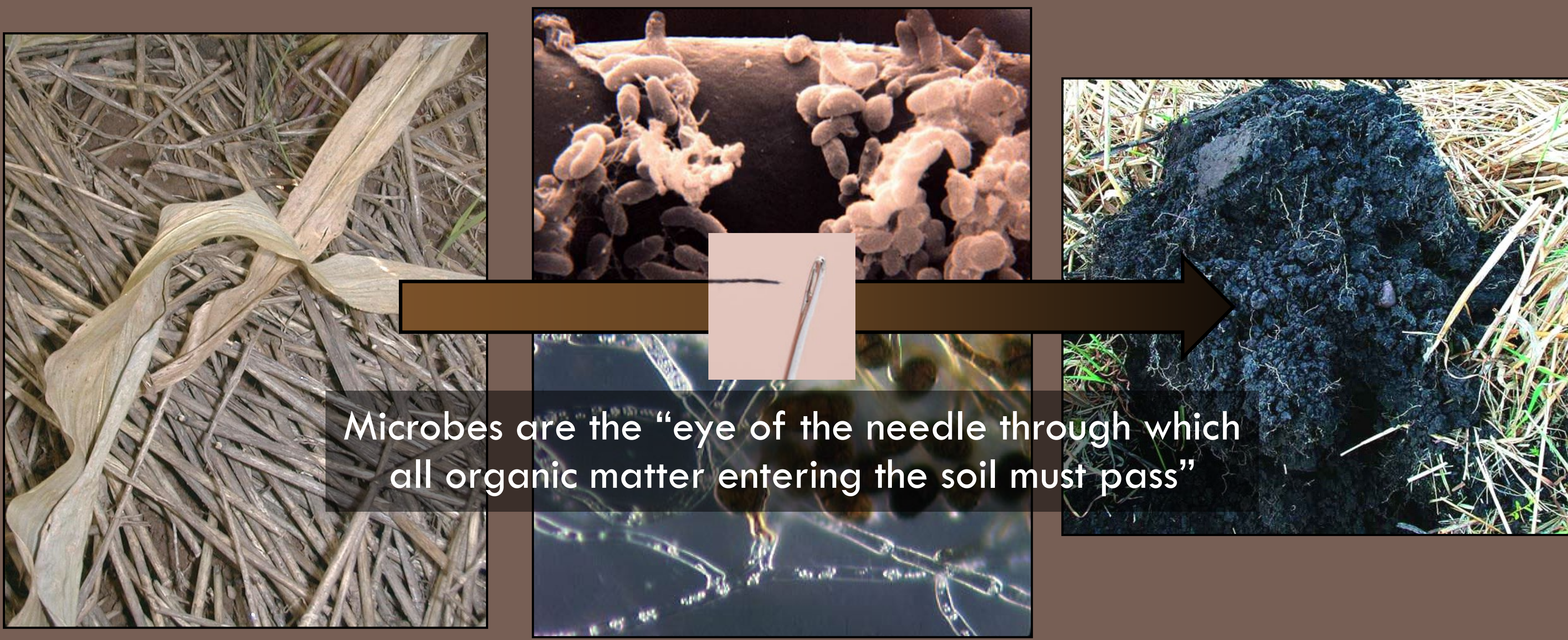
CONTROLS ON SOIL ORGANIC CARBON LEVELS AND EFFECTS OF MANAGEMENT

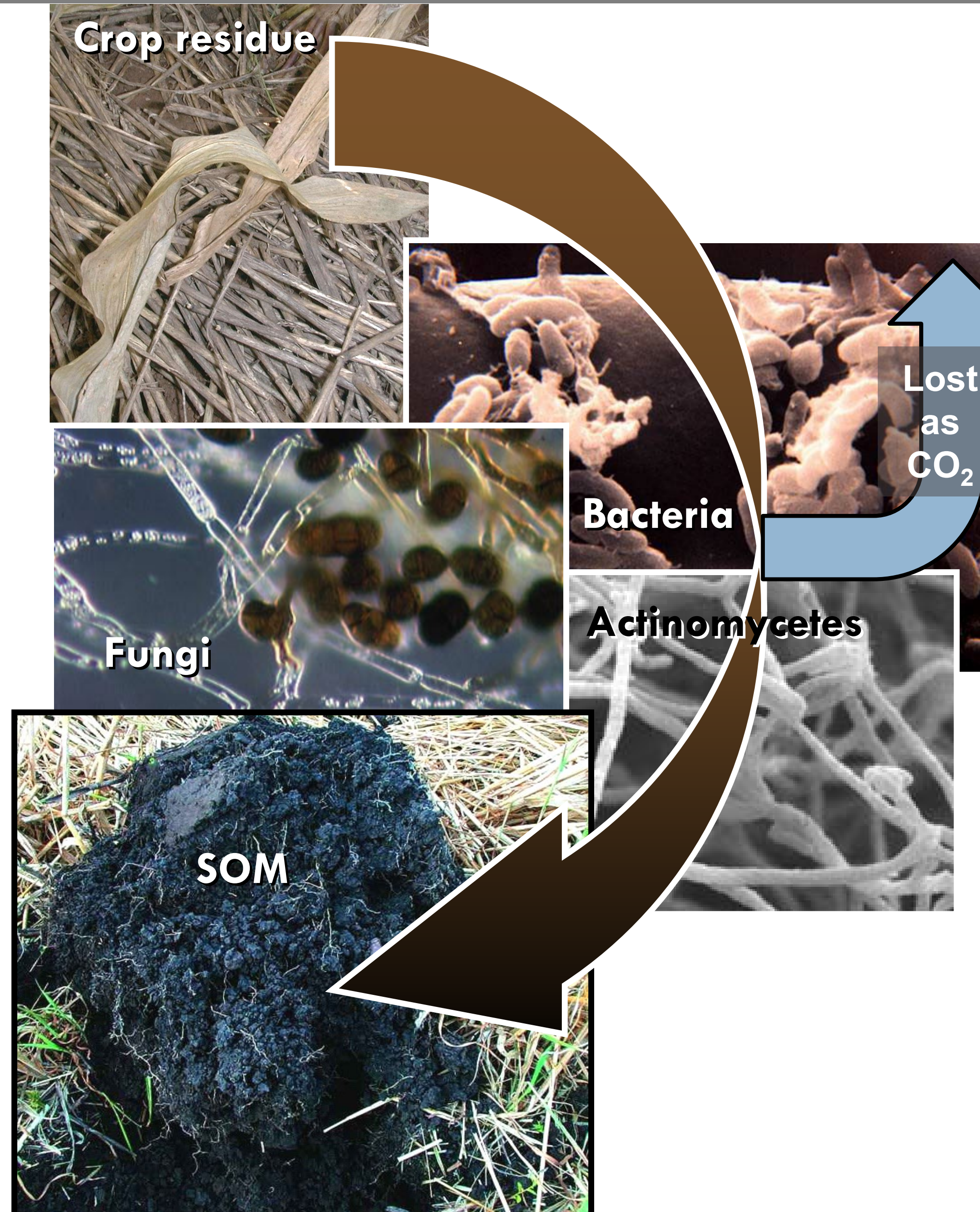


Soil Organic Carbon Lecture Outline

- What is soil organic matter and soil organic carbon (SOC)? & Why is it important?
- How is soil organic carbon stored in soils?
- Natural controls on soil organic carbon cycling and storage
- How does management affect soil organic carbon cycling and sequestration? (Learning from Long-term experiments)
- Getting real on the ability of soils to sequester SOC as part of the climate solution and the issue of "permanence".

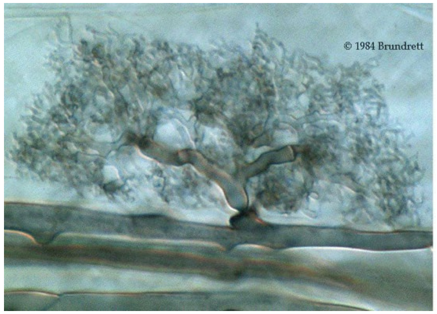
What is Soil Organic Matter (SOM)?

- All material in soil that contains (reduced) carbon.
- SOM is derived from
  - Plant residue (both litter and roots)
  - Animal remains and excreta
  - Living soil microbes (microbial biomass)
- Microbes process fresh organic material → over time some can become stable soil organic matter



The three general “types” of soil organic matter (SOM)

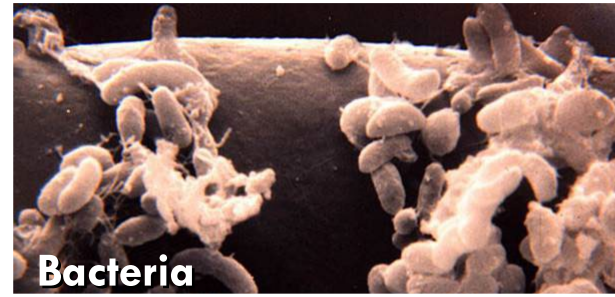
- **Living:** living soil organisms and plant roots
- **Dead:** Plant residues and dead soil biota
- **Very Dead:** Stable soil organic matter

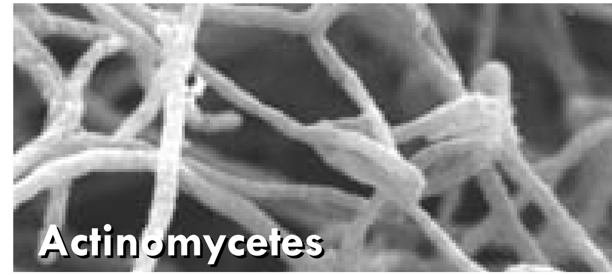


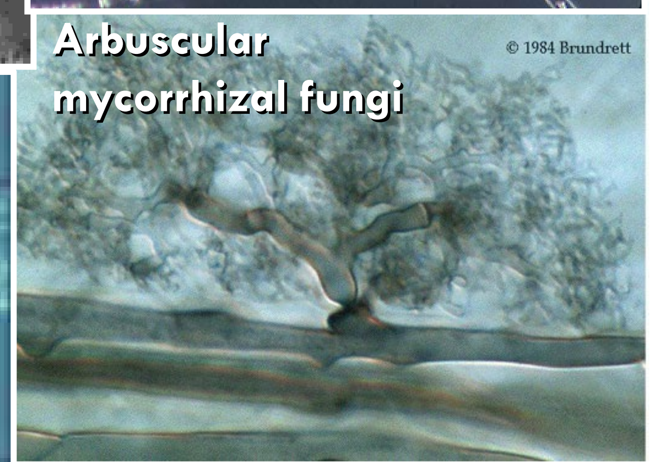
→ ***all three play important roles in helping produce high yield of healthy crops***

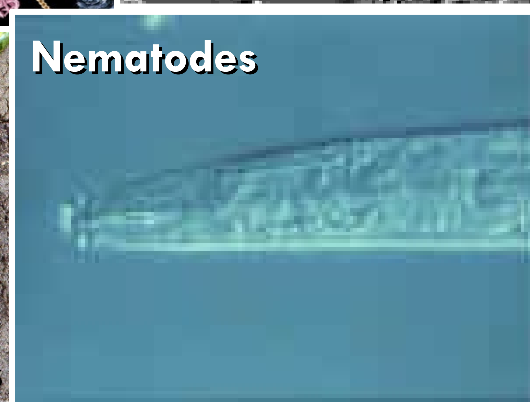
—Living —

- **Organisms of various sizes:** bacteria, fungi, nematodes, earthworms, mites, springtails, etc. AND plant roots
- **Roles**: soil organisms make nutrients available, nutrient acquisition, suppress disease, aggregate soils…









—Dead —

- Recently dead soil organisms and crop residues provide the food (energy and nutrients) for soil organisms to live and function.

