LESSON 4
January 12, 2023

Soil management for organic production: Putting theory into practice

ORGANIC AGRONOMY TRAINING

with Dr. Martin Entz
University of Manitoba

9:00 - 10:15 am CT
Jan. 5, 6, 10, 12, 13, 2023
Live and recorded sessions
free training; CEU credits

- **Rotations, nutrient management**
- **Crop establishment, seeding, tillage**
- **Insects, weeds, disease**
- **Soil health**
- **Q&A, discussion**

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We gratefully acknowledge funding from the Canadian Agricultural Partnership.

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Department of Plant Science
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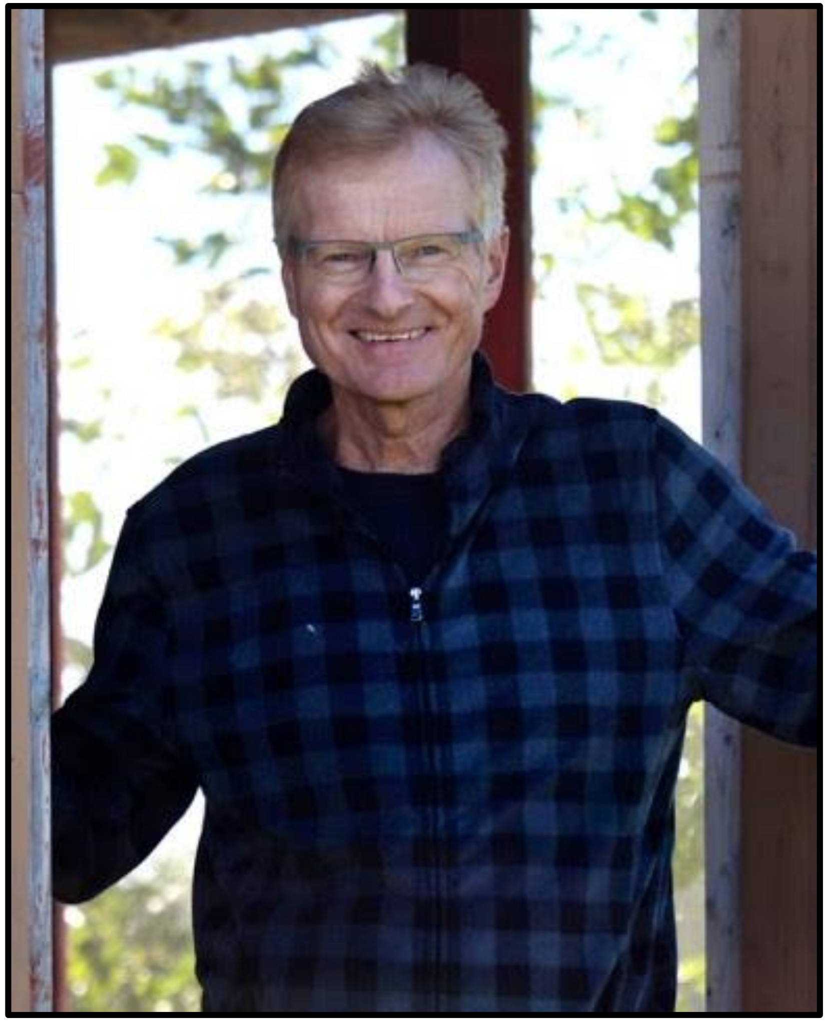
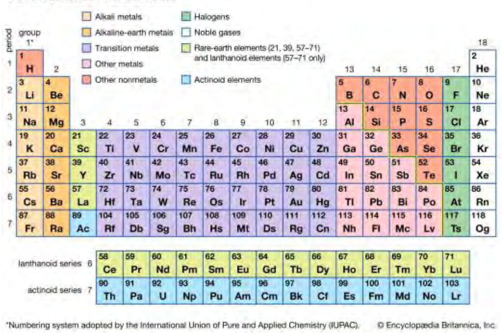
umanitoba.ca/outreach/naturalagriculture/



Lesson 4. Managing soils for organic production: Theory and practice



Periodic table of the elements

🟧 Alkali metals
🟧 Alkaline-earth metals
🟪 Transition metals
🟪 Other metals
🟥 Other nonmetals
🟩 Halogens
☐ Noble gases
🟩 Rare-earth elements (21, 39, 57–71) and lanthanoid elements (57–71 only)
🟦 Actinoid elements

period / group	1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

lanthanoid series 6	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
actinoid series 7	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

*Numbering system adopted by the International Union of Pure and Applied Chemistry (IUPAC).

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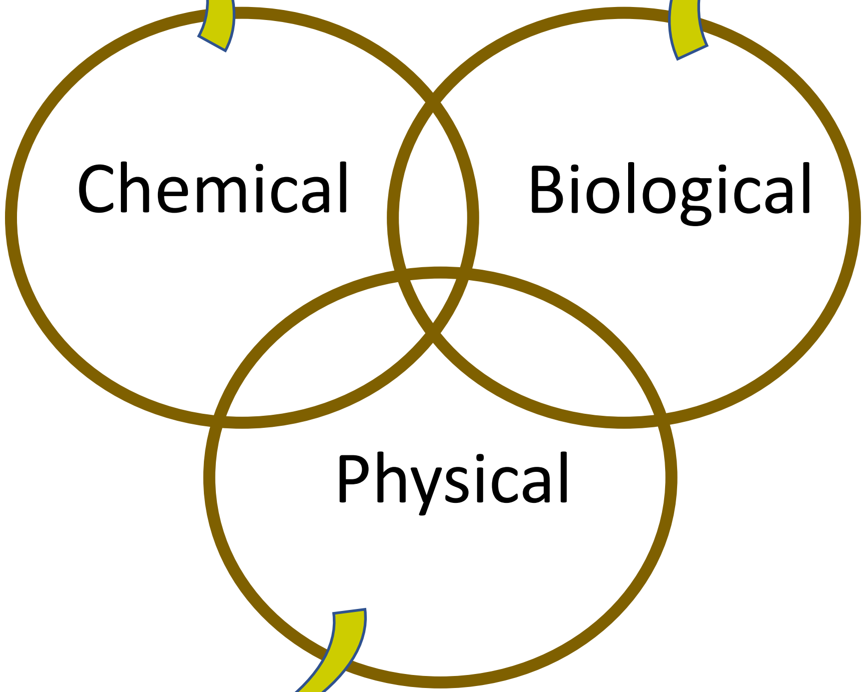


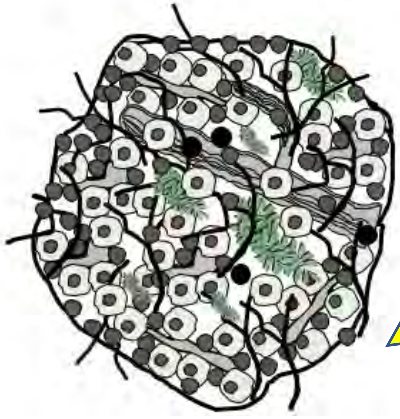
Chemical

Biological

Physical

Soil microbiome

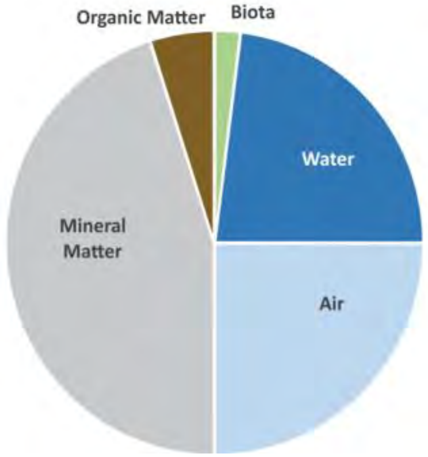
Aggregates



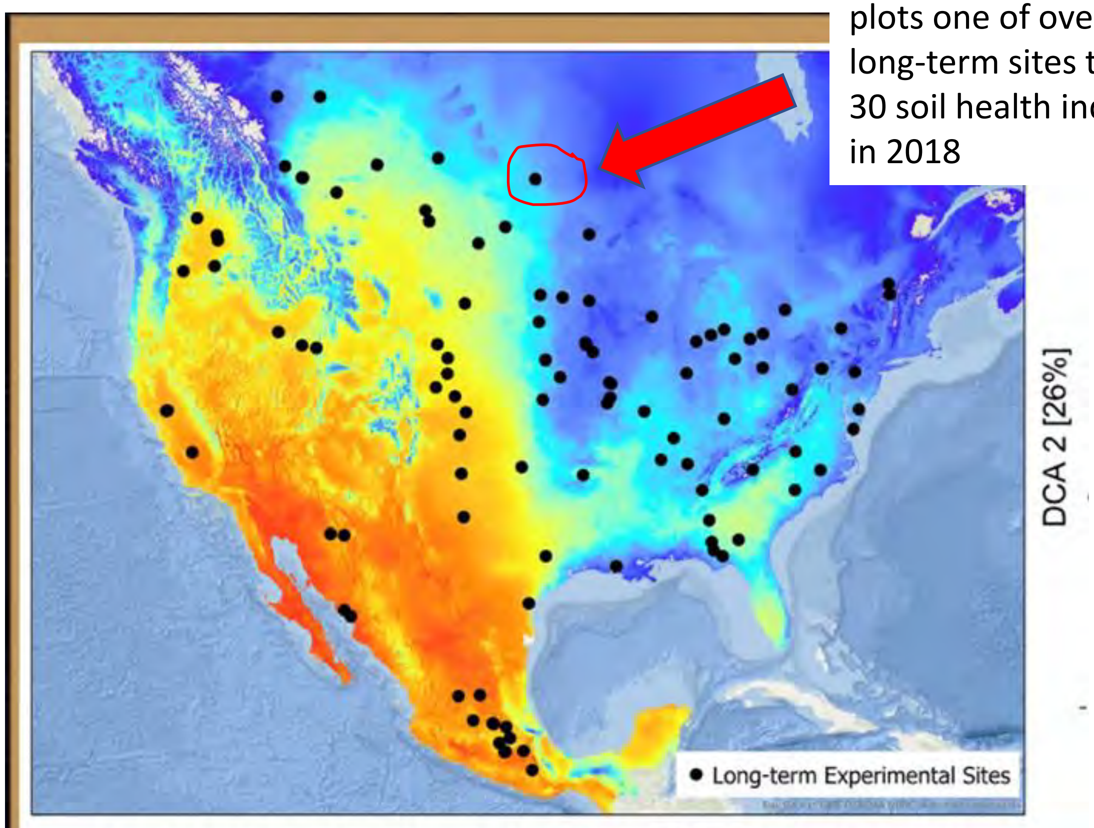
This is the 4th in a series on "Organic Agronomy" prepared and presented by Dr. Martin Entz, Professor of Natural Systems Agriculture, University of Manitoba

Soil organic matter

The most important soil health indicator from the study



UM's Glenlea organic plots one of over 121 long-term sites tested for 30 soil health indicators in 2018



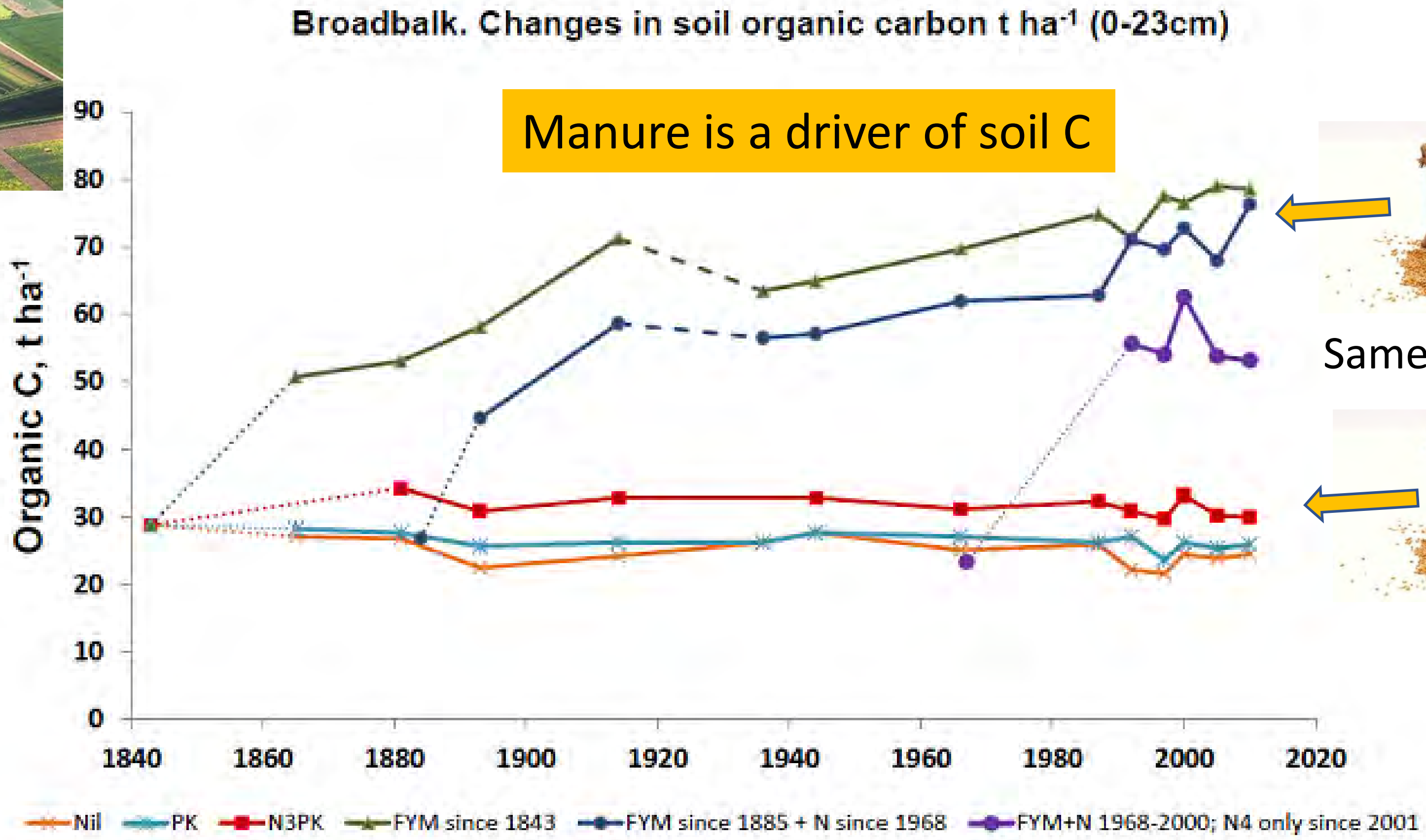
Hargreaves climate moisture deficit and SHI Sites

University of Manitoba

Soil Health Institute

OUR MISSION:
Safeguard and enhance the vitality and productivity of soil through scientific research and advancement.

Manure is a driver of soil C



Broadbalk. Changes in soil organic carbon t ha^{-1} (0-23cm)

Data includes adjustment for changes in bulk density on FYM treatments. All data is from continuous wheat sections. Starting values for all treatments in 1843 and the later FYM treatments were estimated (.......). Decreases between 1914 and 1936 are due to the introduction of regular fallowing in 1926; FYM was not applied in fallow years (- - - -). Updated from Powlson et al, 2012.

© Rothamsted Research, 2014

Same grain yield

1902 Static Fertilization
Experiment
Bad Lauchstädt, Germany

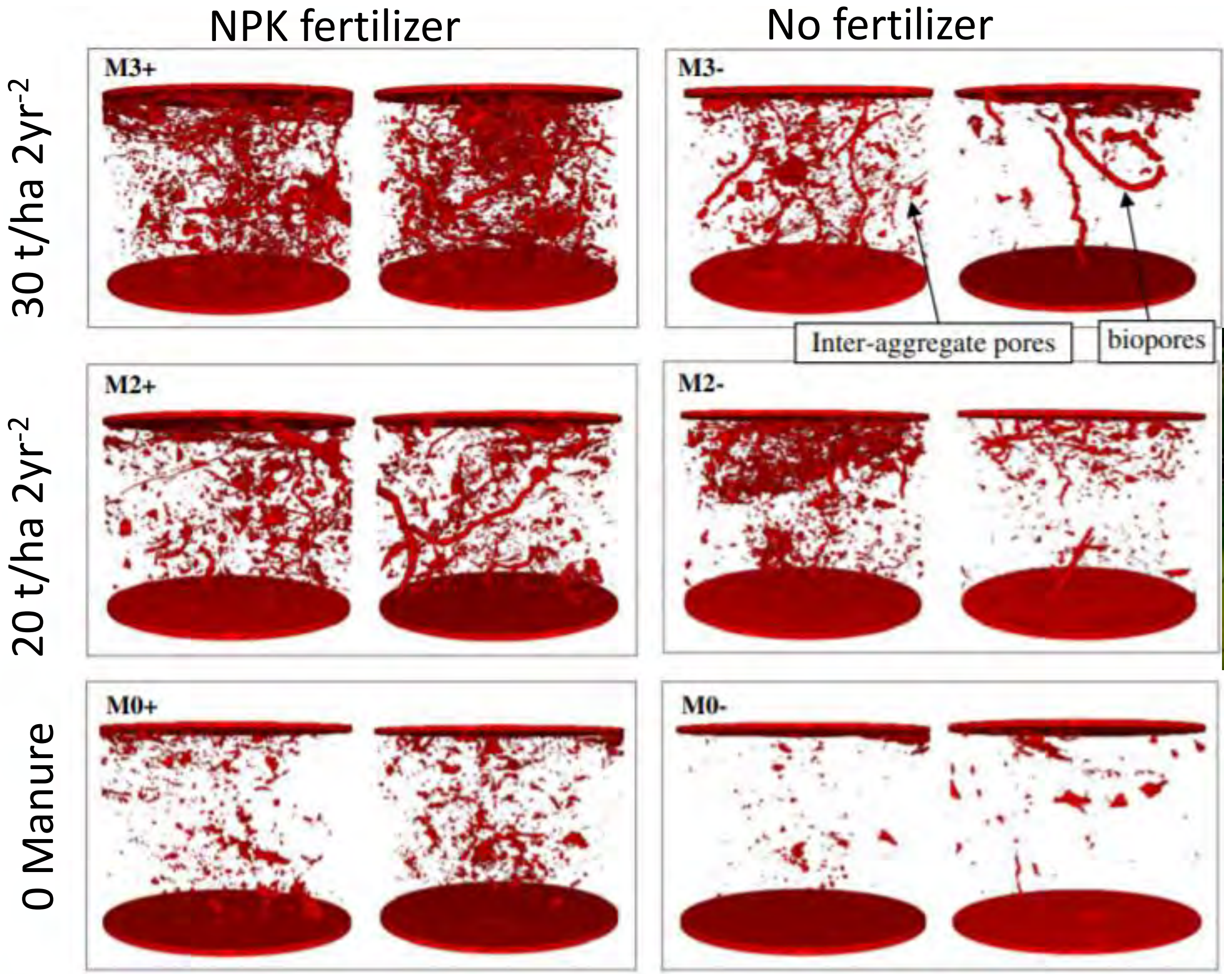
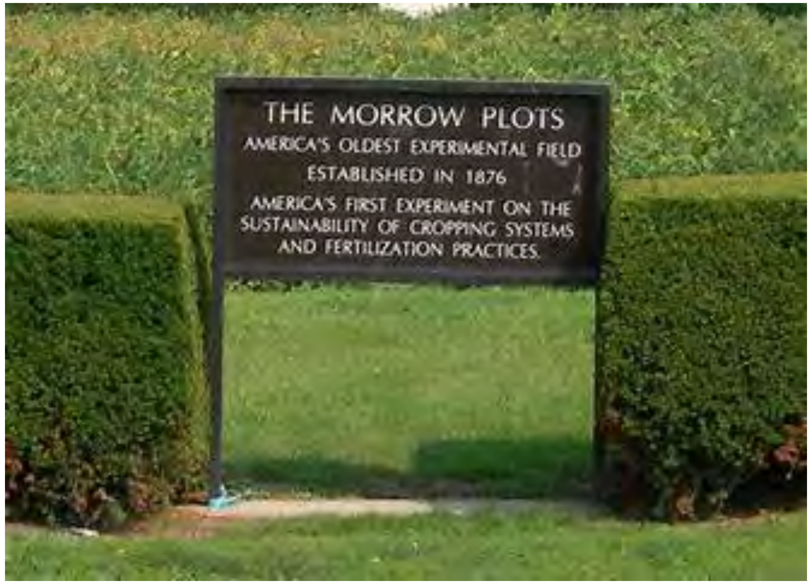


Fig. 5. Three-dimensional renderings of the soils macroporous systems reconstructed from binarized X-ray CT data. Both extracted cores for each plot (treatm

Manure improves soil structure too

Naveed, M., Moldrup, P., Vogel, H.J., Lamandé, M., Wildenschild, D., Tuller, M. and de Jonge, L.W., 2014. Impact of long-term fertilization practice on soil structure evolution. *Geoderma*, *217*, pp.181-189.



Crop rotation is a driver of soil C

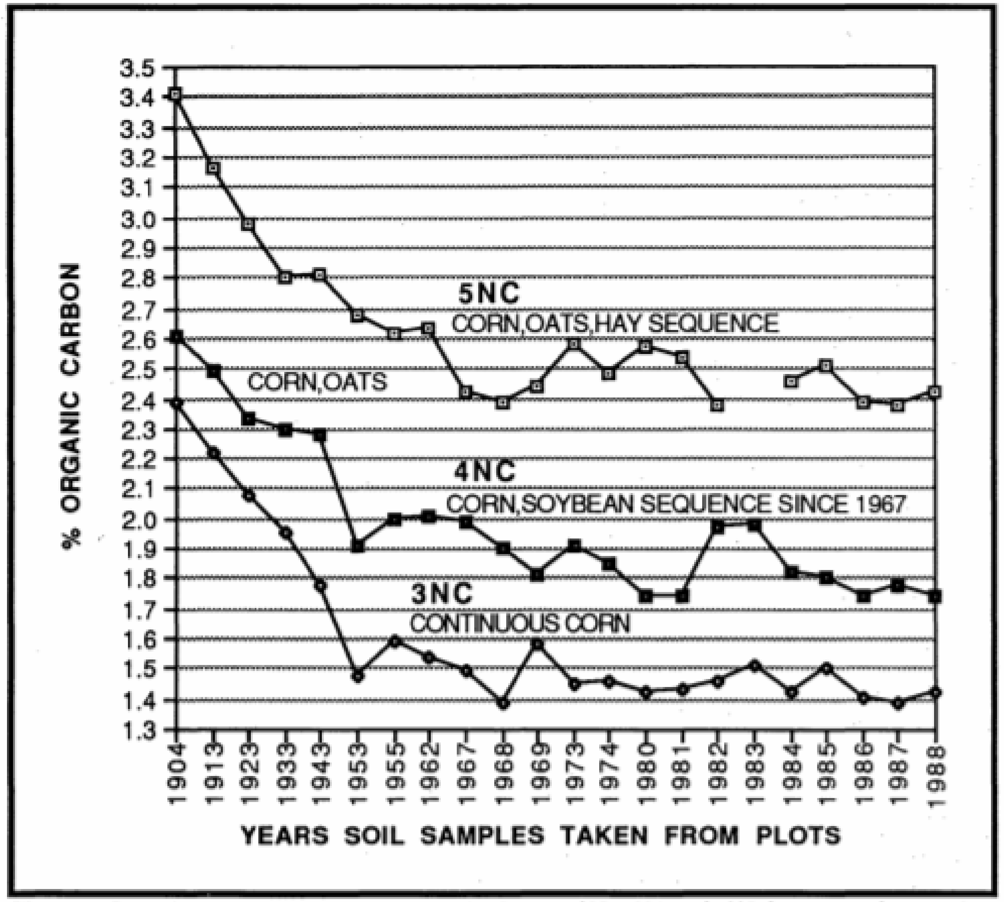


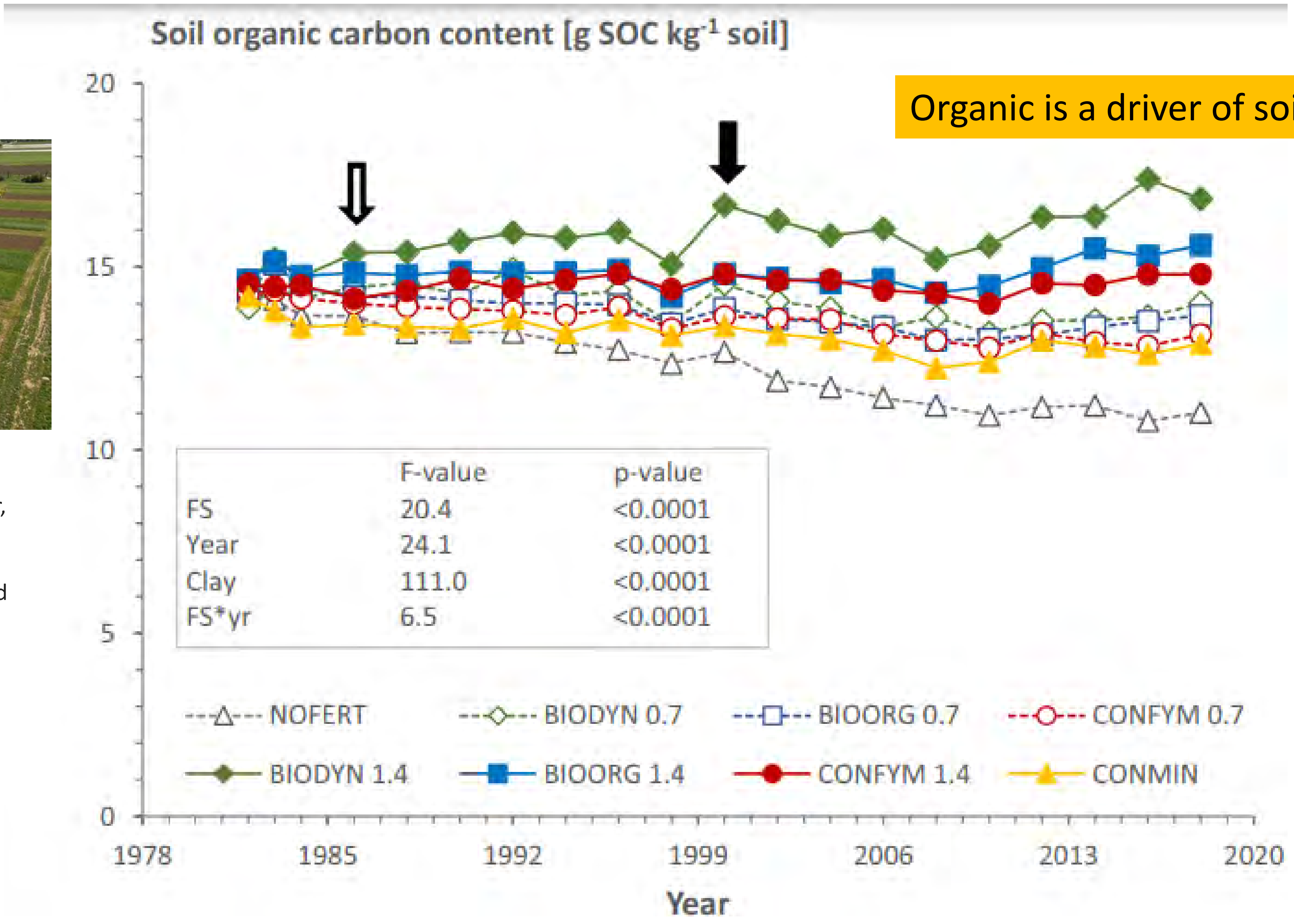
Figure 3. Organic carbon in Morrow Plots soil of plots 3NC, 4NC and 5NC for selected years during 1904 to 1988.

