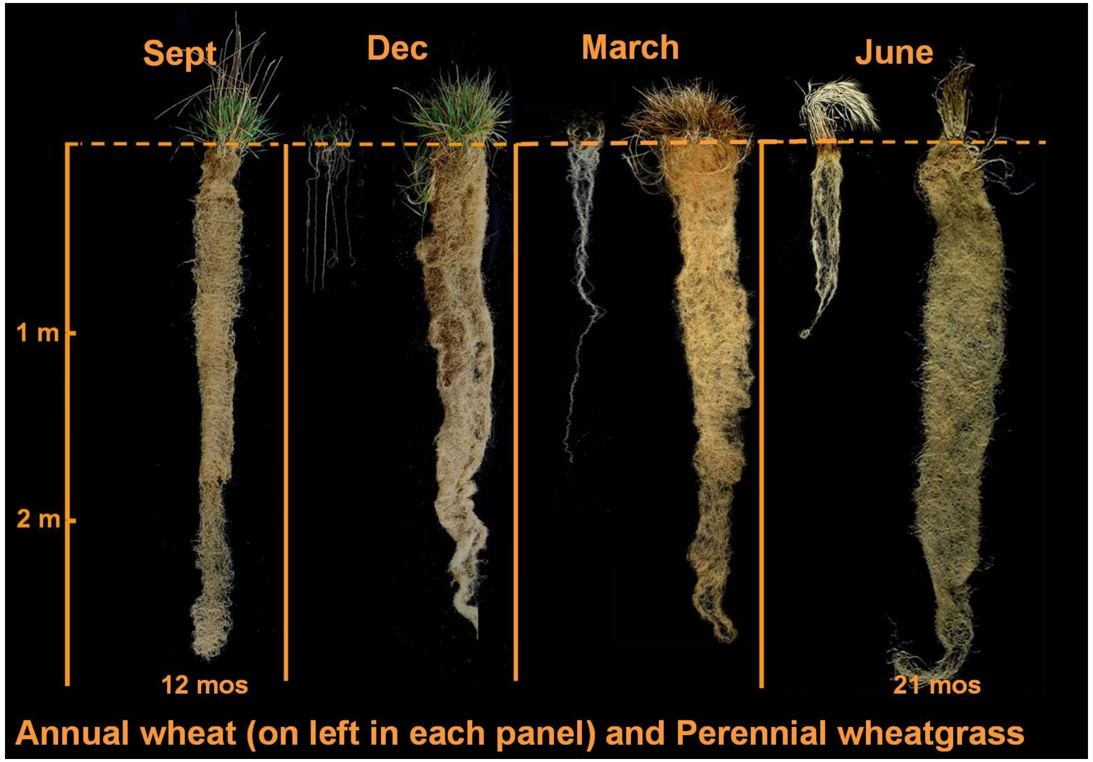
Figure 3. Probability Analysis of Low and High Yields in Simple versus Complex Rotations

347 site years from 11 corn experiment.

Rotation diversity increased yields by an average of 28.1%.

Positive effects were most notable under unfavorable conditions (e.g. drought).

Organic matter quality: what is the big deal with roots?



upload.wikimedia.org/wikipedia/commons/a/a7/4_Seasons_Roots.jpg

Roots can contribute up to 80% as much C as aboveground biomass (Fan et al. 2019).

What is the big deal with roots?