- This is the organic matter that microbes mineralize into plant available nutrients.

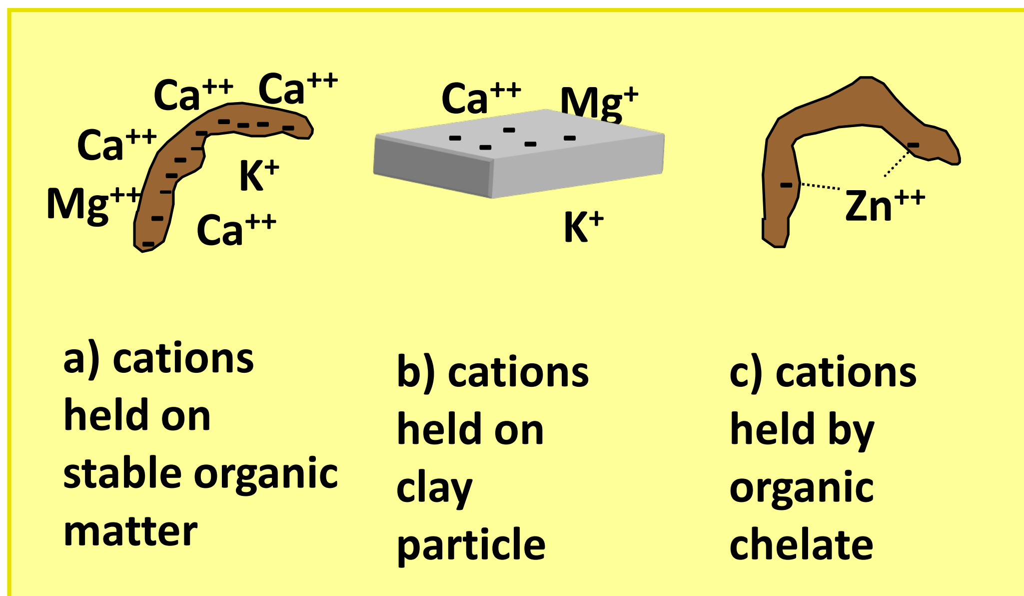
—Very Dead —

Stable soil organic matter

- Protected as mineral-associated organic matter
- Protected as Humus?: the ultimate stage in decomposition (not as important as previously thought)

Benefits:

- Increases soil water holding capacity – through microporosity
- Increases nutrient retention –surface areas hold electrical charges, that draw in and store cations.
- Stores/sequesters carbon



How much Organic Matter in an acre furrow slice of soil?

250 ft

174 ft

Acre furrow slice = 6.7 in or 0.56 ft

3 % SOM

How many 1,000 lb round bales equivalents are in an “acre furrow slice” of soil?

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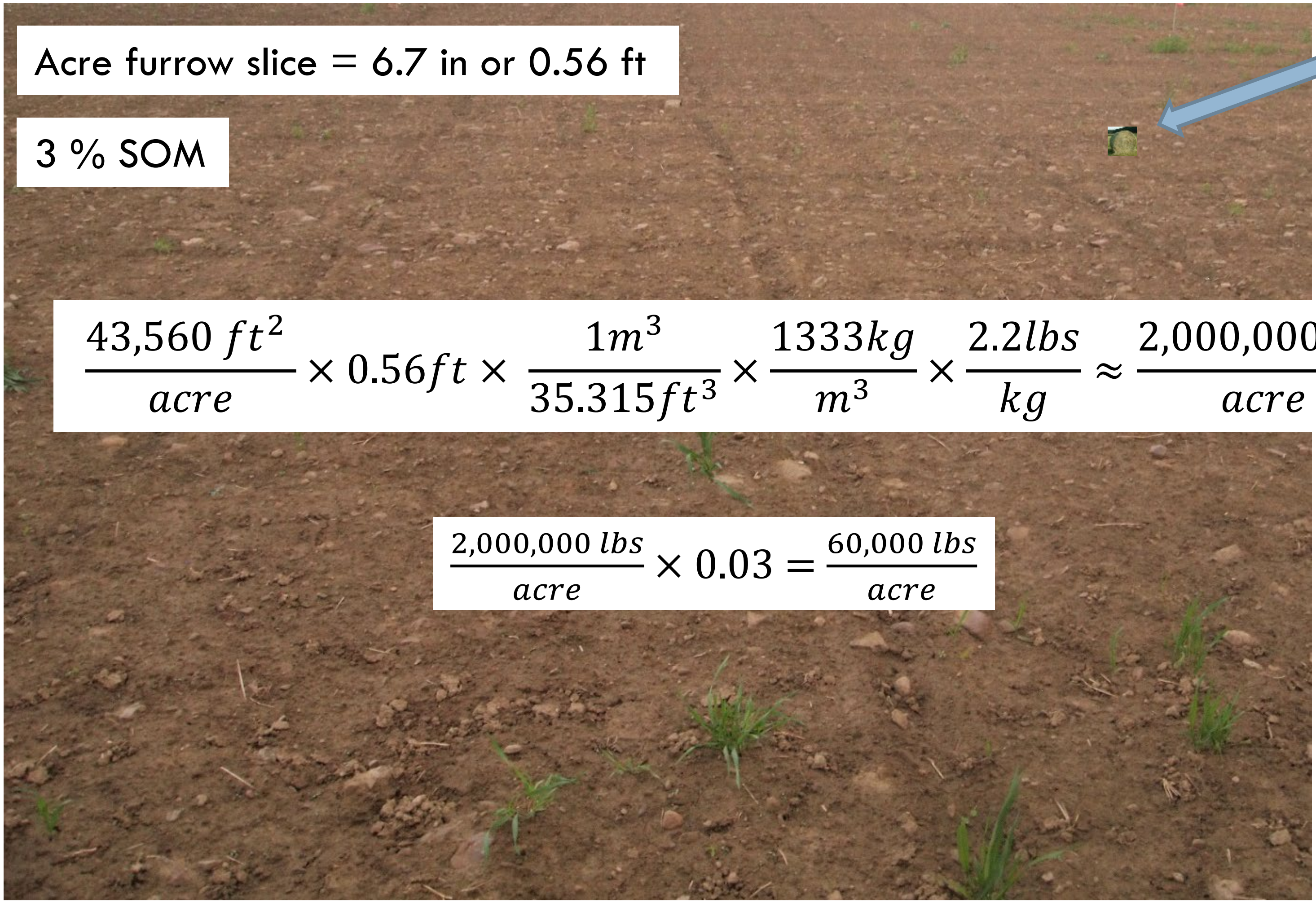


Acre furrow slice = 6.7 in or 0.56 ft

3 % SOM

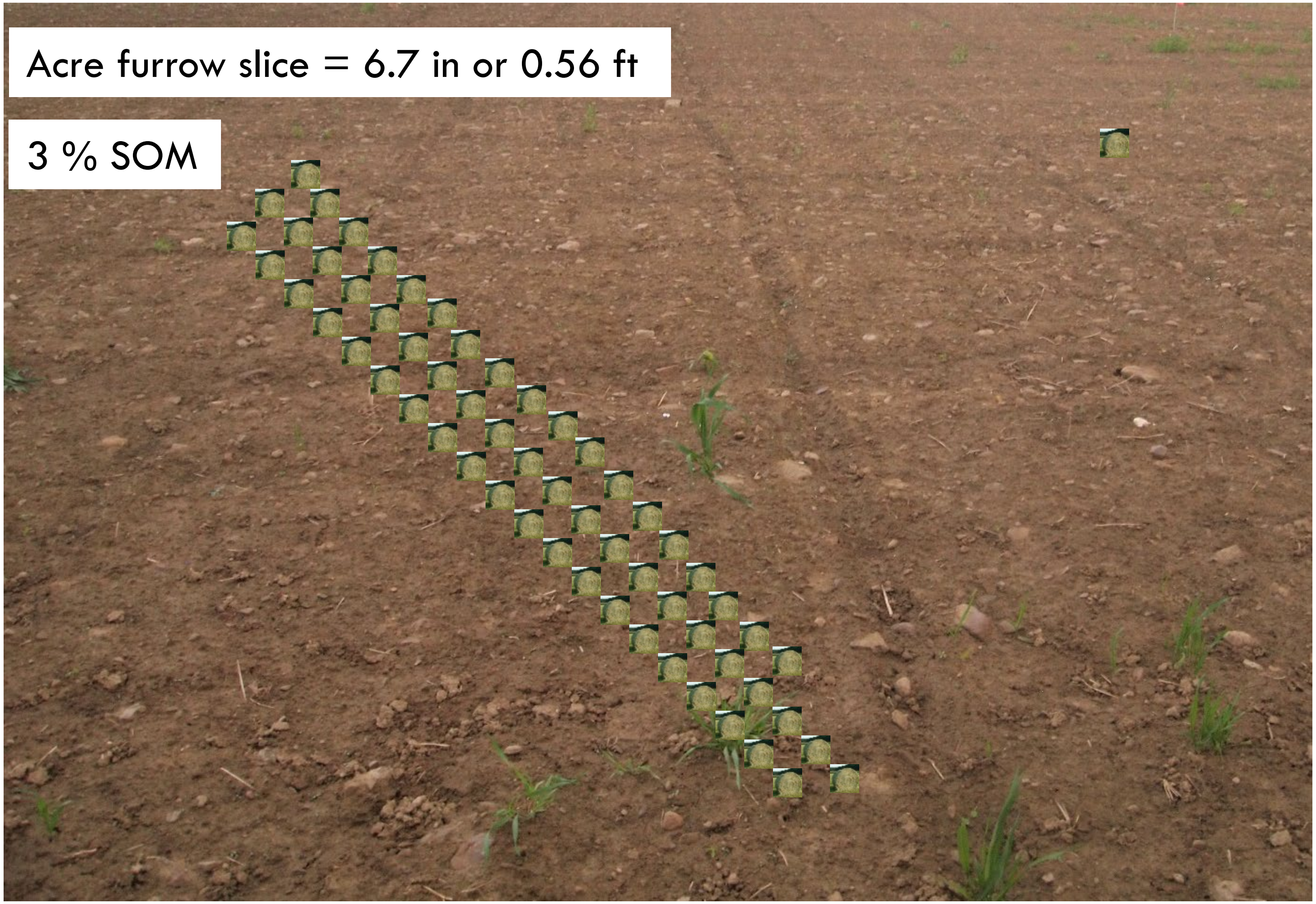
$$\frac{43{,}560\ ft^2}{acre} \times 0.56ft \times \frac{1m^3}{35.315ft^3} \times \frac{1333kg}{m^3} \times \frac{2.2lbs}{kg} \approx \frac{2{,}000{,}000\ lbs}{acre}$$

$$\frac{2{,}000{,}000\ lbs}{acre} \times 0.03 = \frac{60{,}000\ lbs}{acre}$$

How many 1,000 lb round bales equivalents are in an "acre furrow slice" of soil?