Morrow plots, University of Illinois. Started 1876

DOK, Switzerland

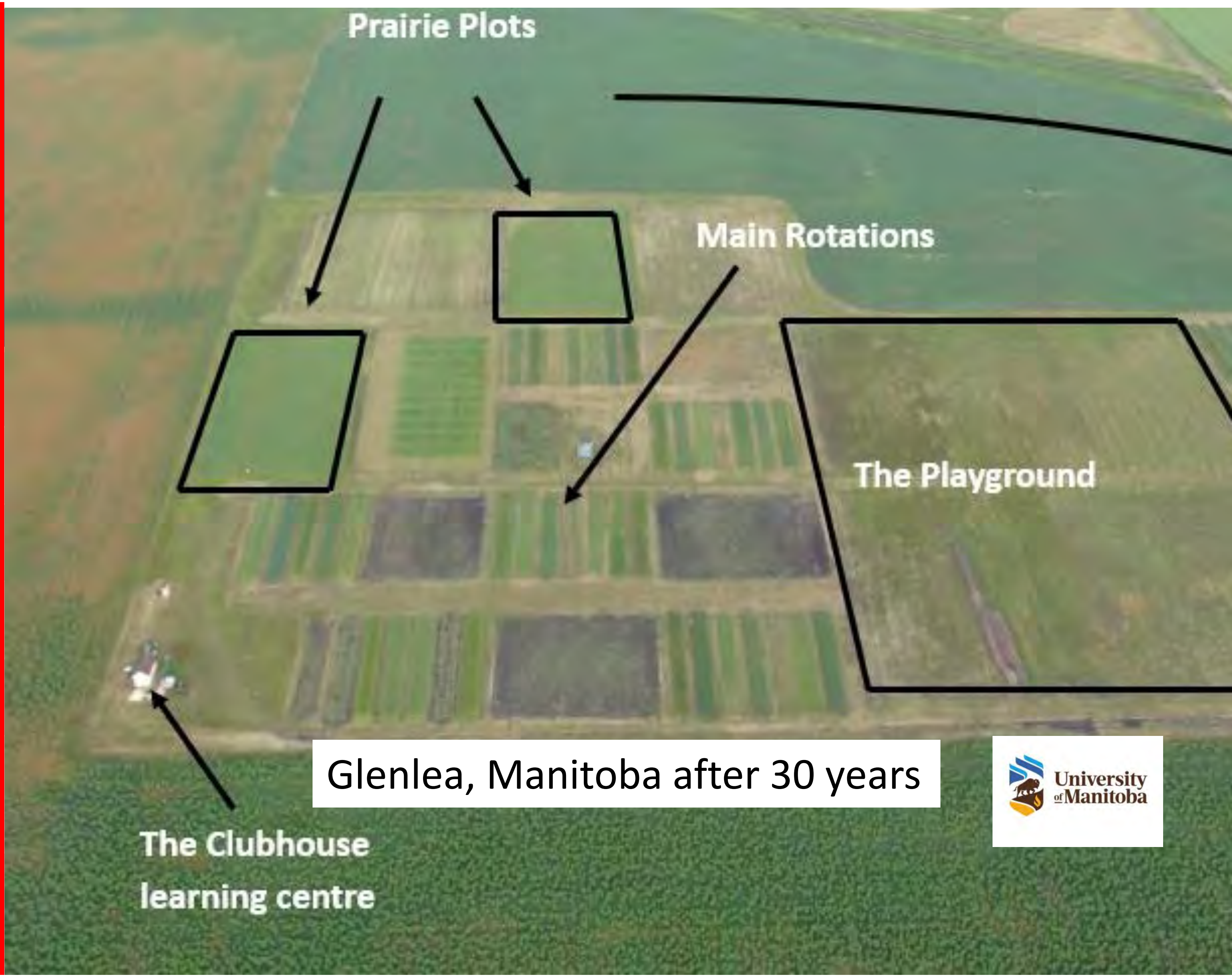
Krause, H.M., Stehle, B., Mayer, J., Mayer, M., Steffens, M., Mäder, P. and Fliessbach, A., 2022. Biological soil quality and soil organic carbon change in biodynamic, organic, and conventional farming systems after 42 years. *Agronomy for Sustainable Development*, *42*(6), pp.1-14.

Organic is a driver of soil C



	F-value	p-value
FS	20.4	<0.0001
Year	24.1	<0.0001
Clay	111.0	<0.0001
FS*yr	6.5	<0.0001

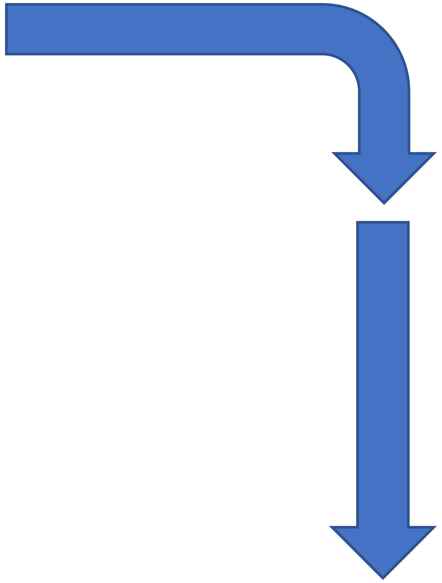
Cropping System	Total C % (Microbial biomass C)
Prairie	4.4 ^{1}(1750a)
Grain only conventional	4.5 (1179c)
Grain only organic	3.7 (1080d)
Forage-grain conventional	3.9 (1476 b)
Forage-grain organic	4.2 (1648a)
Forage-grain organic plus manure	4.5 (1718a)
P value	0.092 (0.0001)



Glenlea, Manitoba after 30 years

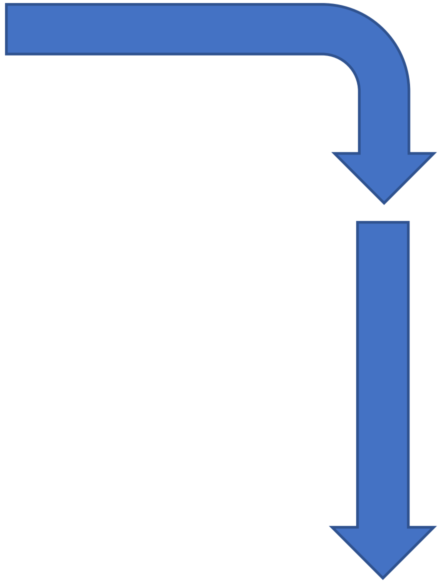
University of Manitoba

How does this material become organic matter?



And, what is soil organic matter?

How does this material become organic matter?



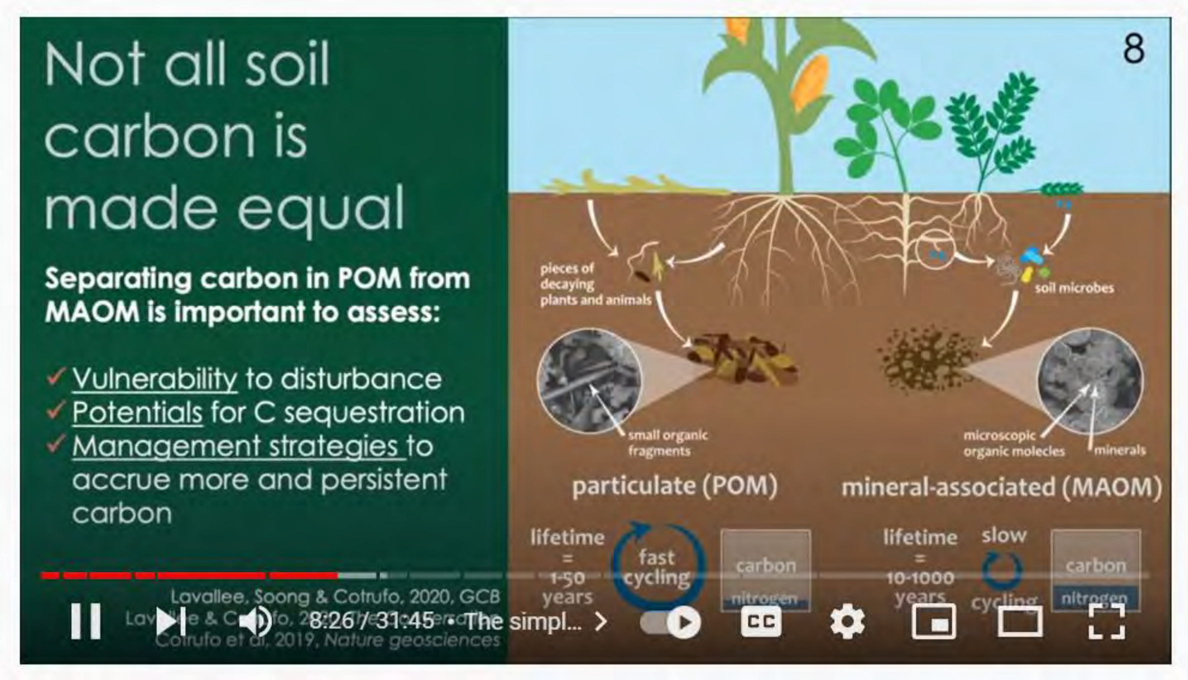
Understanding of organic matter, and how plant material becomes long-term soil organic matter has increased. New theories have been developed and they have been supported by new research.

Diploma and degree students first watch this video: https://source.colostate.edu/csu-study-proposes-new-approach-to-retaining-soil-carbon/

Degree students also watch this video by Dr. Francesca Cotrufo as well: https://www.youtube.com/watch?v=MgYzGWIt71s

And, what is soil organic matter?

What is soil organic matter?



Not all soil carbon is made equal

Separating carbon in POM from MAOM is important to assess:

- ✓ Vulnerability to disturbance
- ✓ Potentials for C sequestration
- ✓ Management strategies to accrue more and persistent carbon

Lavallee, Soong & Cotrufo, 2020, GCB
Lavallee & Cotrufo, 20…
Cotrufo et al, 2019, Nature geosciences

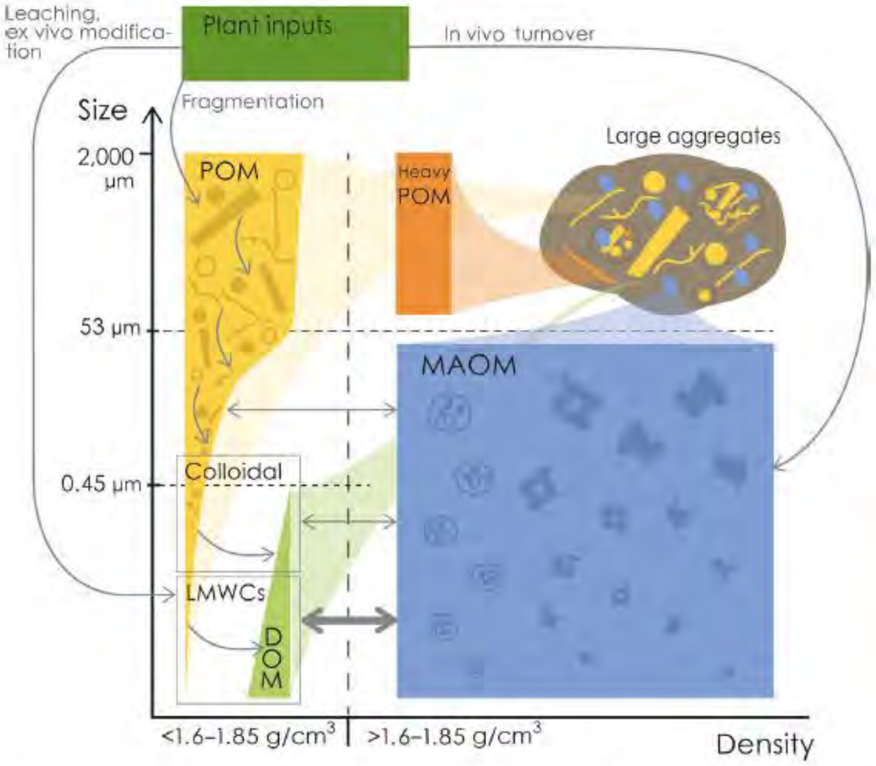
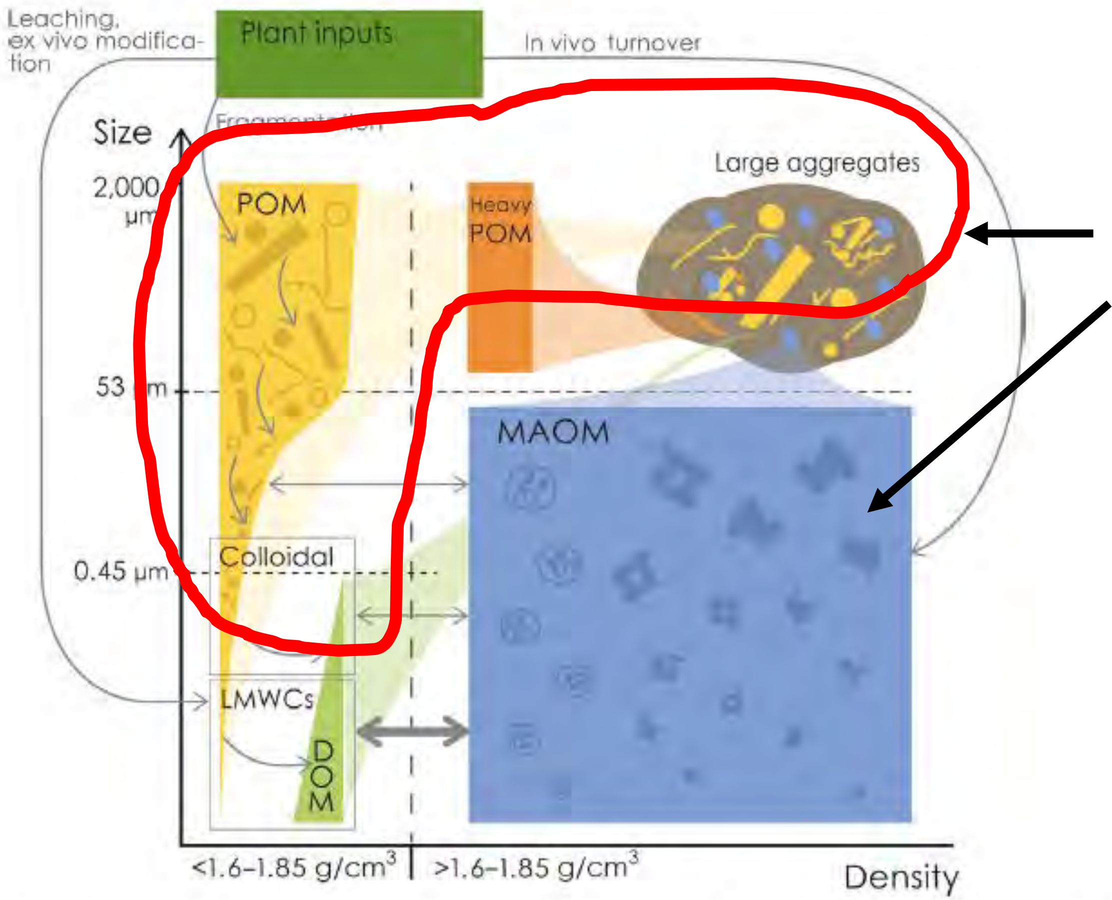


FIGURE 2 Conceptual representation of major soil organic matter (SOM) components discussed in this review. These SOM components are physically defined based on size and density, shown on the y and x axes, respectively. The upper size limit specification for MAOM varies by region, from 20 to 63 µm; we show 53 µm here for simplicity. Dissolved organic matter (DOM) is generally defined as <0.45 µm and water-extractable. Mineral-associated organic matter (MAOM) has multiple forms, including small particulate organic matter (POM)-like structures encapsulated by minerals, organo-mineral clusters, and primary organo-mineral complexes. Large aggregates can contain all other components to varying degrees. LMWCs are low molecular weight compounds. Arrows leading from plant inputs to different components
he publication: the DOM value

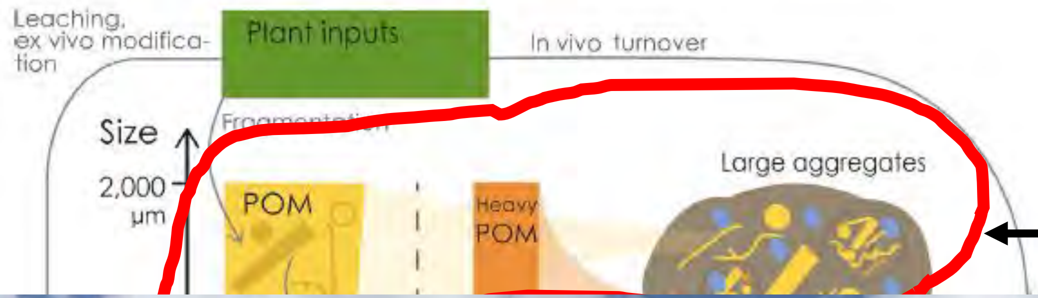
Lavallee, J.M., Soong, J.L. and Cotrufo, M.F., 2020. Conceptualizing soil organic matter into particulate and mineral-associated forms to address global change in the 21st century. *Global Change Biology*, *26*(1), pp.261-273.



<u>Two main soil organic matter pools:</u>

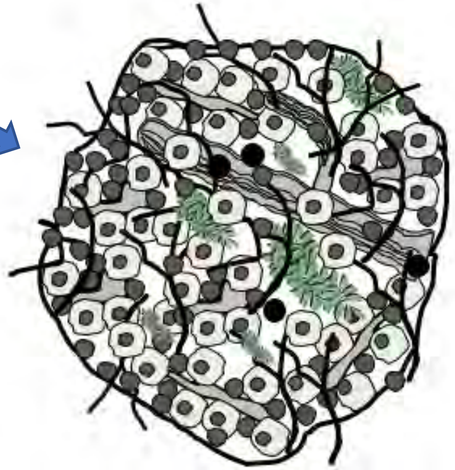
- POM (particulate organic matter)
- MAOM (mineral associated organic matter)

Lavallee, J.M., Soong, J.L. and Cotrufo, M.F., 2020. Conceptualizing soil organic matter into particulate and mineral-associated forms to address global change in the 21st century. *Global Change Biology*, *26*(1), pp.261-273.

