UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Soil Carbon

Fundamentals in Agricultural Systems

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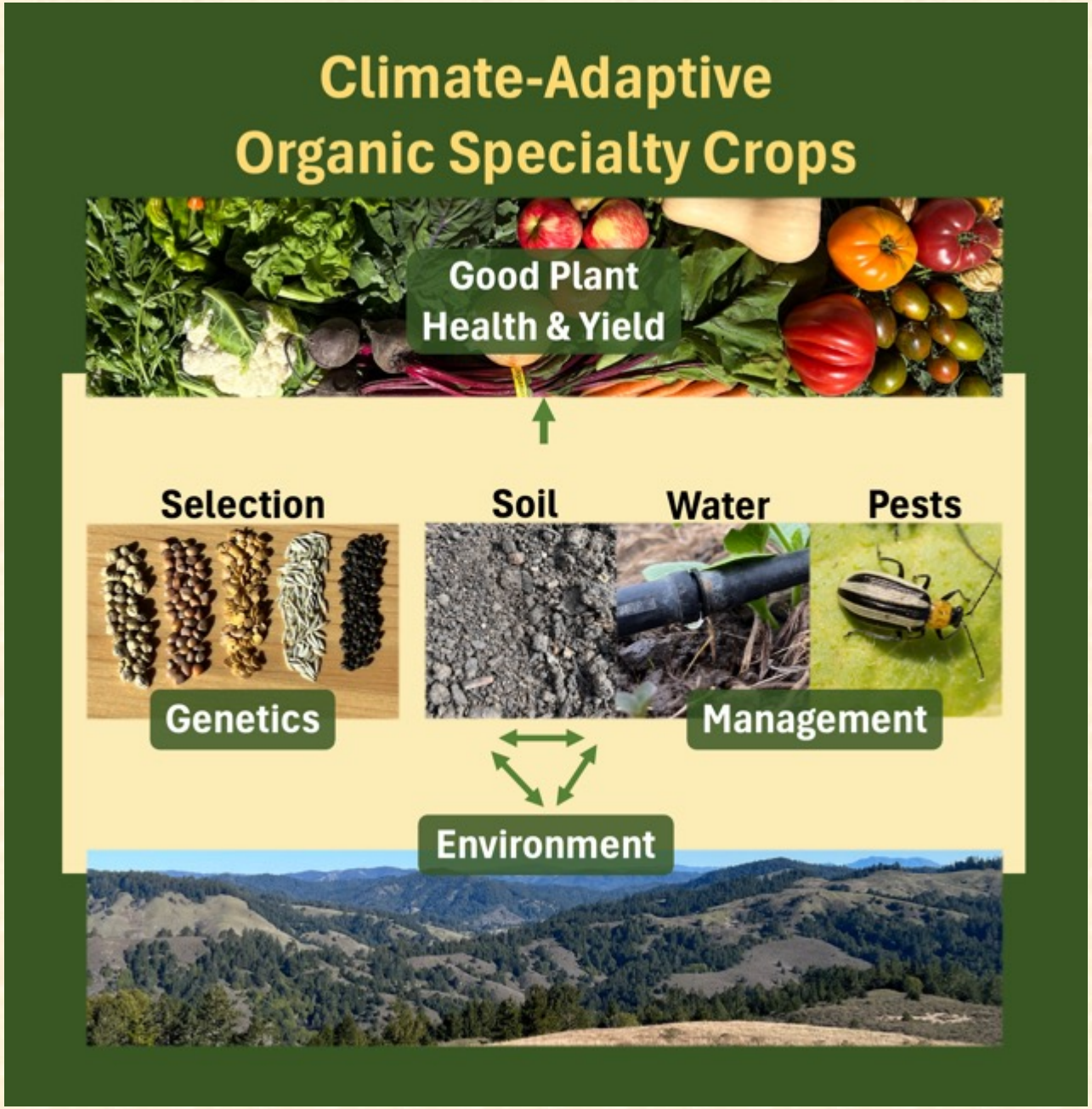
UC Cooperative Extension