250 ft

174 ft

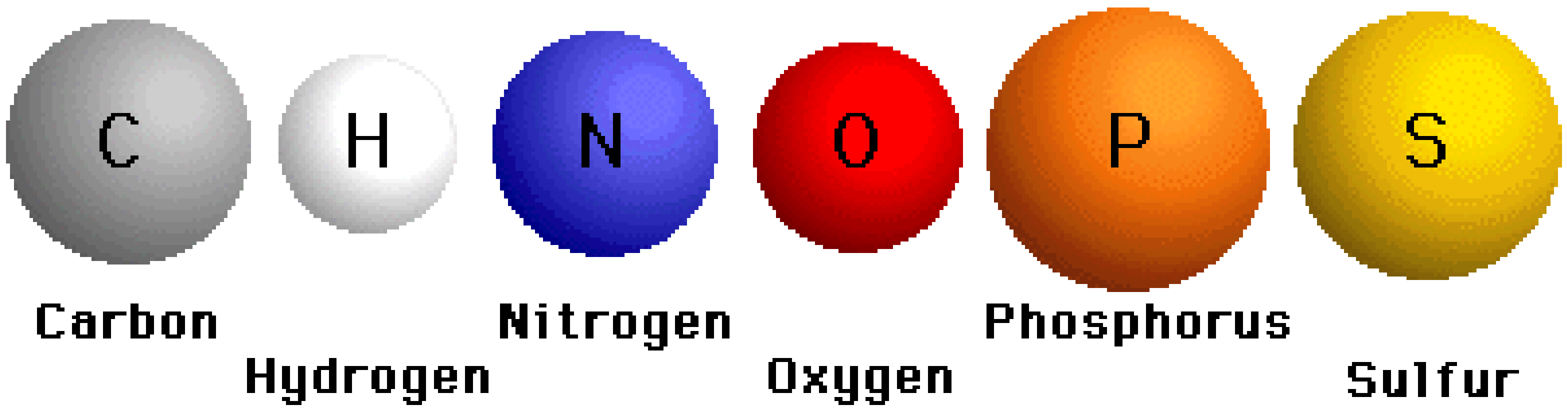


Why is soil organic matter so important?

- Soil Tilth/aggregation…
- Soil pore space and hardness
- Infiltration and Water Retention
- Resilience to storms or draught
- Nutrient availability
- Nutrient retention & CEC
- Increase pH buffering
- Reduce metal toxicity
- Carbon Sequestration
- Beneficial Effects of Soil Organisms…
- Increased nutrient cycling
- Root Growth
- Disease Suppression
- Darkening soil
- Important in C-cycle
- Important in N-cycle
- Important in water cycle
- Climate change Mitigation and Adaptation

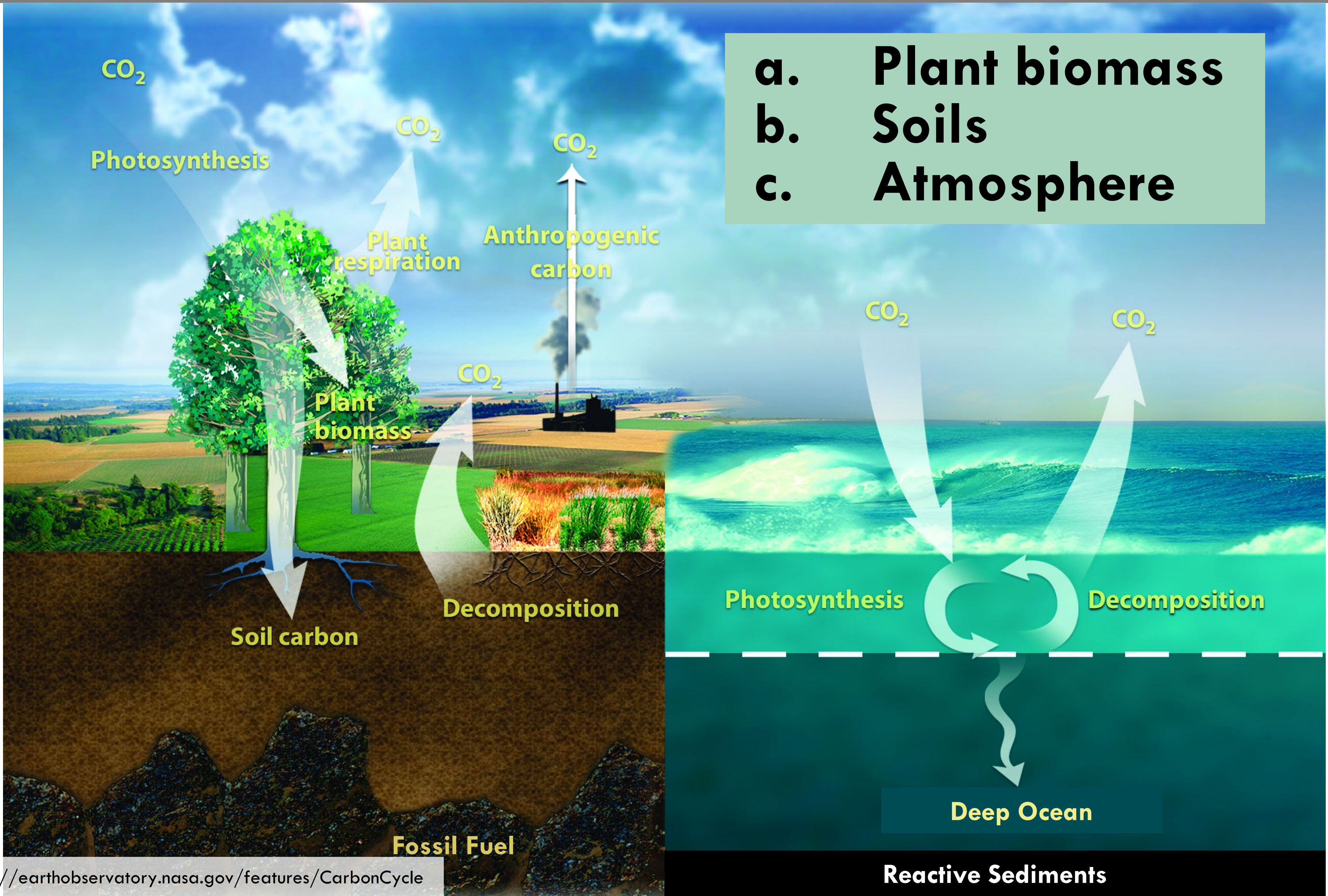
What is Soil Organic Carbon (SOC)?

- Soil organic matter (SOM) is ≈ 50 - 65 % C
- Soil organic carbon (SOC) is a measurement of all the C found in soil organic matter and therefore is about 50-65% of SOM levels
- E.g. if SOM = 3.2 % then SOC = 1.6 – 2.1 %
- Measuring SOC directly is more accurate than just measuring SOM and applying a conversion factor to get SOC
- Don't forget your "CHNOPS" – The main elements that make up organic matter



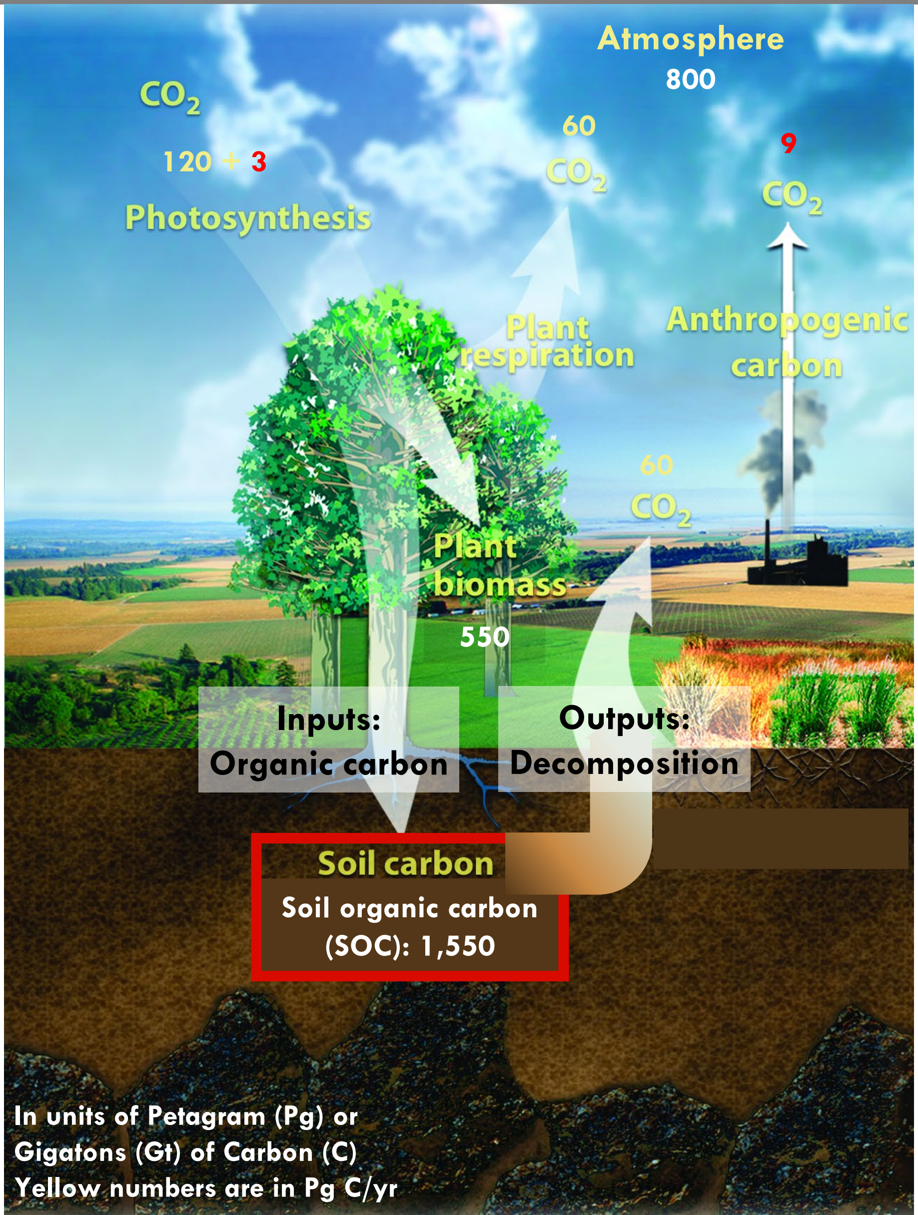
What is the largest terrestrial carbon pool besides fossil fuels and ocean?

a. Plant biomass
b. Soils
c. Atmosphere



https://earthobservatory.nasa.gov/features/CarbonCycle

Soils: The Largest Terrestrial Carbon Sink

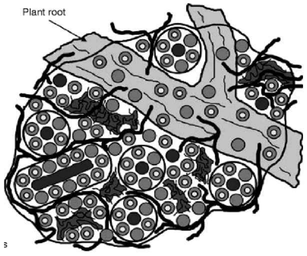


https://earthobservatory.nasa.gov
/features/CarbonCycle

How is Soil Organic Carbon Stored in Soil?