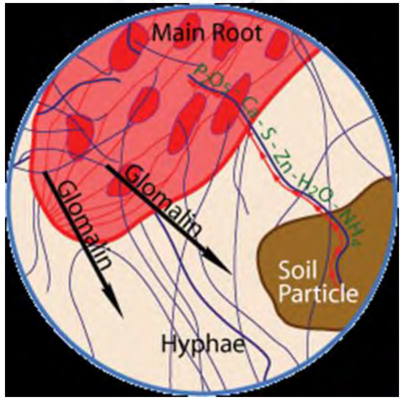


<u>Two main soil organic matter pools:</u>

- POM (particulate organic matter)
  - Residue stabilized in soil aggregates



Aggregates



Lavallee,
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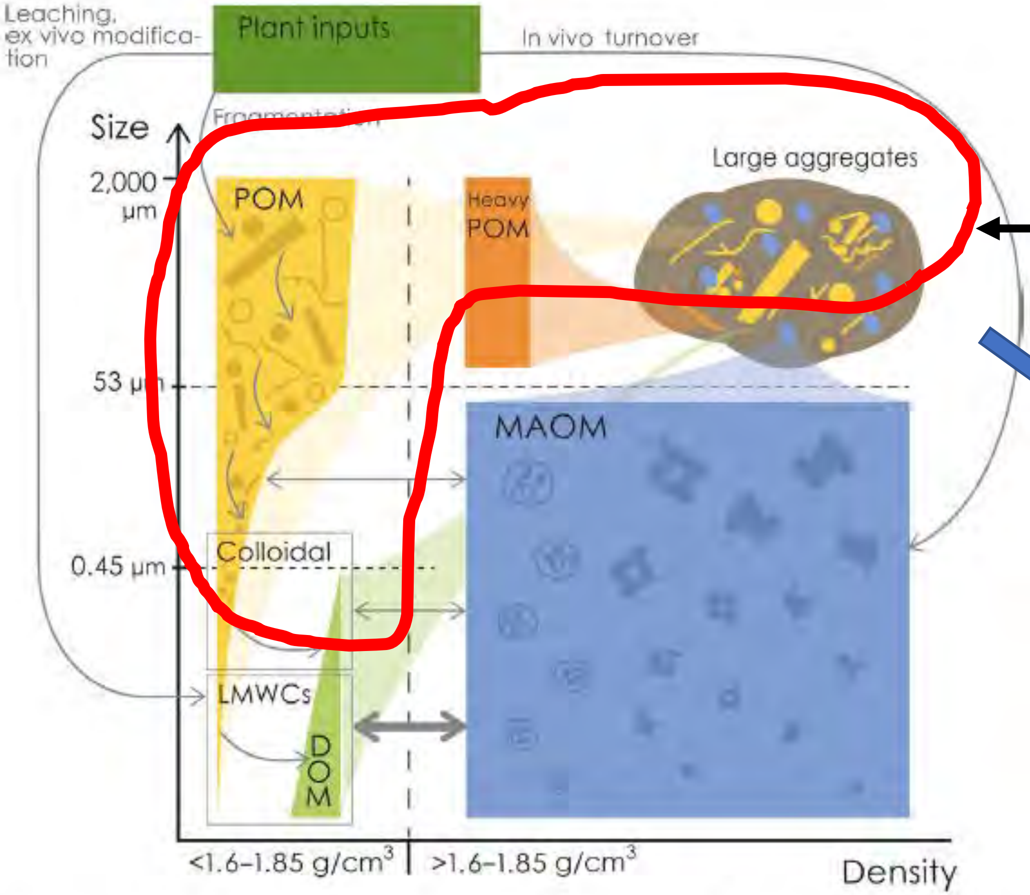
pp.261-27

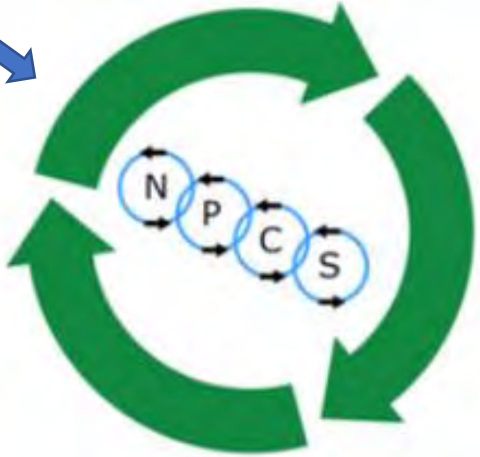
Two main soil organic matter pools:

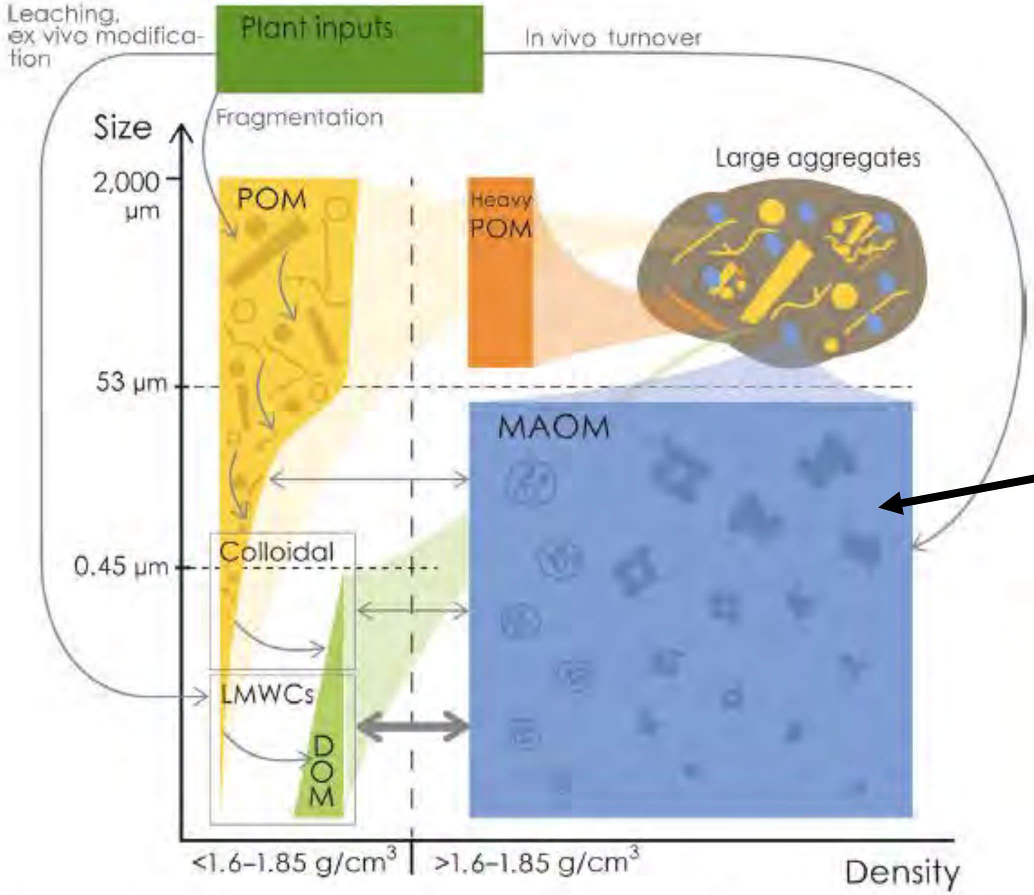
- POM (particulate organic matter)



Lavallee, J.M., Soong, J.L. and Cotrufo, M.F., 2020. Conceptualizing soil organic matter into particulate and mineral-associated forms to address global change in the 21st century. *Global Change Biology*, *26*(1), pp.261-273.

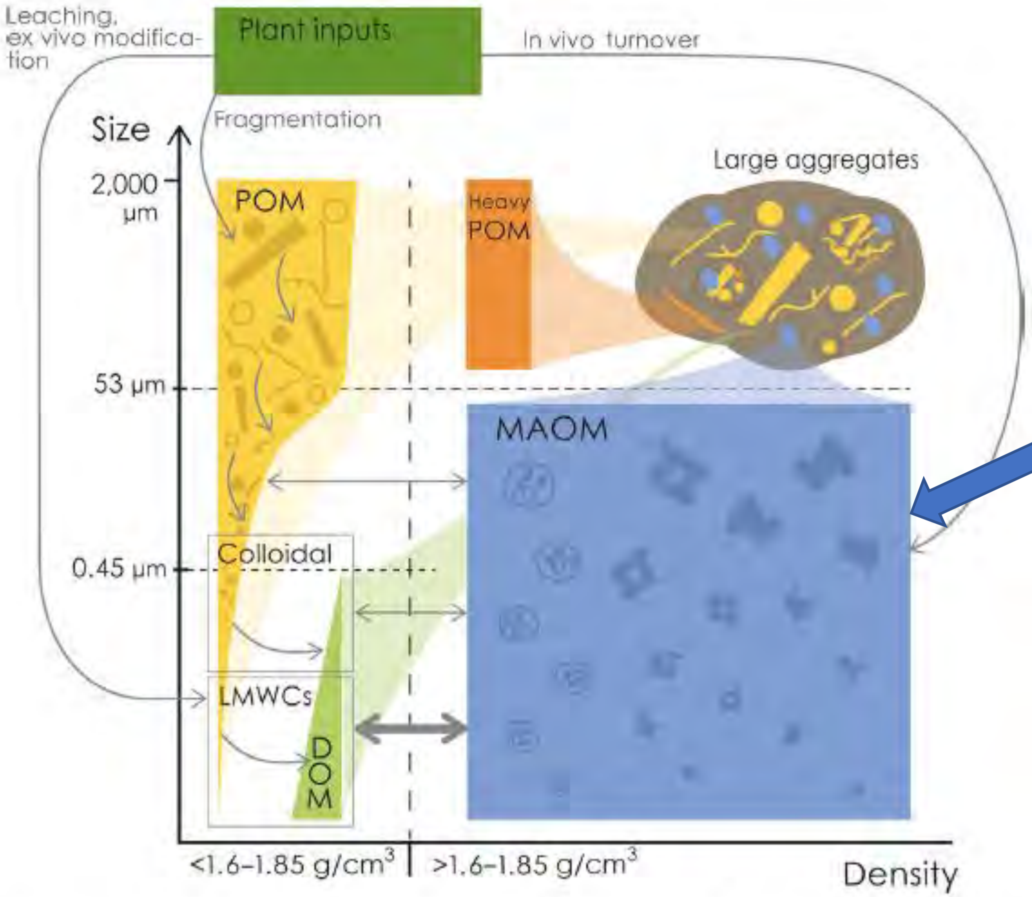
Important for nutrient cycling – which is super important in organic farming.





- MAOM (mineral associated organic matter)
    - Dead microbial cells embedded in clay and silt particles
    - This C long-term stable

Lavallee, J.M., Soong, J.L. and Cotrufo, M.F., 2020. Conceptualizing soil organic matter into particulate and mineral-associated forms to address global change in the 21st century. *Global Change Biology*, *26*(1), pp.261-273.

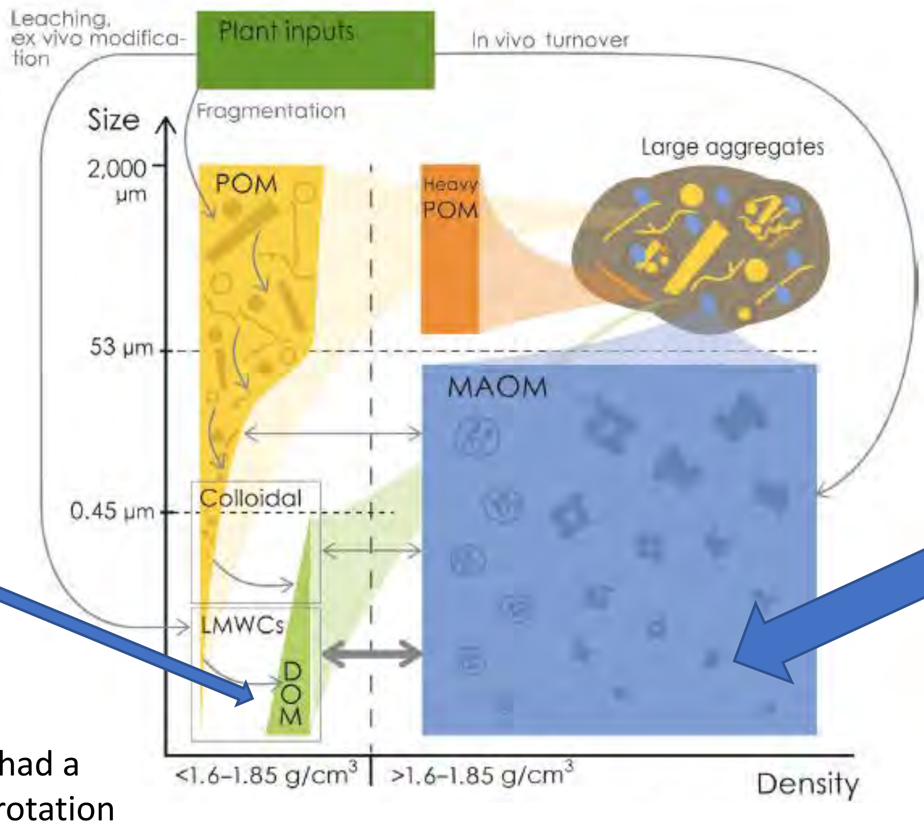


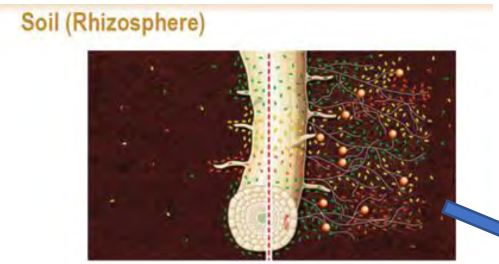
The soil microbiome is the “eye of the needle” as it controls the amount and the efficiency of C entering the MAOM

MAOM

MAOM consists of single molecules or microscopic fragments of organic material from two sources:

- Leached directly from plant material (dissolved organic matter), or
- Fresh plant material that has been chemically transformed by soil microbes





Dissolved organic matter

Forage-grain rotations at Glenlea had a 18% higher DOM than grain only rotation

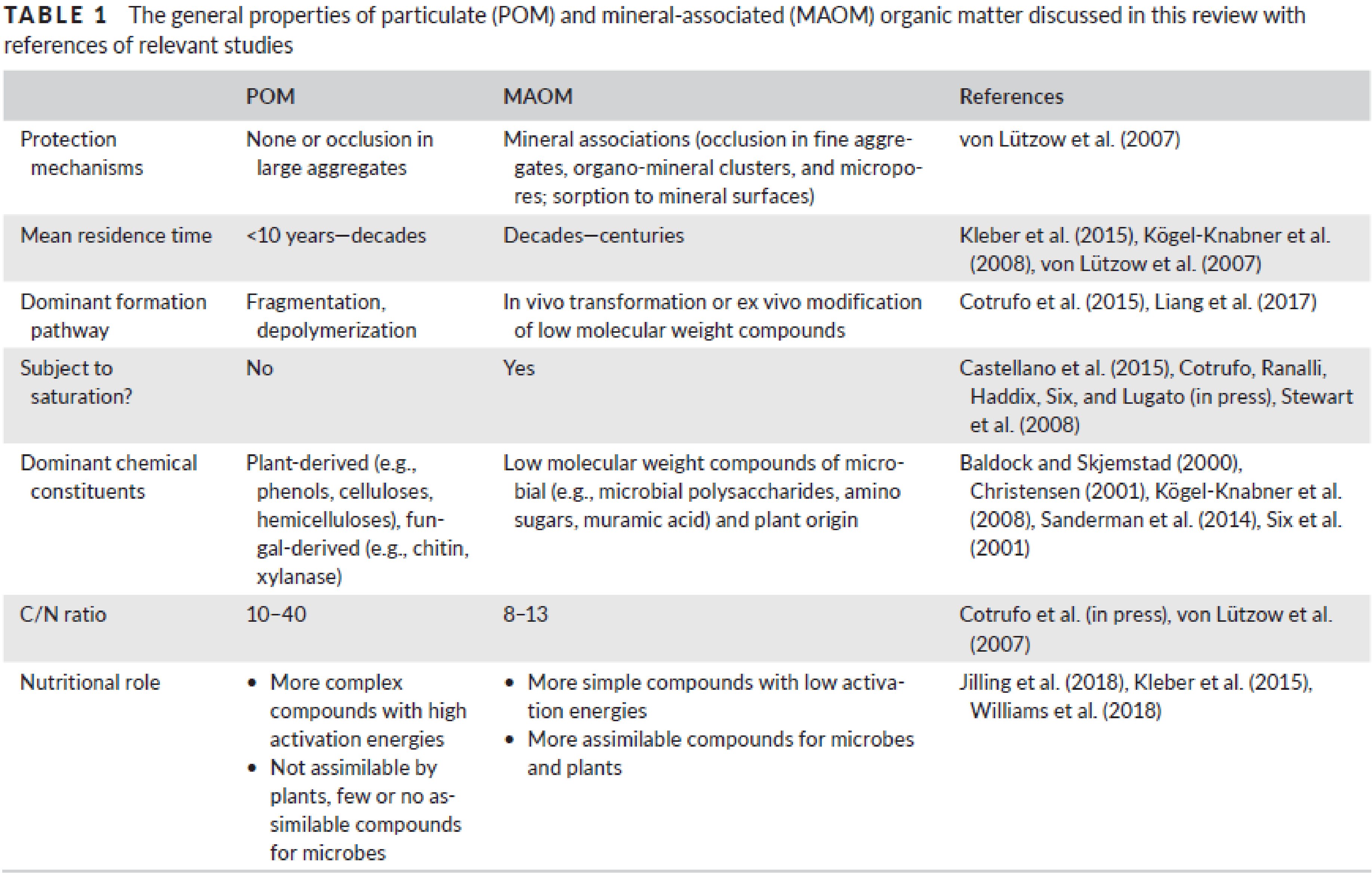
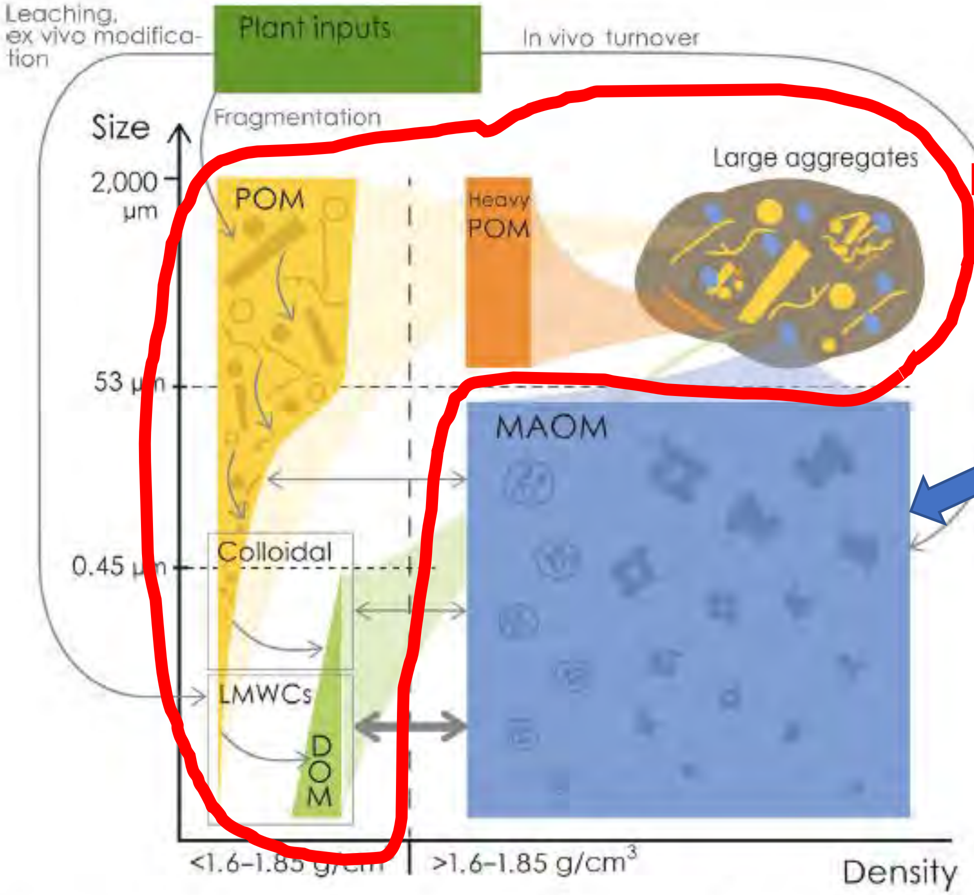


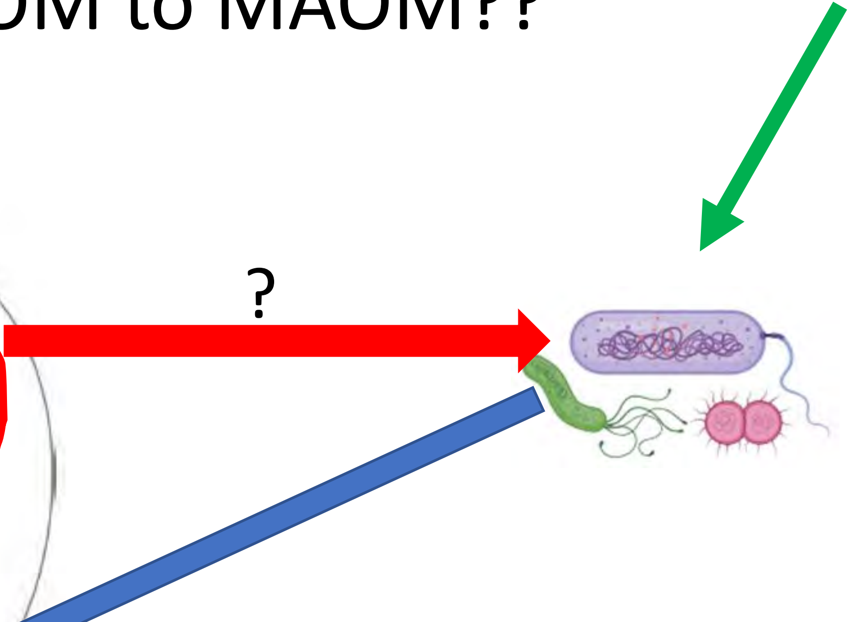
TABLE 1 The general properties of particulate (POM) and mineral-associated (MAOM) organic matter discussed in this review with references of relevant studies

	POM	MAOM	References
Protection mechanisms	None or occlusion in large aggregates	Mineral associations (occlusion in fine aggregates, organo-mineral clusters, and micropores; sorption to mineral surfaces)	von Lützow et al. (2007)
Mean residence time	<10 years—decades	Decades—centuries	Kleber et al. (2015), Kögel-Knabner et al. (2008), von Lützow et al. (2007)
Dominant formation pathway	Fragmentation, depolymerization	In vivo transformation or ex vivo modification of low molecular weight compounds	Cotrufo et al. (2015), Liang et al. (2017)
Subject to saturation?	No	Yes	Castellano et al. (2015), Cotrufo, Ranalli, Haddix, Six, and Lugato (in press), Stewart et al. (2008)
Dominant chemical constituents	Plant-derived (e.g., phenols, celluloses, hemicelluloses), fungal-derived (e.g., chitin, xylanase)	Low molecular weight compounds of microbial (e.g., microbial polysaccharides, amino sugars, muramic acid) and plant origin	Baldock and Skjemstad (2000), Christensen (2001), Kögel-Knabner et al. (2008), Sanderman et al. (2014), Six et al. (2001)
C/N ratio	10–40	8–13	Cotrufo et al. (in press), von Lützow et al. (2007)
Nutritional role	• More complex compounds with high activation energies • Not assimilable by plants, few or no assimilable compounds for microbes	• More simple compounds with low activation energies • More assimilable compounds for microbes and plants	Jilling et al. (2018), Kleber et al. (2015), Williams et al. (2018)

Source: Lavallee, J.M., Soong, J.L. and Cotrufo, M.F., 2020. Conceptualizing soil organic matter into particulate and mineral-associated forms to address global change in the 21st century. *Global Change Biology*, *26*(1), pp.261-273.

POM to MAOM??

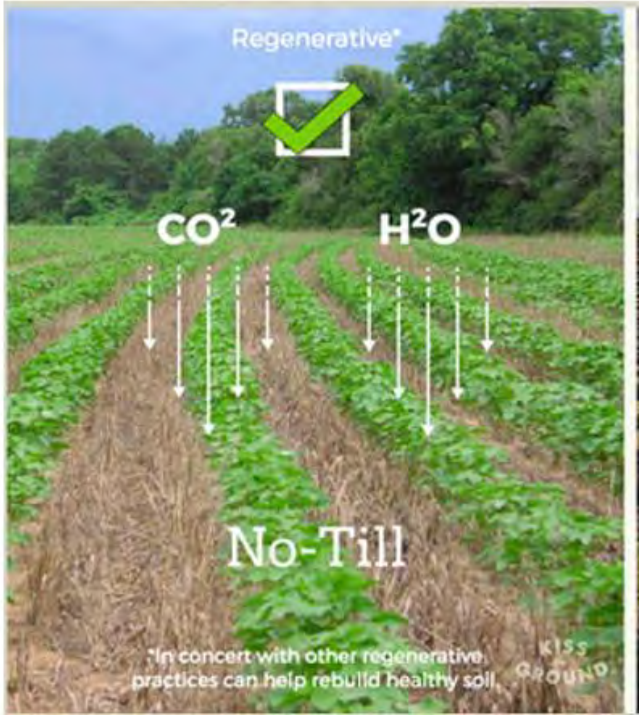




"There was no consistent indication that formation of MAOM occurred from the decomposition of POM, suggesting that MAOM and POM are formed by two separate pathways."

Haddix, M.L., Gregorich, E.G., Helgason, B.L., Janzen, H., Ellert, B.H. and Cotrufo, M.F., 2020. Climate, carbon content, and soil texture control the independent formation and persistence of particulate and mineral-associated organic matter in soil. *Geoderma*, *363*, p.114160.

Soil C capture high on the agenda.