Rhizodeposition can account for 1-10% of net photosynthate C stored

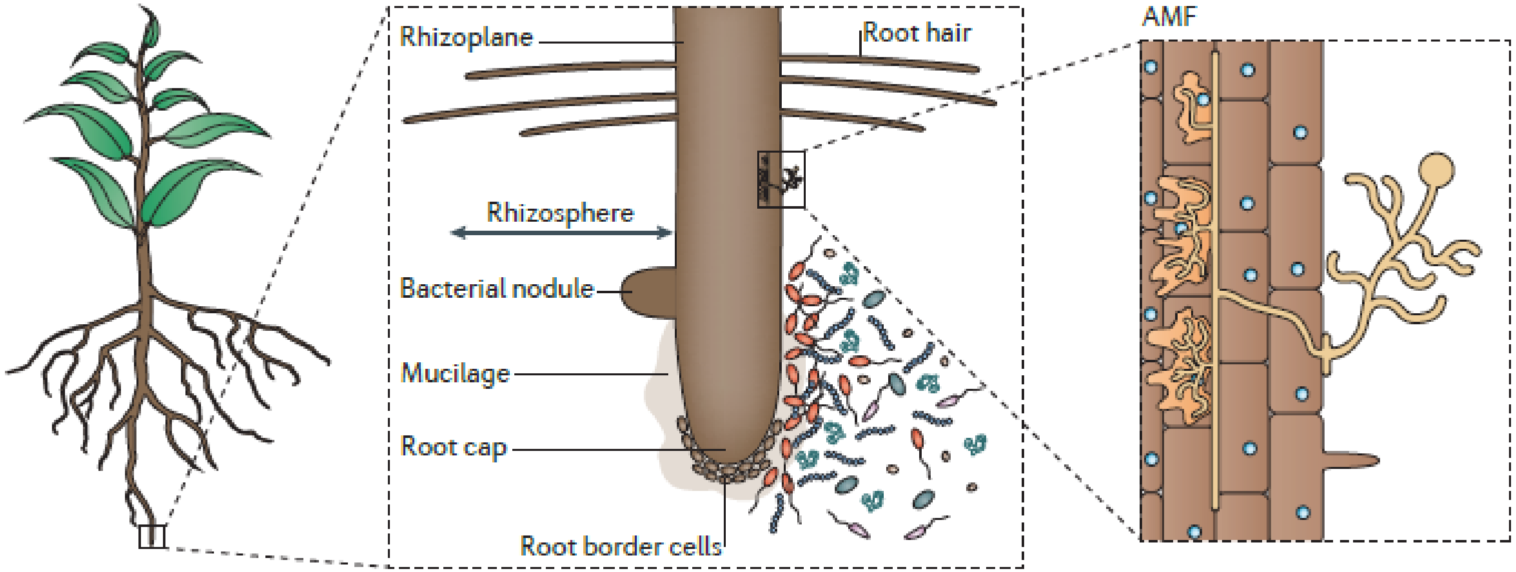
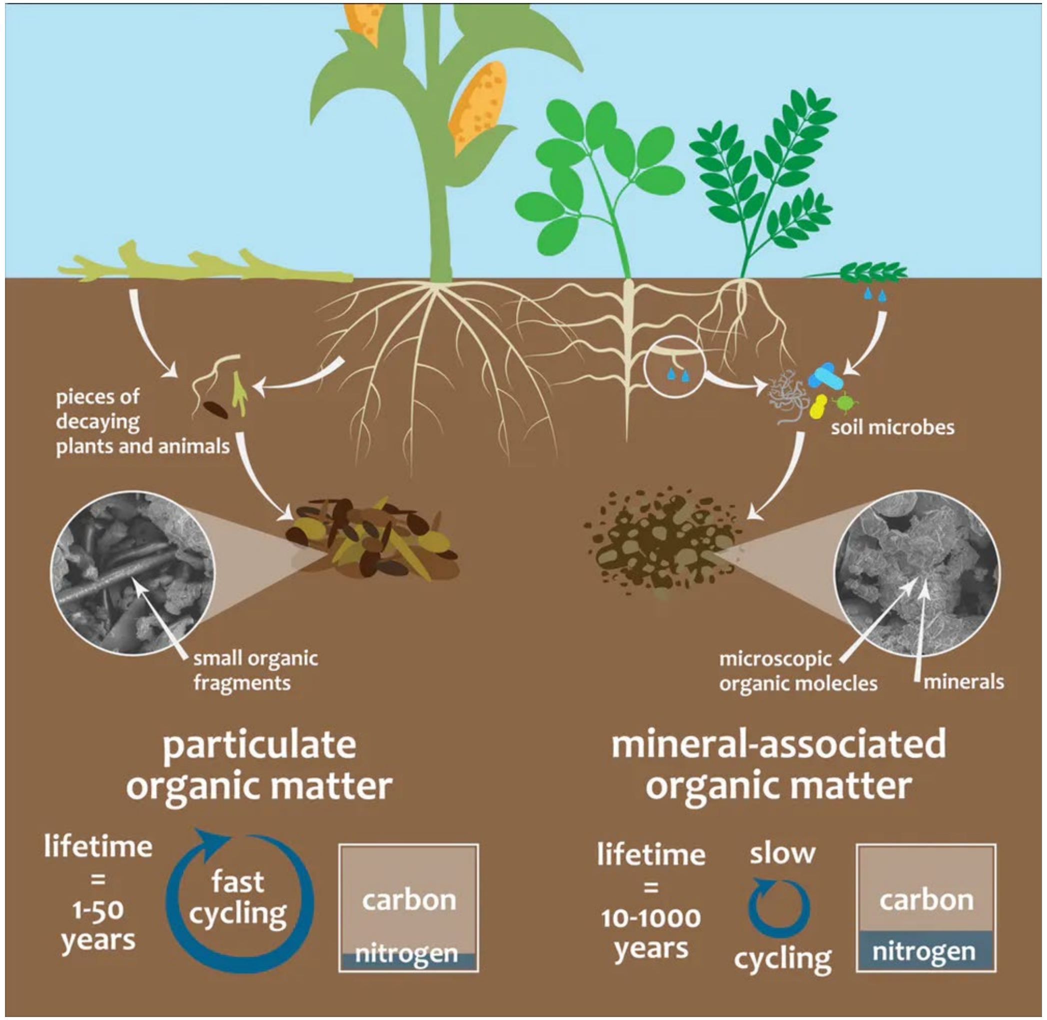


