PURDUE UNIVERSITY | Agronomy

Soil microbes help sequester carbon. But, can we achieve that in intensive agroecosystems?

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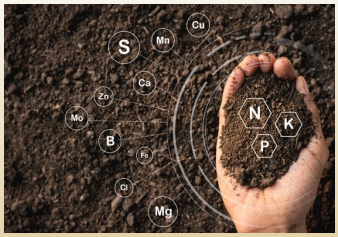
Indiana CCA Conference
Dec 20, 2023

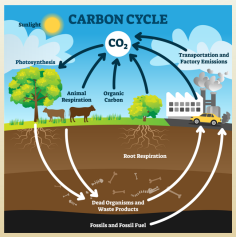
1

Why soil carbon/soil organic matter?



Soil organic matter (SOM) contains N, P, S, and other nutrients, thereby supporting crop production

SOM supports the soil food web and enhances biodiversity

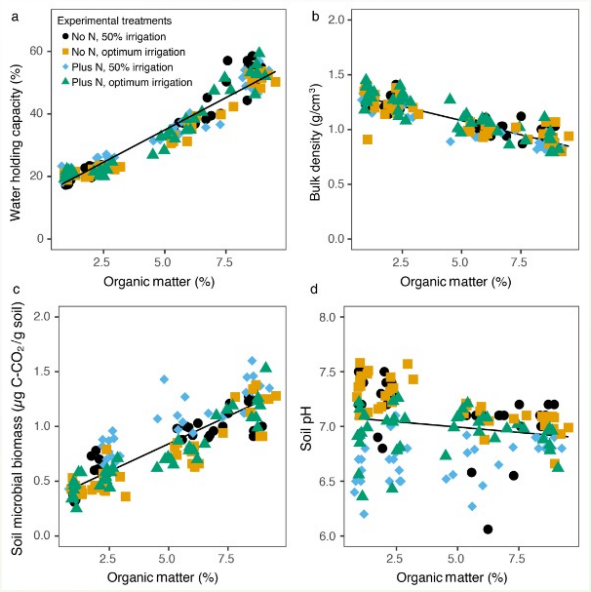


SOM regulates global carbon and water cycle

2

SOM/Soil carbon is central to soil health

Dr. Emily Oldfield
Environmental Defense Fund



Oldfield et al., 2020

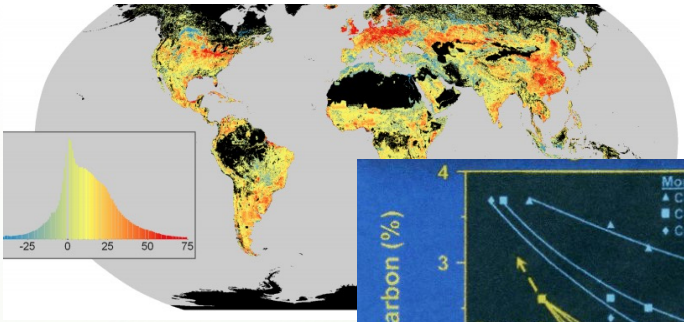
3

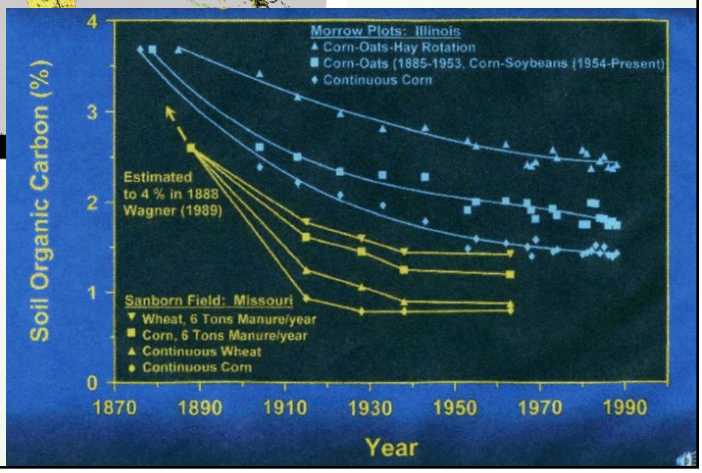
Soil carbon debt of 12,000 years of human land use

PNAS

Jonathan Sanderman[a,1,2], Tomislav Hengl[b,1], and Gregory J. Fiske[a]