Tillage

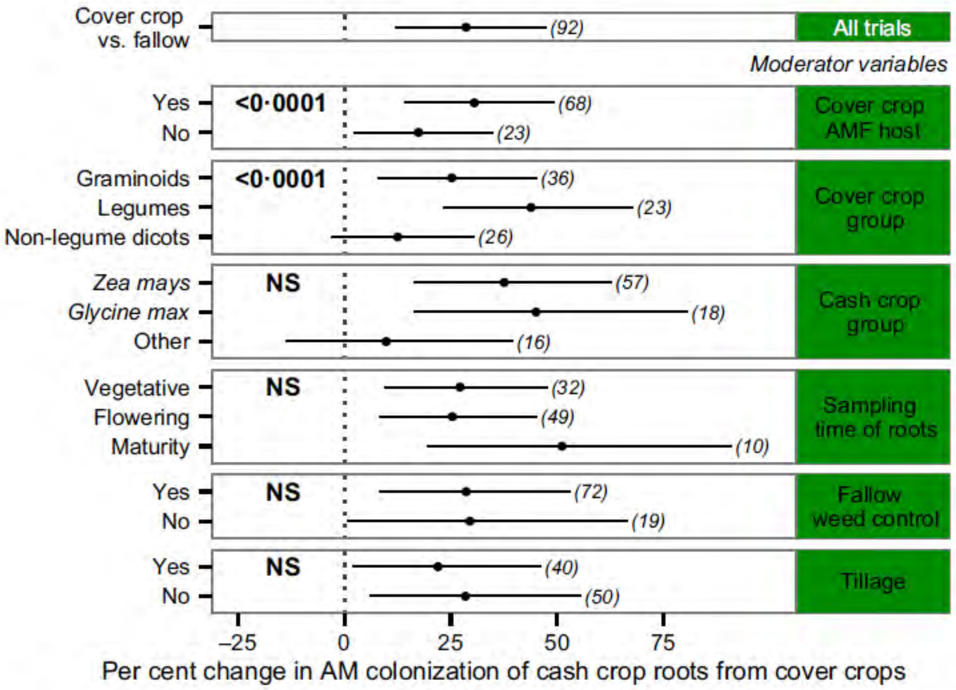


Fig. 1. Meta-analysis results of the change in arbuscular mycorrhizal fungi colonization of cash crop roots in response to fall/winter cover cropping from field experiments in five continents. Error bars represent 95% confidence intervals. Omnibus tests of significance for moderator variables are shown on the left (NS: 'not significant'). The number of observations in each category is shown in parentheses. [Colour figure can be viewed at wileyonlinelibrary.com]

Journal of Applied Ecology

BRITISH ECOLOGICAL SOCIETY

Journal of Applied Ecology 2016, **54**, 1785–1793 doi: 10.1111/1365-2664.12815

Ecological intensification and arbuscular mycorrhizas: a meta-analysis of tillage and cover crop effects

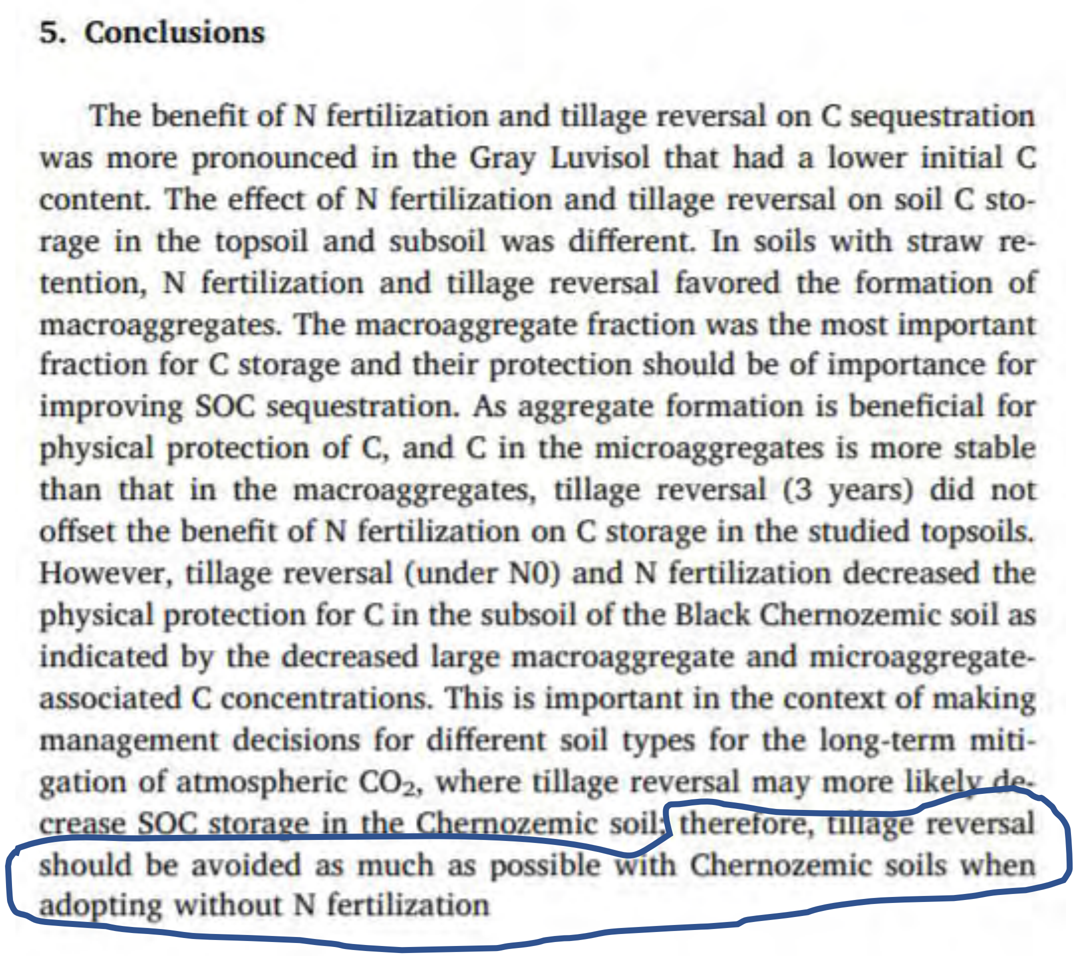
Timothy M. Bowles[1]*, Louise E. Jackson[2], Malina Loeher[2] and Timothy R. Cavagnaro[3]

[1]Department of Environmental Science, Policy and Management, University of California Berkeley, Berkeley, CA 94720, USA; [2]Department of Land, Air and Water Resources, University of California Davis, Davis, CA 95616, USA; and [3]The Waite Research Institute and School of Agriculture, Food and Wine, University of Adelaide, Waite Campus, PMB1, Glen Osmond, SA 5064, Australia

MANAGEMENT IMPLICATIONS AND CONCLUSIONS

This meta-analysis shows that cover cropping and reducing soil disturbance are strategies that farmers can use to increase AM formation and potentially alter the AMF community across a wide range of soil types and cash crops. Specifically, combining no-till and legume cover cropping would best increase AMF colonization of cash crop roots, highlighting positive interactions across management practices. But cover cropping even appears to counteract some of the negative impacts of soil disturbance on AM formation. System approaches that combine cover cropping and reduced tillage with other AM-promoting practices like crop diversification and organic management (Oehl *et al.* 2004; Verbruggen *et al.* 2010) may offer the most promise for enhancing AM communities, while also increasing soil C storage and nutrient cycling, and reducing nutrient losses and soil erosion (Quemada *et al.* 2013; McDaniel, Tiemann & Grandy 2014; Schipanski *et al.* 2014). Fostering indigenous AMF

Does tillage reversal (going from no-till to tilled) affect soil health?



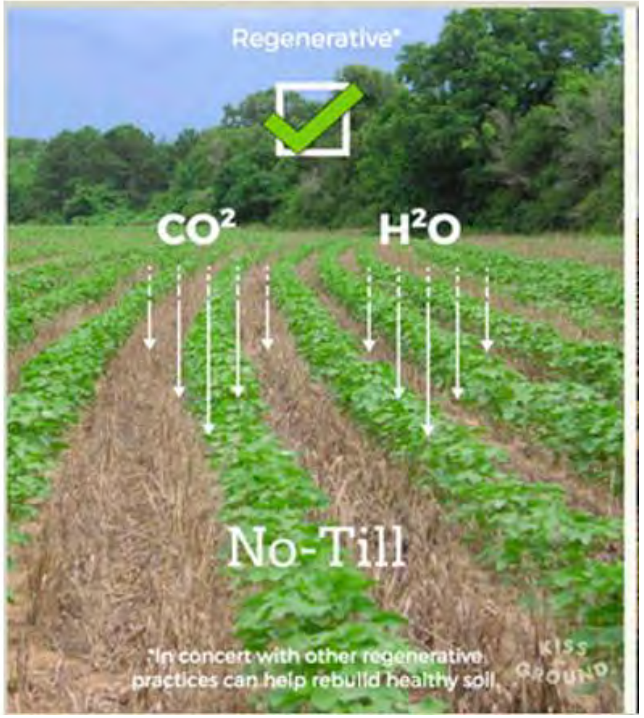
5. Conclusions

The benefit of N fertilization and tillage reversal on C sequestration was more pronounced in the Gray Luvisol that had a lower initial C content. The effect of N fertilization and tillage reversal on soil C storage in the topsoil and subsoil was different. In soils with straw retention, N fertilization and tillage reversal favored the formation of macroaggregates. The macroaggregate fraction was the most important fraction for C storage and their protection should be of importance for improving SOC sequestration. As aggregate formation is beneficial for physical protection of C, and C in the microaggregates is more stable than that in the macroaggregates, tillage reversal (3 years) did not offset the benefit of N fertilization on C storage in the studied topsoils. However, tillage reversal (under N0) and N fertilization decreased the physical protection for C in the subsoil of the Black Chernozemic soil as indicated by the decreased large macroaggregate and microaggregate-associated C concentrations. This is important in the context of making management decisions for different soil types for the long-term mitigation of atmospheric CO_2, where tillage reversal may more likely decrease SOC storage in the Chernozemic soil; therefore, tillage reversal should be avoided as much as possible with Chernozemic soils when adopting without N fertilization

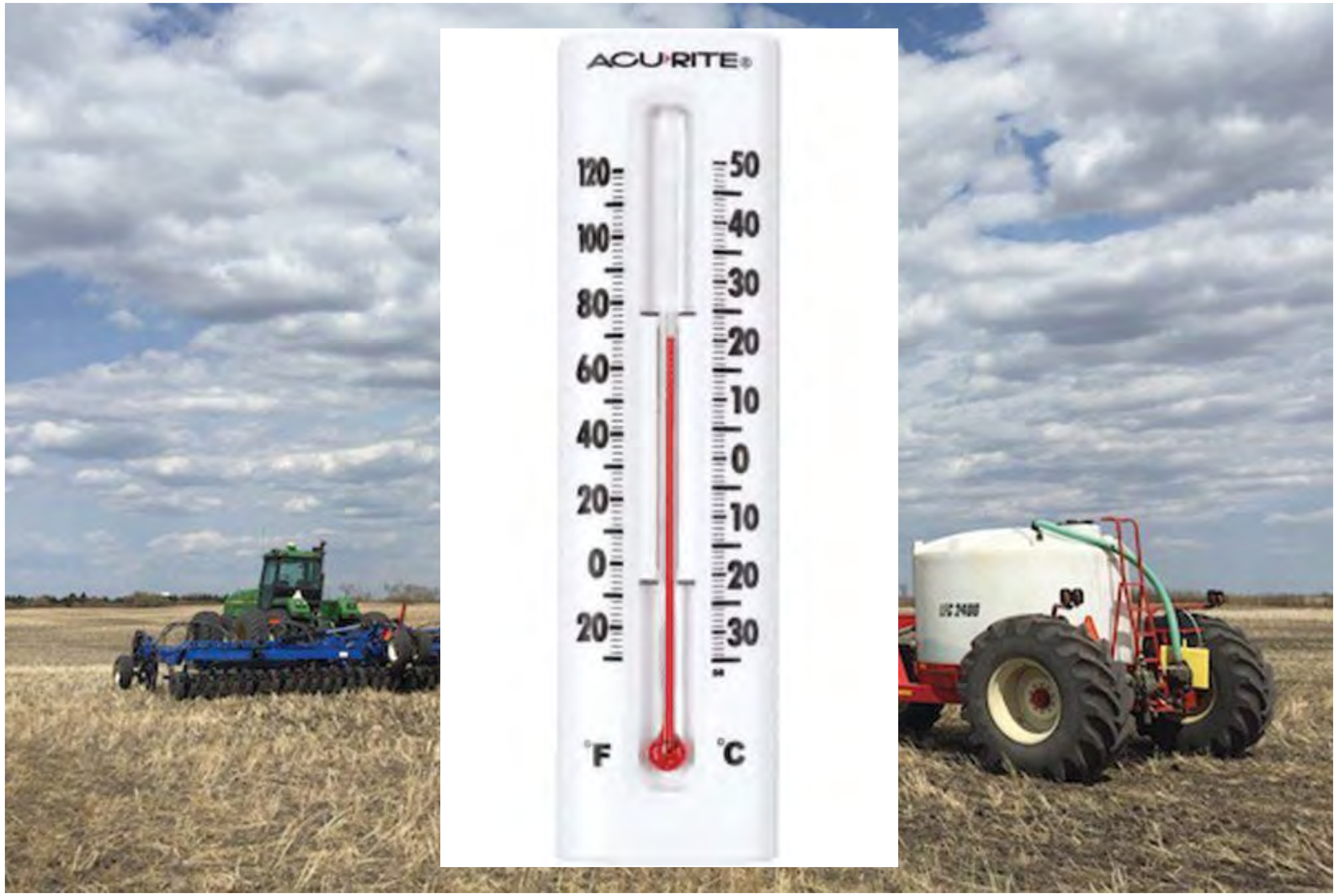
Therefore, if tillage is part of the cropping system, N additions are important. In organic this means adding legumes to the crop rotation.

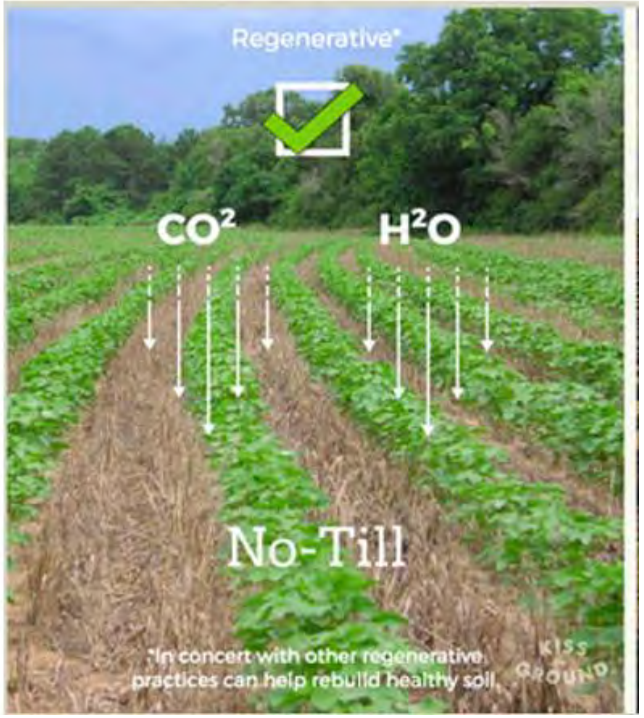
Sun, L., Feng, Y., Dyck, M.F., Puurveen, D. and Chang, S.X., 2020. Tillage reversal did not reverse N fertilization enhanced C storage in a Black Chernozem and a Gray Luvisol. *Geoderma*, *370*, p.114355.

Soil C capture high on the agenda.

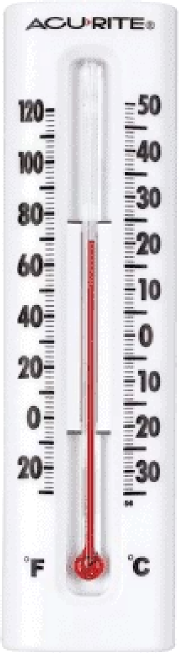


The global warming wild card



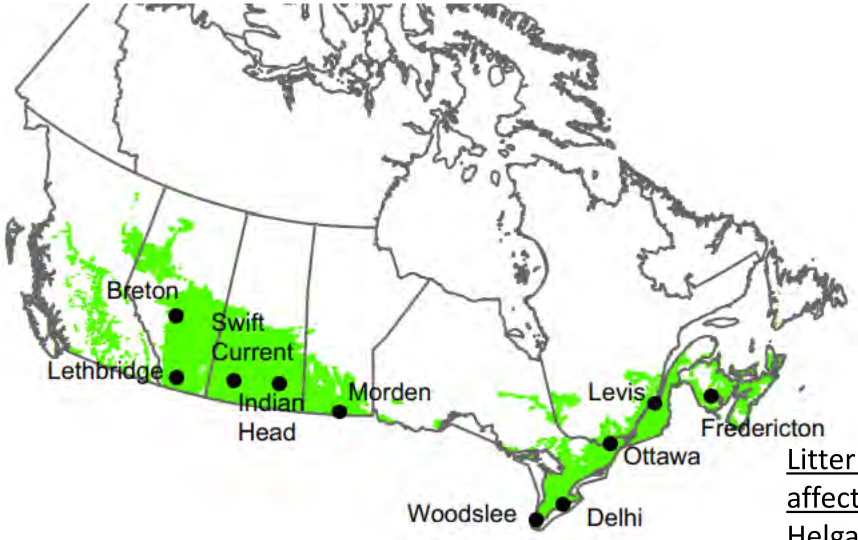


Global temperature is increasing



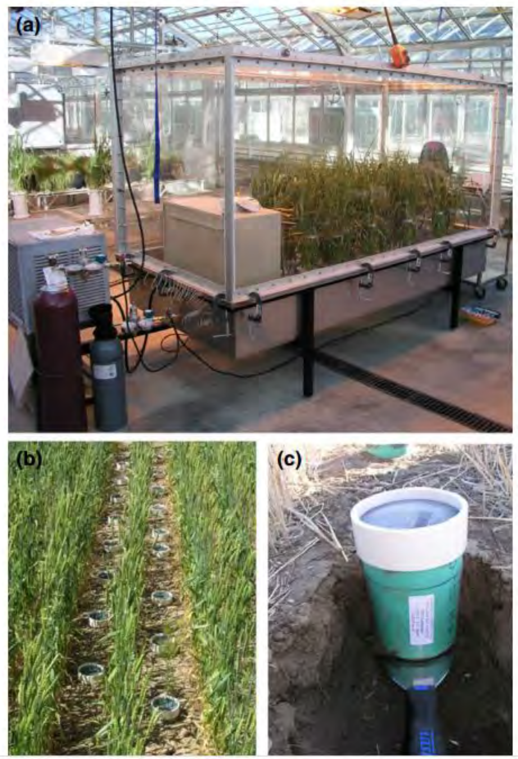
Increasing global temperature defeats soil C capture.

“Our study demonstrates an overriding predominance of temperature in governing the rate of residue decay, superseding that of extreme differences in soil properties and moisture in temperate climates across southern Canada.”

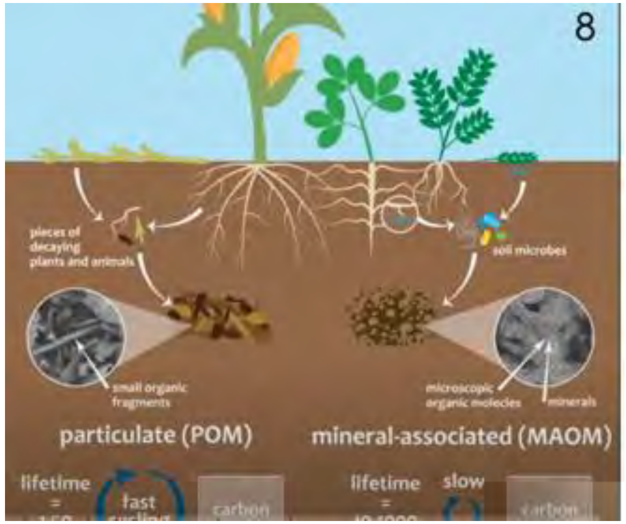


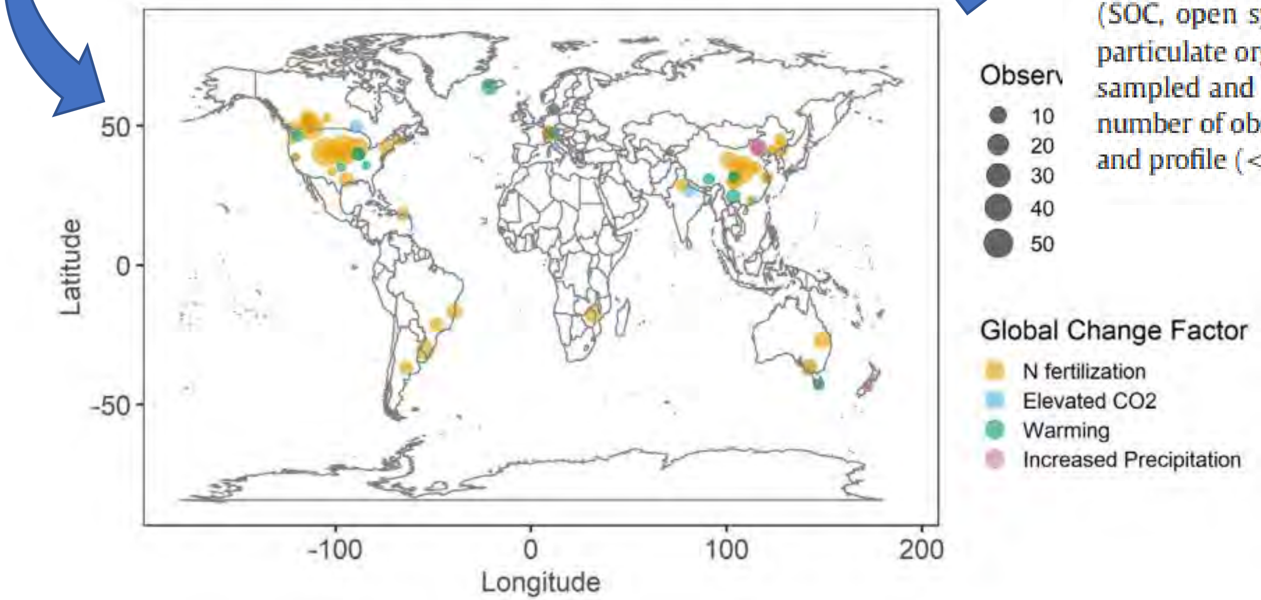
Litter decay controlled by temperature, not soil properties, affecting future soil carbonEG Gregorich, H Janzen, BH Ellert, BL Helgason, B Qian, BJ Zebarth, ...
Global Change Biology 23 (4), 1725-1734

1728 E. G. GREGORICH *et al.*



Which C pool most vulnerable?