- Strong chemical bonds between organic matter and fine silt and clay

- Inside small aggregates (physically protected from decomposition)



Aggregate

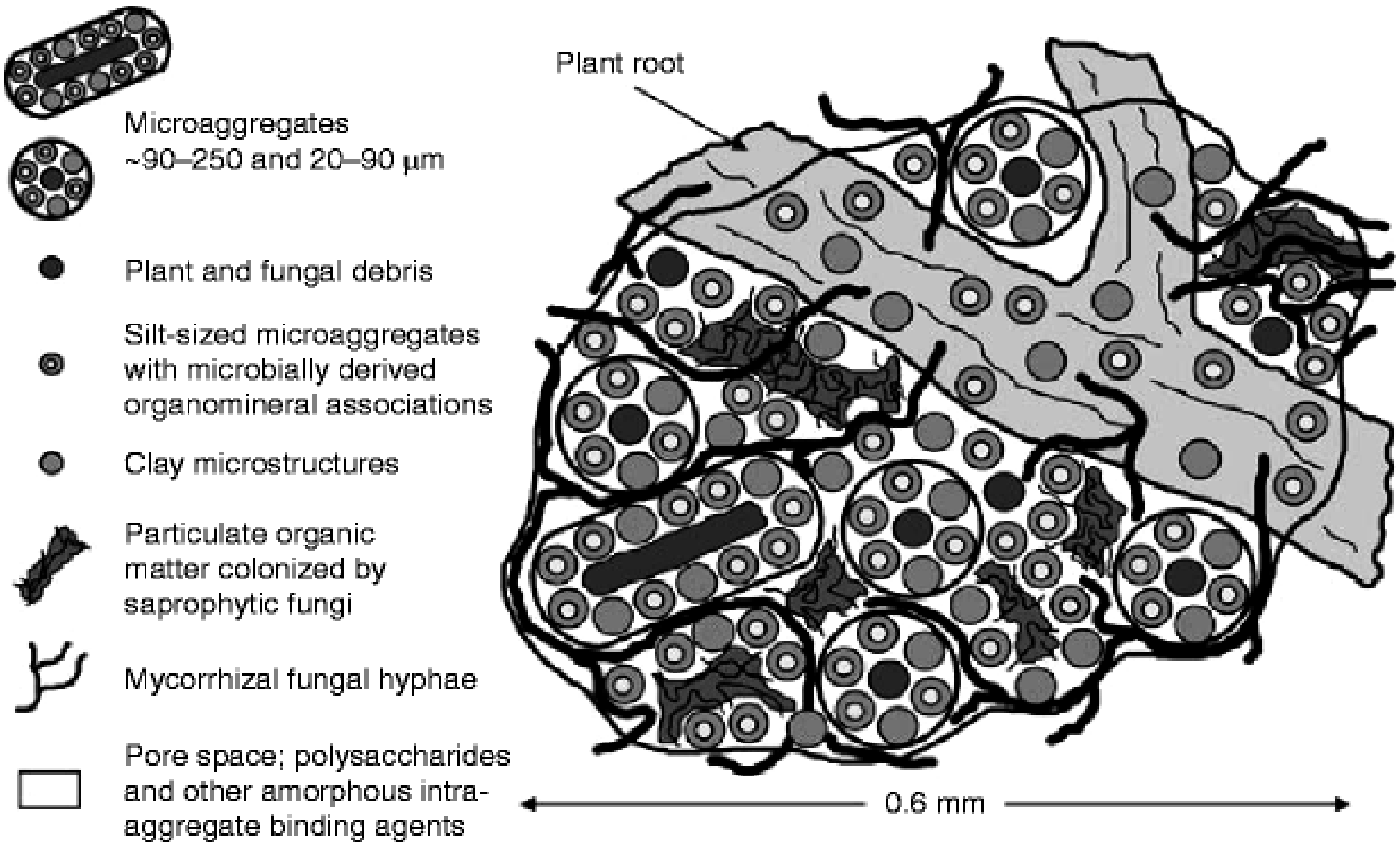
- Humification: produces stable/complex substances such as humic materials that are resistant to biological decomposition

Much less important than we previously thought

- Char produced by incomplete burning

Remember Terra Preta Soils

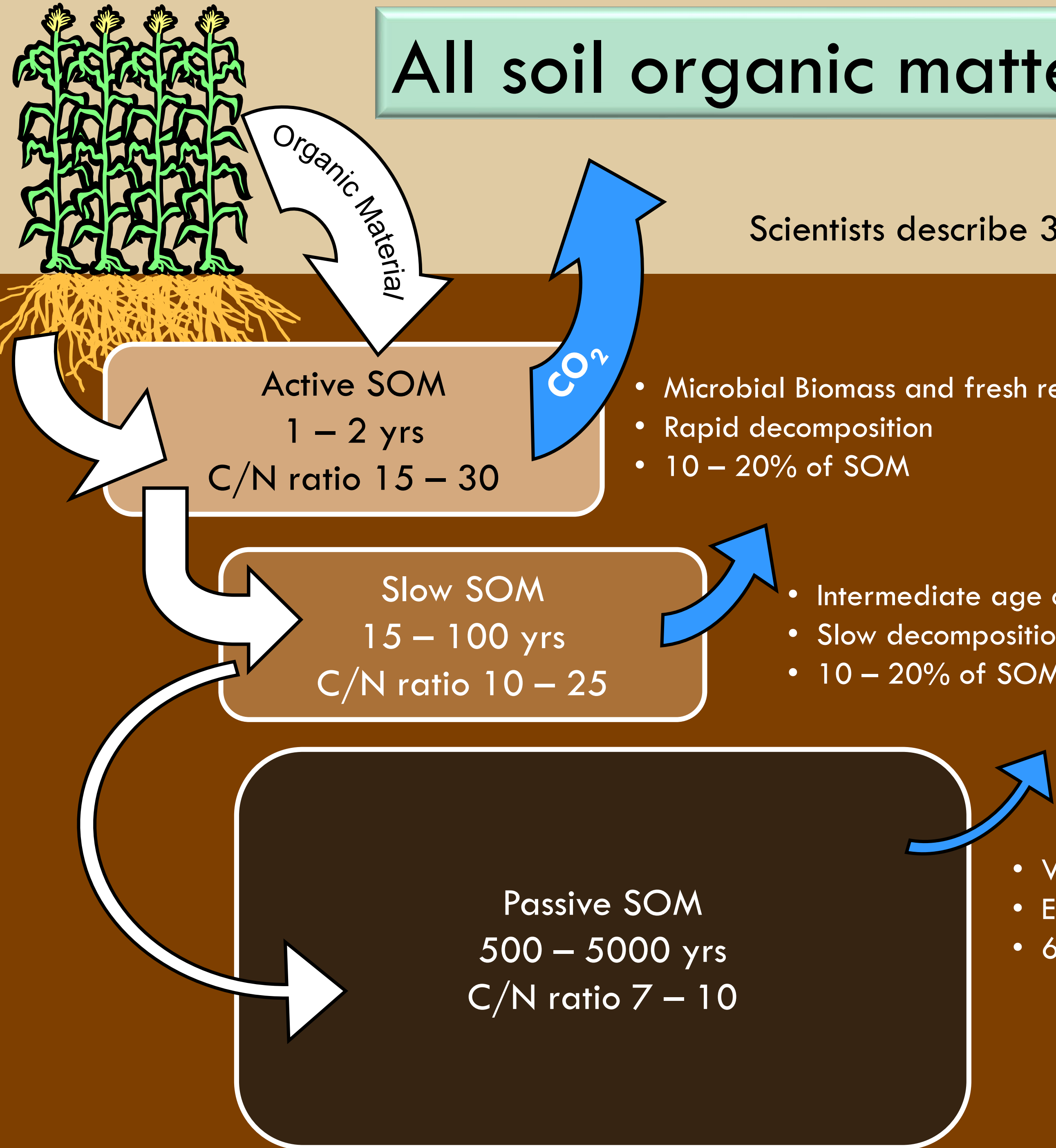
Physical Protection of Organic Carbon in Soil Aggregates



Conceptual diagram of aggregate hierarchy illustrating microaggregates inside a macroaggregates (Jastrow et al., 2007, Encyclopedia of Agrophysics

All soil organic matter is not equal

Scientists describe 3 pools of soil organic matter



- Microbial Biomass and fresh residues
- Rapid decomposition
- 10 – 20% of SOM

- Intermediate age organic material
- Slow decomposition
- 10 – 20% of SOM

- Very stable organic material
- Extremely slow decomposition
- 60 – 80% of SOM

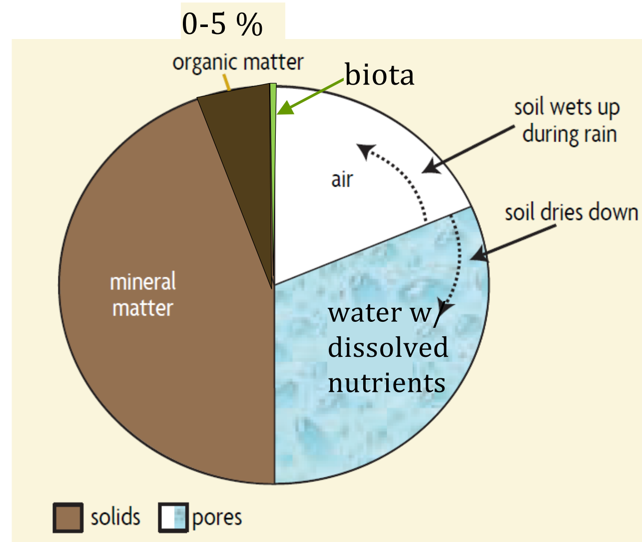
Theoretical pools of soil organic matter

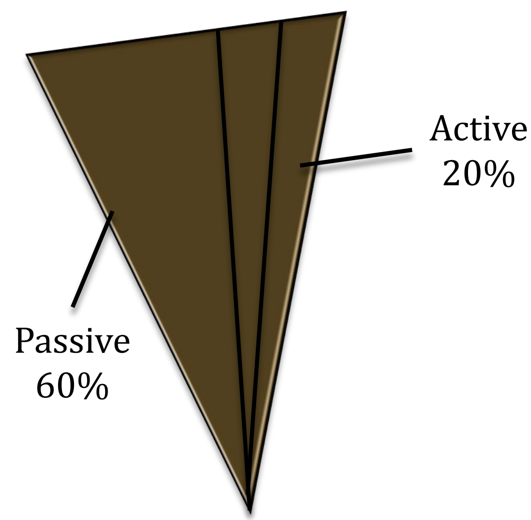
Active SOM

- unprotected soil organic matter
- rapid decomposition
- high C:N ratio

Passive SOM

- Stable/Protected soil organic matter
- Slow decomposition
- High cation exchange and Water holding capacities





What Controls Soil Organic Matter Accumulation and Cycling?