Figure 2 | The rhizosphere. The rhizosphere is a narrow zone of soil (a few millimetres wide) that surrounds and is influenced by plant roots. The schematic shows magnified pictures of the rhizosphere, containing saprophytic and symbiotic bacteria and fungi, including arbuscular mycorrhizal fungi (AMF). AMF inset modified, with permission, from REF. 158

Philippot et al. 2013. Nat Rev Microbiol 11:789-799

What is the big deal with roots?



Emerging evidence that root C is preferentially stabilized.

(Rasse et al. 2005, Sokol et al. 2019).

Graphic: J. Lavallee

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Regulates:

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Is a source of:

- nutrients for plants and microbes
- energy (food) for microorganisms


Photo: Soil Science Society of America ACSESS Digital Library

Soil organic matter provides resilience to stress

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College of Agriculture and Bioresources
DEPARTMENT OF SOIL SCIENCE
AGBIO.USASK.CA

Thank you

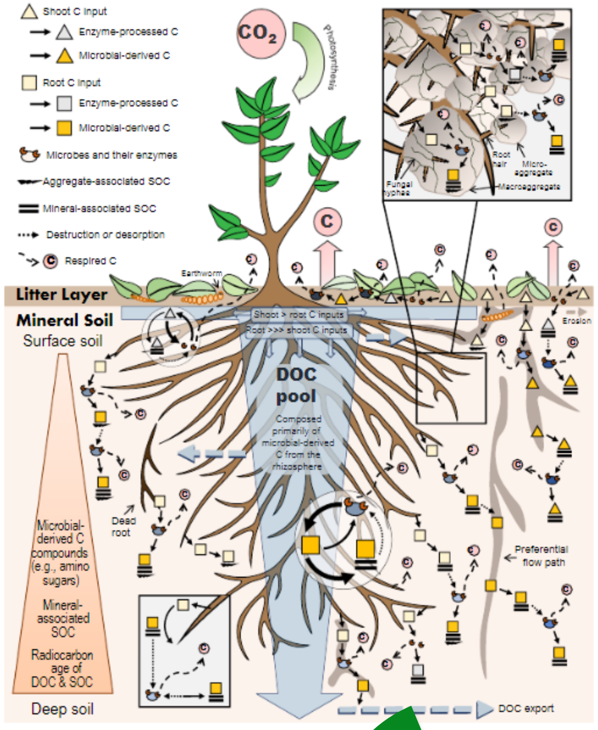
Soil Microbial Ecology Program

microorganisms

- Soil carbon stabilization/ destabilization
- Nutrient cycling and prevention of losses (improved efficiency)
- Plant-microbe interactions

Bobbi.Helgason@usask.ca

How is soil organic matter retained?