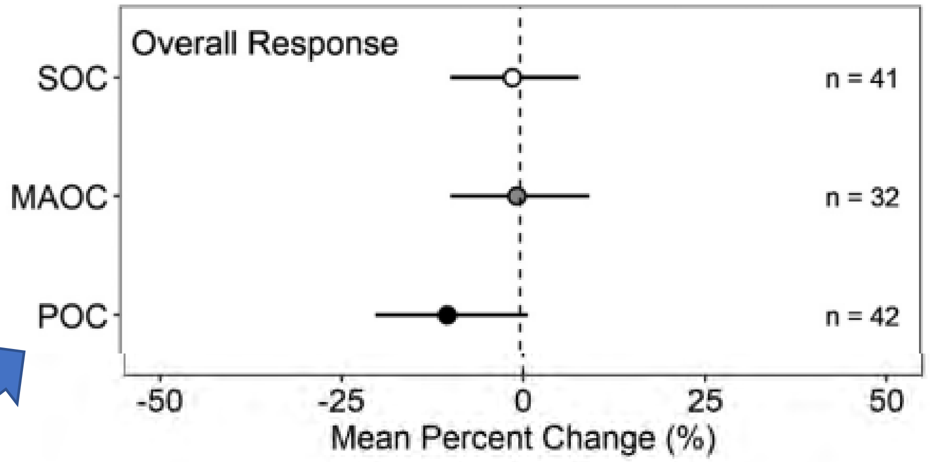
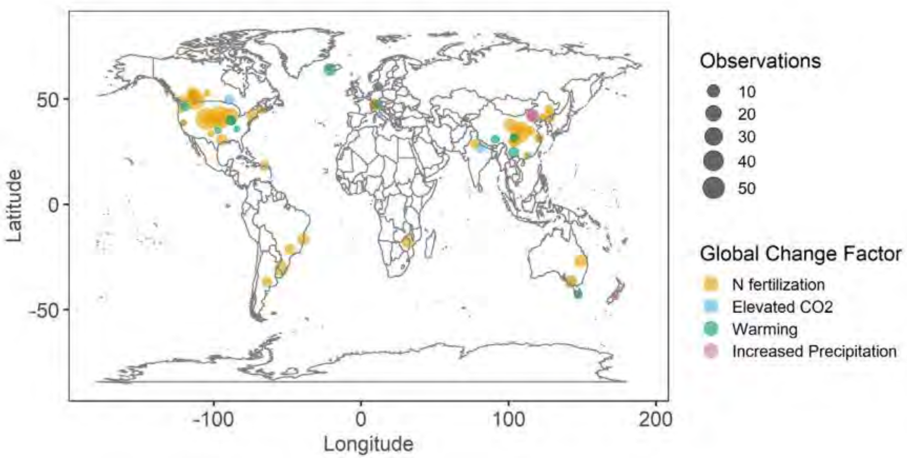
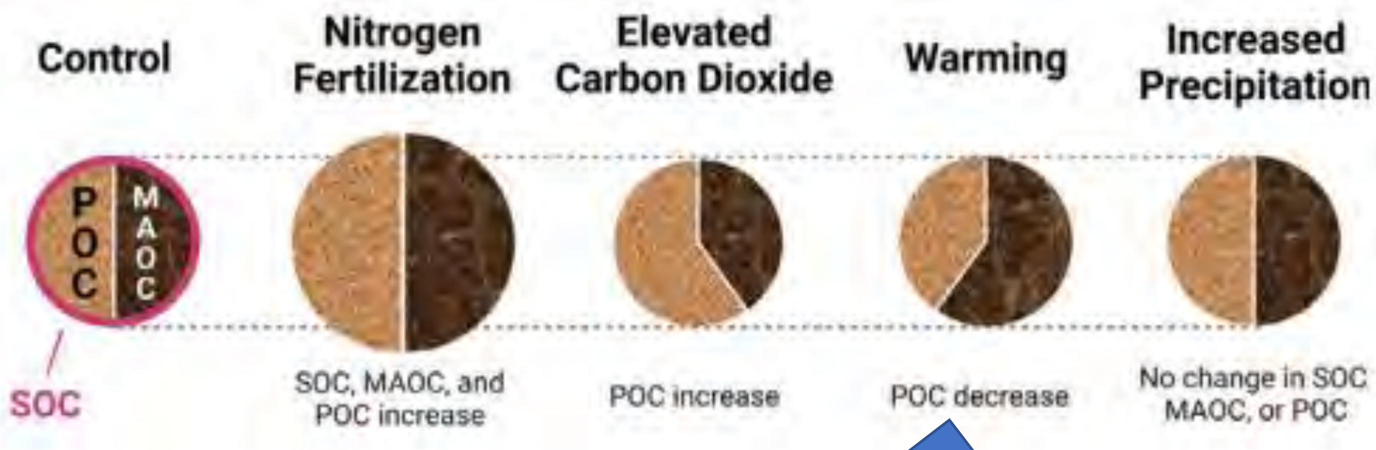


Fig. 4. Mean responses of carbon concentrations (g C kg soil-1) in total soil organic carbon (SOC, open symbol), mineral-associated organic carbon (MAOC, grey symbol), and particulate organic carbon (POC, black symbol) to warming as moderated by soil depth sampled and land cover type using published data with 95% confidence intervals and number of observations. Soil depth is defined as surface (< 10 cm), subsoil (10–30 cm), and profile (< 10 cm to > 10 cm).

Rocci, K.S., Lavallee, J.M., Stewart, C.E. and Cotrufo, M.F., 2021. Soil organic carbon response to global environmental change depends on its distribution between mineral-associated and particulate organic matter: A meta-analysis. *Science of The Total Environment*, *793*, p.148569.





<u>Soil warming </u>more damaging that air temperature increases

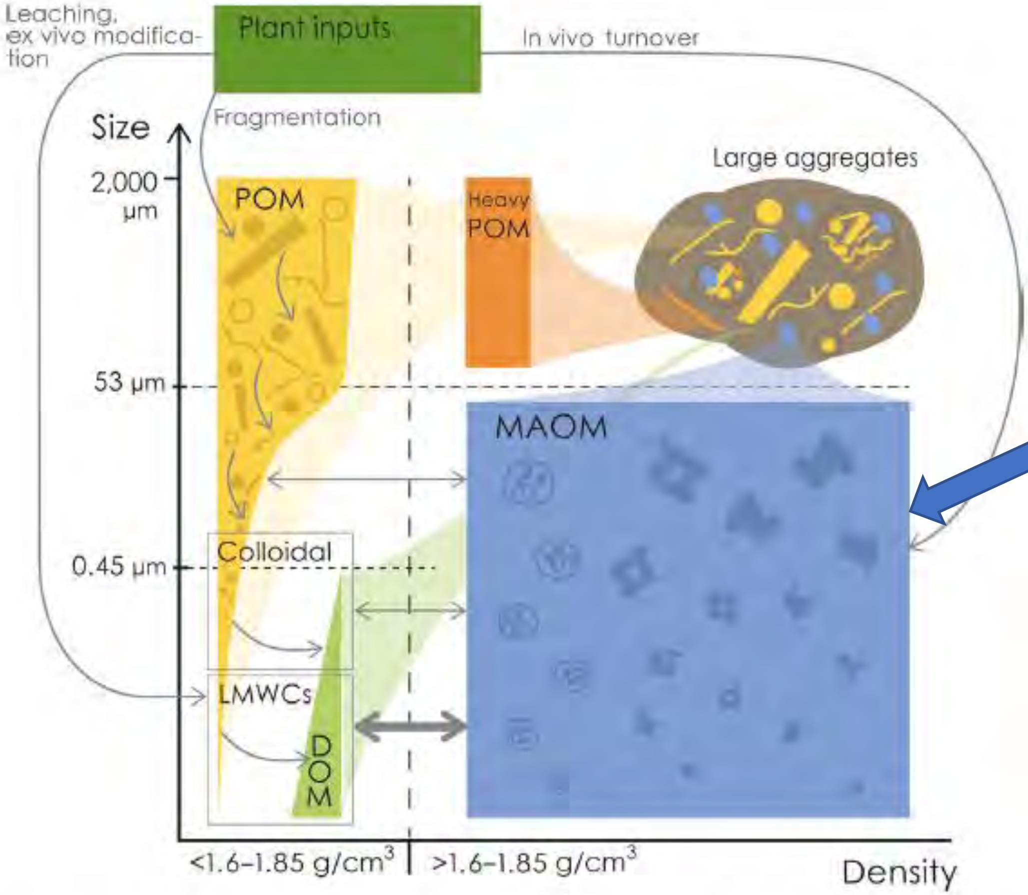
Rocci, K.S., Lavallee, J.M., Stewart, C.E. and Cotrufo, M.F., 2021. Soil organic carbon response to global environmental change depends on its distribution between mineral-associated and particulate organic matter: A meta-analysis. *Science of The Total Environment*, *793*, p.148569.

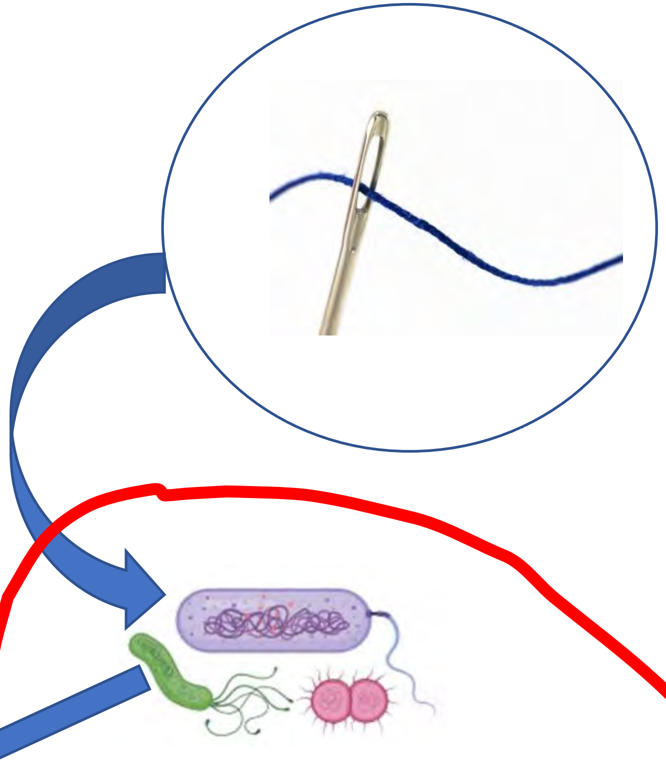
Keep soil covered and cooler: Eg. Small grains in Ontario organic corn-soy system

Sweet clover green manure

Red clover green manure

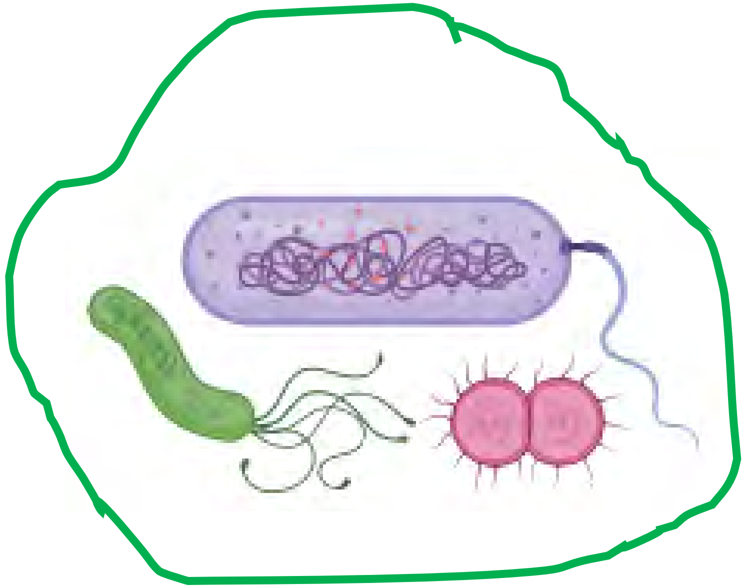
OK, back to the process of soil organic matter formation!



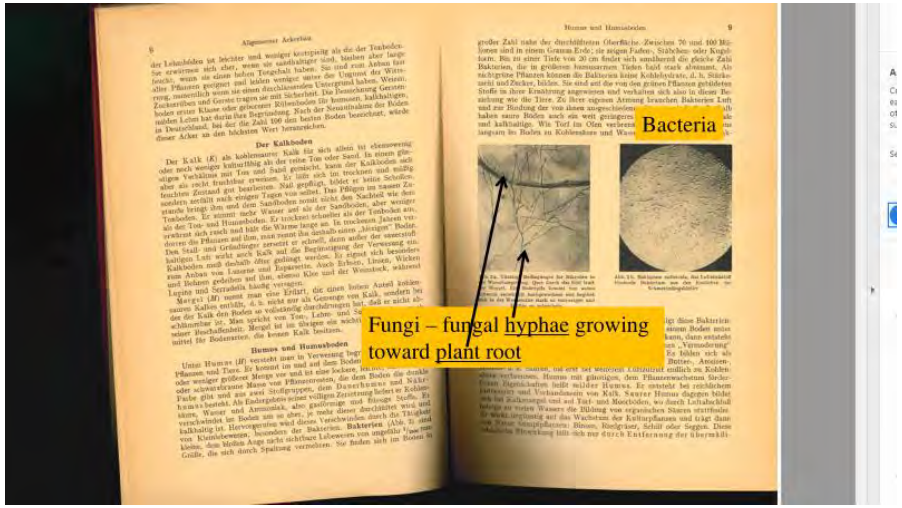


The soil microbiome is the "eye of the needle" as it controls the amount and the efficiency of C entering the MAOM

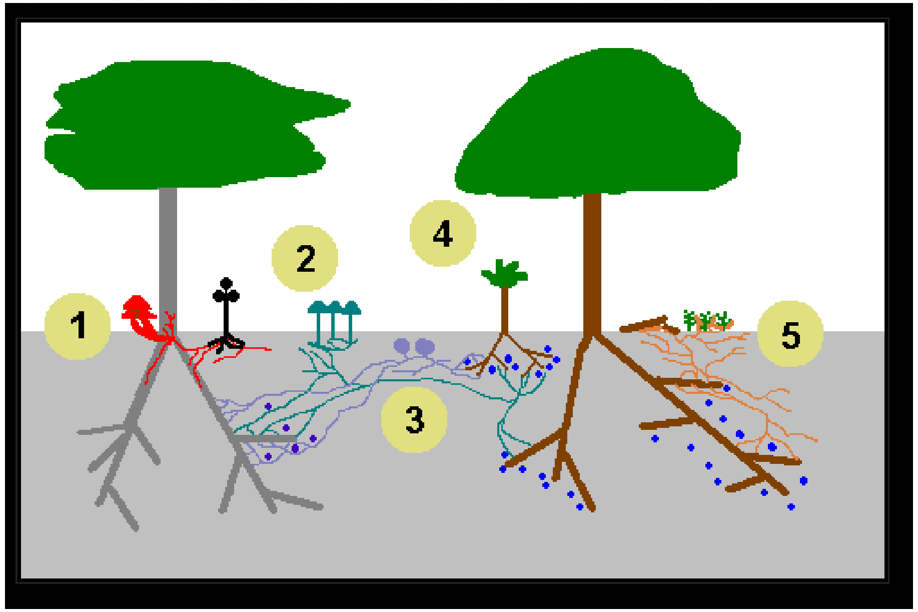
Evidence that soil microbial function can be enhanced in organically managed cropping systems



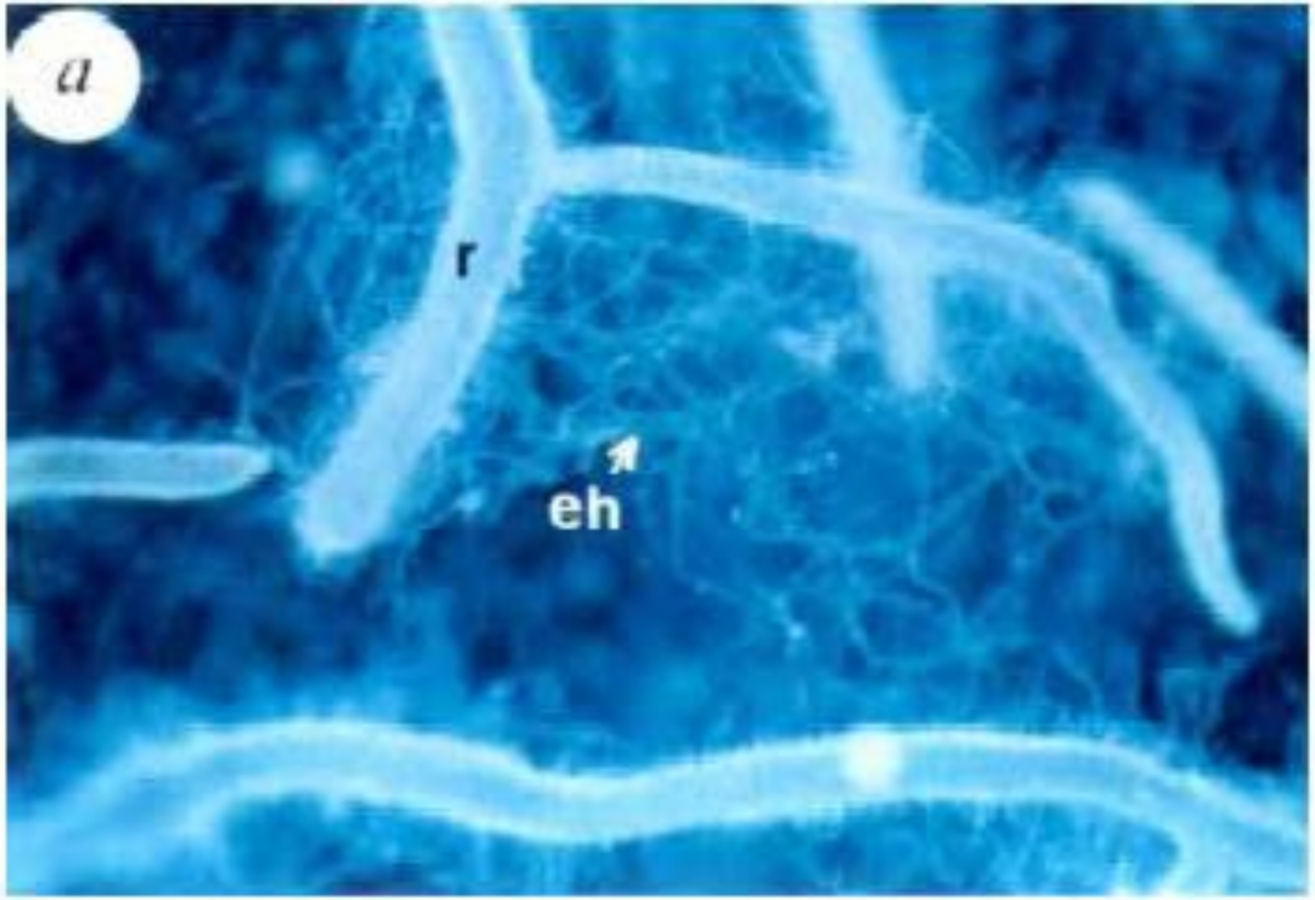
- DOK study in Switzerland, since 1987
- Kellogg study in Michigan, since 1988
- Century experiment, California, since 1992
- Glenlea study in Manitoba, since 1992
- AAFC Prairie studies (not organic)



Symbiosis between plants and fungus (not bacterial inoculants)

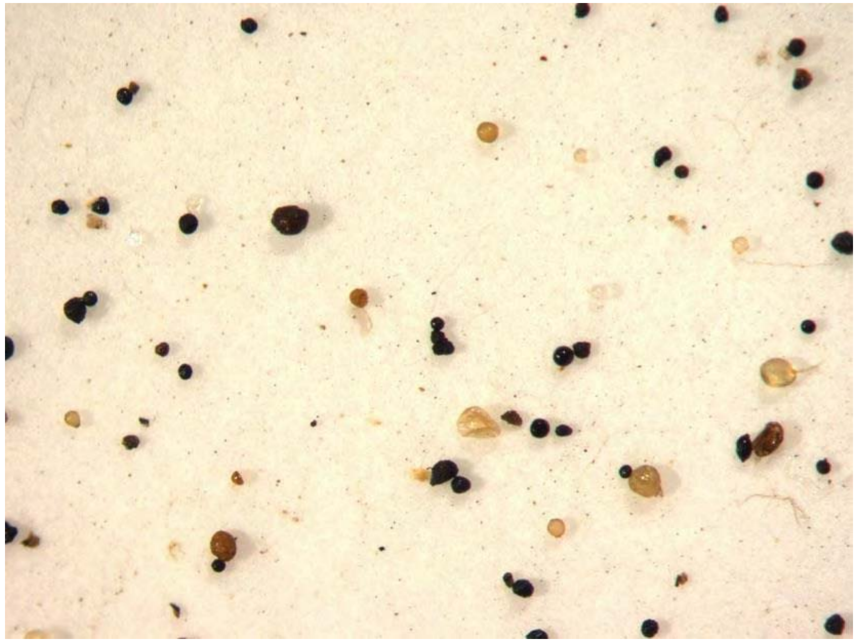


- AMF increase phosphorous uptake
  - Up to 4 times (Karagiannidis and Hadjisava-Zinoviadi, 1998)
  - Due to increases soil surface area explored
  - P inflow into AMF 6x greater than into root hairs (Bolan, 1991)
  - AMF can take over P acquisition from roots (Smith et al., 2003)
- AMF also increase Zn, Cu and other nutrients

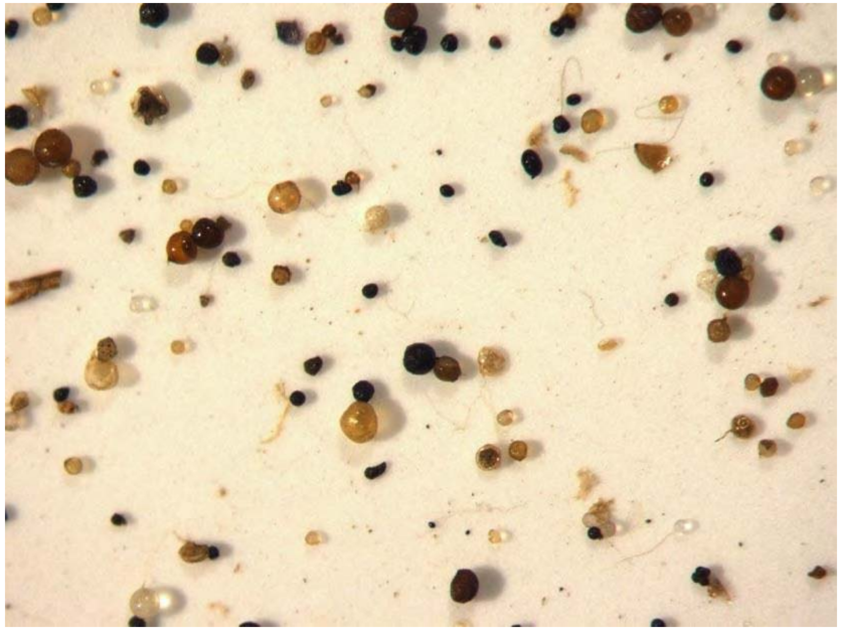


Mycorrhizal spore density and diversity (100g soil)

Welsh et al. 2006. U of M Soil Science, unpublished.



Conventional

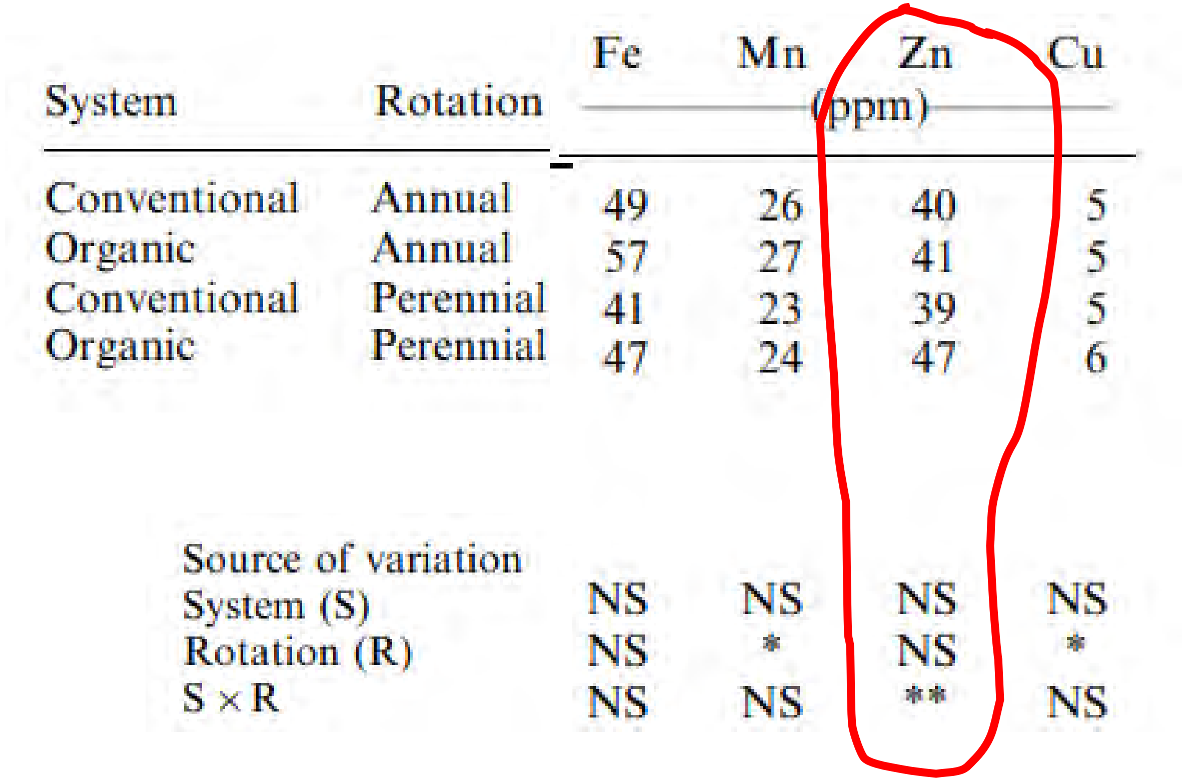


Organic

Glenlea rotation

Cropping System		[4]AMF total colonization
Prairie		
Grain only convent		
Grain only organic		
Forage-grain conve		
Forage-grain organi		
Forage-grain organic plus manure		35.7
P value		0.05

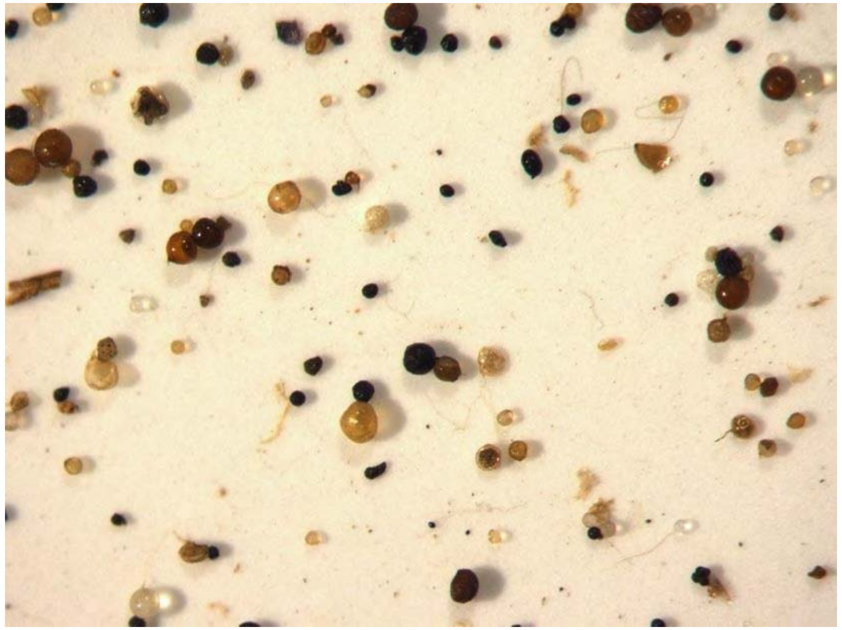
Organic crops greater mycorrhizal association, which may explain some higher micronutrients in wheat seeds.



