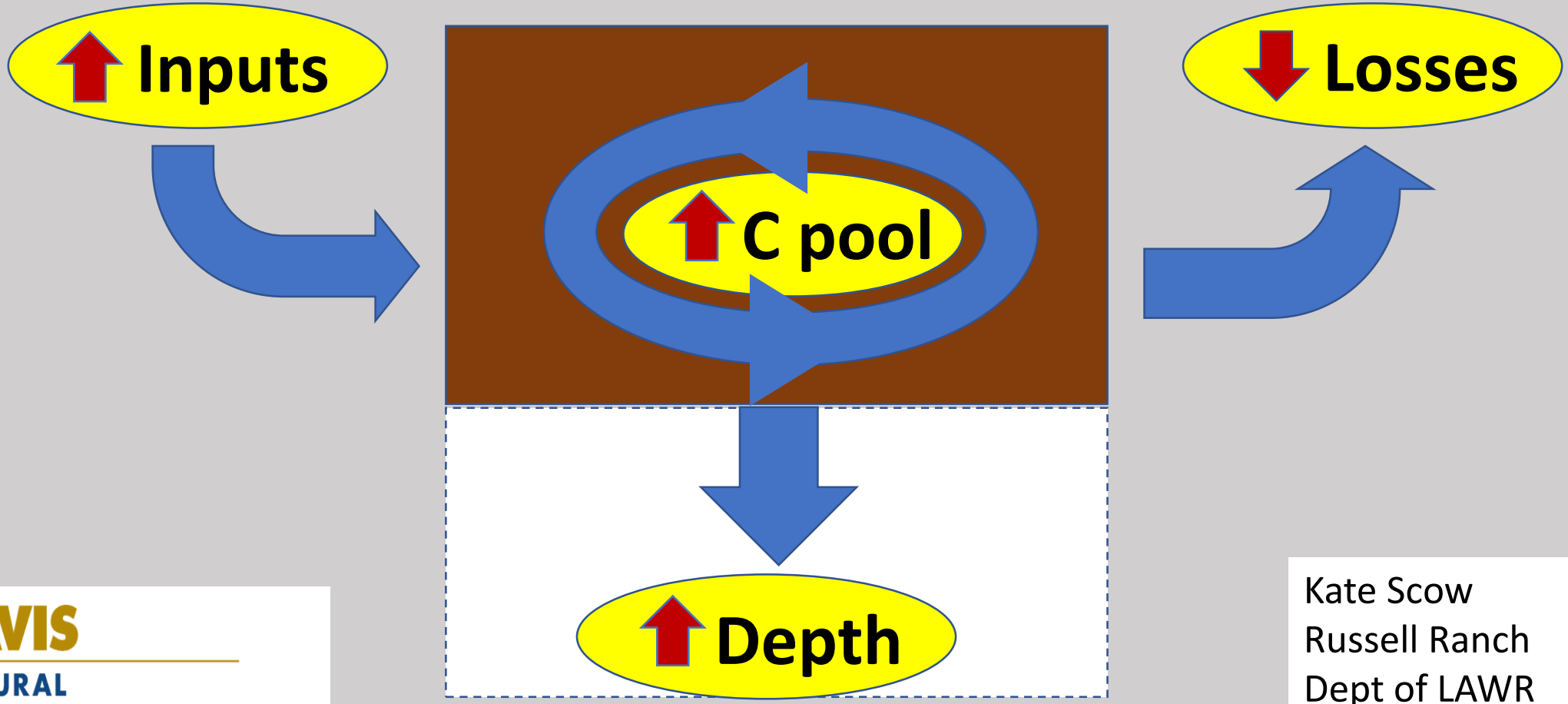
How can we increase soil carbon in cropping systems?



UCDAVIS
AGRICULTURAL SUSTAINABILITY INSTITUTE

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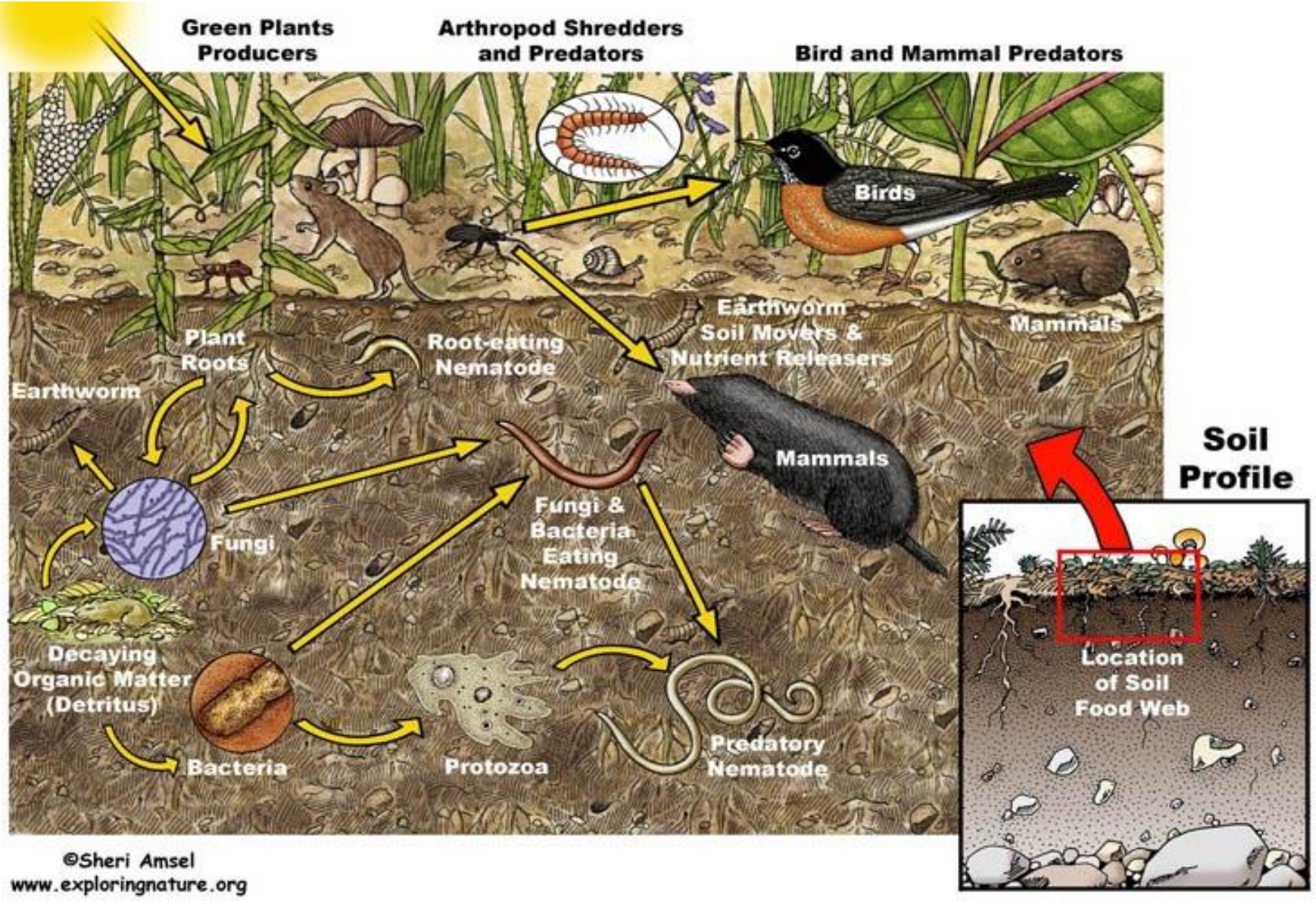
And what does soil carbon have to do with soil life?