<u>Natural factors</u> { Climate / Soil Type

- Climate
- Soil Type

Balance between inputs and Losses → Equilibrium

Human Management

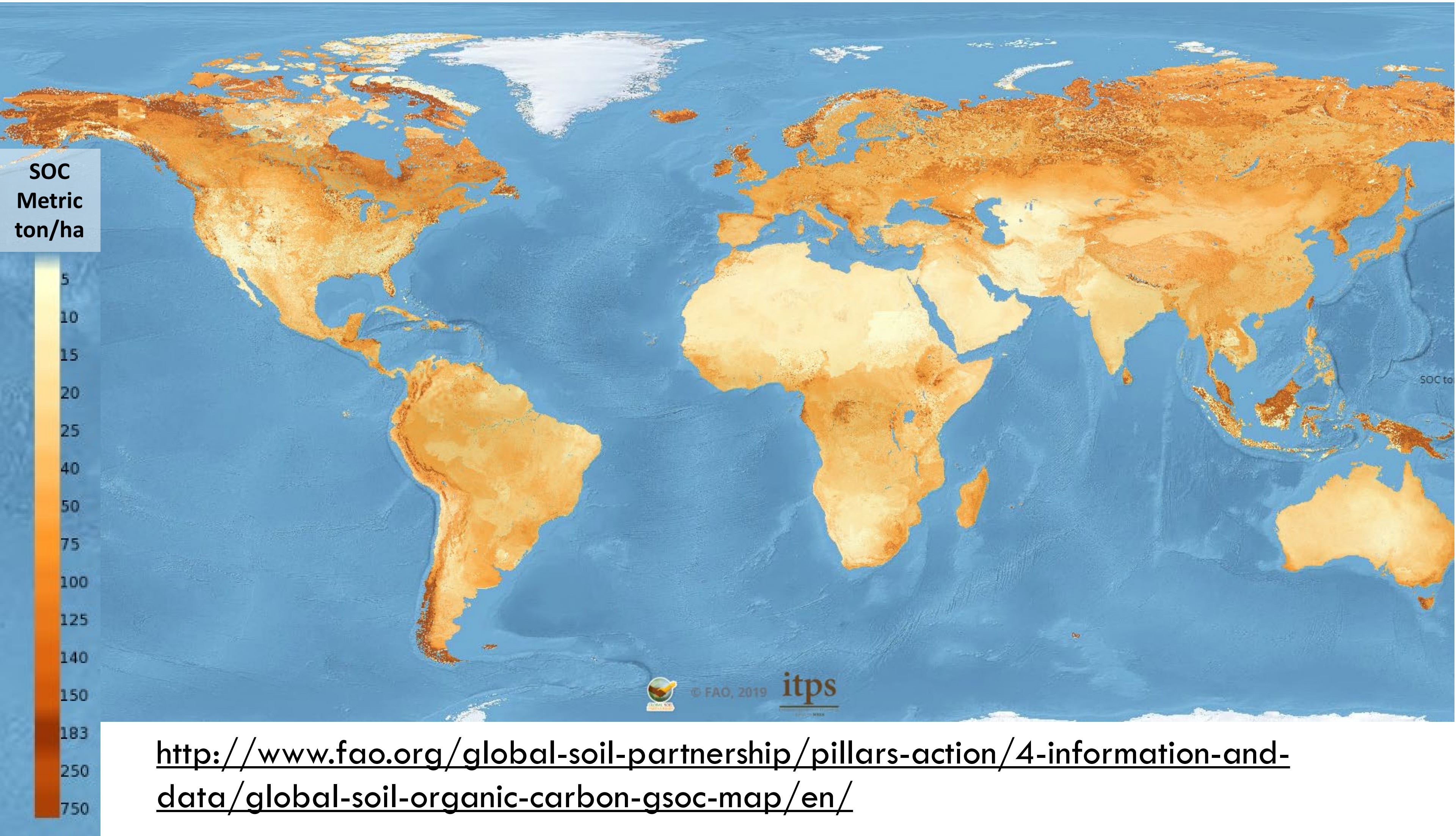
- Crop Rotation
- Cover Crops
- Tillage

Thinking globally: What ecosystem would you expect to find soils with the highest amounts of organic matter?

A. Deserts
B. Tropical rainforest
C. Prairies
D. Boreal forests (northern Canada, Siberia, Alaska)
E. Mixed deciduous hardwood forests (moist, temperate)

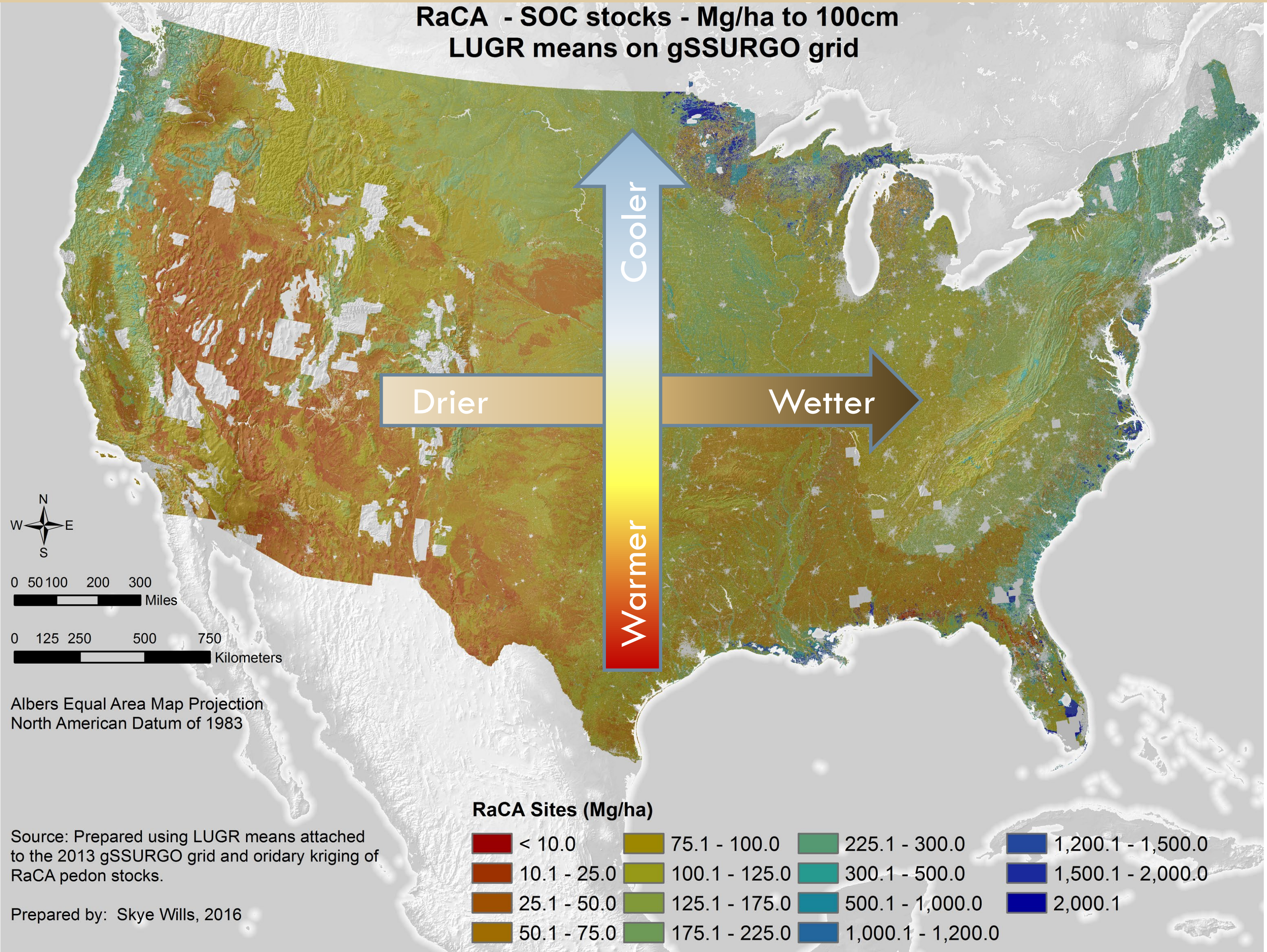
Explain Why?

Boreal, Tundra, and Peatlands store the most soil organic carbon of any biomes because:
low temp. and wet soils slow rates of decomposition



http://www.fao.org/global-soil-partnership/pillars-action/4-information-and-data/global-soil-organic-carbon-gsoc-map/en/

Effect of temperature and moisture on SOC stocks in U.S.



Finer textured soils can store more organic matter than coarse textured soils

Texture	n	Soil Organic Matter %	est. Soil Organic Carbon %
Coarse	407	2.5 c	1.6
Loam	714	3.0 b	2.0
Silt Loam	583	3.7 a	2.4
Fine	46	4.1 a	2.7

Data from NYS Soil Health Characterization Report

Remember that soil organic matter is stabilized by its association with fine silt and clay particles

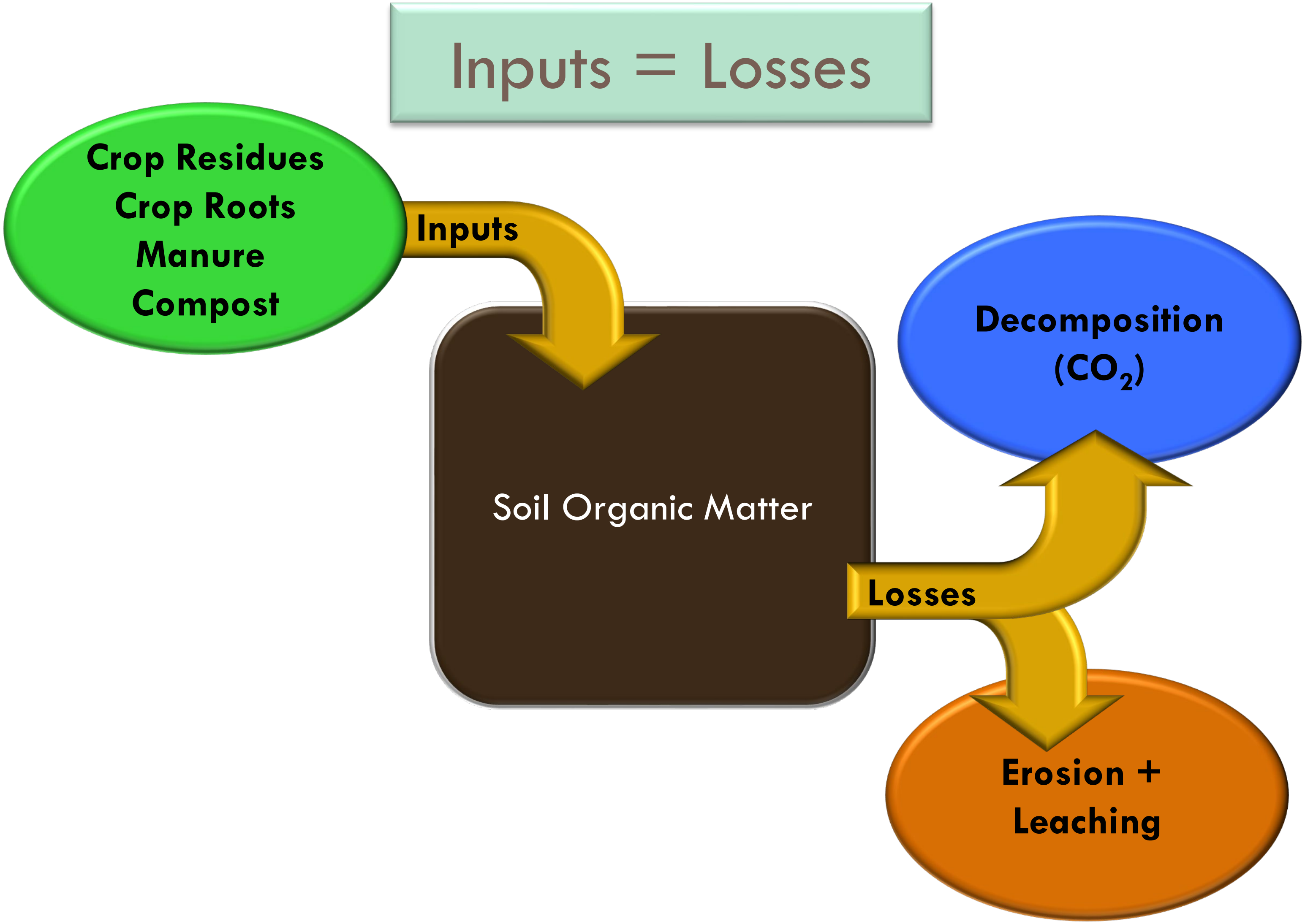
What Controls Soil Organic Matter Accumulation and Cycling?