System	Rotation	Fe	Mn	Zn	Cu
		(ppm)			
Conventional	Annual	49	26	40	5
Organic	Annual	57	27	41	5
Conventional	Perennial	41	23	39	5
Organic	Perennial	47	24	47	6
Source of variation					
System (S)		NS	NS	NS	NS
Rotation (R)		NS	*	NS	*
S × R		NS	NS	**	NS

Turmel, M.S., Entz, M.H., Bamford, K. and Thiessen Martens, J.R., 2009. The influence of crop rotation on the mineral nutrient content of organic vs. conventionally produced wheat grain: Preliminary results from a long-term field study. *Canadian Journal of Plant Science*, *89*(5), pp.915-919.

Mycorrhizal increase “tillage resistance”



Organic

Soil pH

Acidic soils called real threat for Prairies

Retired agronomist worries low pH soil could soon become a major headache due to zero tillage and increased nitrogen use

BY ROBERT ARNASON
WINNIPEG BUREAU

Nearly two dozen counties in Montana have problems with acidic soils and a few farmers in the state have bought lime spreaders to increase the pH of their soils.

"(They) growers have seen tremendous yield losses due to acidity and spreading lime has shown great benefits," said Manbir Rakkar, an assistant research professor in Land Resources and Environmental Sciences at Montana State University.

"Montana growers have spent (about) $55,000 to purchase lime spreaders, showing they take it seriously."

That sort of expenditure isn't commonplace, but many farmers across Montana are worried about acidic soils and researchers are keeping a close eye on the problem.

"Montana State University soil scientists... crop advisers, and producers have now identified fields in 23 Montana counties with locations where the top zero to six inches of soil have pH below 5.5, some as low as 3.8," says a Montana State University website.

A number of those counties are next to Montana's border with Canada. So, it's possible that acidic soils are also a problem in southern Alberta.

But few farmers or soil scientists in Alberta are paying attention, says a retired agronomy research scientist with Alberta Agriculture.

Ross McKenzie is worried that low pH soils could soon become a major headache for prairie farmers. That's because the same factors that cause acidic soils, zero tillage and increased use of nitrogen fertilizer are also present in Alberta.

"I've been retired for nine years, it's something we've been pointing out that people need to be (studying)," McKenzie said a few days before Christmas. "It's not something that (anyone) is working on.... It's an issue right now and it's gradually going to become a greater problem."

Decades ago, experts from Alberta Agriculture monitored the soil pH in the grey soils of northern Alberta, which are naturally more acidic than brown and black soils.

That research and recommendations about managing low pH soils eventually faded away.

> ***It's really a matter of watching your soil***
> ***Once you see they're at six or less... the***
> ***cerned you should be... Once you're dropping be***
> ***you have to take things more seriously.***
>
> **ROSS MCKENZIE**
> RETIRED AGRONOMY RESEARCH SCIENTIST

"Since 2000, there really hasn't been any significant work on acid soils," McKenzie said from his home in Lethbridge.

However, over the last 25 to 30 years, with the shift to reduced tillage and increased rates of nitrogen fertilizer, the soils in Alberta and other parts of the Prairies have likely become more acidic.

"Really it's a concern for farmers across Western Canada, in my opinion," McKenzie said.

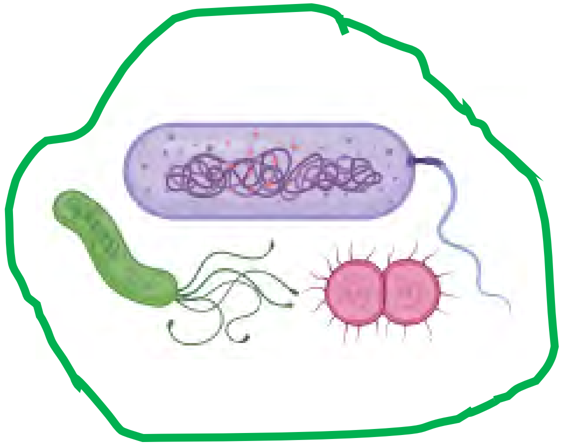
"It's really a matter of watching your soil pH levels. Once you see
they're at six or le
concerned you
Once you're drop
then you have t
more seriously."

Sometimes, farn
pH is a logarithm
ing that a pH of
more acidic than
"(And) a pH of
more acidic than
McKenzie said,
can take a long
back to neutral.

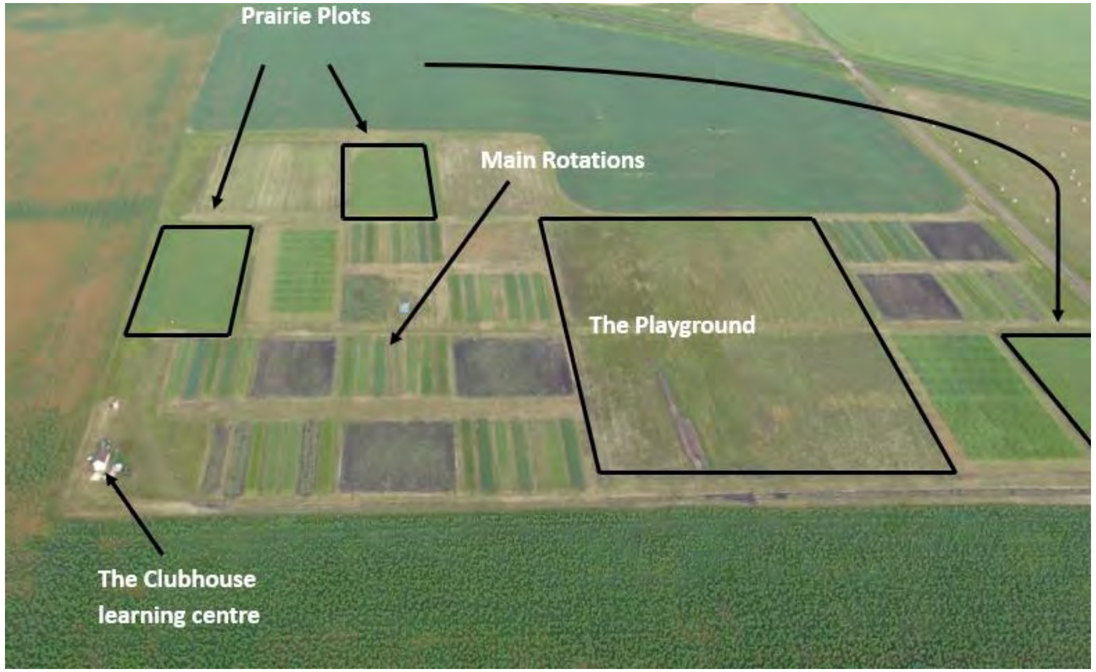
robert.arnaso

pH lower in Conv

Organic	7.46
Conventional	6.47



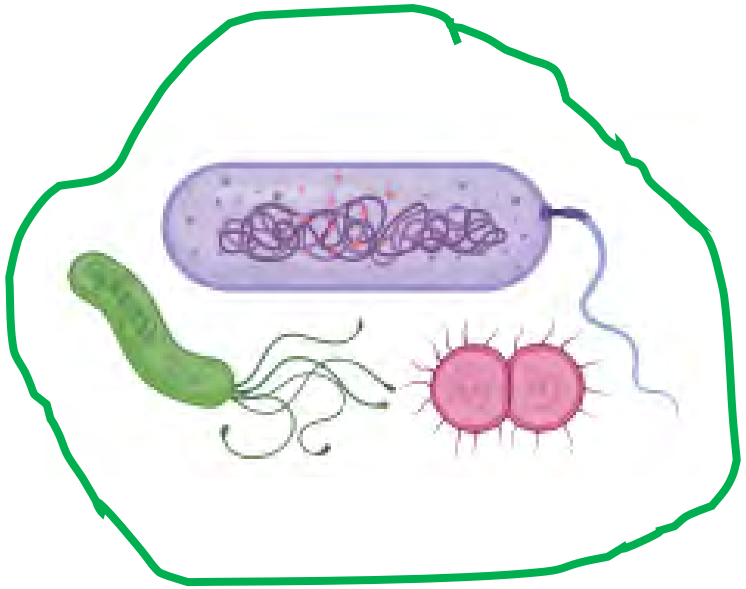
Li, R., Khafipour, E., Krause, D.O., Entz, M.H., de Kievit, T.R. and Fernando, W.D., 2012. Pyrosequencing reveals the influence of organic and conventional farming systems on bacterial communities. *PloS one*, *7*(12), p.e51897.



Evidence that soil microbial function can be enhanced in organically managed cropping systems

Organic systems maintain more neutral soil pH

- DOK study in Switzerland, since 1987
- Kellogg study in Michigan, since 1988
- Glenlea study in Manitoba, since 1992
- AAFC Prairie studies (not organic)



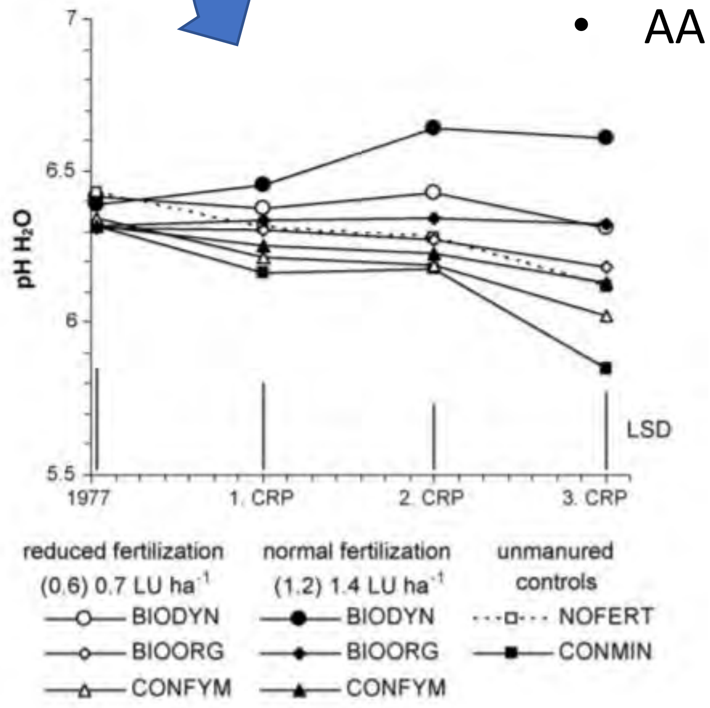
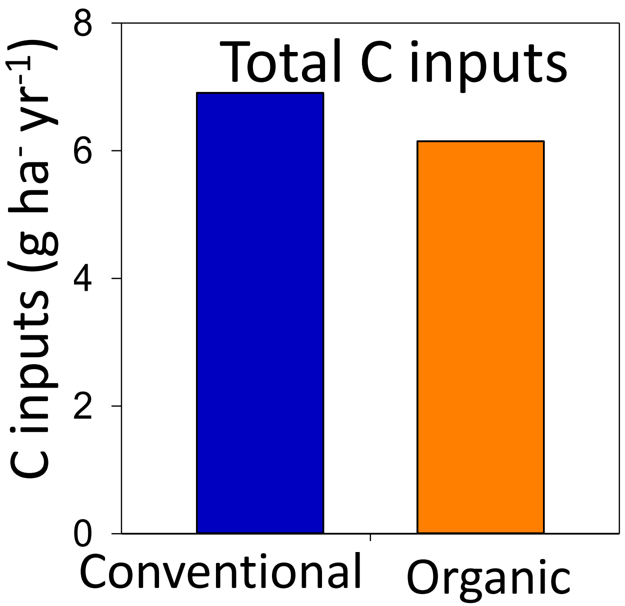
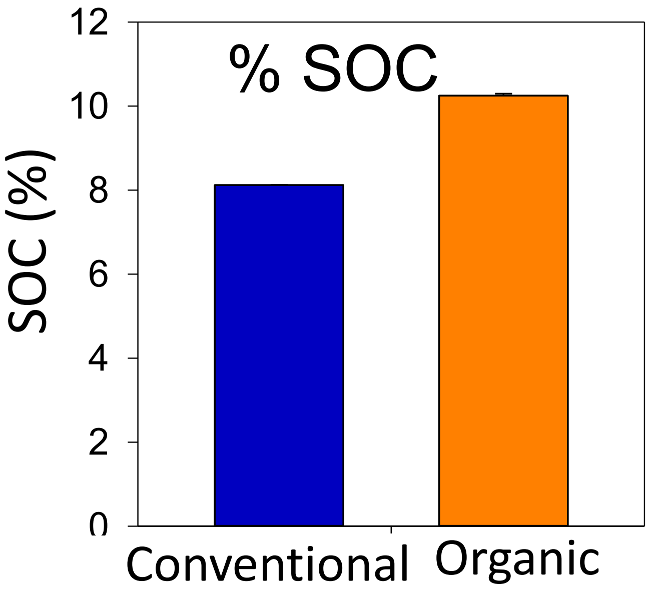


Fig. 4. Average pH (H_2O) values for each crop rotation period (CRP) in comparison to the initial values before the start of the DOK long-term field experiment in 1977. $n = 12$; LSD: least significant difference; LU: livestock units ha^{-1} for the first and second CRP in parentheses and the third CRP.

Story telling time…

Kellogg Biological Station LTER, SW Michigan





🟦 Conventional
🟧 Organic

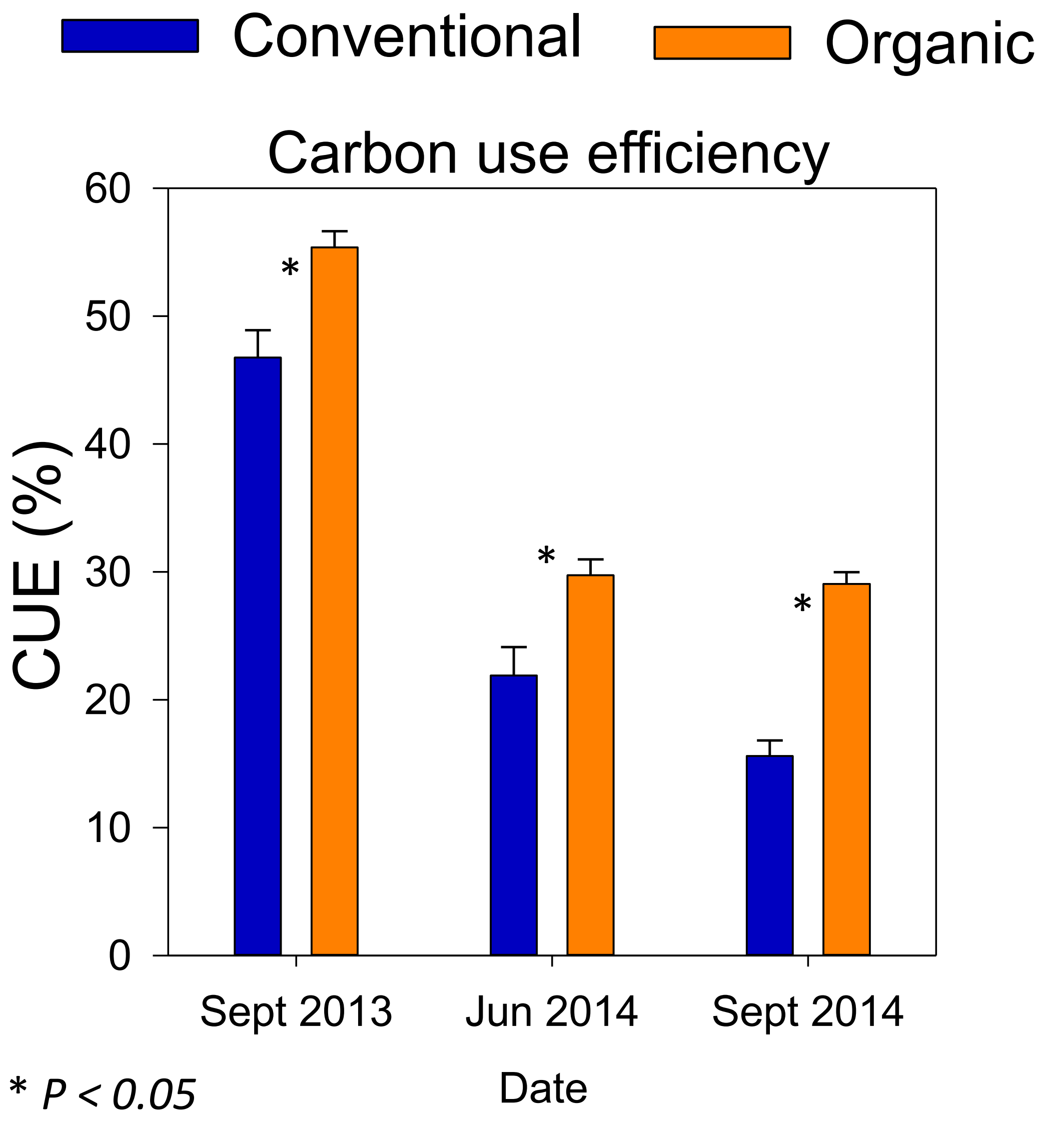
Conventional: corn-sov-wheat rotation
Organic: corn-**rye**-soy-wheat-**clover**

Really!!!
How can fewer total C inputs result in more soil organic carbon?

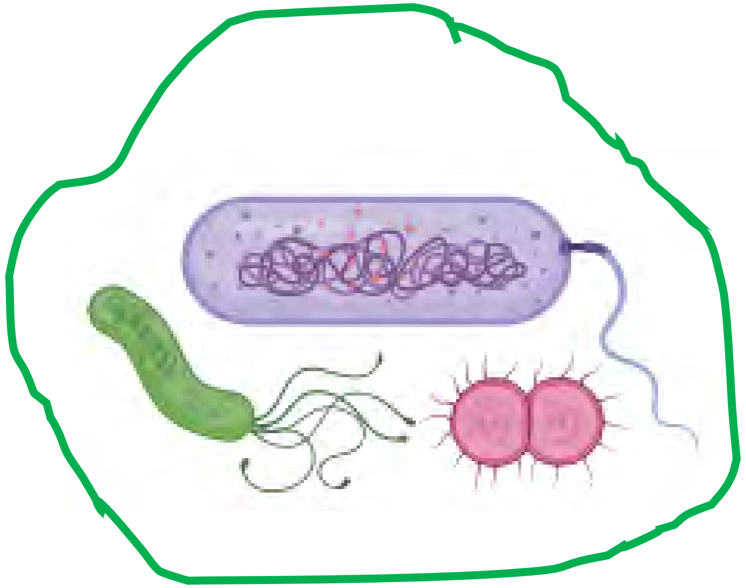
Kallenbach, C.M., Grandy, A.S., Frey, S.D. and Diefendorf, A.F., 2015. Microbial physiology and necromass regulate agricultural soil carbon accumulation. *Soil Biology and Biochemistry*, *91*, pp.279-290.

Answer: Microbial Carbon Use Efficiency and Growth Rate is Higher in Organic

Slide credit: Cynthia Kallenbach



* $P < 0.05$

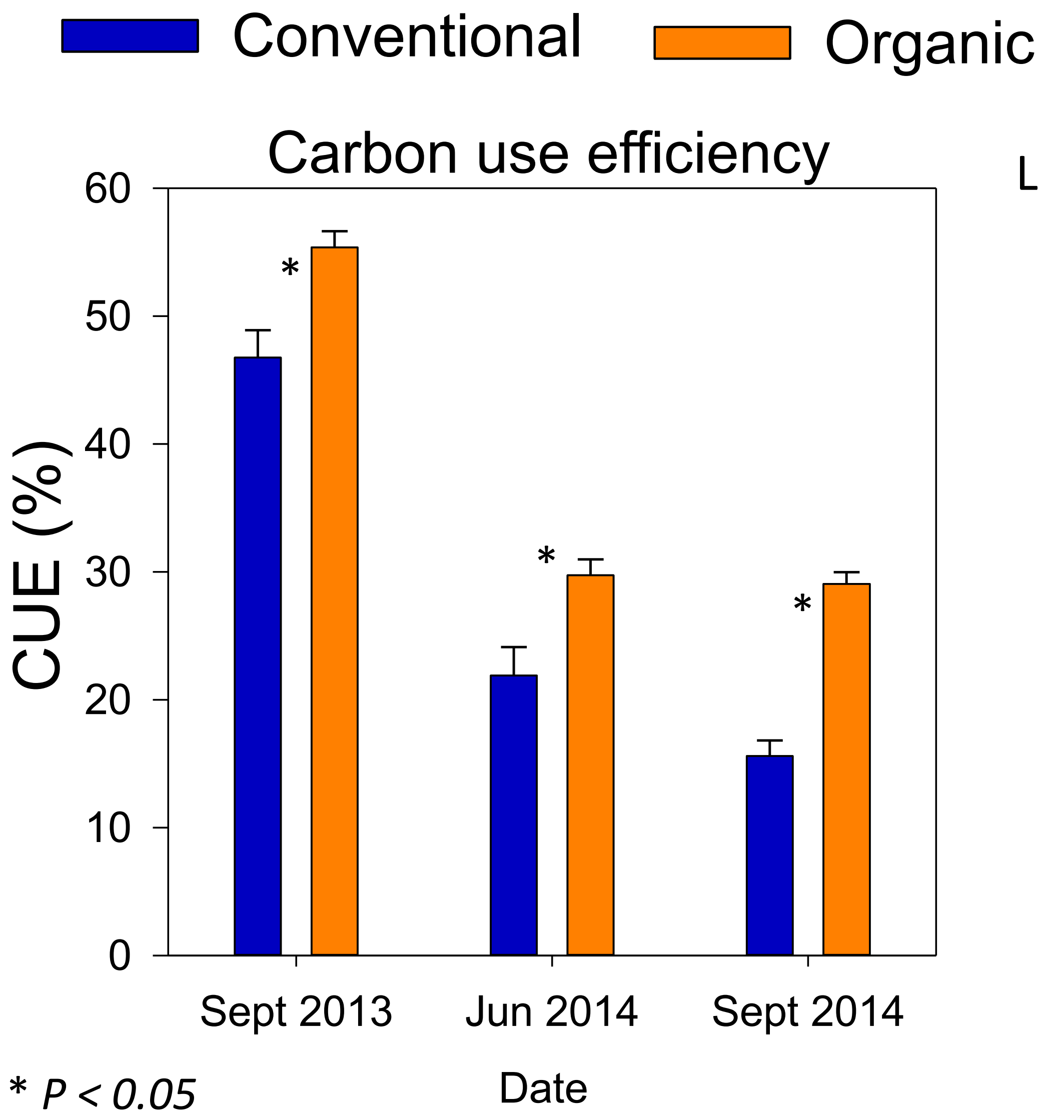


Kallenbach, C.M., et al. 2015. Microbial physiology and necromass regulate agricultural soil carbon accumulation. *Soil Biology and Biochemistry*, *91*, pp.279-290.