How is soil organic matter NOT made?

Previously we thought process was "humification". Decomposition/modification (e.g. condensation) of plant and other organic matter, leading to humus as final product.

SOIL ORGANIC MATTER

↓ Removal of recognizable plant debris using size and density

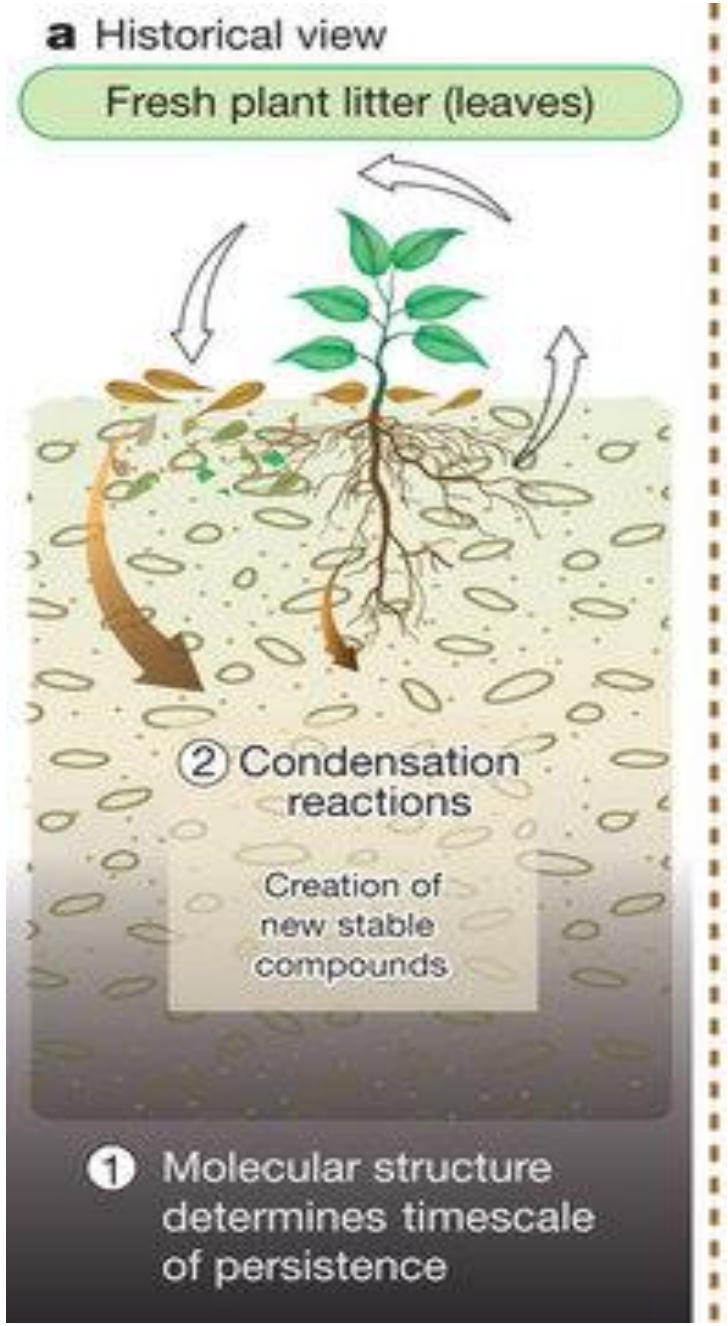
MACROORGANIC MATTER OR LIGHT FRACTION

HUMUS

↓ Removal of polyvalent cations using acid or complexing agent. Extraction with NaOH in N_2

HUMIC SUBSTANCES

HUMIN	HUMIC ACID	FULVIC ACID
Insoluble in alkali Insoluble in acid	Soluble in alkali Insoluble in acid	Soluble in alkali Soluble in acid