Natural factors { Climate, Soil Type

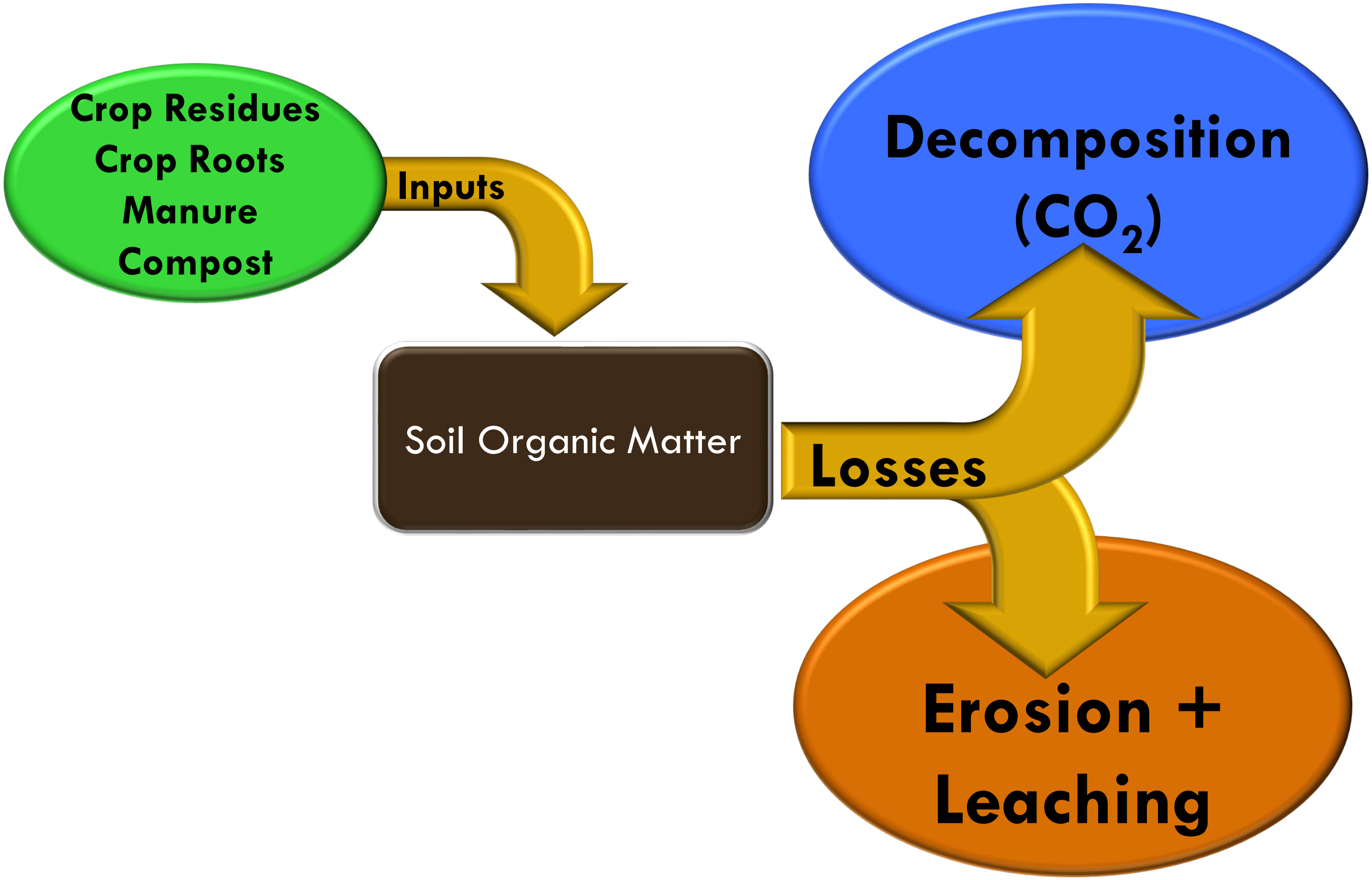
- Climate
- Soil Type

Balance between inputs and Losses → Equilibrium

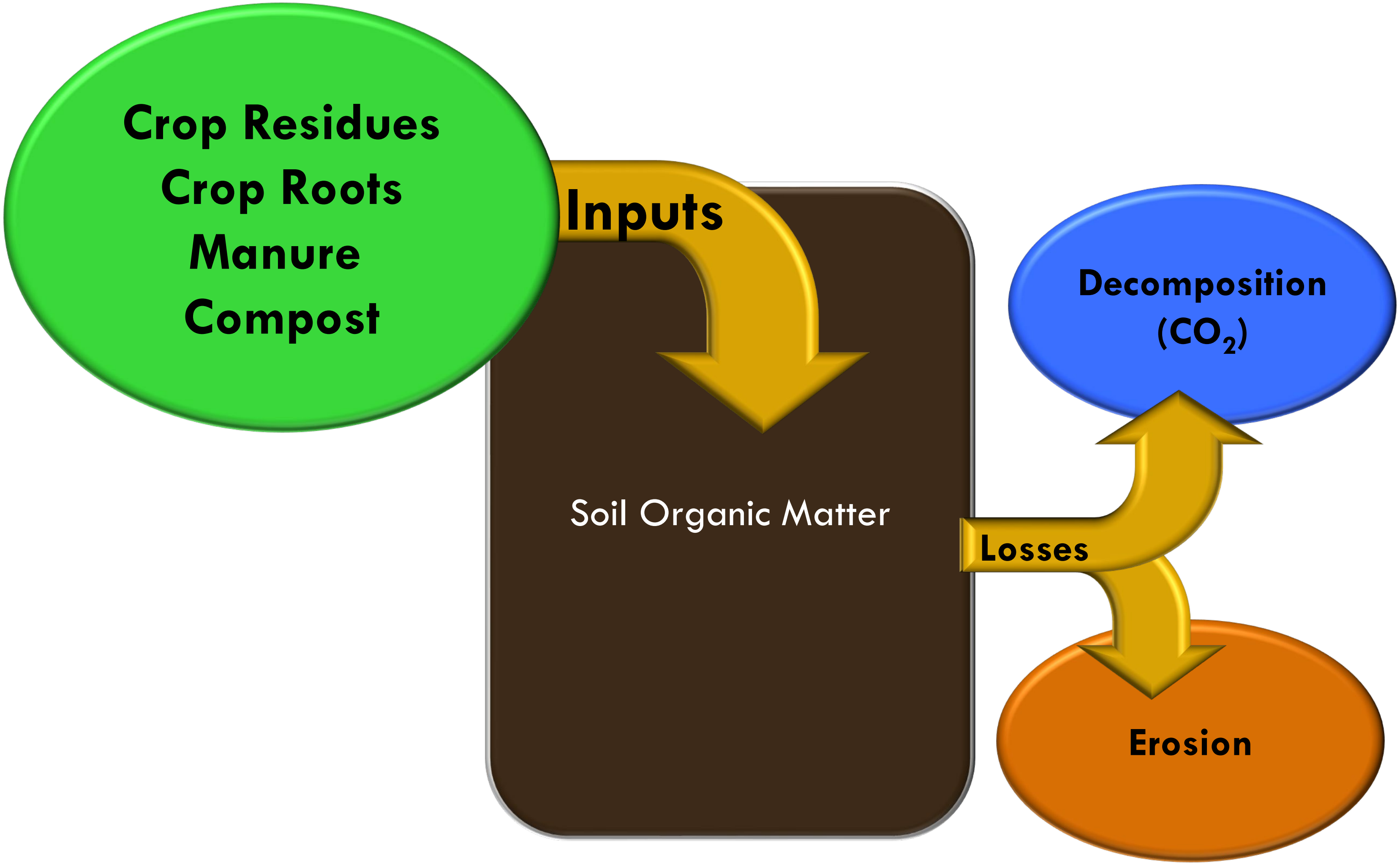
There is a constant turnover of organic material in soil



If losses increase and inputs remain constant, SOM will decrease



If inputs increase and losses remain the same, SOM will increase



When Gains are Greater than Losses: Saturate Organic Matter Content

(for a while…)

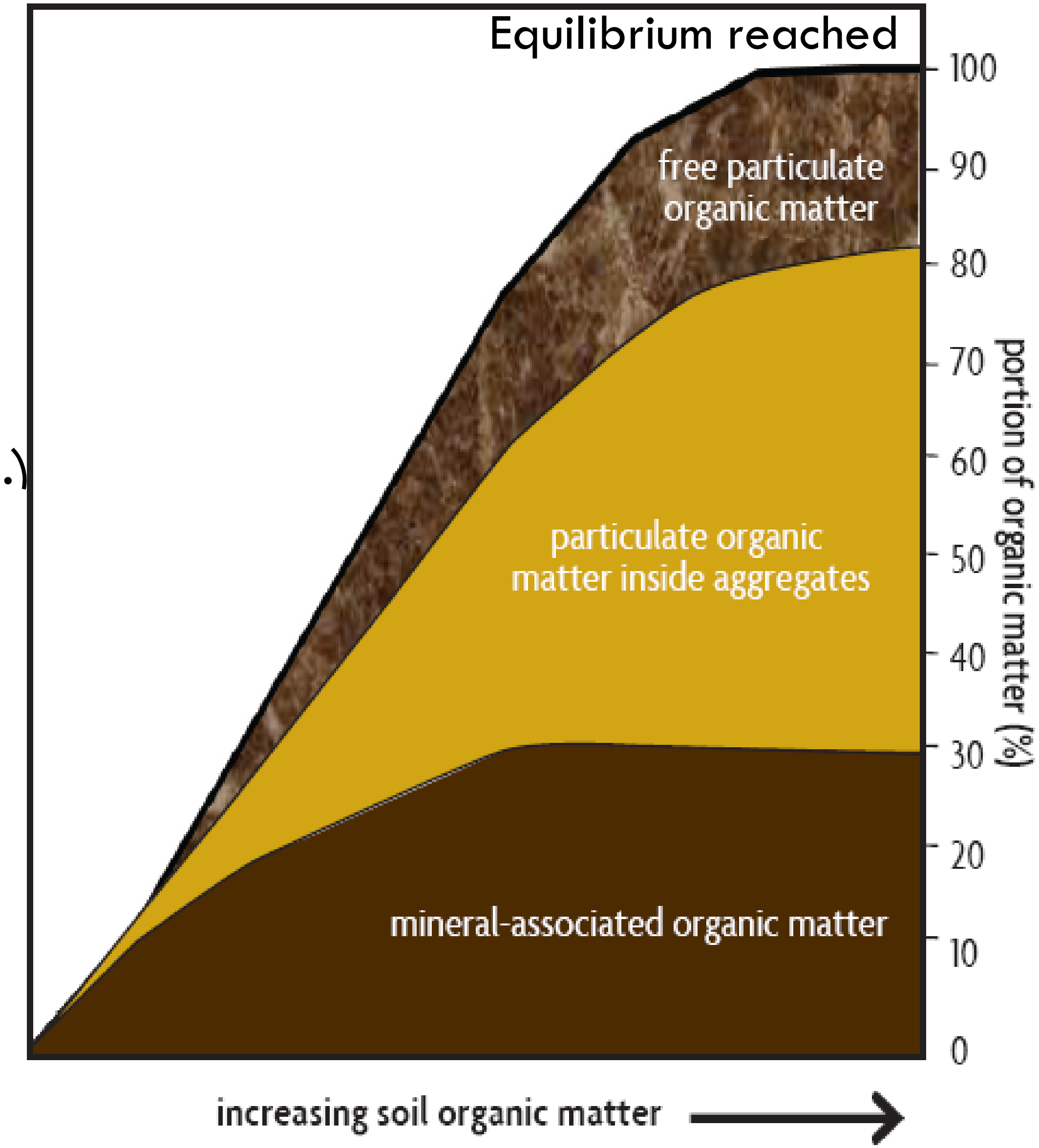


Figure 3.6. Organic matter changes in soil as practices favoring buildup are implemented. Redrawn and modified from Angers (1992).

What Controls Soil Organic Matter Accumulation and Cycling?