Dr. Jon Sanderman
Woodwell Climate Research Center

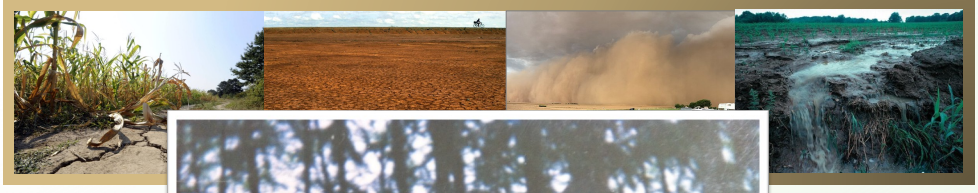


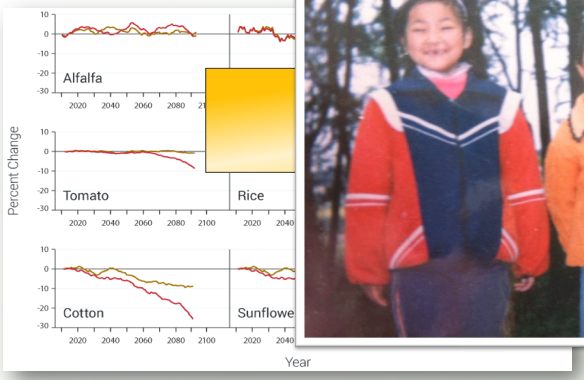


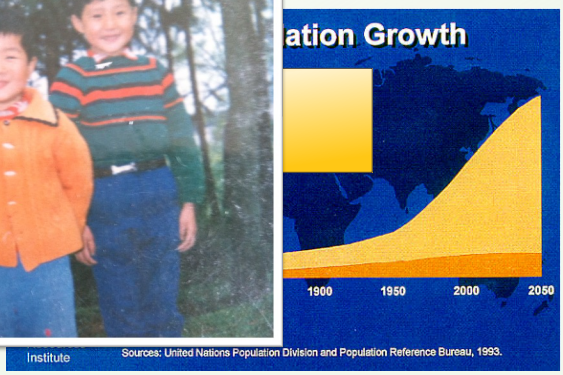
133 Pg soil C loss due to agriculture

4

Global cropping soils have been massively degraded







Source: globalchange.gov

5

We need to try to rebuild soil carbon stock, to support long-term agricultural sustainability

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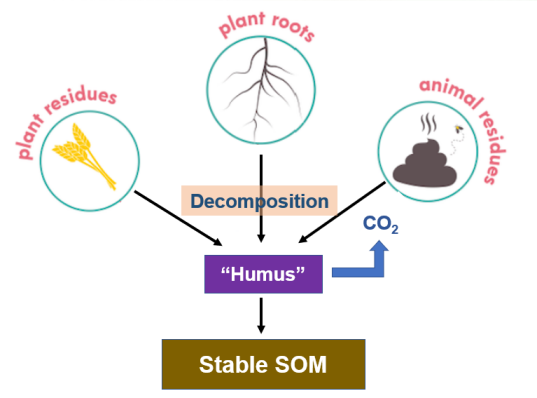
Soil organic matter formation



- Recalcitrant C that is difficult for microbes to decompose will persist in the soil;
- Initial decomposition products will be further transformed into larger, complex materials.

(What we learned in textbooks)

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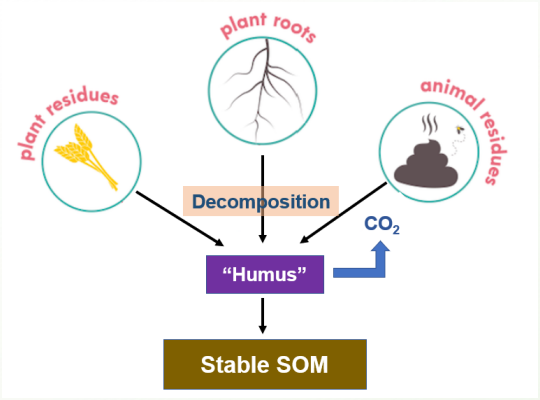
Question: how can we enhance SOM building in agroecosystems?



Strategy #1

Reduce C output
(Reducing tillage and disturbance)

Strategy #2

Increase C input
(Cover cropping; Residue retention; Organic amendment; Perennialization)

Strategy #3

More *recalcitrant* plant C input
(to slow down decomposition)

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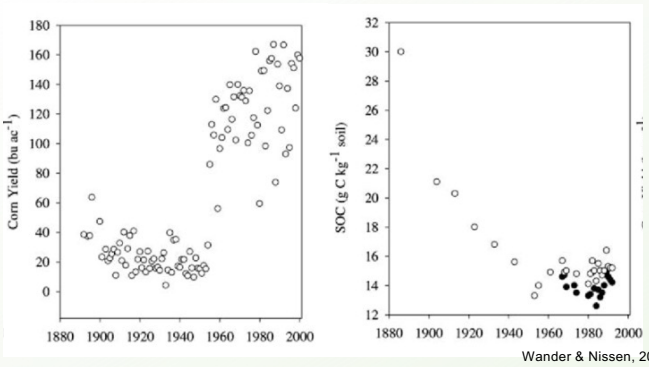
However, more recalcitrant plant C inputs do not always lead to soil C gains…



Wander & Nissen, 2003

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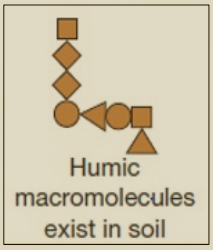
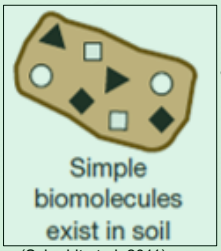
Understanding the nature of soil organic matter (SOM): A paradigm shift



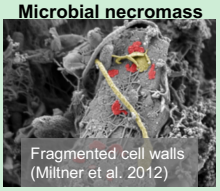
- Historically, we believed complex-structured, humic polymers were a major source of stable SOM.



(Schmidt et al. 2011).

- Direct high-resolution observation found simple-structured, microbial necromass (dead biomass) form stable SOM.

Microbial necromass



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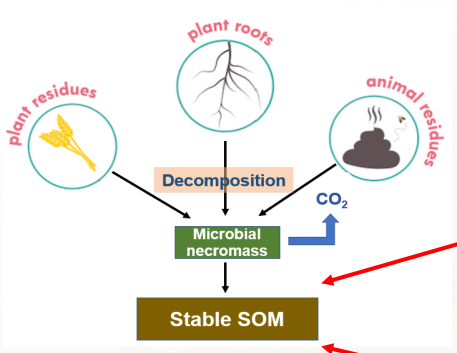
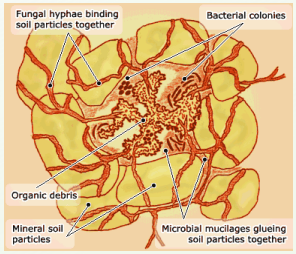


All raw C (plant or animal residues) will go through the "microbial funnel"; nothing is really recalcitrant



- Majority of SOM is from *microbial necromass*.
- Protection by small aggregates and/or organo-mineral associations leads to SOM persistence and accrual.