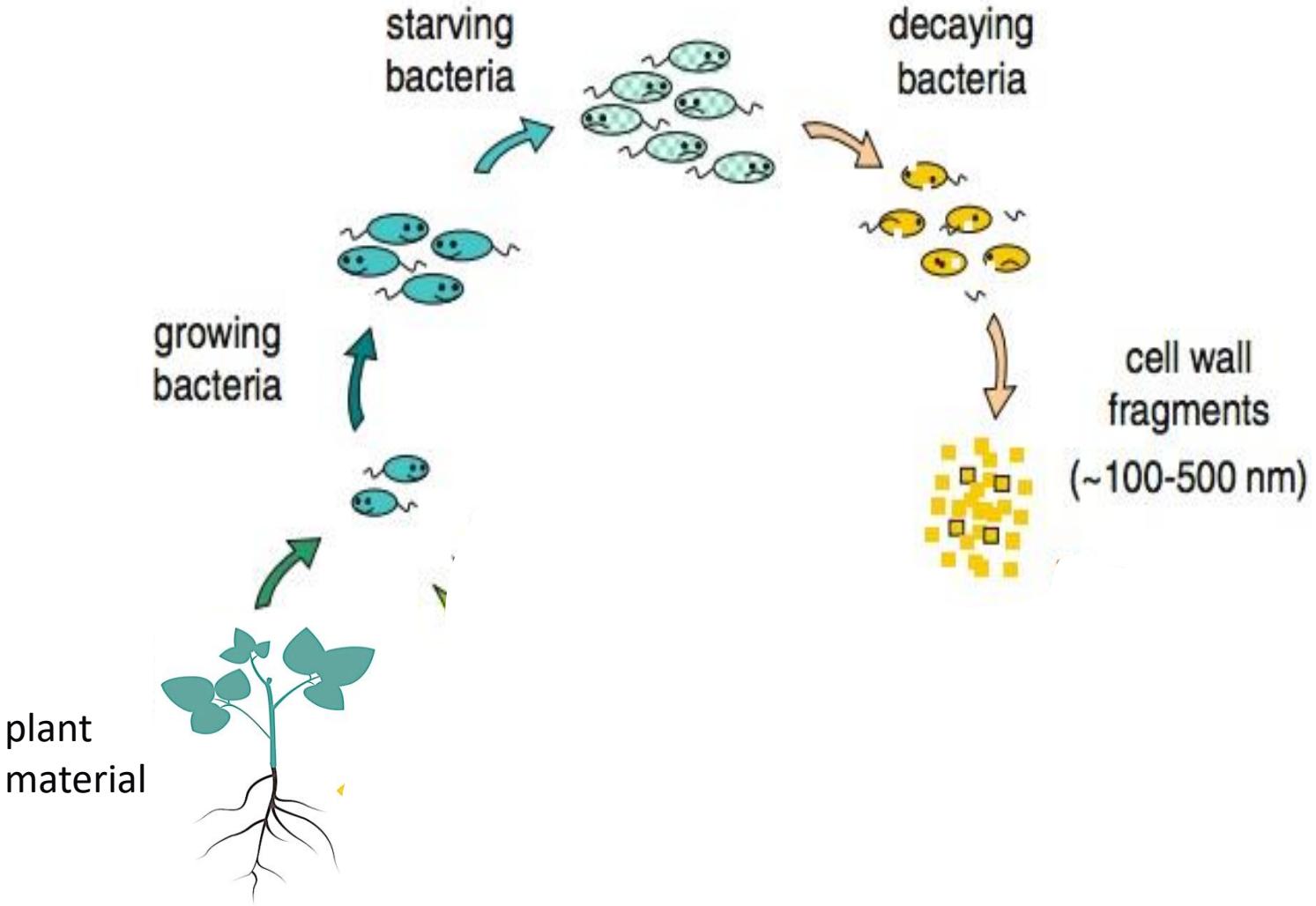
These are laboratory artifacts

New conceptual model—a lot has changed.

New non-invasive tools to look at soil organic matter, isotopes to track carbon flow, technologies to characterize soil microbial communities.

Soil organic matter formation: (STEP 1) Transformation of plant residues into microbial cells and by-products

Microbes are enzymatic drivers who convert plant residue C into their cells, die and provide the “feedstock” for SOM formation



Science News *... from universities, journals, and other research organizations*

Fertile Soil Doesn't Fall from the Sky: Contribution of Bacterial Remnants to Soil Fertility Has Been Underestimated Until Now

Dec. 14, 2012 — Remains of dead bacteria have far greater meaning for soils than previously assumed. Around 40 per cent of the microbial biomass is converted to organic soil components, write researchers from the Helmholtz Centre for Environmental Research (UFZ), the Technische Universität Dresden (Technical University of Dresden) , the University of Stockholm, the Max-Planck-Institut für Entwicklungsbiologie (Max Planck Institute for Developmental Biology) and the Leibniz-Universität Hannover (Leibniz University Hannover) in the journal *Biogeochemistry*.

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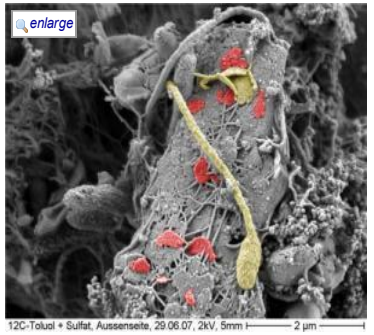
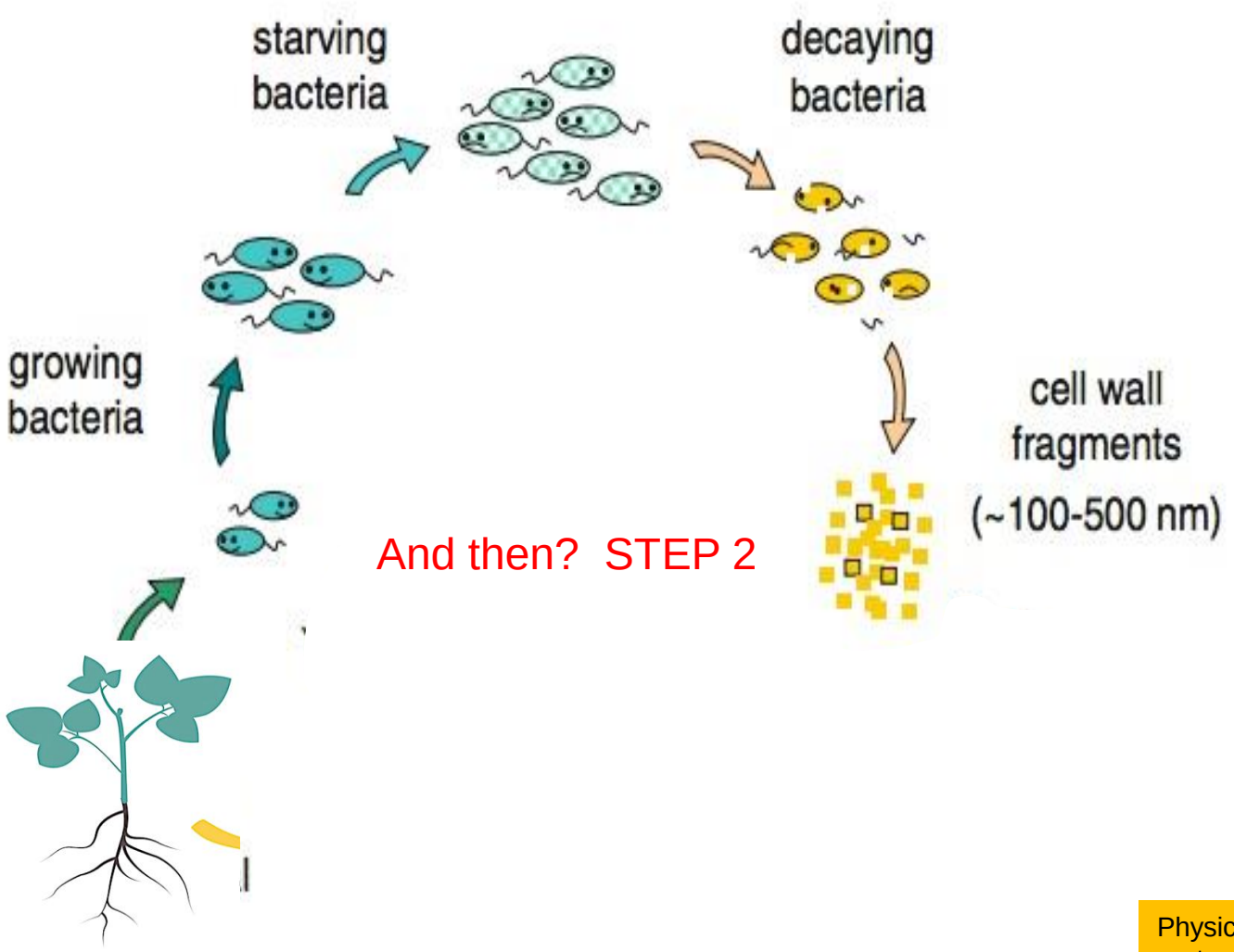
Until now, it was assumed that the organic components of the soil were composed mostly of decomposed plant material which is directly