Soil Syst. **2019**, *3*, 28; doi:10.3390/soilsystems3020028

3 destabilizing factors:

1) Release from aggregates
   - Tillage, freeze-thaw, wet-dry cycles, bioturbation
2) Desorption from minerals
   - Soil pH, increased moisture
3) Increased biotic metabolism
   - Quality of litter, quality of soil organic matter, microbial carbon use efficiency

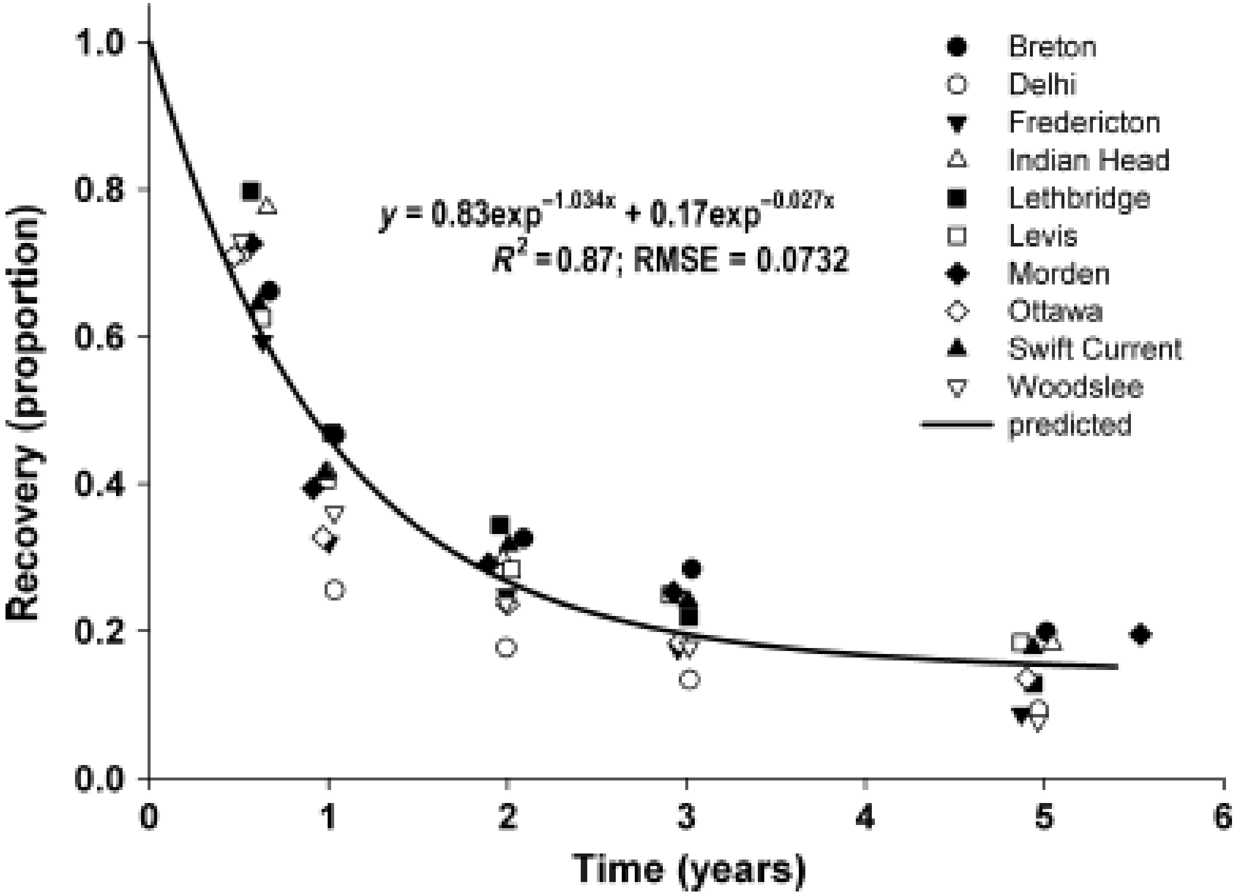
Inputs
- **Plant C**
- Soil amendments

Microbial decomposition

soil organic matter

Outputs
- **Respiration** (CO_2 & CH_4)