Natural factors
- Climate
- Soil Type

Balance between inputs and Losses → Equilibrium

Human Management
- Crop Rotation
- Cover Crops
- Tillage

But… SOM will not continue to increase or decrease indefinitely

Organic Matter Accumulation depends on **additions, climate, and soil type**

Table 3.2

Estimated Levels of Soil Organic Matter after Many Years with Various Rates of Decomposition (Mineralization) and Residue Additions*

Equilibrium when Gains = Losses

		Annual rate of SOM decomposition (%)				
		Fine textured, poorly drained ⟷				Coarse textured, well drained
Annual organic material additions	Added to soil if 20% remains after one year	1	2	3	4	5
-----lbs per acre per year-----		-----final % organic matter in soil-----				
2,500	500	2.5	1.3	0.8	0.6	0.5
5,000	1,000	5.0	2.5	1.7	1.3	1.0
7,500	1,500	7.5	3.8	2.5	1.9	1.5
10,000	2,000	10.0	5.0	3.3	2.5	2.0

*Assumes upper 6 inches of soil weighs 2 million pounds.

What management changes can be made to increase *input* of organic material?

Return more crop residues

Add cover crops

Diversify crop rotations

Add other sources of organic material

The effect of crop rotation on SOC levels:

Rotations with greater inputs (continuous corn vs. continuous soybean) increase SOC levels

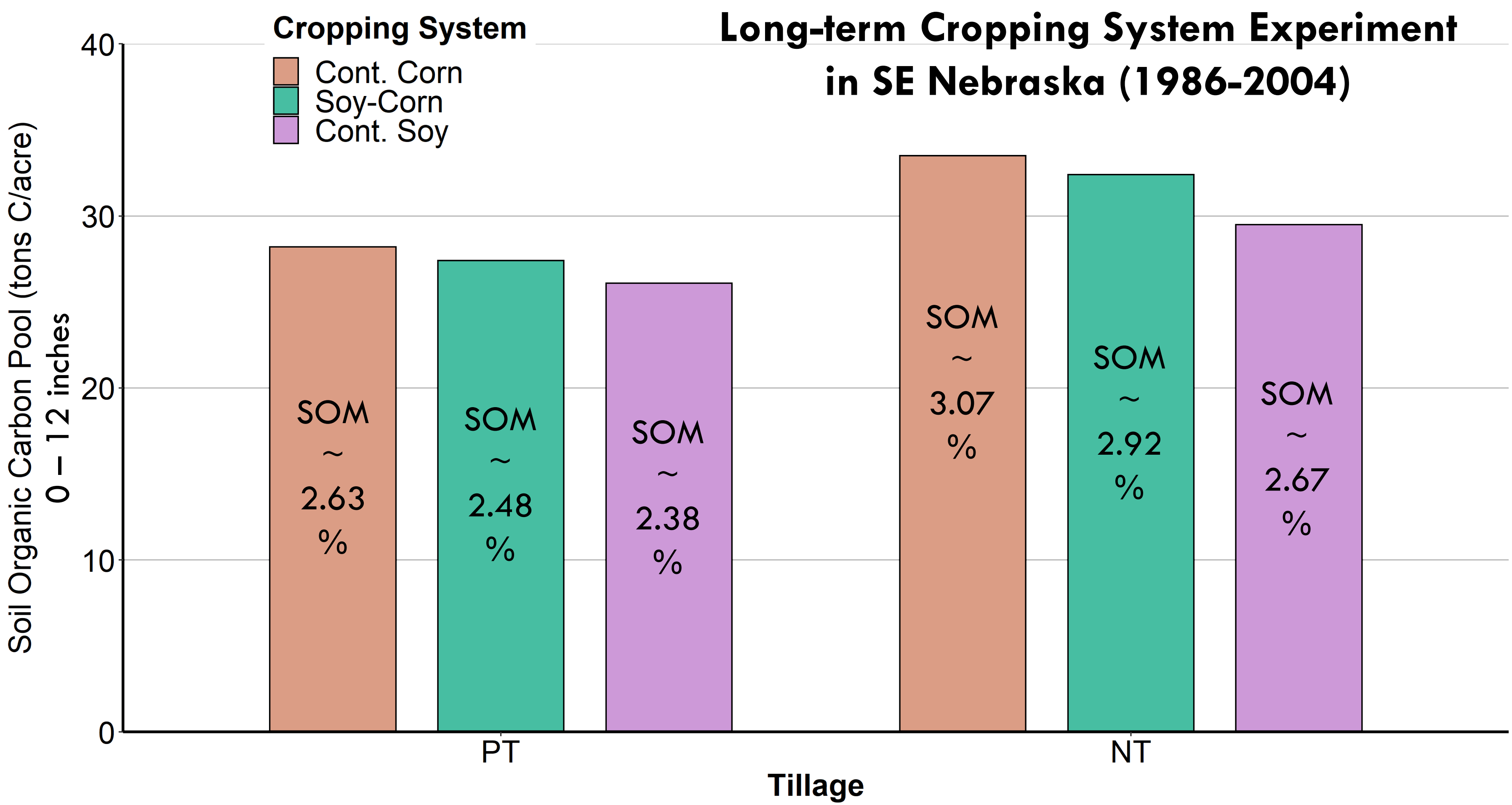


Figure recreated by Joseph Amsili from Varvel and Wilhelm 2010: Long-term soil organic carbon as affected by tillage and cropping systems

Cover crops increase soil organic carbon (or maintain)

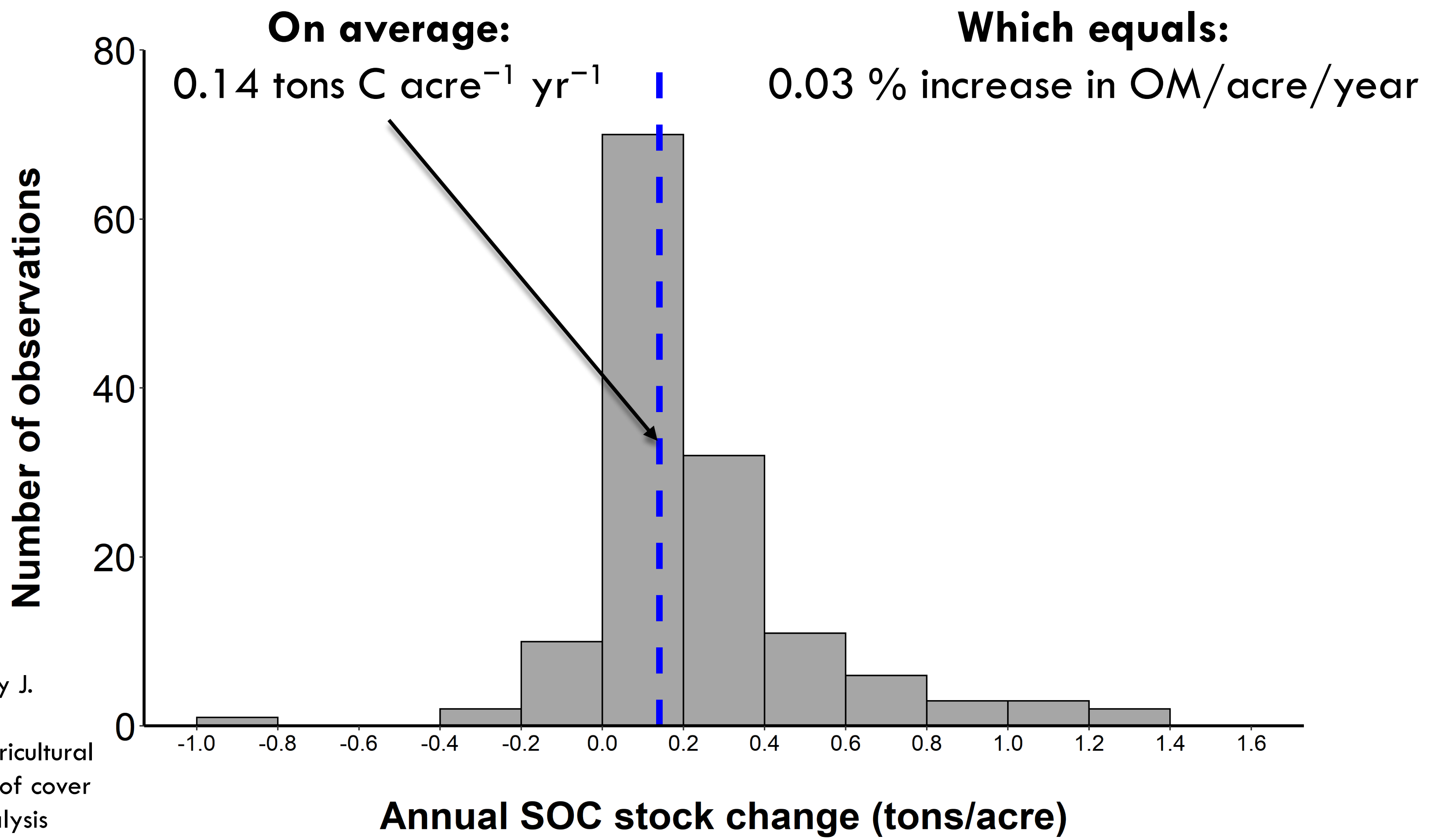


Fig. 3. Histogram of annual change of soil carbon due to cover cropping in comparison to fallow winter.

Figure recreated by J. Amsili from Carbon sequestration in agricultural soils via cultivation of cover crops - A meta-analysis C. Poeplau, AND A. Don. 2015. Agriculture, Ecosystems and Environment Journal.

What management changes can be made to decrease SOM losses?

Decrease erosion

Decrease tillage

How does tillage affect SOM decomposition?

- Residues are mixed with soil
  - Physically breaks residue into smaller pieces
  - Intimate contact between soil and residue
- Aerates soil
- Breaks apart soil aggregates, exposes protected SOM to decomposition
- Promotes erosion losses

No-till crop production

- Crop residue left on surface
- Protects soil, reduced erosion
- Slowed decomposition of crop residues
- Minimum disturbance of soil structure

Tillage Intensity

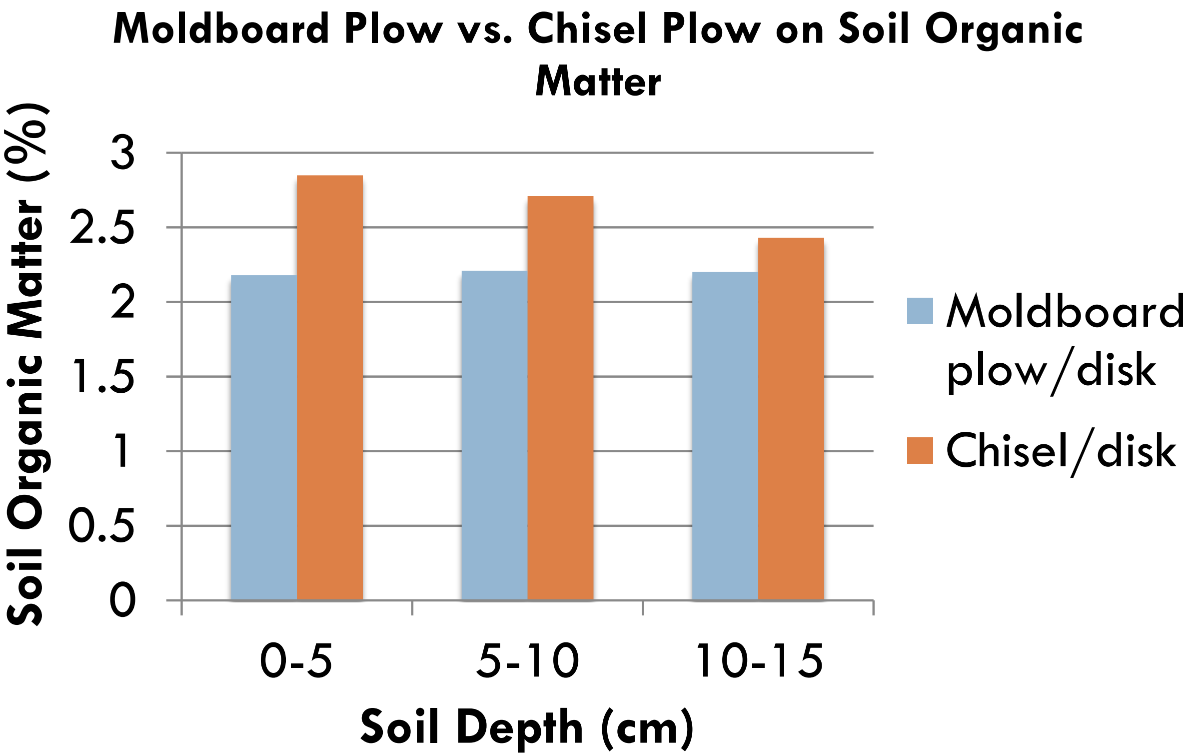
Moldboard Plow

Chisel Plow

No-Till Drill

Tillage Intensity Affects % SOM Levels

- Long-term tillage field study at Penn State
- Moldboard Plow/Disk treatment lead to decreased SOM levels over time compared to Chisel Plow/ Disk