The electron micrograph shows bacteria (Hyphomicrobium sp.; Yellow) growing up partly on solid surfaces, floors and sediment grains. During

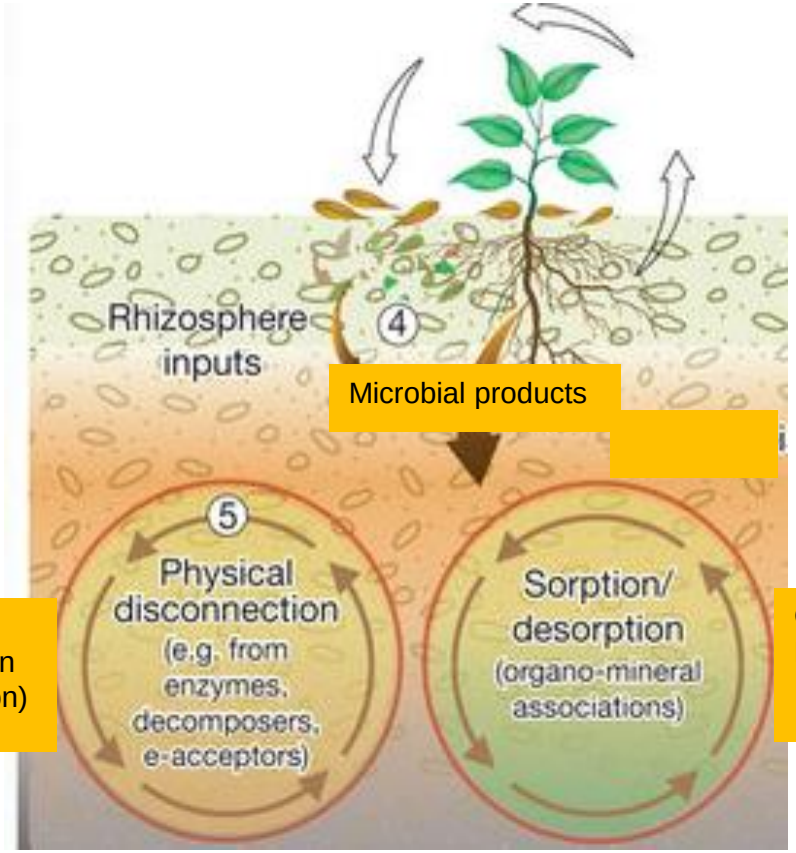
50-80% of SOM is simply dead microbial bodies. If you want to increase SOM, you must build microbial biomass.

Soil organic matter formation: (STEP 2) stabilization of organic material in soil



And then? STEP 2

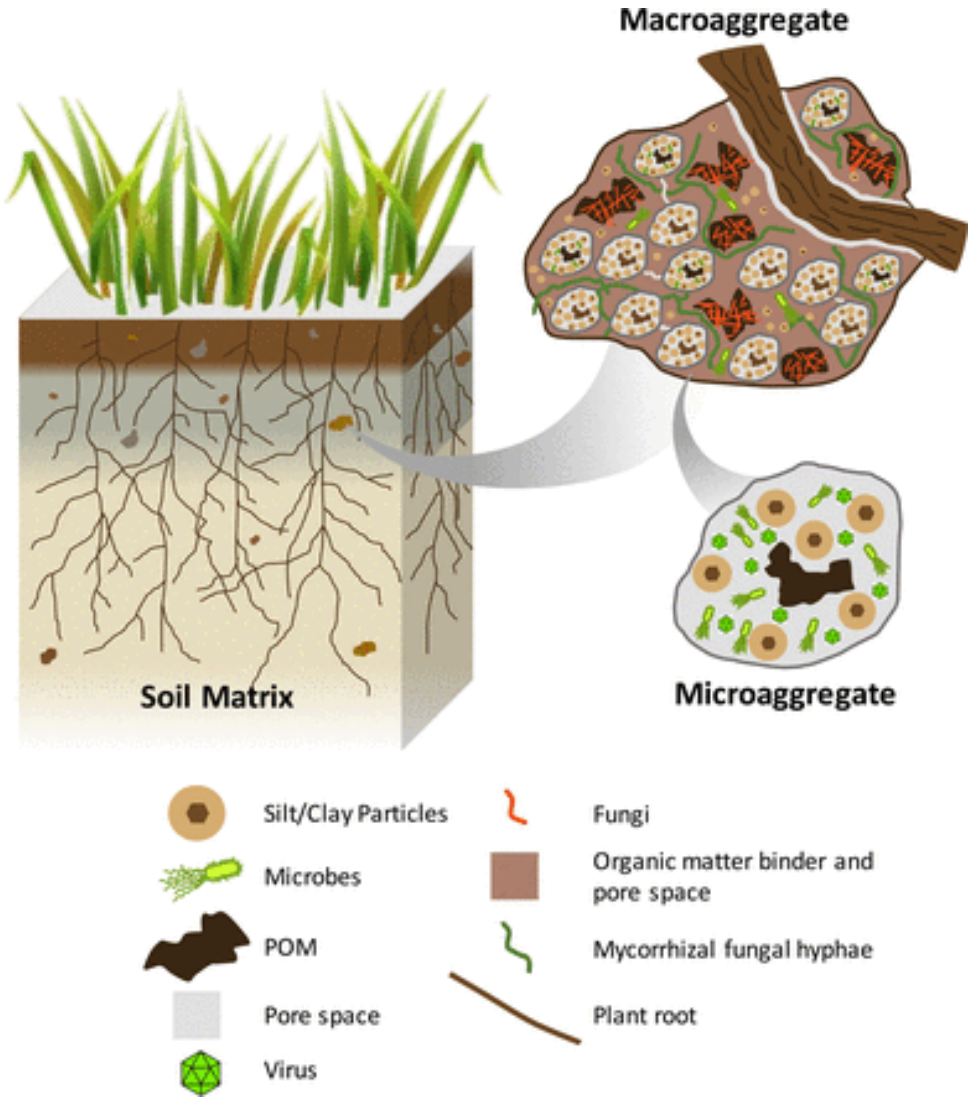
To stabilize SOM, the C from microbial bodies needs to bind with soil minerals and/or be trapped in small pores



Physical protection (occlusion)