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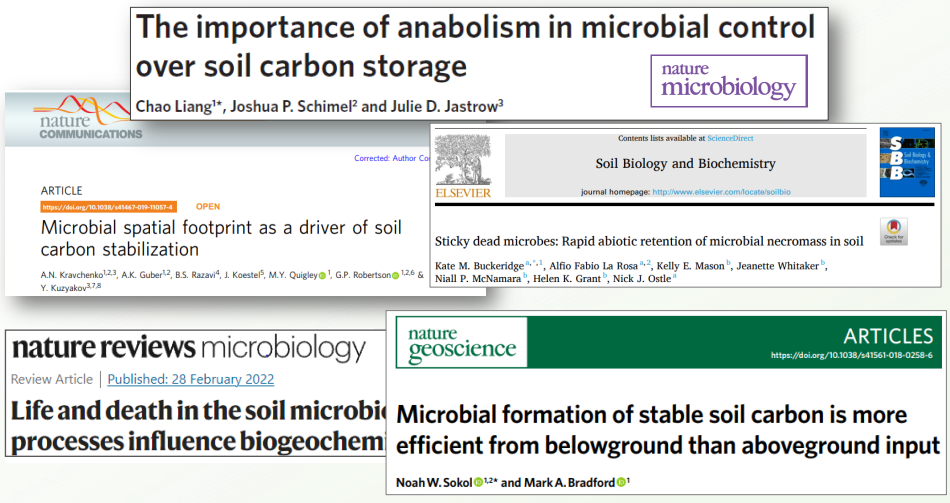

Question: how can we design agricultural systems to enhance the microbially-driven SOM building?

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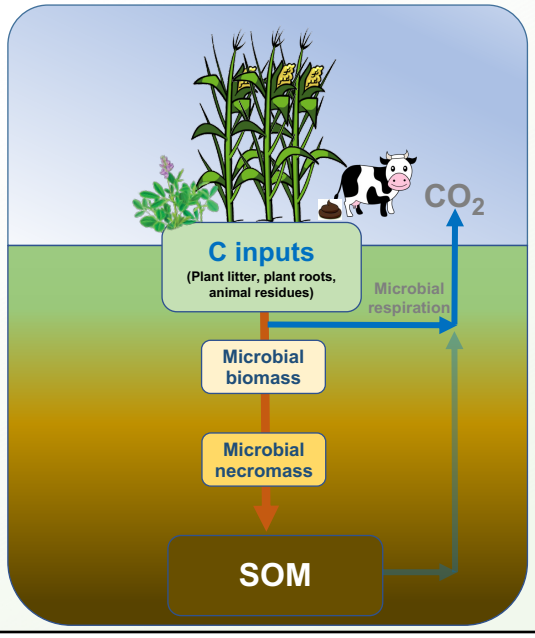
Question: how can we enhance SOM building in agroecosystems?



Strategy #1

Reduce C output
(Reducing tillage and disturbance)

Strategy #2

Increase C input
(Cover cropping; Residue retention; Organic amendment; Perennialization)

Strategy #3

Enhance microbial biomass and necromass production
(Feed them better food)

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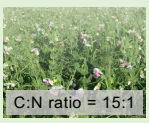
$$\text{Microbial C use efficiency (CUE)} = \frac{\text{Microbial biomass}\sim C}{\text{Microbial biomass}\sim C + CO_2\sim C}$$

Microbes like

Root exudates

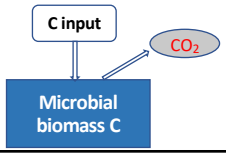
Low C:N ratio materials (legumes, compost, manure, etc.)



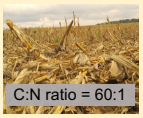
High CUE:

More C assimilated into biomass;

less C lost through respiration



Microbes dislike



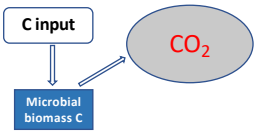
High C:N ratio materials

(Corn stover, wheat straw, matured cereal rye, etc.)

Low CUE:

Less C assimilated into biomass,

more C lost through respiration



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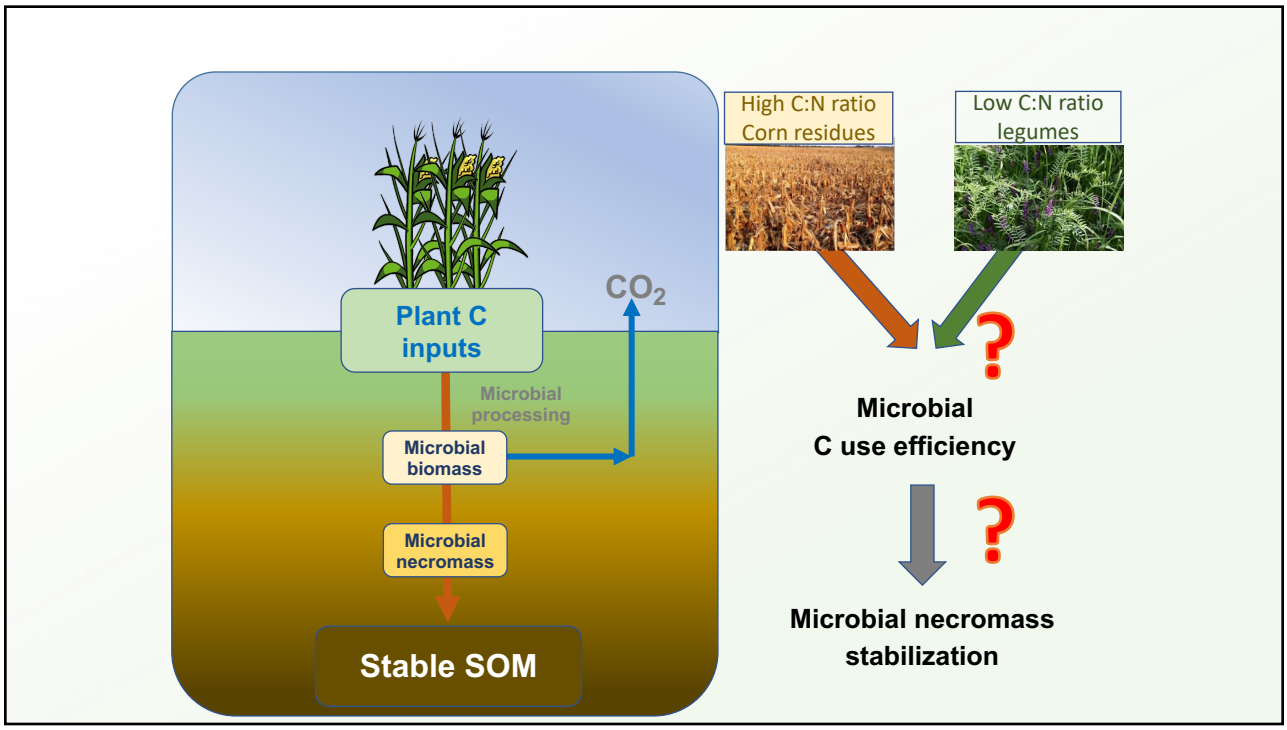
Plant C inputs
CO_2
Microbial processing
Microbial biomass
Microbial necromass
Stable SOM
High C:N ratio
Corn residues
Low C:N ratio
legumes
?
Microbial
C use efficiency
?
Microbial necromass
stabilization

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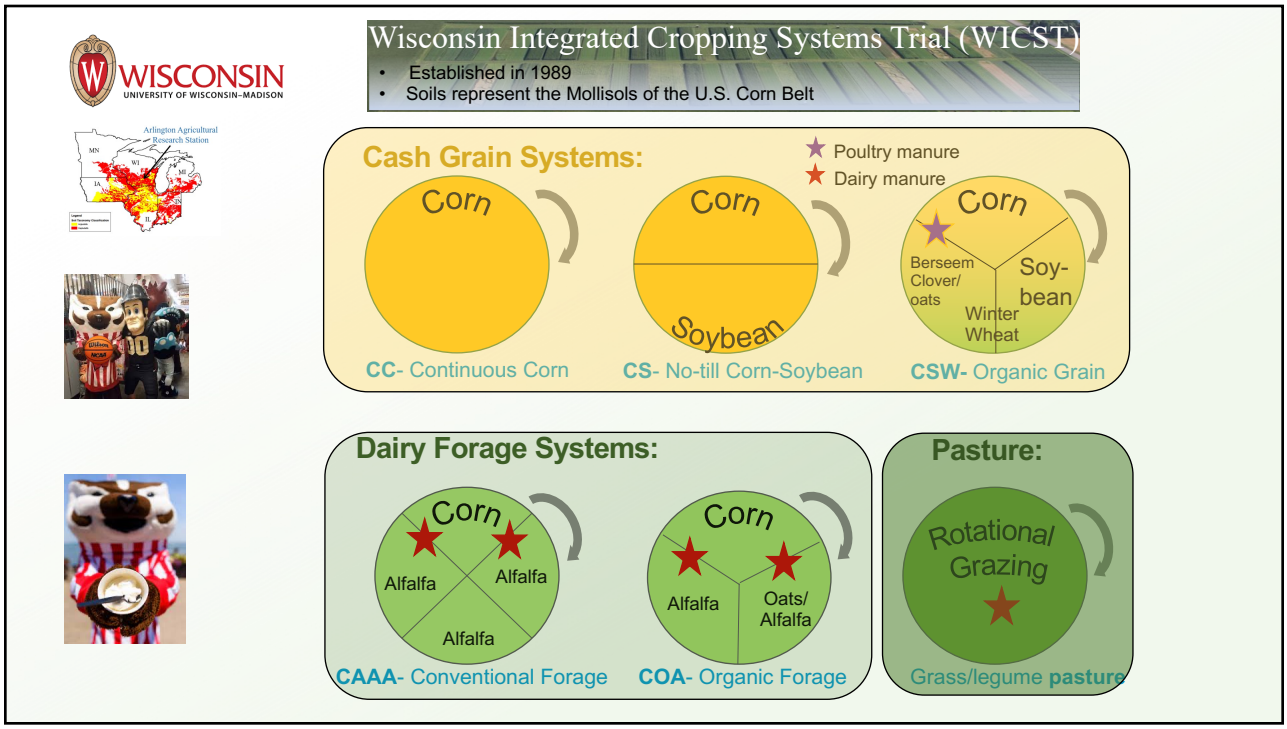
WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON
Wisconsin Integrated Cropping Systems Trial (WICST)
• Established in 1989
• Soils represent the Mollisols of the U.S. Corn Belt
Arlington Agricultural Research Station
Cash Grain Systems:
Poultry manure
Dairy manure
Corn
Corn
Soybean
Corn
Berseem Clover/ oats
Soy-bean
Winter Wheat
CC- Continuous Corn
CS- No-till Corn-Soybean
CSW- Organic Grain
Dairy Forage Systems:
Corn
Alfalfa
Alfalfa
Alfalfa
Corn
Alfalfa
Oats/ Alfalfa
CAAA- Conventional Forage
COA- Organic Forage
Pasture:
Rotational Grazing
Grass/legume pasture

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Cash Grain Systems

Most intensive cropping

Dairy Forage Systems

More diversity, Legumes/Manure

Grazed Perennial Pasture

More diversity & perenniality, Legumes & Manure, livestock

Increasing diversity, perenniality, and *quality (lower C:N ratio)* of plant inputs

Questions:

1) How do these distinct management systems affect soil microbial C use efficiency (CUE, microbial physiology) and microbial necromass accumulation?
2) Can systems with inputs of lower C:N ratio effectively enhance SOM?