Sonoma, Marin, Napa Counties

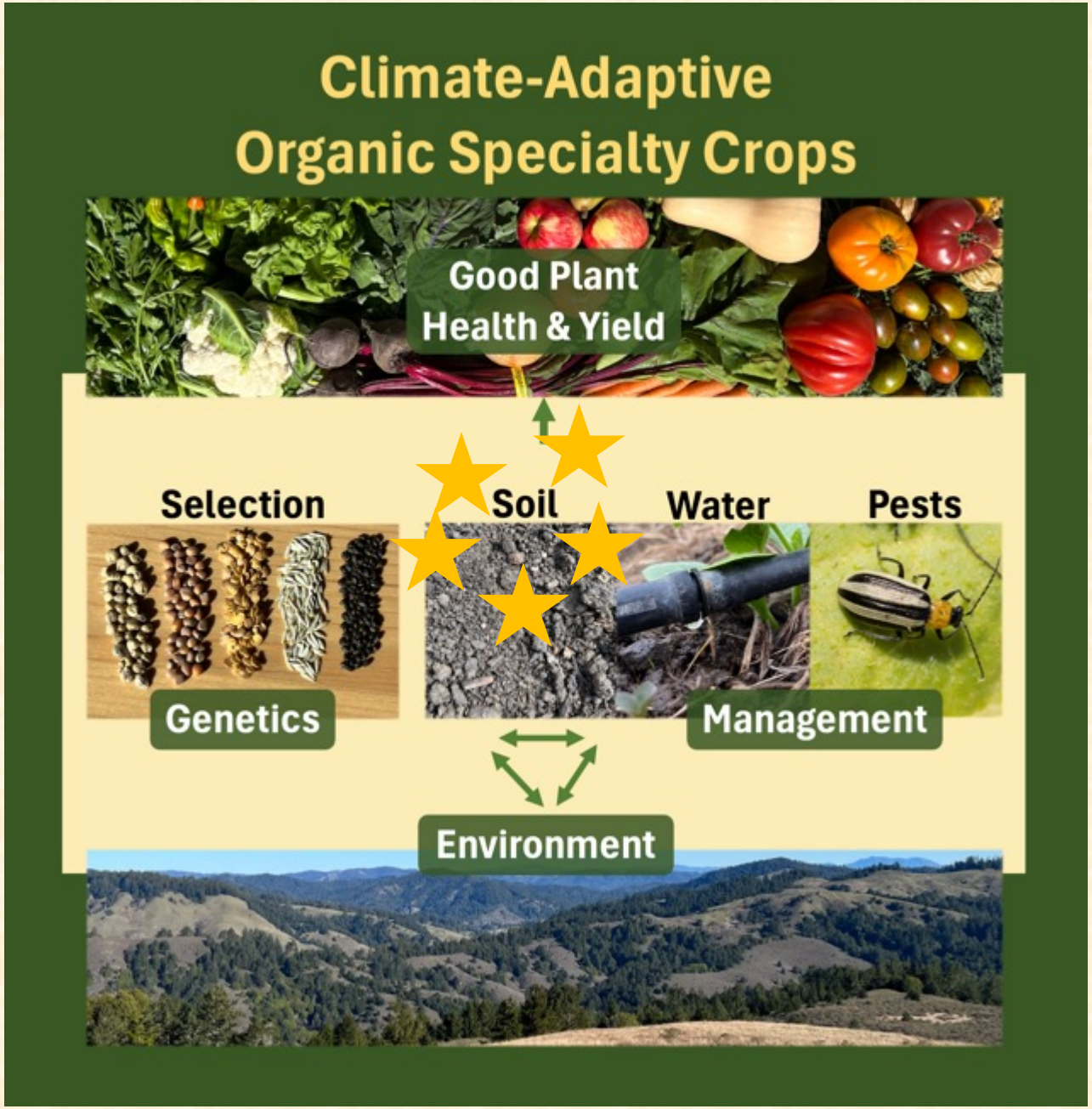
Extension Program

- Specialty Crops Advisor with UC Cooperative Extension
- I work with orchard & vegetable growers (but not grapes—that's Chris)
- Spent last year conducting a Needs Assessment (thank you!!)