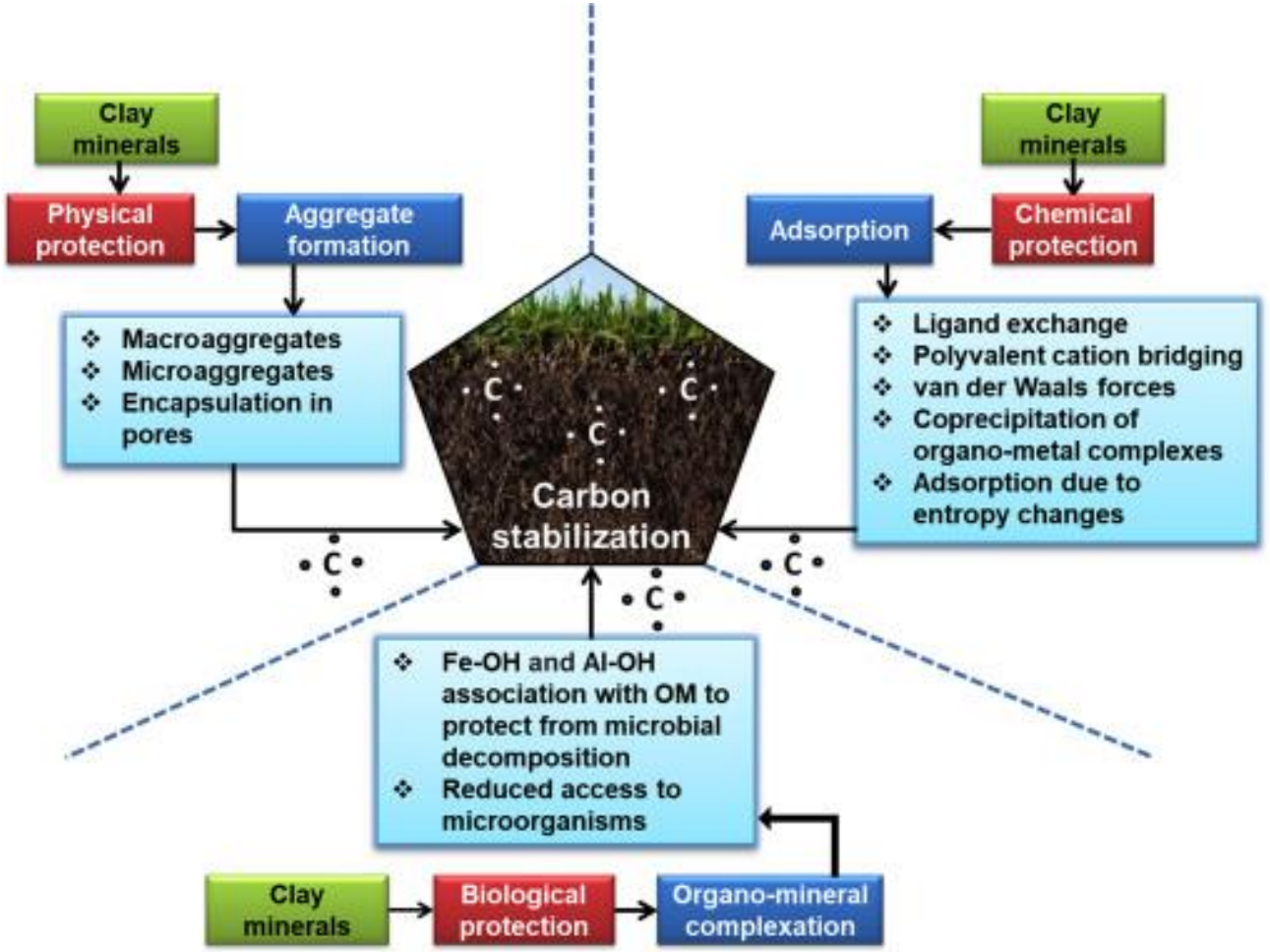
Chemical Protection

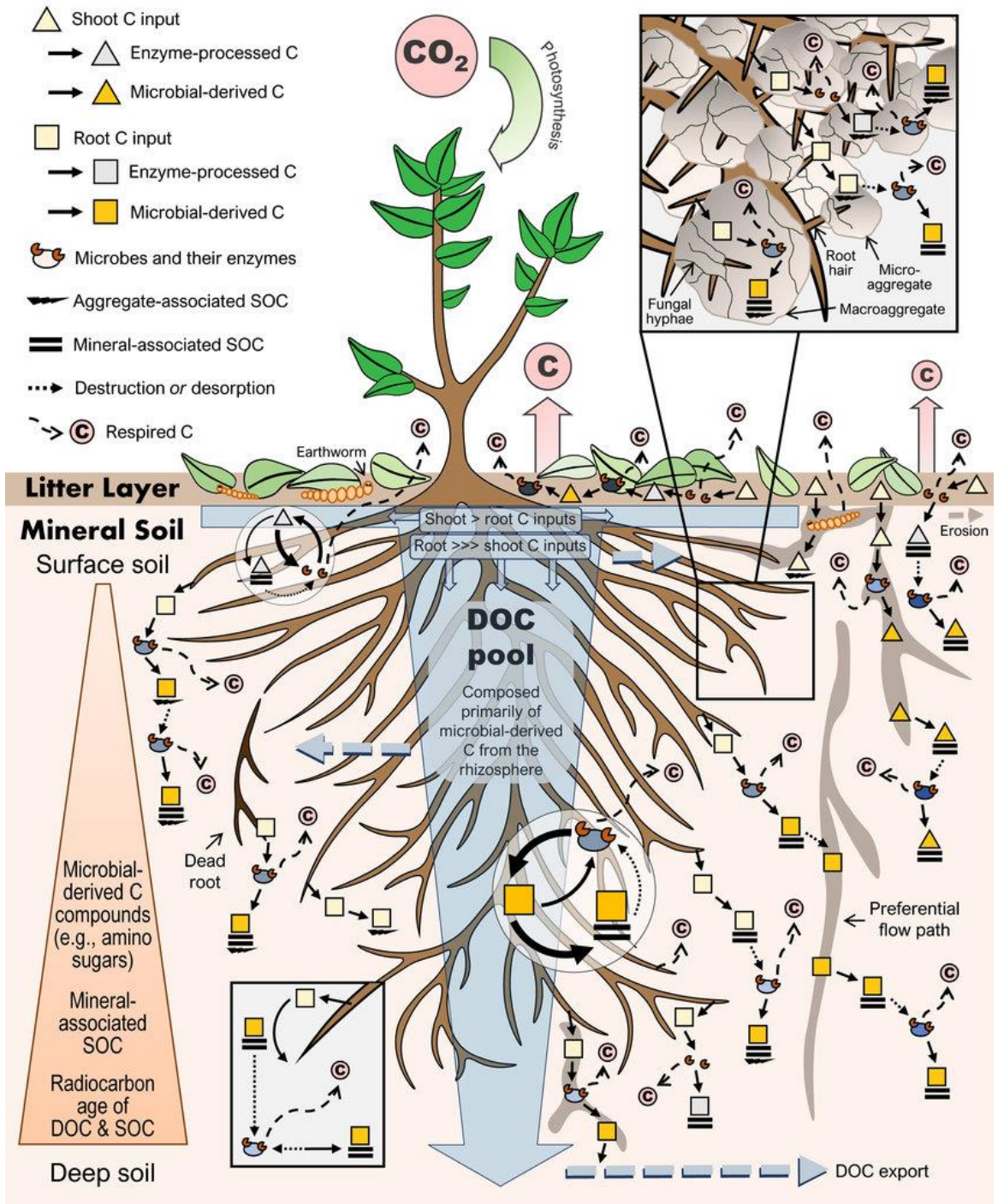
Schmidt et al. 2011 Nature 478, 49–56; Miltner et al. 2012