Microbial Carbon Use Efficiency and Growth Rate is Higher in Organic

Slide credit: Cynthia Kallenbach

Kallenbach, C.M., et al. 2015. Microbial physiology and necromass regulate agricultural soil carbon accumulation. *Soil Biology and Biochemistry*, *91*, pp.279-290.



* *P* < 0.05

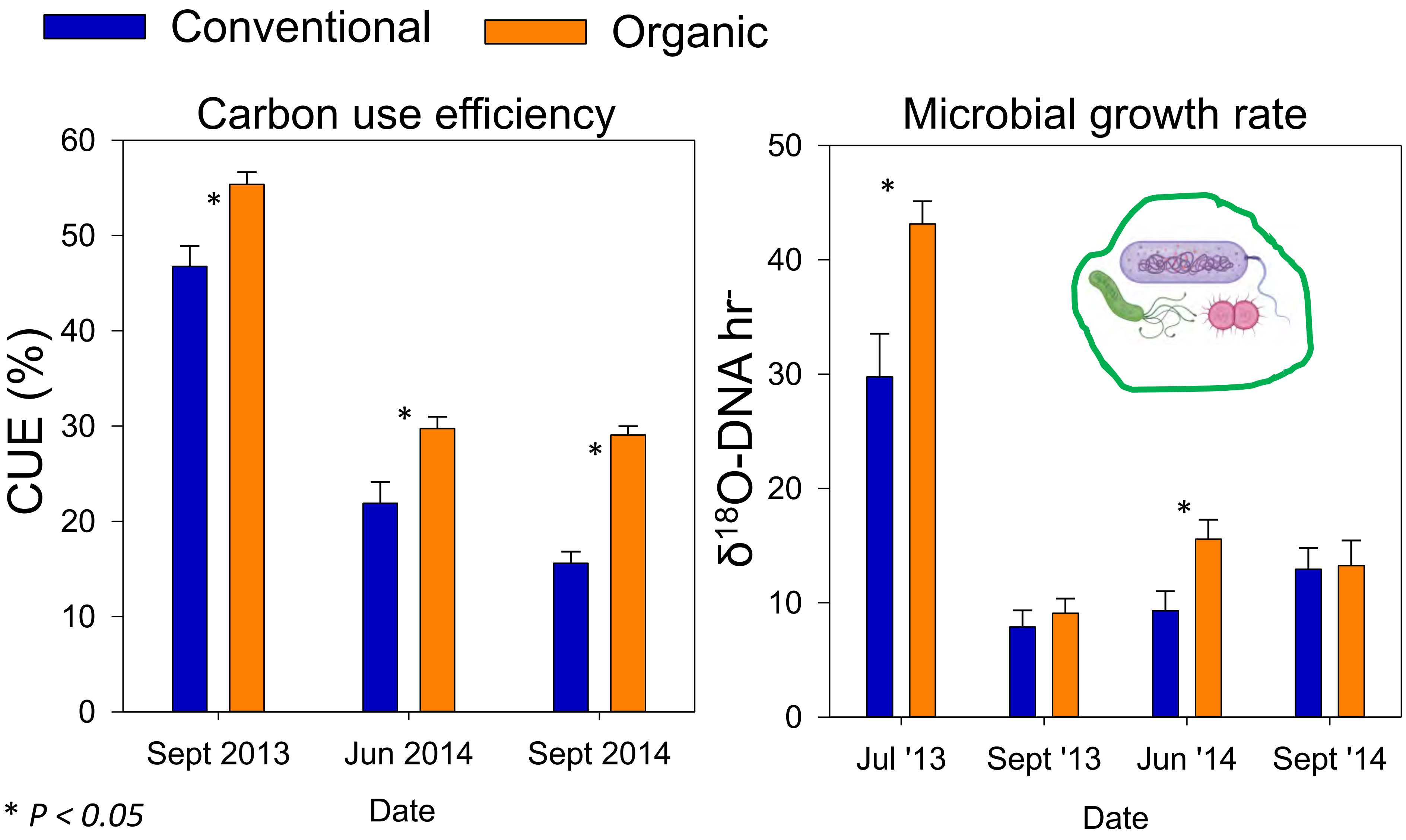
Low carbon use efficiency – lots of slippage

High carbon use efficiency – no/less slippage

Microbial Carbon Use Efficiency and Growth Rate is Higher in Organic

Slide credit: Cynthia Kallenbach

Kallenbach, C.M., et al. 2015. Microbial physiology and necromass regulate agricultural soil carbon accumulation. *Soil Biology and Biochemistry*, *91*, pp.279-290.



* *P* < 0.05

Soil C efficiency at DOK Trial, Basel, Switzerland

Soil energy efficiency

https://glten.org/experiments/161

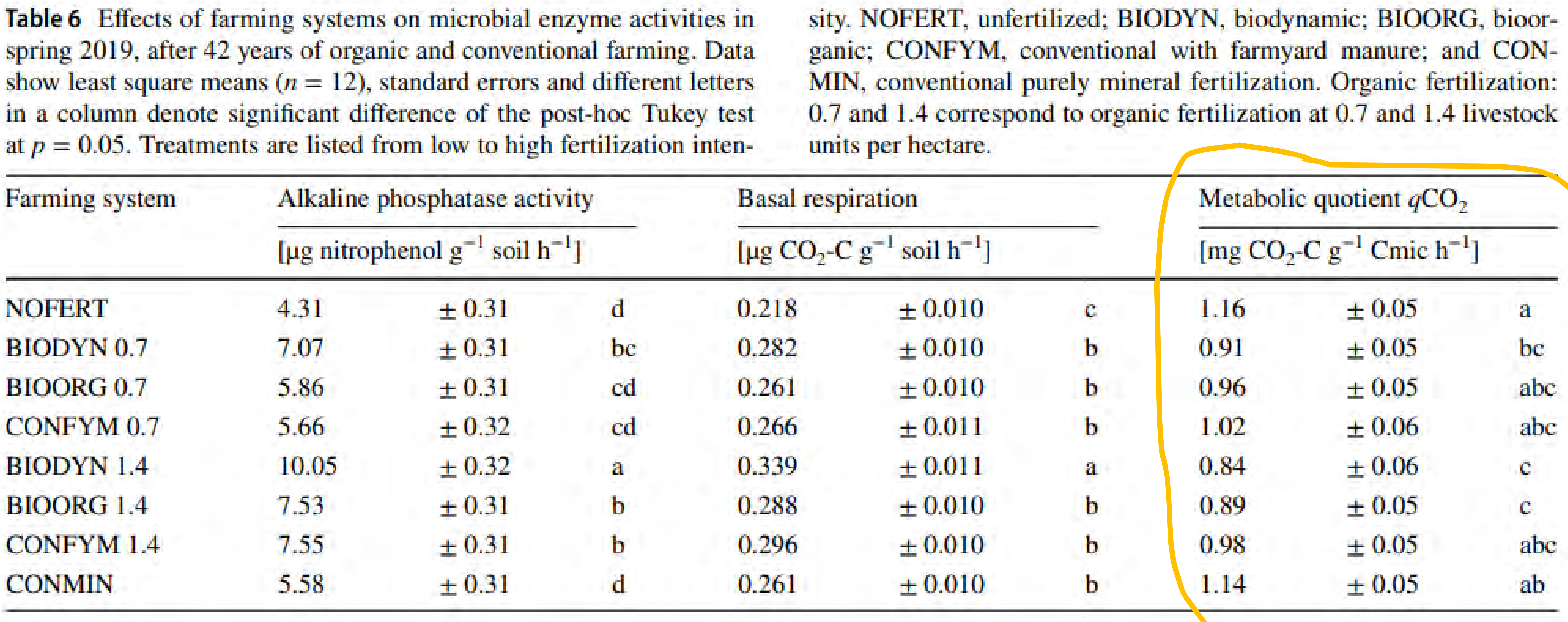


Table 6 Effects of farming systems on microbial enzyme activities in spring 2019, after 42 years of organic and conventional farming. Data show least square means ($n = 12$), standard errors and different letters in a column denote significant difference of the post-hoc Tukey test at $p = 0.05$. Treatments are listed from low to high fertilization intensity. NOFERT, unfertilized; BIODYN, biodynamic; BIOORG, bioorganic; CONFYM, conventional with farmyard manure; and CONMIN, conventional purely mineral fertilization. Organic fertilization: 0.7 and 1.4 correspond to organic fertilization at 0.7 and 1.4 livestock units per hectare.

Farming system	Alkaline phosphatase activity			Basal respiration			Metabolic quotient qCO_2		
	[µg nitrophenol g^{-1} soil h^{-1}]			[µg CO_2-C g^{-1} soil h^{-1}]			[mg CO_2-C g^{-1} Cmic h^{-1}]		
NOFERT	4.31	± 0.31	d	0.218	± 0.010	c	1.16	± 0.05	a
BIODYN 0.7	7.07	± 0.31	bc	0.282	± 0.010	b	0.91	± 0.05	bc
BIOORG 0.7	5.86	± 0.31	cd	0.261	± 0.010	b	0.96	± 0.05	abc
CONFYM 0.7	5.66	± 0.32	cd	0.266	± 0.011	b	1.02	± 0.06	abc
BIODYN 1.4	10.05	± 0.32	a	0.339	± 0.011	a	0.84	± 0.06	c
BIOORG 1.4	7.53	± 0.31	b	0.288	± 0.010	b	0.89	± 0.05	c
CONFYM 1.4	7.55	± 0.31	b	0.296	± 0.010	b	0.98	± 0.05	abc
CONMIN	5.58	± 0.31	d	0.261	± 0.010	b	1.14	± 0.05	ab

Krause, H.M., Stehle, B., Mayer, J., Mayer, M., Steffens, M., Mäder, P. and Fliessbach, A., 2022. Biological soil quality and soil organic carbon change in biodynamic, organic, and conventional farming systems after 42 years. *Agronomy for Sustainable Development*, *42*(6), pp.1-14.

Energy efficiency of soil – lower is better

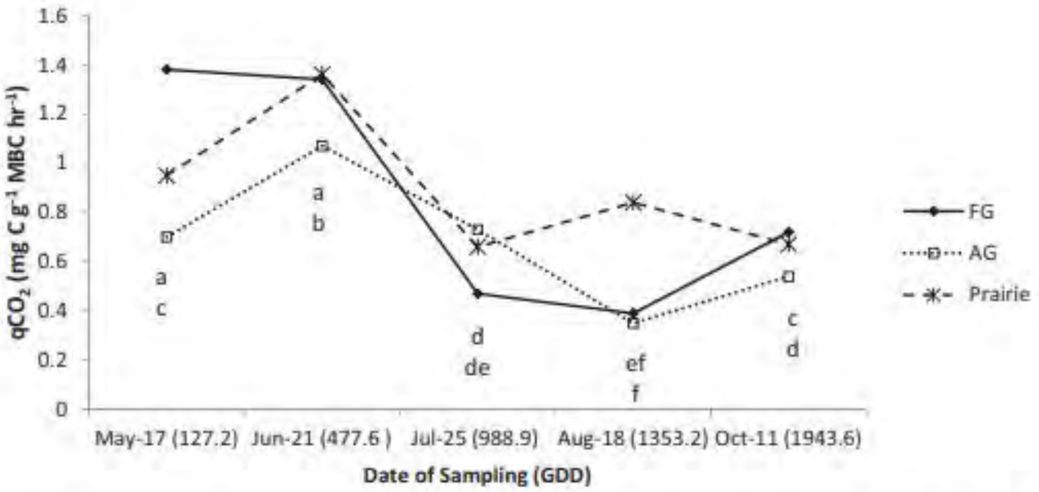
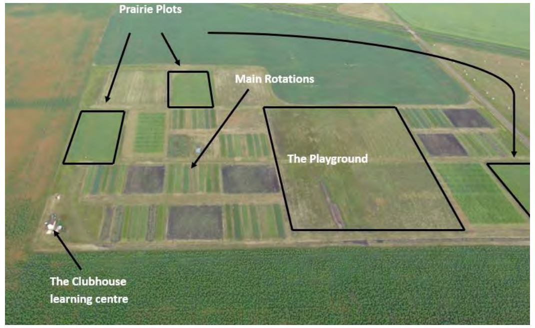


Fig. 3. Microbial metabolic quotient measurements (mg CO_2-C g^{-1}MBC h^{-1}) in forage-grain (FG), and annual-grain (AG) rotations, and a restored native perennial grassland (Prairie) over the 2011 growing season at Glenlea, Manitoba, Canada. Letters represent significant differences ($P < 0.05$) within and across FG and AG data series only. Prairie not included in analysis.



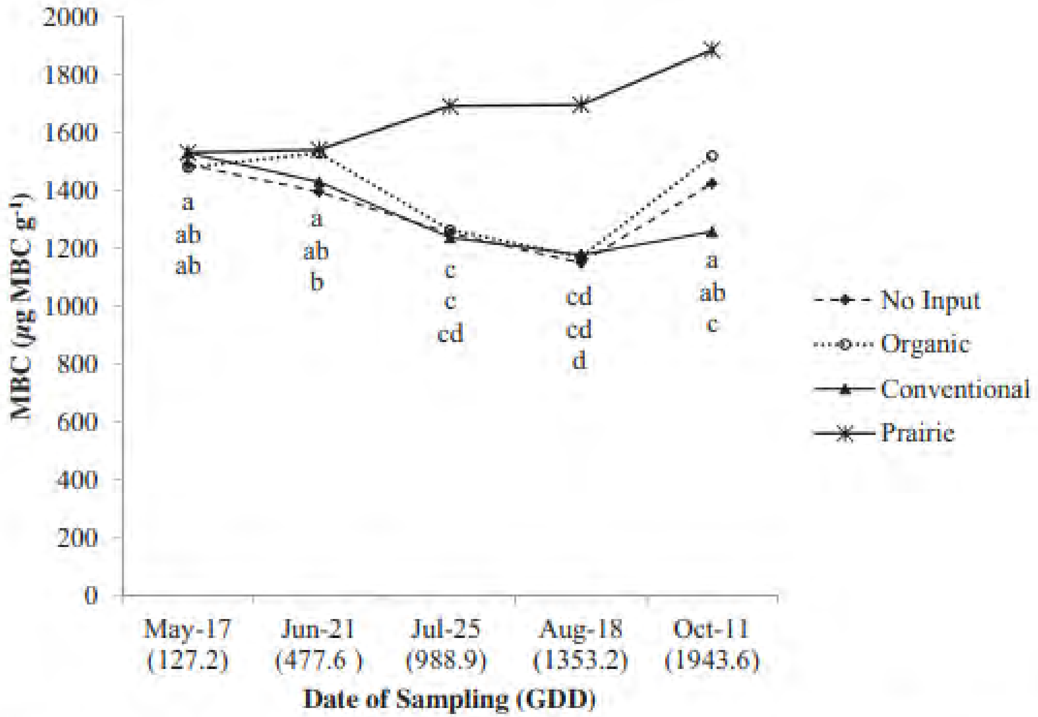
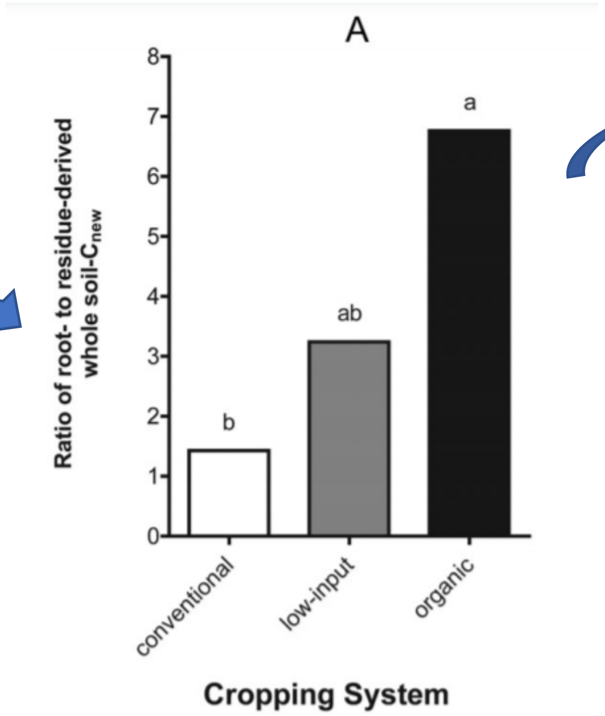


Fig. 1. Microbial biomass carbon (MBC) in organic without compost (No-Input), organic with compost (Organic), conventional (Conventional) and restored native perennial grassland (Prairie) treatments over the 2011 growing season at Glenlea, Manitoba, Canada. Different letters for mean values of cropped treatments signify differences ($P < 0.05$) across treatments and dates. Prairie not included in analysis.

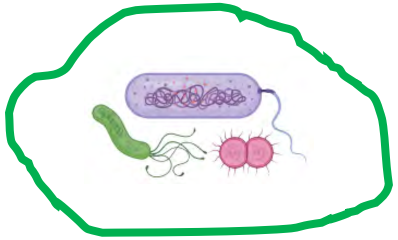
Braman, S., Tenuta, M. and Entz, M.H., 2016. Selected soil biological parameters measured in the 19th year of a long term organic-conventional comparison study in Canada. *Agriculture, Ecosystems & Environment*, *233*, pp.343-351.

Russell Ranch, UC Davis, California

We know that soil microbes like root material better than shoot material.



More evidence that organically managed soils have higher carbon use efficiency



Kong and Six (2010) observed that carbon from a winter hairy vetch cover crop in a tomato-corn crop rotation in California was stored <u>more efficiently in SOM under organic</u> than conventional conditions.

Kong, A.Y. and Six, J., 2010. Tracing root vs. residue carbon into soils from conventional and alternative cropping systems. *Soil Science Society of America Journal*, *74*(4), pp.1201-1210.

Provisioning: The soil as a source of nutrients for organic crop production

Organic matter supplies N for crops: Provisioning

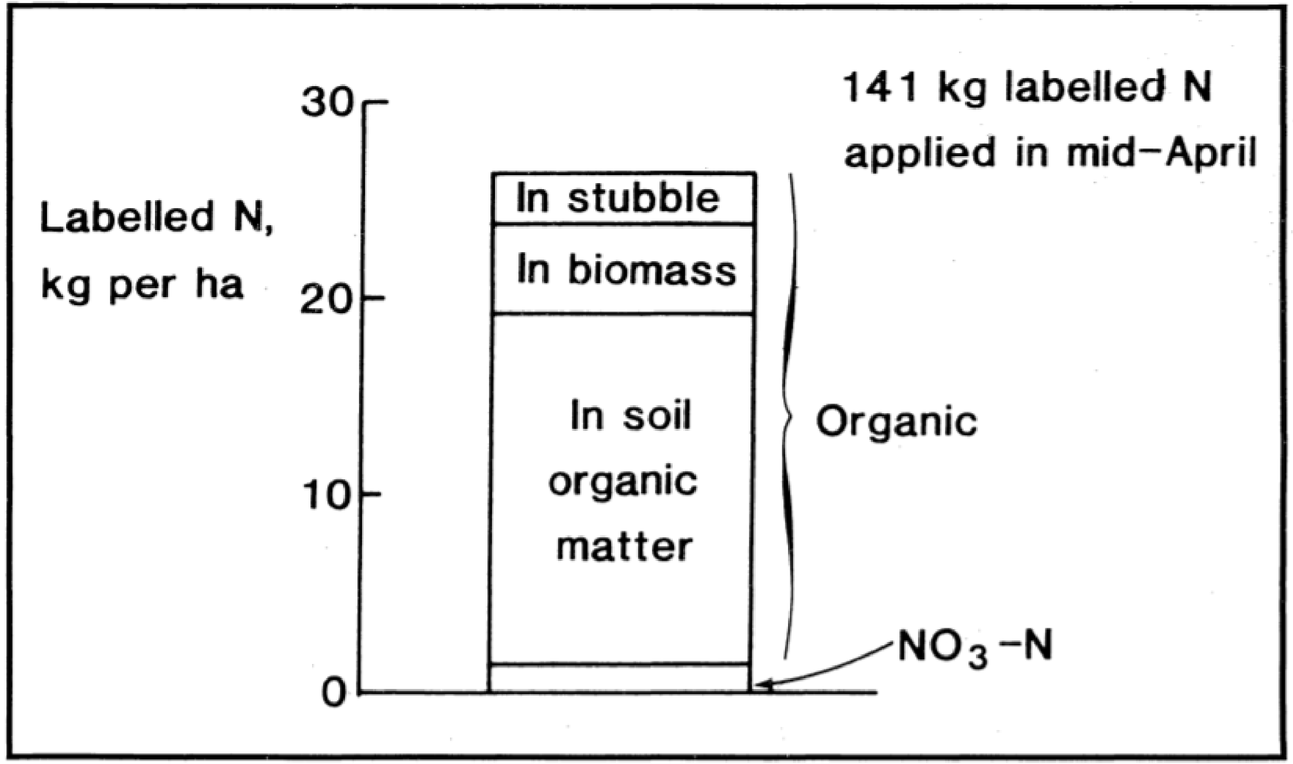


Figure 6. Distribution immediately after harvest of the ^{15}N labelled fertilizer nitrogen found in soil following the applicaiton of 144 kg N/ha in April.

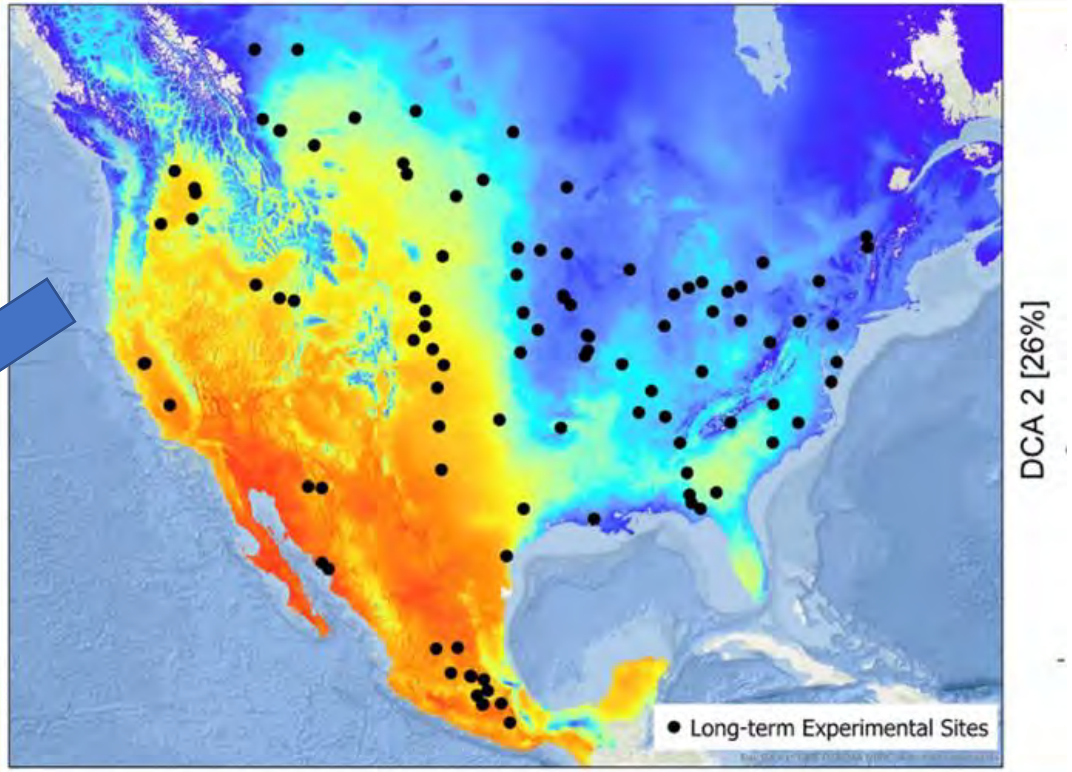
Glendining, M.J., Poulton, P.R., Powlson, D.S. and Jenkinson, D.S., 1997. Fate of 15 N-labelled fertilizer applied to spring barley grown on soils of contrasting nutrient status. Plant and Soil, 195(1), pp.83-98.