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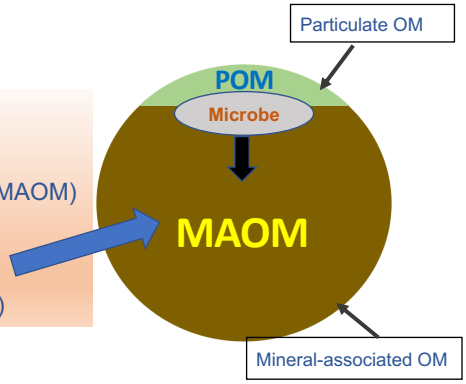
Methodologies:

- SOM fractionation
  - Particulate Organic Matter (POM)
  - Mineral-associated Organic Matter (MAOM)
- Diffuse reflectance infrared fourier transform spectroscopy (DRIFTS)
  - C composition (aromatic vs aliphatic)



- Microbial C use efficiency (CUE)= $\frac{^{13}C - Microbial\ biomass}{^{13}C - Microbial\ biomass + 13CO_2}$
  ^{13}C substrate tracing
- Microbial necromass
  (Amino sugars, biomarkers of microbial cell walls)
- Oxidative enzyme activities
  (Potential of SOM loss)

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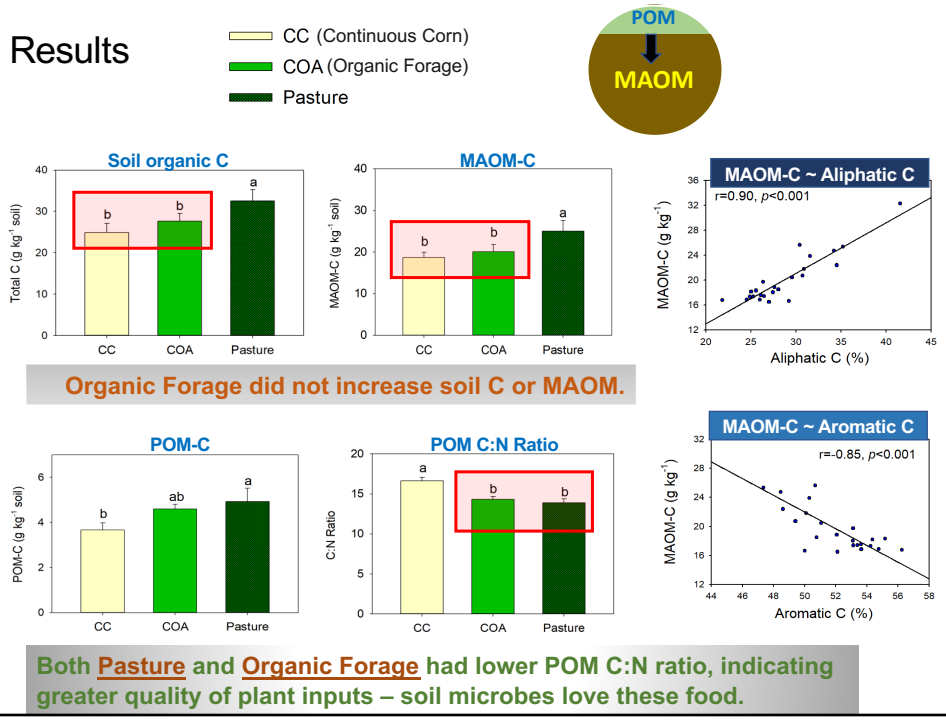
Results



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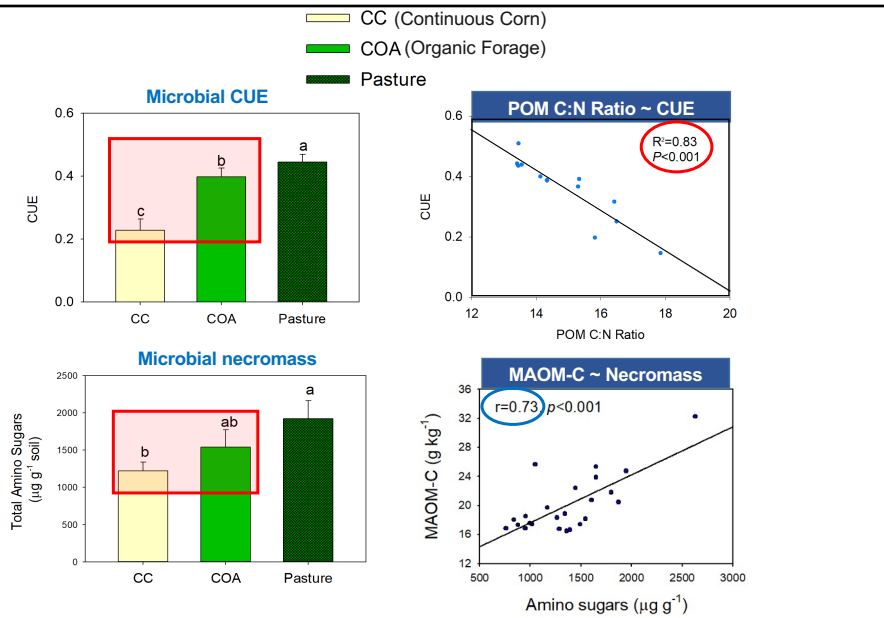