Protection in soil aggregates

Variety of soil carbon-mineral associations



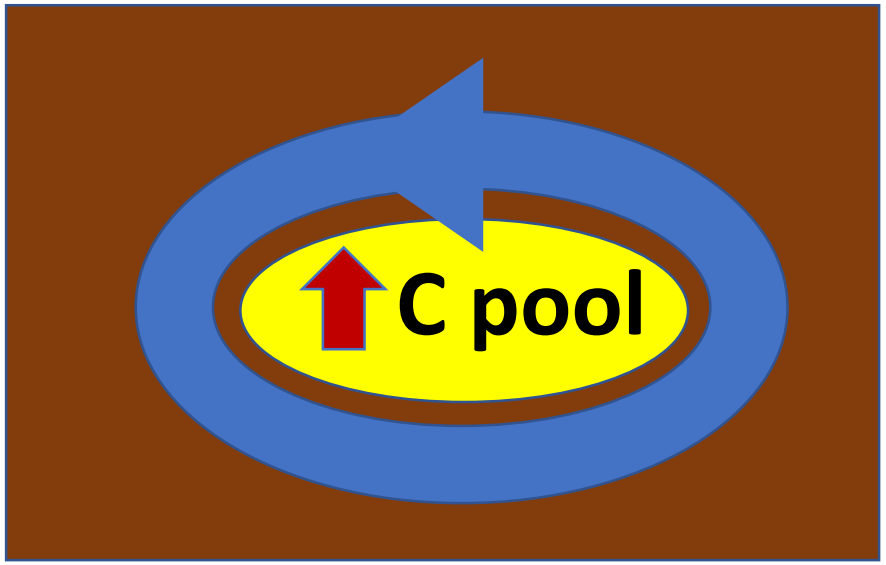


Putting it all together

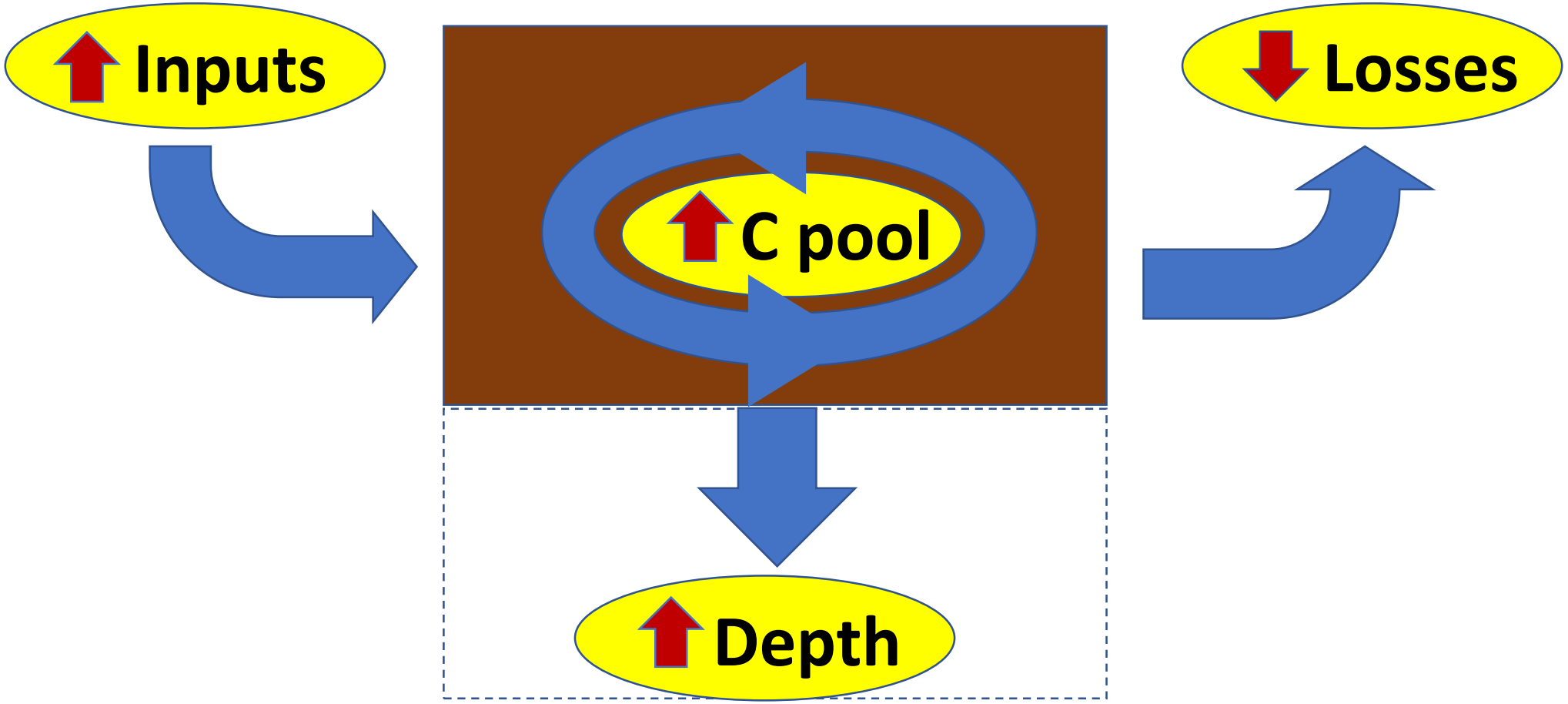
Gross, C.D. and Harrison, R.B., 2019. The case for digging deeper: soil organic carbon storage, dynamics, and controls in our changing world. *Soil Systems*, *3*(2), p.28.

Implications and questions about microbial feedstocks

- We must feed the soil--synthetic fertilizer is not enough. And continuously. How much, how often?
- Are more degradable substrates better than less degradable substrates to build carbon?
- Are microbes getting all nutrients they need to build cells: N, P, K, S? Enriched inputs?
- How does microbial community composition (e.g. fungi vs bacteria) and diversity affect SOM formation?
- Can SOM be formed under conditions harsh for microbial activity (dry, hot, high salinity)?

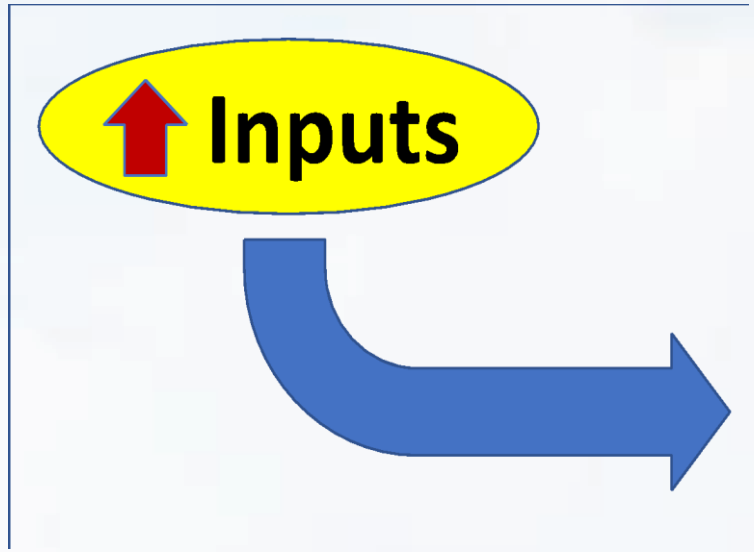


What can we do to increase soil carbon?