Cropping System	Total C % (Microbial biomass C)	[2]Potentially mineralizable nitrogen mg N/kg	Inorganic P Mg/kg	[3]Water stable aggregates	N-Acetyl β-Glucosaminidase mg pNP kg^{-1} soil hr^{-1}	Phosphomonoesterase (alkaline buffer) mg pNP kg^{-1} soil hr^{-1}	Arylsulfatase	[4]AMF total colonization
Prairie	4.4 [1](1750a)	114 b	18.2 a	87.3 a	127	406 ab	148.7 c	77.0
Grain only conventional	4.5 (1179c)	141 b	15.1 a	79 bc	148	370 b	132.9 c	32.3
Grain only organic	3.7 (1080d)	124 b	19.5 a	76 c	155	361 b	187.2 bc	49.7
Forage-grain conventional	3.9 (1476 b)	140 b	10.7 b	75.3 c	180	364 b	147.2 c	28.0
Forage-grain organic	4.2 (1648a)	135 b	5.3 c	80 bc	176	538 a	252.2 b	45.0
Forage-grain organic plus manure	4.5 (1718a)	189 a	16.5 a	82.6 a	184	561 a	327.9 a	35.7
P value	0.092 (0.0001)	0.0013	0.0001	0.0001	0.068	0.0024	0.0001	0.05 [5](0.001)*

Cropping System	Total C % (Microbial biomass C)	^{2}Potentially mineralizable nitrogen mg N/kg	Inorganic P Mg/kg	^{3}Water stable aggregates	N-Acetyl β-Glucosaminidase mg pNP kg^{-1} soil hr^{-1}	Phosphomonoesterase (alkaline buffer) mg pNP kg^{-1} soil hr^{-1}	Arylsulfatase	^{4}AMF total colonization
Prairie	4.4 ^{1}(1750a)	114 b	18.2 a	87.3 a	127	406 ab	148.7 c	77.0
Grain only conventional	4.5 (1179c)	141 b	15.1 a	79 bc	148	370 b	132.9 c	32.3
Grain only organic	3.7 (1080d)	124 b	19.5 a	76 c	155	361 b	187.2 bc	49.7
Forage-grain conventional	3.9 (1476 b)	140 b	10.7 b	75.3 c	180	364 b	147.2 c	28.0
Forage-grain organic	4.2 (1648a)	135 b	5.3 c	80 bc	176	538 a	252.2 b	45.0
Forage-grain organic plus manure	4.5 (1718a)	189 a	16.5 a	82.6 a	184	561 a	327.9 a	35.7
P value	0.092 (0.0001)	0.0013	0.0001	0.0001	0.068	0.0024	0.0001	0.05 ^{5}(0.001)*

Lowest enzyme levels almost always in conventional systems

One surprise in the data from across the region was that where grazing was included, SOM increased.



Hargreaves climate moisture deficit and SHI Sites

Soil Health Institute

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Safeguard and enhance the vitality and productivity of soil through scientific research and advancement.

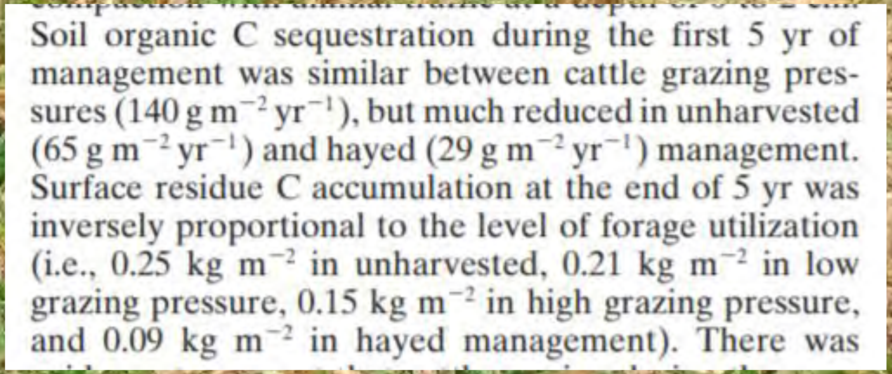
Grazing 5 year Bermudagrass stand increased soil C

Soil C sequestration

(Mg ha^{-1} yr^{-1}) (0-5 yr):

Hayed	**0.30**
Unharvested	**0.65**
Grazed	**1.40**

Franzluebbers et al. (2001) Soil Sci. Soc. Am. J. 65:834-841



Soil organic C sequestration during the first 5 yr of management was similar between cattle grazing pressures (140 g m^{-2} yr^{-1}), but much reduced in unharvested (65 g m^{-2} yr^{-1}) and hayed (29 g m^{-2} yr^{-1}) management. Surface residue C accumulation at the end of 5 yr was inversely proportional to the level of forage utilization (i.e., 0.25 kg m^{-2} in unharvested, 0.21 kg m^{-2} in low grazing pressure, 0.15 kg m^{-2} in high grazing pressure, and 0.09 kg m^{-2} in hayed management). There was

Grazing stimulates root C exudation

"Grazers stimulated aboveground, belowground, and whole-grassland productivity by 21%, 35%, and 32%, respectively. Root production was stimulated seven times more (217 g/m2) than shoot production (30 g/m2), indicating that the major effect of herbivores in this system was a positive feedback on root growth."

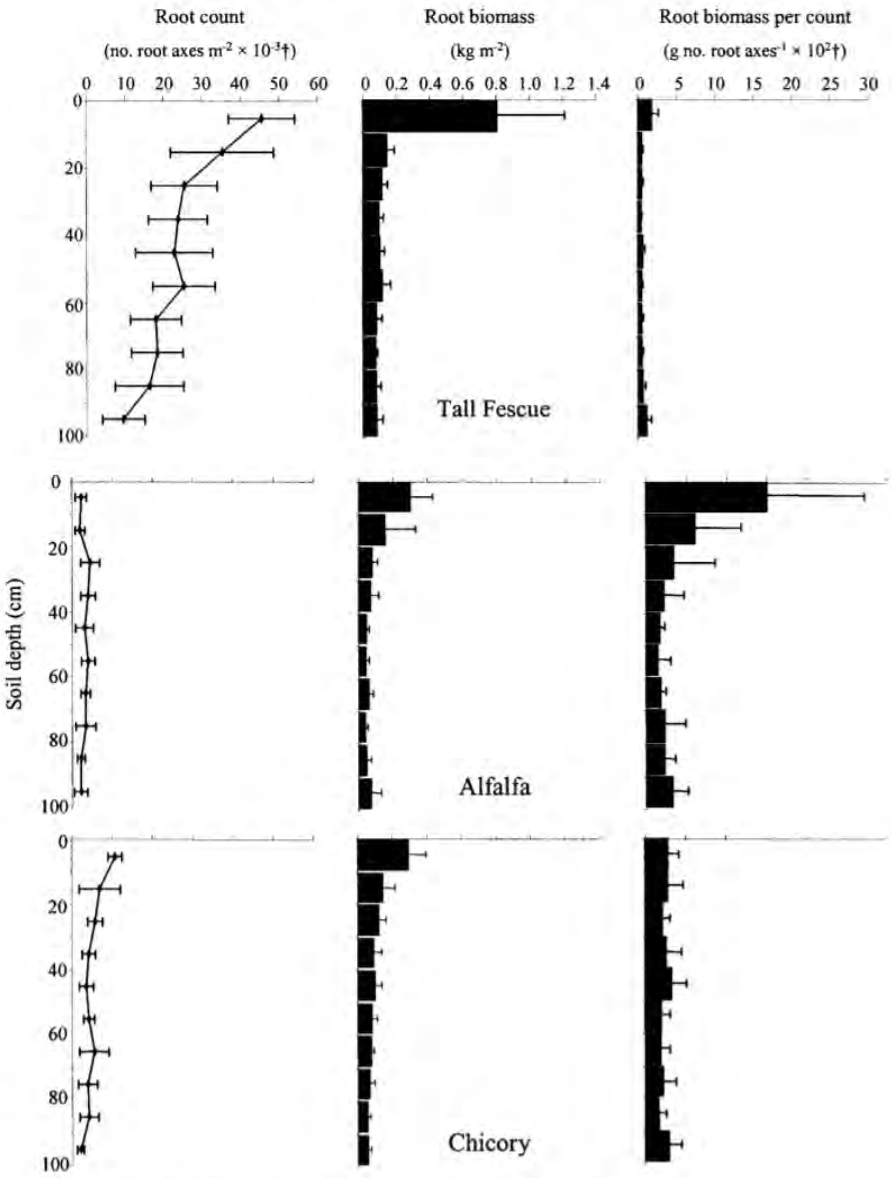
Frank, D.A., Kuns, M.M. and Guido, D.R., 2002. Consumer control of grassland plant production. *Ecology*, *83*(3), pp.602-606.

Defoliation stimulated C exudation from roots by 1.5-fold, which concomitantly increased rhizospheric microbial biomass by the same factor. The facilitating effects of defoliation on rhizospheric processes resulted in positive feedback on soil inorganic N pools and leaf N content, which increased by 1.2- and 1.5-fold respectively.

Hamilton III, E.W., Frank, D.A., Hinchey, P.M. and Murray, T.R., 2008. Defoliation induces root exudation and triggers positive rhizospheric feedbacks in a temperate grassland. *Soil Biology and Biochemistry*, *40*(11), pp.2865-2873.

Deep-rooted perennials to add C to subsoil

GENTILE ET AL. — ROOT CHARACTERIZATION OF FORAGE SPECIES 787



† Reported values equal actual values times the indicated factor.

Fig. 1. Root count, root biomass, and root biomass per count distributions of three forage stands to a depth of 1 m. Values are means of eight replicates with horizontal bars representing the standard errors of the means.

"Greater increase in SOC at depth may be associated with a greater proliferation and turnover of fine roots at depth, or alternatively may reflect the movement down the profile of soluble C compounds from the roots as a result of the movement of water after heavy rainfall events".

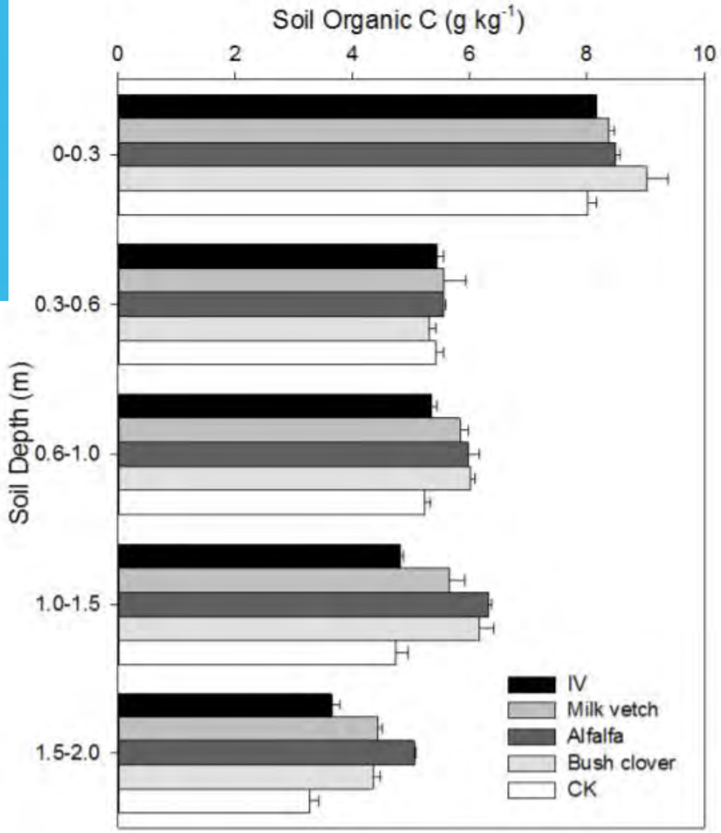


Figure 2. Profile of soil organic carbon (SOC) concentration in May 2004 (IV) and in October 2010 under three forage legumes: milk vetch, alfalfa and bush clover, and bare soil (CK). Bars give + one standard error of the mean ($n = 3$).

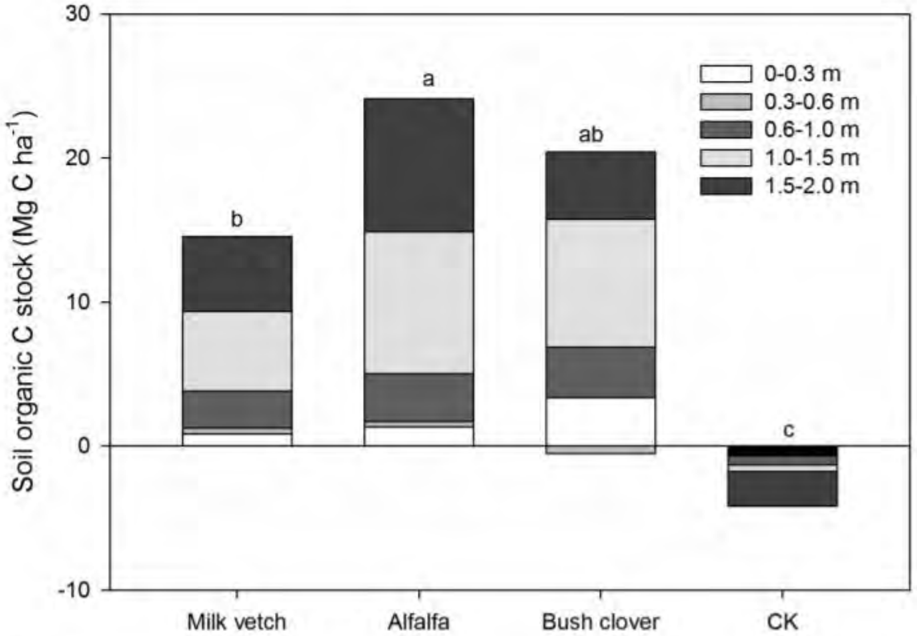
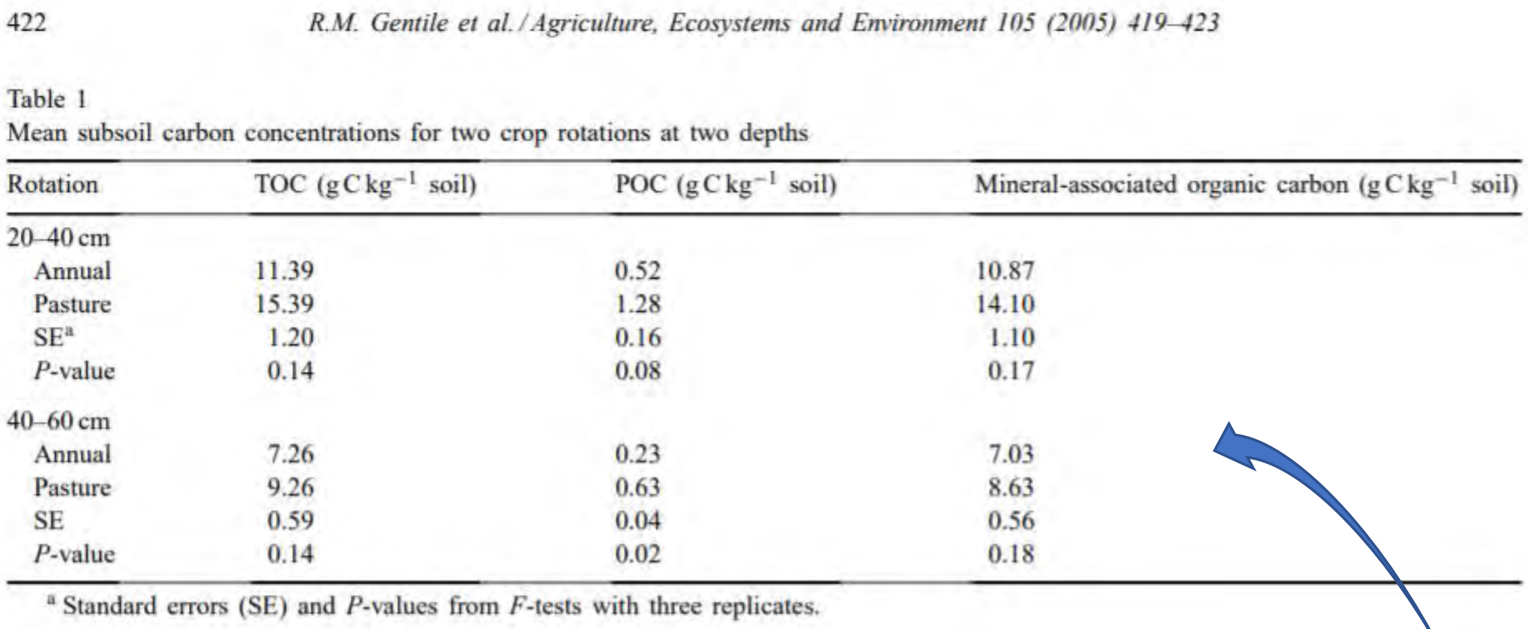


Figure 5. Change in soil organic carbon amount (stock) in different soil layers under milk vetc alfalfa, bush clover and bare soil (CK) from May 2004 to October 2010. Different letters indicat significant differences ($P < 0.05$) between total carbon stocks.

Ojeda, J.J., Caviglia, O.P. and Agnusdei, M.G., 2018. Vertical distribution of root biomass and soil carbon stocks in forage cropping systems. *Plant and soil*, *423*(1-2), pp.175-191.



422 *R.M. Gentile et al. / Agriculture, Ecosystems and Environment 105 (2005) 419–423*

Table 1
Mean subsoil carbon concentrations for two crop rotations at two depths

Rotation	TOC ($g\,C\,kg^{-1}$ soil)	POC ($g\,C\,kg^{-1}$ soil)	Mineral-associated organic carbon ($g\,C\,kg^{-1}$ soil)
20–40 cm			
Annual	11.39	0.52	10.87
Pasture	15.39	1.28	14.10
SE[a]	1.20	0.16	1.10
P-value	0.14	0.08	0.17
40–60 cm			
Annual	7.26	0.23	7.03
Pasture	9.26	0.63	8.63
SE	0.59	0.04	0.56
P-value	0.14	0.02	0.18

[a] Standard errors (SE) and *P*-values from *F*-tests with three replicates.

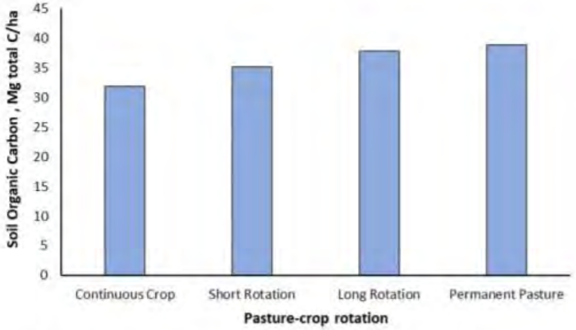


Figure 4. Crop–livestock rotation impact on soil organic carbon (SOC, 0–15 cm depth) from the 'Palo a Pique' long-term experiment (1995–2003). Content of SOC in continuous cropping was significantly lower than SOC in the other rotations. Adapted from Terra et al. [18].

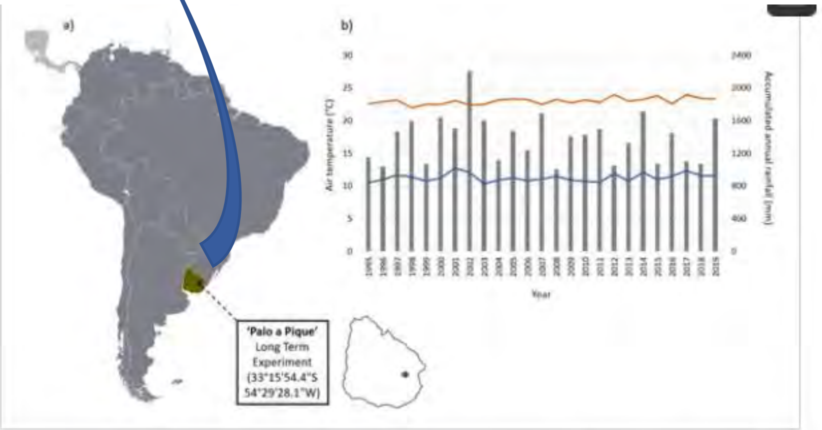
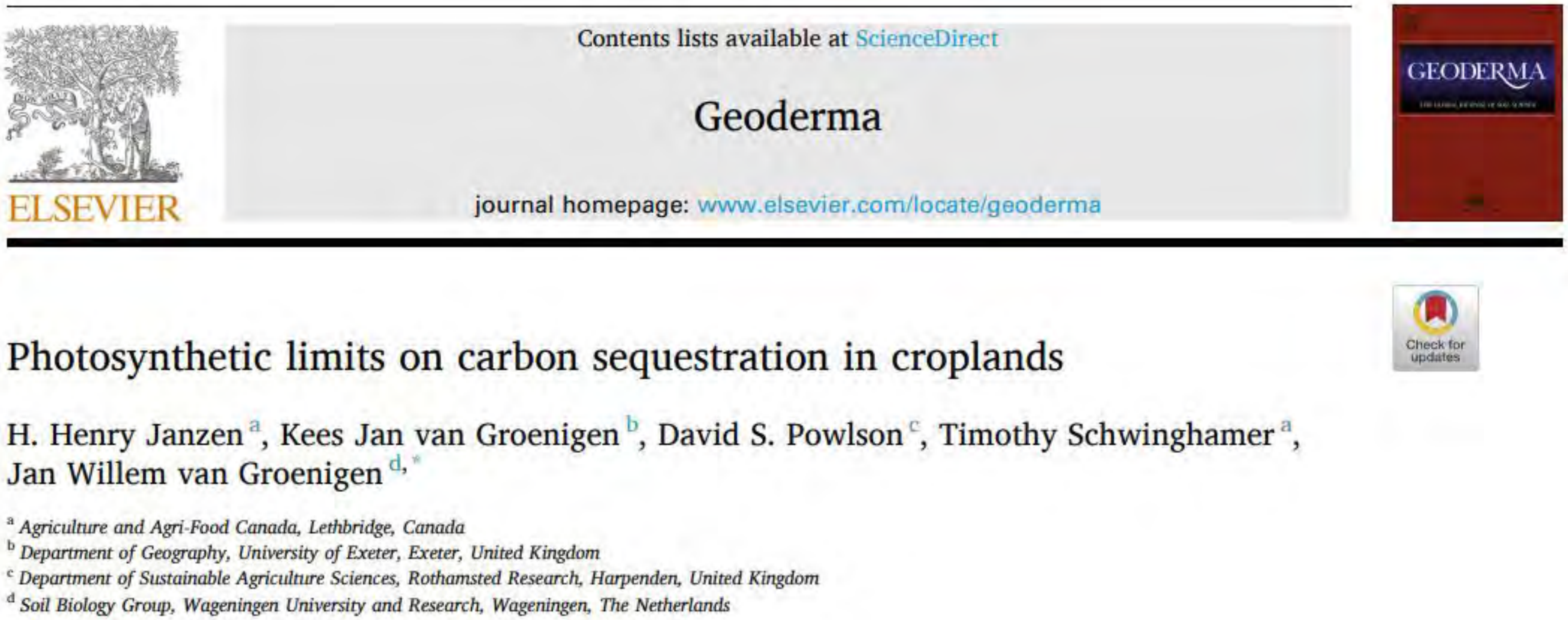


Figure 1. Location of the 'Palo a Pique' long-term experiment of the National Institute of Agricultural Research (INIA) in Uruguay (**a**), and annual accumulated rainfall (grey bars), mean maximum air temperature (orange line) and mean minimum air temperature (blue line) from 1995 to 2019 (**b**).



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Photosynthetic limits on carbon sequestration in croplands

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“The higher the plant growth, the more C is available for both harvest and replenishment of soil organic matter. One strategy, for example, is continued research toward greater use of perennial crops, including forages, which maintain photosynthesis for longer durations, and allocate more C to plant parts not subject to harvest and removal, notably in rooting systems (Glover et al., 2010). Where perennial systems are not feasible, their benefits can be mimicked by extending and enhancing photosynthesis through measures such as cover cropping, diversified cropping schemes, judicious crop nutrition, and promoting perennials in unharvested landscape areas (Asbjornsen et al., 2014; King and Blesh, 2018)”.

Keep soil covered and cooler: Eg. Small grains in Ontario organic corn-soy system

Thank you again for your attention. I am looking forward to tomorrow’s Q and A session

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