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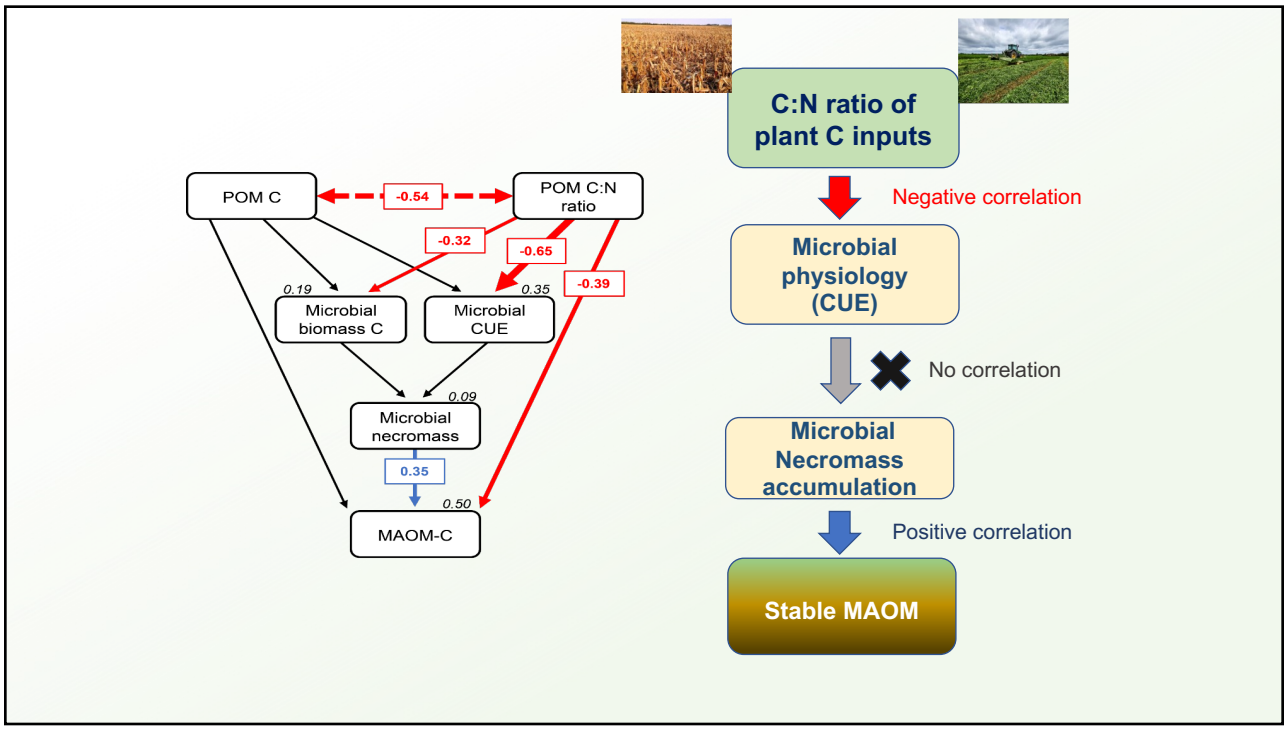

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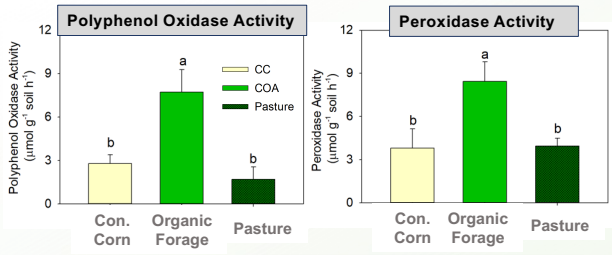
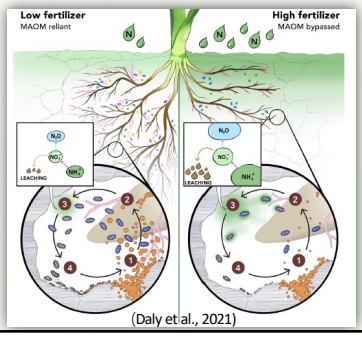
Failing to deliver: The Organic Forage system that had *legume and manure* inputs could not stabilize microbial necromass - Why?



- **Organic Forage has higher oxidative enzyme activities, indicating a faster SOM mineralization than Pasture.**

Plant nutrient demand under low-input?



Disturbance?