Add organic amendments

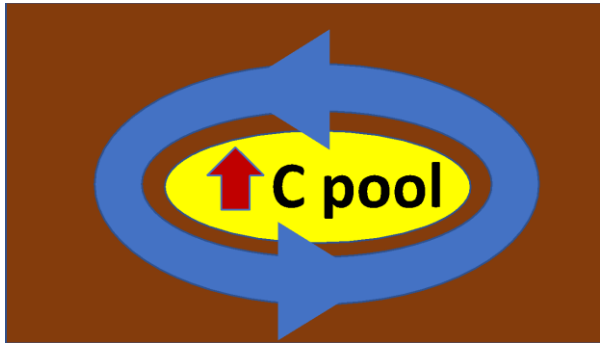
- aim for slow release of carbon over the course of the year
  - steady food supply for microbes
- variety of organic compounds



Sources:

- organic amendments: compost (from variety of sources), manure solids and slurries, biodigestate, biosolids (?)
- Integrated animal systems: manure and urine
- Others?: biochar not very degradable, compost tea low in carbon concentration

Create carbon “in place”



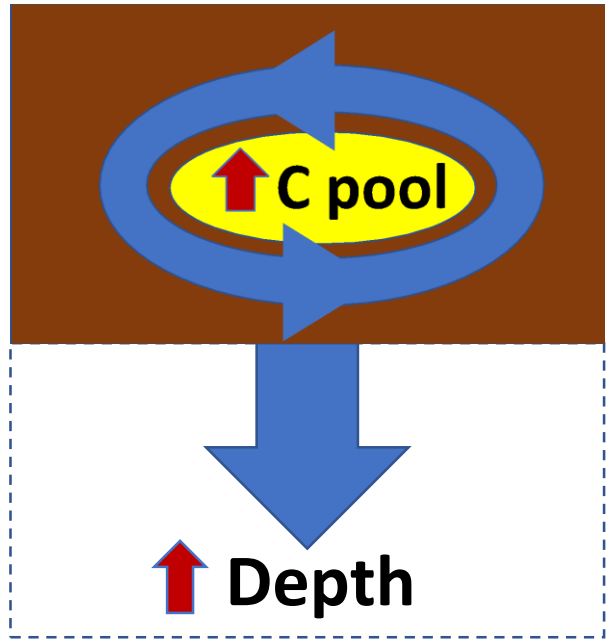
- Crop residues (biomass varies)
- Soil cover for more of year
  - steady food supply
- Roots--variety of exudates/dead roots
  - promote metabolic diversity
  - deep roots
- Cover crops (e.g. legumes)
  - N inputs