Extension Program



Extension Program



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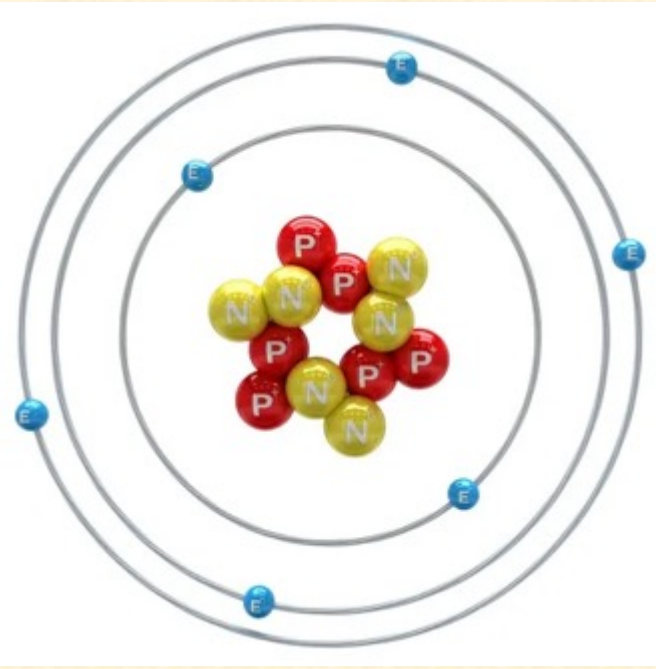
Outline

1. The Carbon Cycle: the Big Picture
2. Carbon Dynamics in the Soil
3. Soil Organic Matter
4. Different Forms of Carbon in Ag Systems

What is Carbon?

- Any atom with 6 protons is a carbon atom
- 15th most abundant element in Earth's crust
- 4th most abundant element in the universe
- Nonmetallic
- Tetravalent: allows 4 electrons to form covalent chemical bonds