System	Tillage Index
Continuous Corn	1
Organic forage	0.67
Pasture	0

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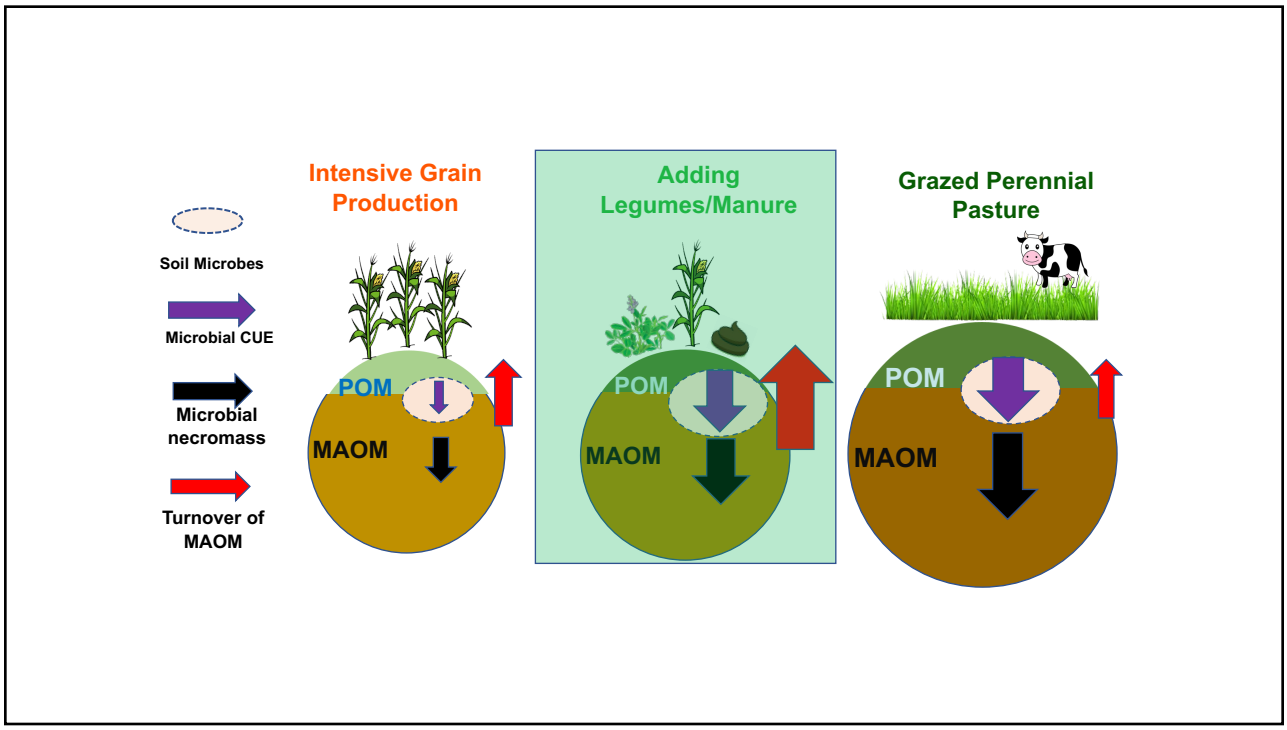

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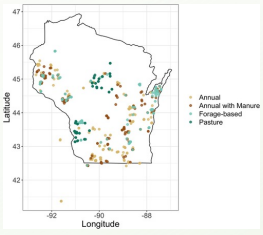
Dr. Matt Ruark
University of Wisconsin-Madison

Agricultural & Environmental Letters

RESEARCH LETTER | Open Access

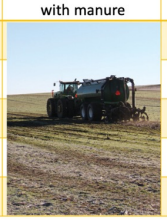
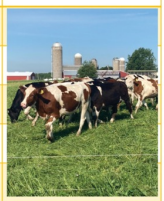
Cropping systems with perennial vegetation and livestock integration promote soil health

Abigail J. Augarten, Lindsay Chamberlain Malone, Gregory S. Richardson, Randall D. Jackson, Michel A. Wattiaux, Shawn P. Conley, Amber M. Radatz, Eric T. Cooley, Matthew D. Ruark



Increasing integration of soil health principles:
↑ soil cover, ↓ soil disturbance, ↑ crop diversity, ↑ continuous living roots, ↑ livestock integration

CROPPING SYSTEM

		annual rotation		annual rotation with manure		forage-based with perennial		grazed pasture
Biological indicators of soil health	SOM		=		=		<	
	POXC		<		<		=	
	MinC		<		<		<	
	ACE		=		=		<	
	PMN		=		<		<	

Increasing biological indicators of soil health

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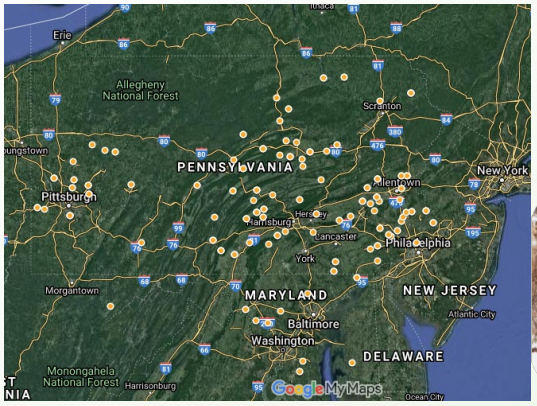

Dr. Franklin Egan
PASA Sustainable Agriculture

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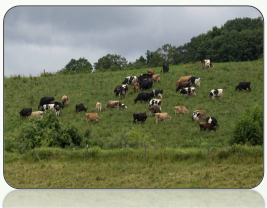
Participating Farms



	Row Crop	Vegetables	Pastured Livestock
2016		12	
2017	4	26	
2018	15	40	8
2019	27	58	21

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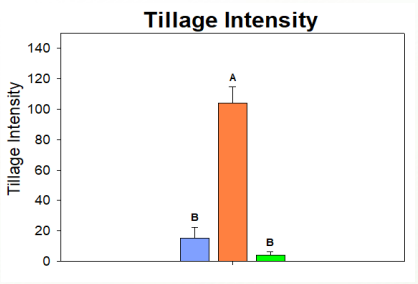
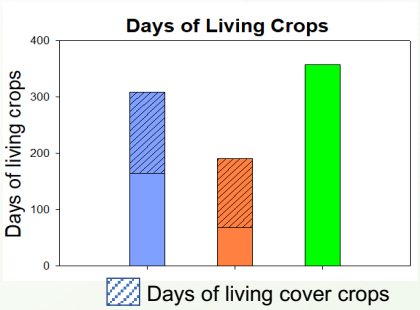
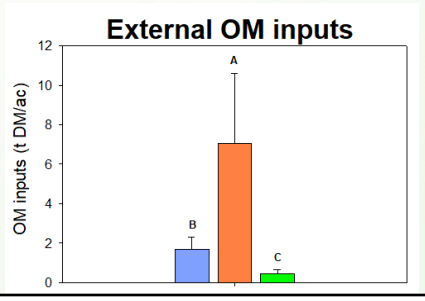
Management indicators of the three systems