Intercropping

Cover crops

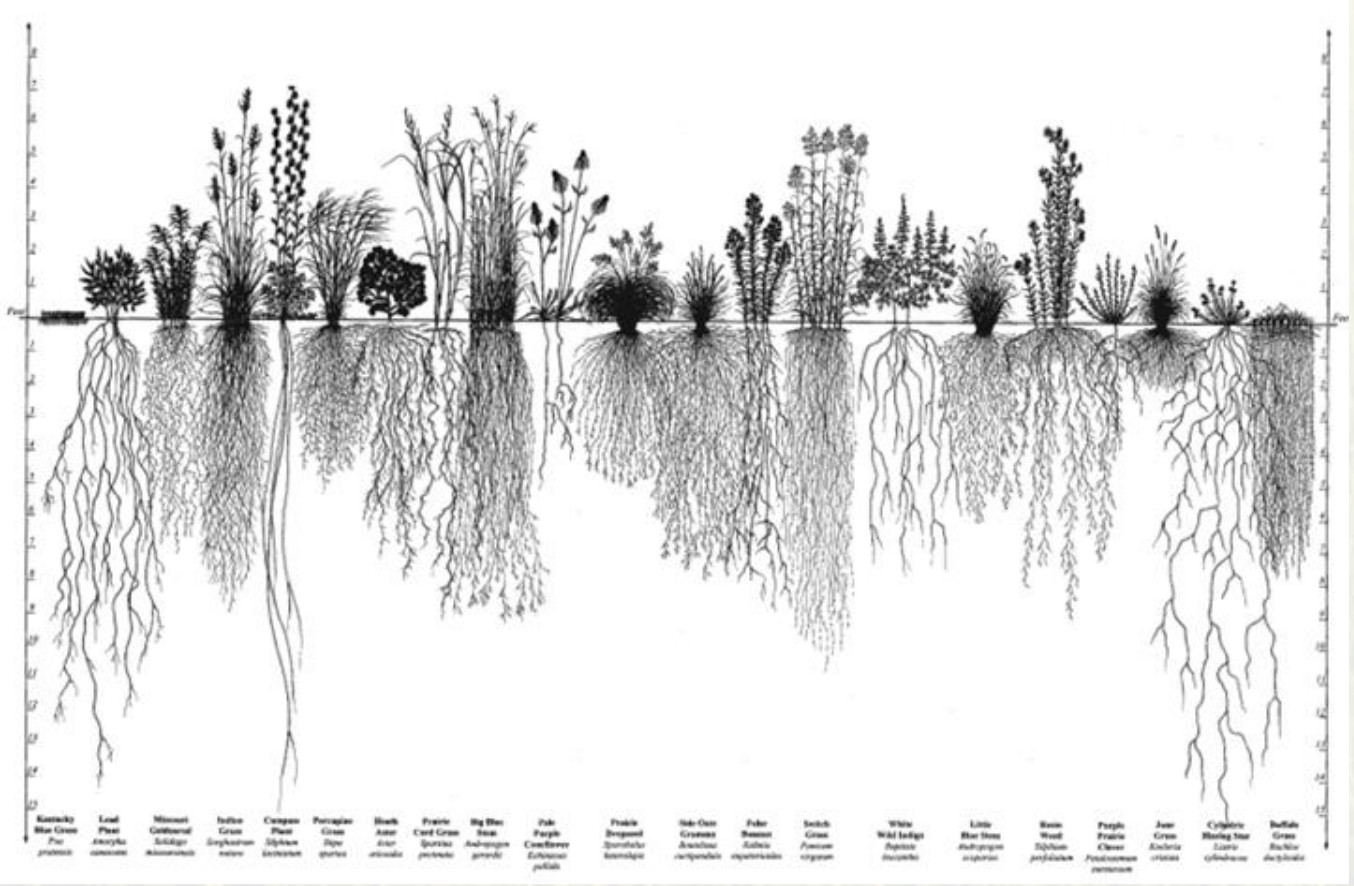
Crop rotations

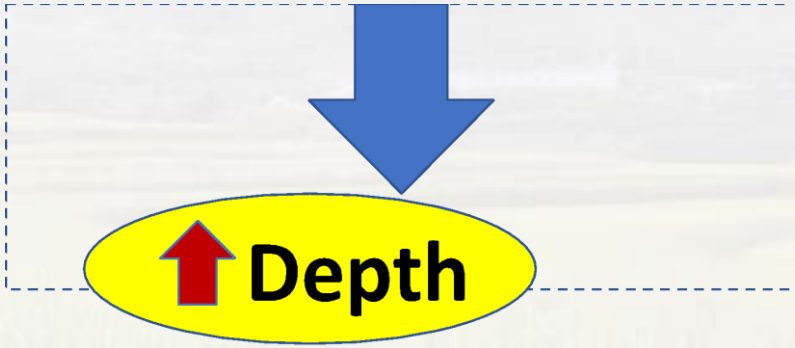
Increase “size” (or capacity) of soil reservoir



- Texture: Some (but not too much) clay is best. Is it possible to build SOM in sandy soils? Can added minerals help?
- Soil structure: good aggregation essential to preserve SOM
- Increase size of reservoir by increasing target depth. Is it important to distribute carbon inputs throughout soil (e.g. increase mineral/OM ratio, move C deeper where clay content is higher? What is role of water as vehicle?

Improve root systems





Annual crop varieties have been bred for systems that provide water and mineral fertilizers.

- Maximized
  - above-ground biomass (fruits, leaves etc)
- Reduced
  - root system extent
  - root colonization by beneficial organisms
  - root exudates
  - organic mass when plants die

Kernza ® is a grain-producing perennial wheatgrass

- Cousin of annual wheat; **dual-use** cool season rhizomatous grass[1]
- **40 farmers** in Midwest U.S.A. **growing Kernza** (170 ha)[2]
- **40** international **research groups working on Kernza**[3]
- Recent studies observed economic and environmental benefits associated with Kernza vs. annual wheat cultivation [2,4]

1 m

2 m

12 mos

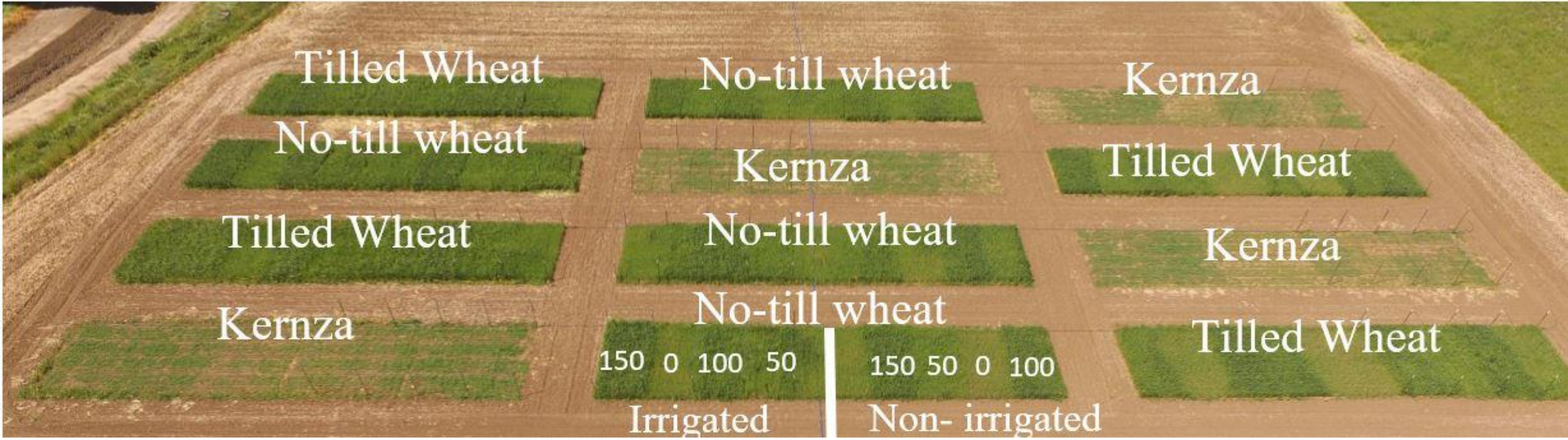
21 mos

Can This Breakfast Cereal Help Save The Planet?

Heard on Weekend Edition Saturday

DAN CHARLES

A bowl of Honey Toasted Kernza. General Mills made 6,000 boxes of the cereal and is passing them out to spread the word about perennial grains.

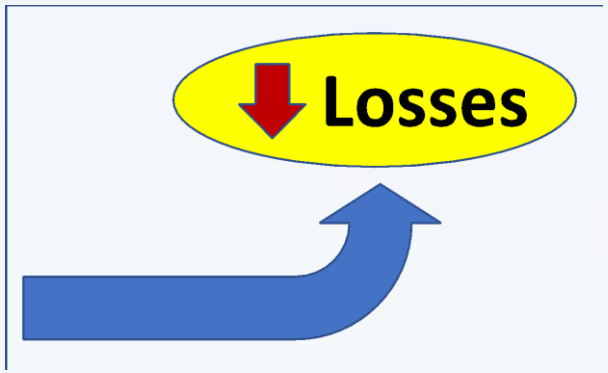


How does Kernza's aboveground **productivity** and **ecosystem services** (including C sequestration) compare to tilled and no-till annual wheat along gradients of nitrogen and water in the Mediterranean climate of California?

- Kernza established in 2018 at Russell Ranch Sustainable Agriculture Facility
- Split-split plot design with 4 field replicates
- **Cropping system type** (main plot), **irrigation** (subplot), **nitrogen fertilization** (sub-sub plot)

- Non-irrigated Kernza yields were almost 2X higher than irrigated yields
- N fertilization slightly increased grain yield but dramatically increased aboveground biomass
- Kernza grain yields were significantly lower than annual wheat, but total aboveground biomass was greater
- 2019 biomass and grain yields were comparable to results from other US regions

Reduce disturbance



Benefits

- Stalk incorporation
- Weed managment

Issues

- Loss of soil C through exposing C, adding oxygen
- Fungal symbiont network disturbance
- Compaction

Benefits

- Increased soil C near surface
- Improved soil structure

Issues

- Soil C doesn't have as much access to minerals.
- Soil C doesn't move deeper?
- Herbicide use

Take home messages

- Soil is a dynamic living system
- Need to consider deeper soil profiles when accounting for soil C
- To maximize soil C and health:
  - Add organic amendments
  - Increase plant cover
  - Improve root systems
  - Reduce disturbance