Moldboard Plow

Chisel Plow

Increased tillage intensity leads to greater losses of soil organic carbon

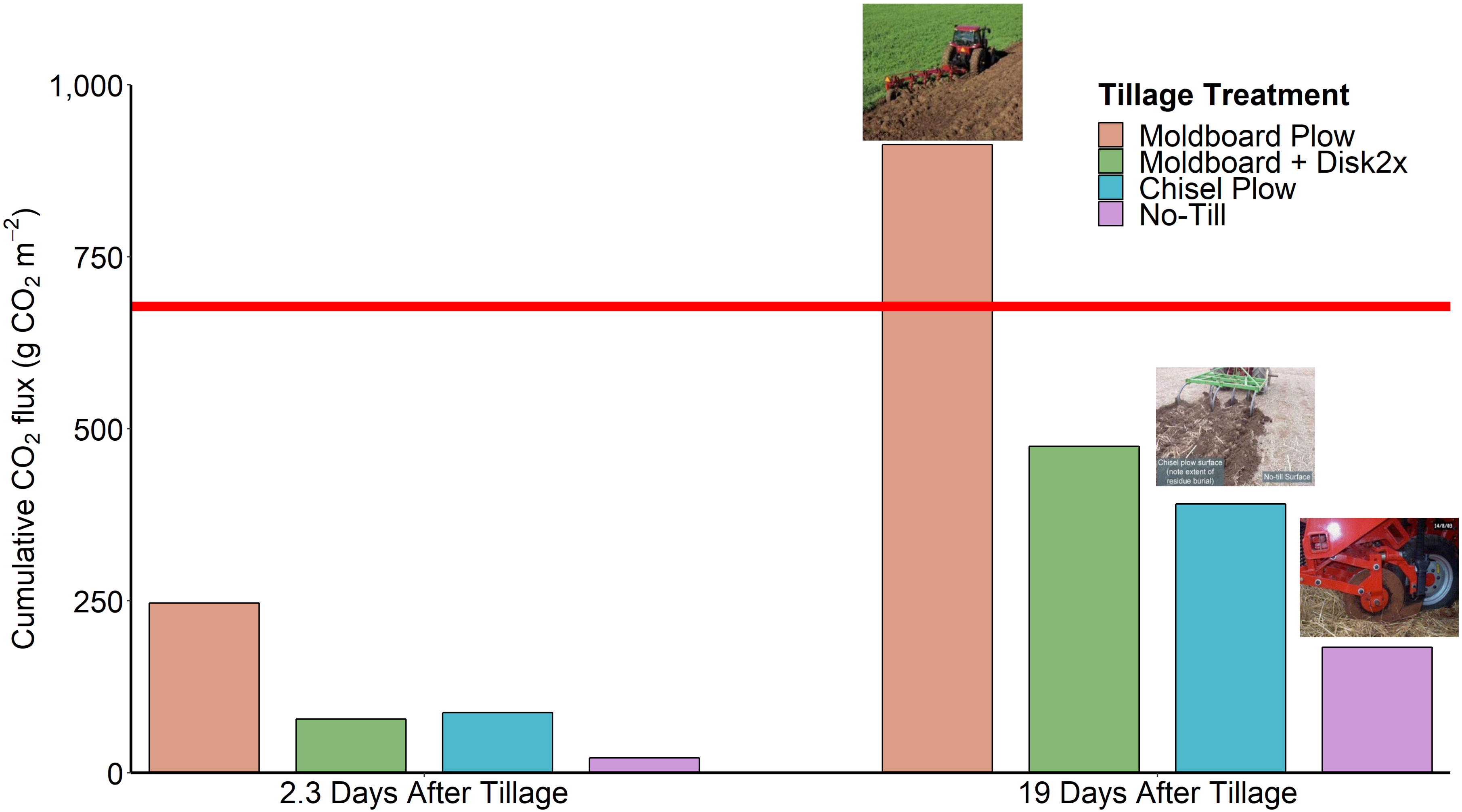


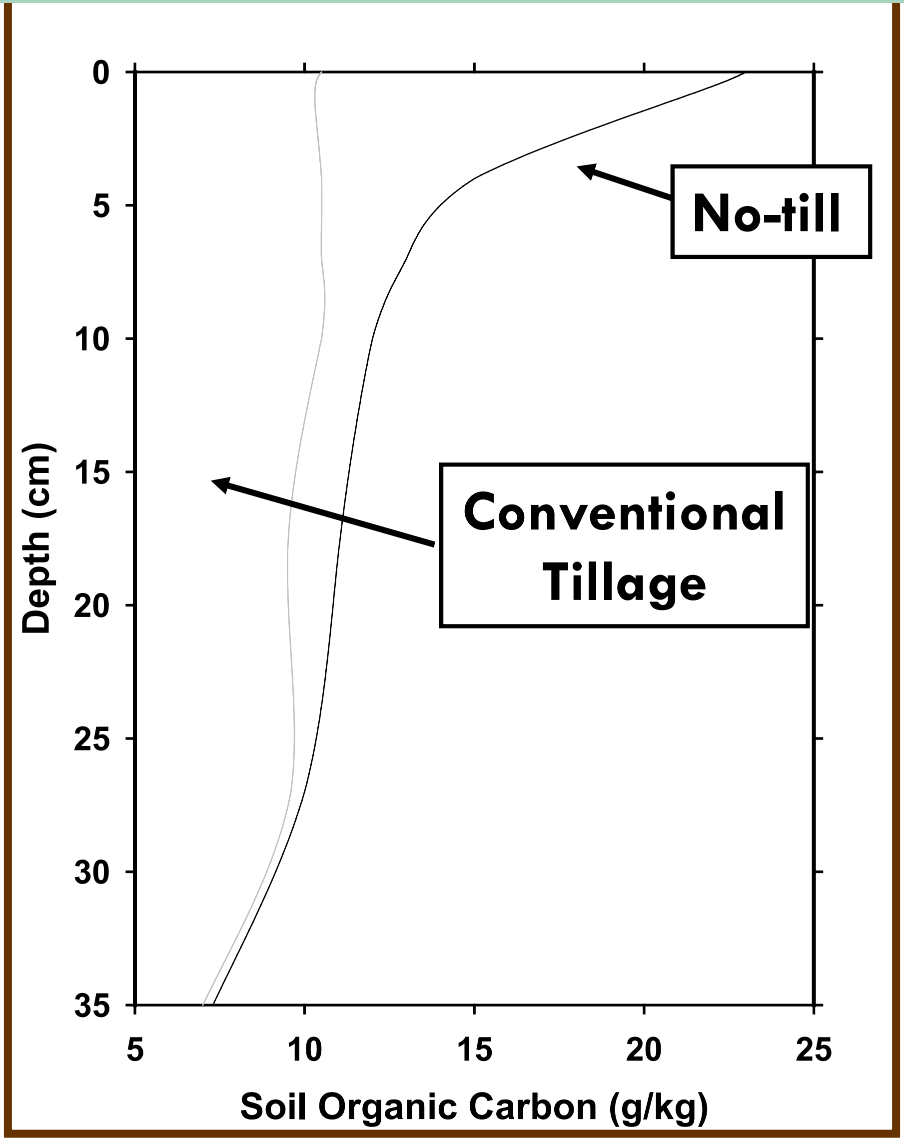
Figure recreated by Joseph Amsili from Reicosky 1997: Tillage induced CO2 emission from soil

Distribution of organic matter in soil under conventional and no tillage

What we see when we

Compare tillage systems

to a depth of 30 cm = 1 ft:



Getting real on the ability of soils to sequester organic carbon as a climate mitigation strategy

What we see on the news:

Getting real on the ability of soils to sequester organic carbon as a climate mitigation strategy

What we see from government initiatives:

Where 4 per mil initiative came from:

- 8.9 Gigatons C / 2400 Gigatons C (0-2 meters) = 0.4 % (or 4 per mil)

Issues with the statement: “we can halt the annual increase in CO_2 in the atmosphere”:

1) They considered the global carbon stock (2400 Gigatons C), but there is only potential for this strategy in managed agricultural lands (600 Gigatons C – (0-1 meters)) → A 0.4 % increase on this land in this stock each year could offset 20-35% of global greenhouse gas emissions.
2) 0-1 meter depth is also widely optimistic.
3) Certain soils become saturated with carbon. Soils with SOC further from saturation build up C faster vs. pasture soils would have much more limited capacity.
4) This solution is only applicable over the next 50 years. AKA we can't endlessly sequester C in soils

Agriculture

Getting real on the ability of soils to sequester organic carbon as a climate mitigation strategy

What we see from non-profits and unpublished documents:

"Data from farming and grazing studies show the power of exemplary regenerative systems that, if achieved globally, would drawdown more than

Issues with this report:

1) To the public, you see a graph and think truth, but they used one estimate from cropping systems and one estimate from a grazing system and scaled it up across all cropland and grazing land globally. Immediately after, they note that this is just a thought experiment to illustrate the power of SOC sequestration.
2) Shows grazing as a larger solution to SOC sequestration than annual cropping systems, which is very misleading

REGENERATIVE AGRICULTURE
and the SOIL CARBON SOLUTION

SEPTEMBER 2020

AUTHORED BY:
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RODALE INSTITUTE

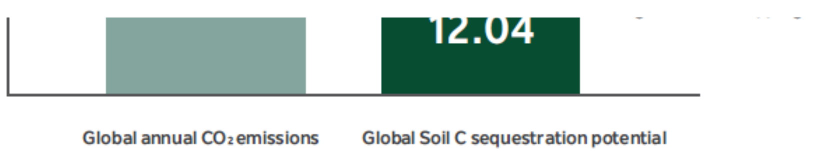

FIGURE 1: Carbon sequestration potential of global adoption of regenerative agriculture

Getting real on the ability of soils to sequester organic carbon as a climate mitigation strategy

What the most optimistic soil scientists have published for the United States

A recent estimate for the United States suggests that it is possible to sequester 68 Tg C yr^{-1} (250 Tg CO_2e) in croplands and grasslands with **substantial investments in this area** (Chambers, et al., 2016), equivalent to approximately **36% of total US agricultural emissions or 3.7% of total US emissions in 2018** (EPA, 2020).

FEATURE

doi:10.2489/jswc.71.3.68A

Soil carbon sequestration potential of US croplands and grasslands: Implementing the 4 per Thousand Initiative

Adam Chambers, Rattan Lal, and Keith Paustian

2016. Journal of Soil and Water Conservation