- Physical transport (erosion, leaching) *relocation

Crop residue decomposition: most plant C turns over quickly

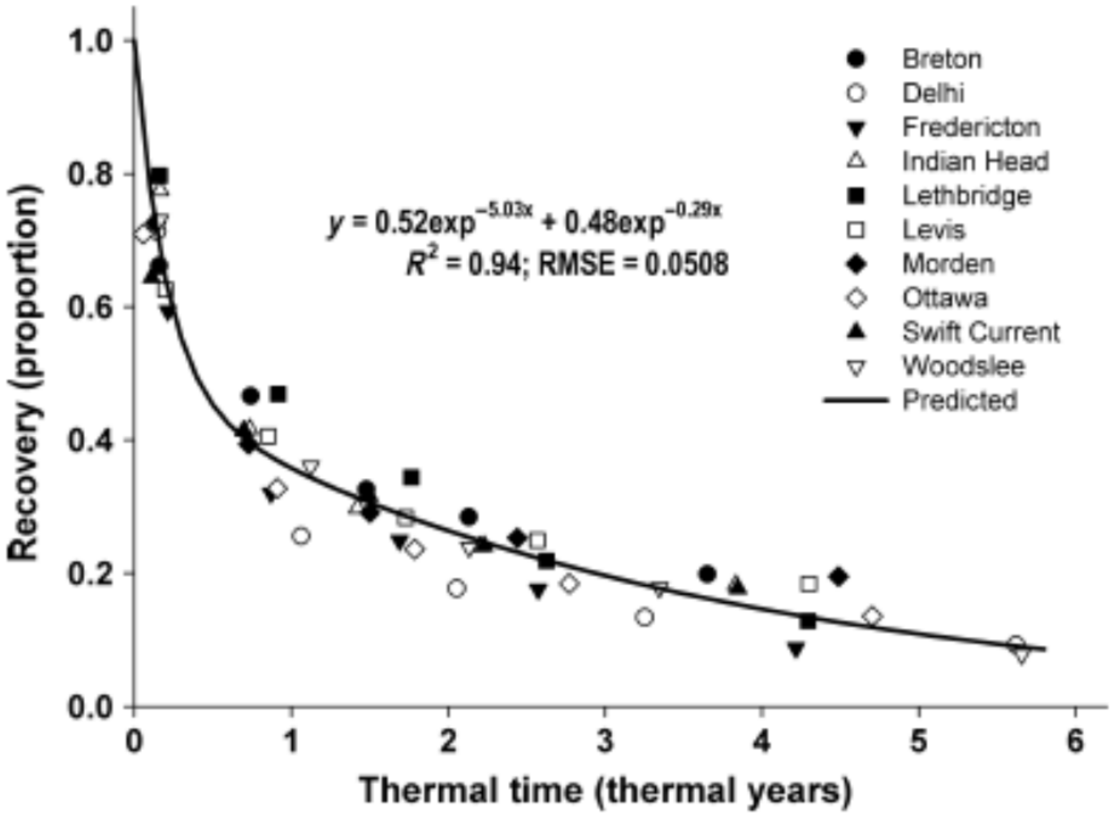


Less residue remained:

- in sandy soil
- in warmer, wetter climates

How do we *predict* decomposition?

Crop residue decomposition: what if our soils get warmer?



Time to 50% decomposition (labile carbon):

- 1-4 months less

Time to 90% decomposition (stable carbon):

- 1 year faster @cool sites
- 2 years faster @ warm sites