Row Crop
Vegetable
Pastured Livestock

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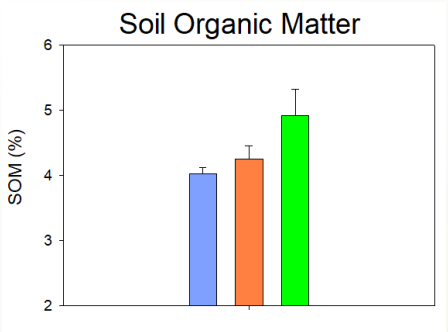
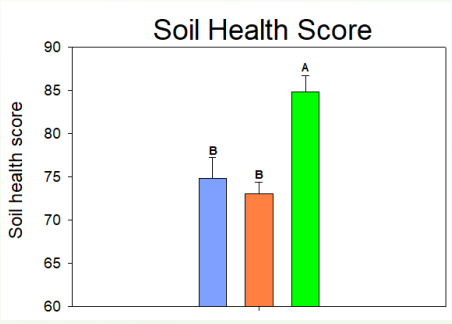
Overall soil health score of 3 systems





Row Crop
Vegetable
Pastured Livestock

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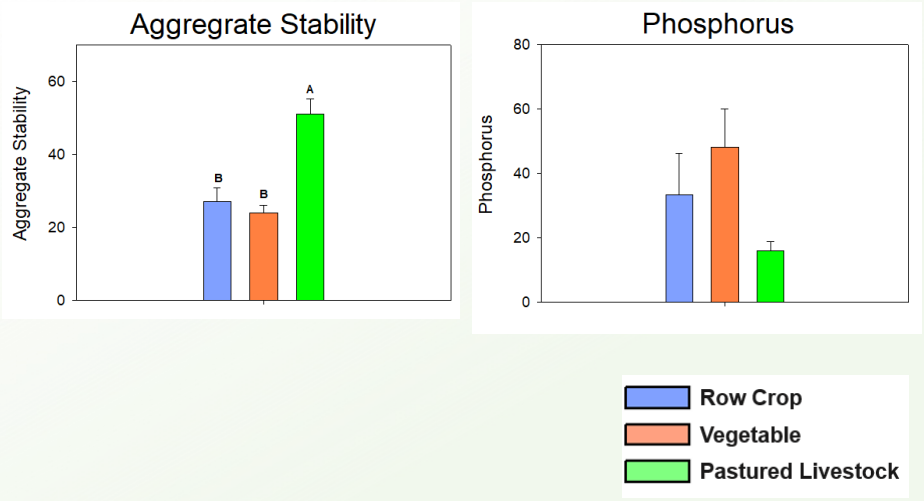
Soil health indicators



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One participating vegetable farm

- Farm purchased in 1996;
- Annual compost application from 1997 to 2008.

	1997	2008	2019
P	Low	Very High	Too High
K	Low	High	High
pH	5.9	7	7.5
Organic Matter	2.10%	5.80%	8.70%

Indicator	Value	Rating	Constraints
Predicted Available Water Capacity	0.32	99	
Surface Hardness			Not rated: No Field Penetrometer Readings Submitted
Subsurface Hardness			Not rated: No Field Penetrometer Readings Submitted
Aggregate Stability	23.4	33	
Organic Matter	8.7	99	
ACE Soil Protein Index	24.4	99	
Soil Respiration	1.1	96	
Active Carbon	1373	99	
Soil pH	7.5	94	
Extractable Phosphorus	320.1	0	High Phosphorus, Environmental Impact Risk

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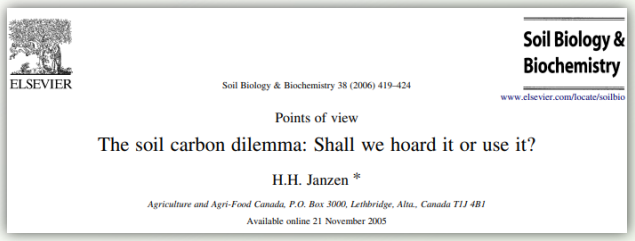
Takeaways

- Microbes play a substantial role in SOM formation, but their effects on soil C are a "*double-edged sword*".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Points of view

The soil carbon dilemma: Shall we hoard it or use it?

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Available online 21 November 2005

Dr. Henry Janzen
Agriculture and
Agri-Food Canada

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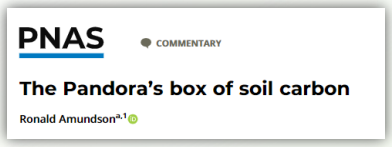
Takeaways

- Even though we now know more about the microbial role in SOM formation, it remains inherently difficult to accrue soil C in intensive annual production systems.


PNAS COMMENTARY

The Pandora's box of soil carbon

Ronald Amundson[a,1]

Dr. Ron Amundson
University of
California Berkeley

"Presumably, all scientists (and planetary citizens) would love to push 133 Gt of C back into the global soil box. **But this just doesn't appear to be an easy or rapid goal to accomplish.** Farming is a several-millennia-old experiment, one that remains far removed from perfection. It is a complex system, subject to unexpected feedbacks—including those of a warming planet. A scientifically holistic approach to farming has a major opportunity to integrate differing strategies to climatically improve the system as a whole, rather than placing undue emphasis on a single component, organic C."

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PURDUE CULTIVATE PRODUCE SUSTAIN
AGRONOMY
SOIL PLANTS WATER

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