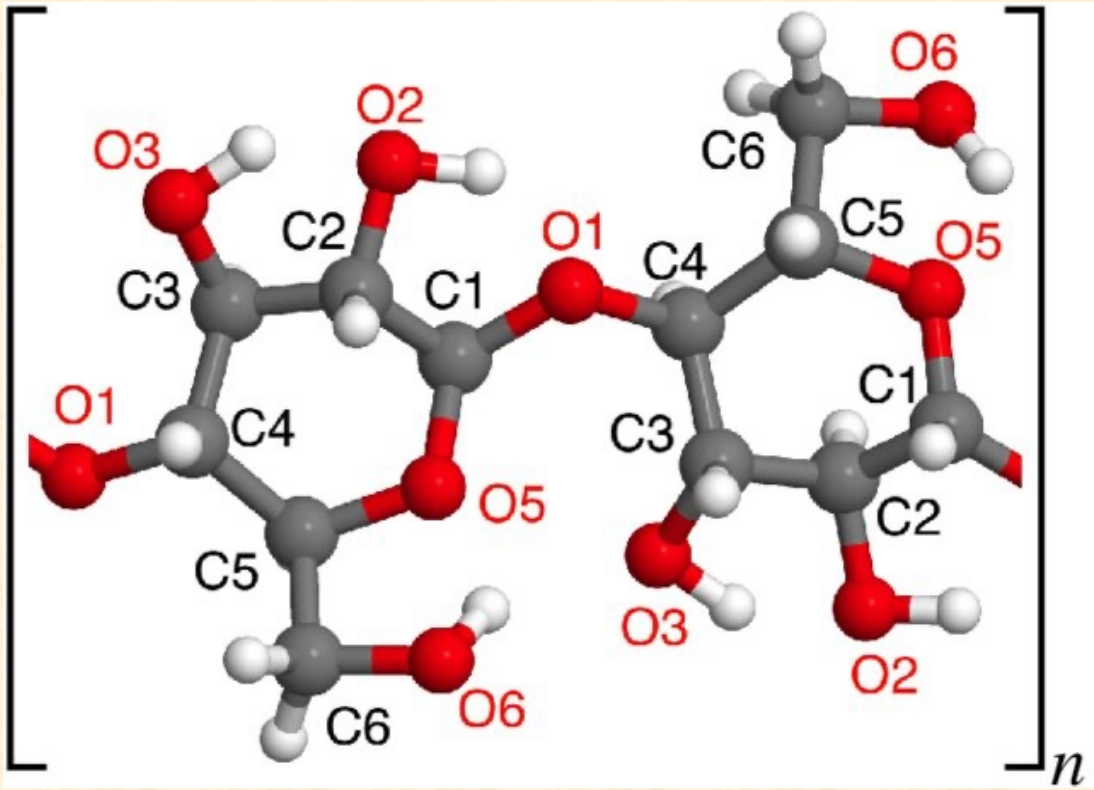


(Live Science)

What is Carbon?

- Why is it special? It's the element of life!
- It can bond in a wide variety of shapes with many elements
  - Diverse structures in living things (DNA, proteins, carbohydrates, etc.)
- Carbon-carbon bonds are great building blocks: strong enough to be stable, but can be broken and rearranged

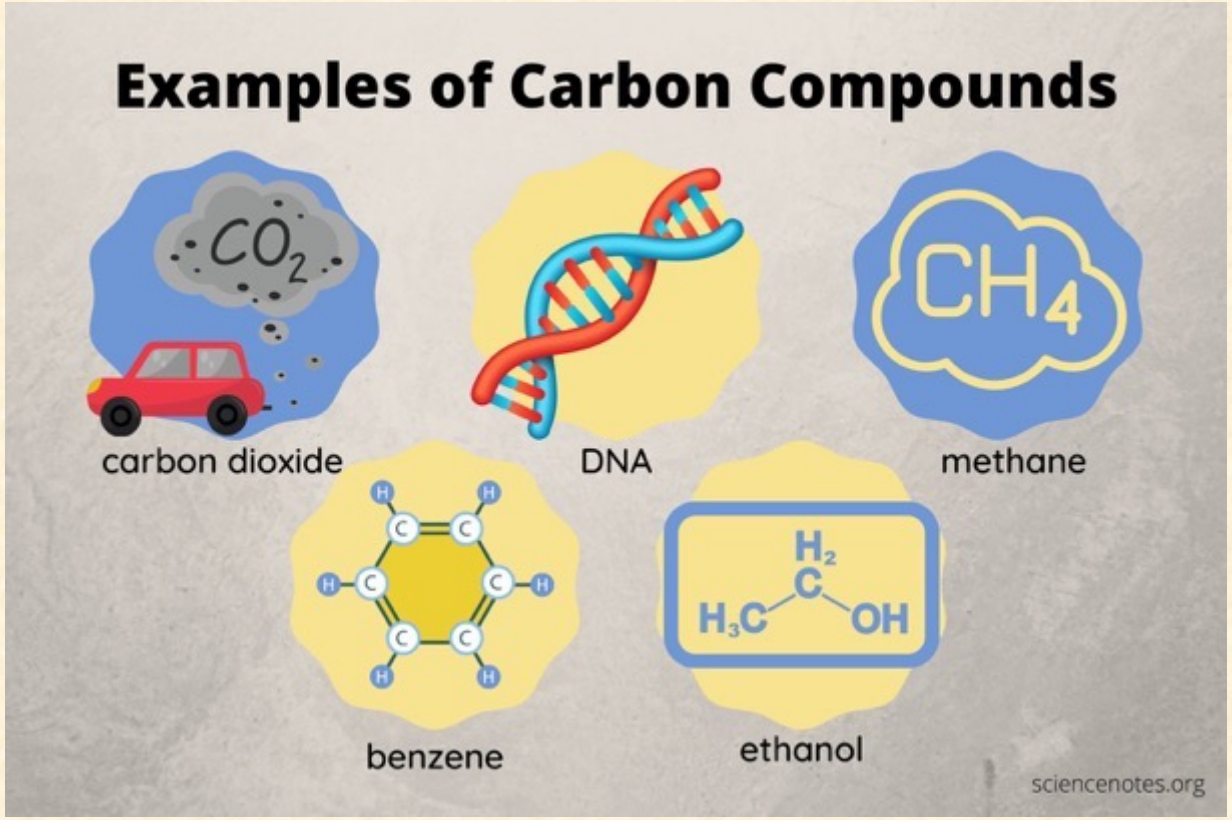
Carbon (in grey) is essential for the structure of cellulose, an important component of plant cell walls



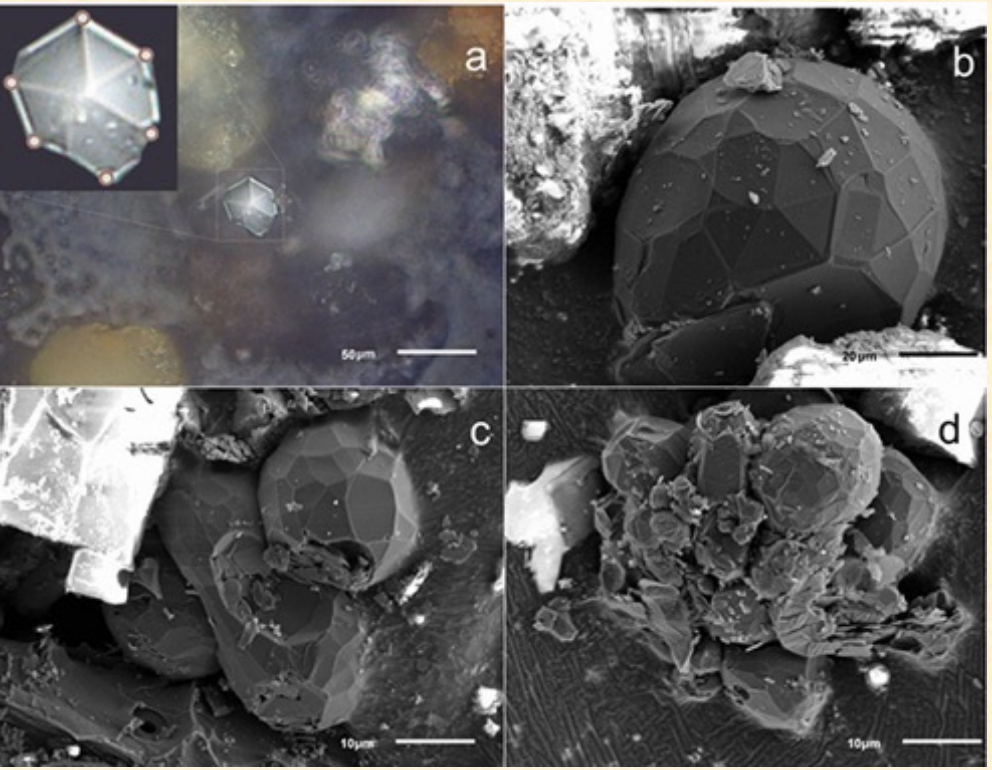
(Bering et al. 2021)

What is Carbon?

- Organic compounds contain carbon
- Immense range of organic compounds
- CO_2 and CH_4 are the primary controllers of earth's climate since the origin of our atmosphere



(Helmenstine, Science Notes)



Images of carbon microcrystals (Taskaev and Khovaylo, EPJ Plus, Innovation News Network)

- Carbon-rich meteorites bombarded Earth's primordial surface and contributed carbon
  - Hydrocarbons, organic acids, amino compounds
  - Hypothesized contributions to the evolution of life
- Resulted in complex processes leading to the transfer of C across Earth's mantle, waterways, atmosphere, land & life resulting in the Carbon Cycle

The Carbon Cycle - Geological

- The geological carbon cycle:
  - Has dominated the fate of carbon throughout Earth's history
  - Processes like long-term weathering, accumulation, release of CO2, carbonic acid in precipitation dissolving rocks, etc.
- ...not our focus today, but this is the big-picture geological context

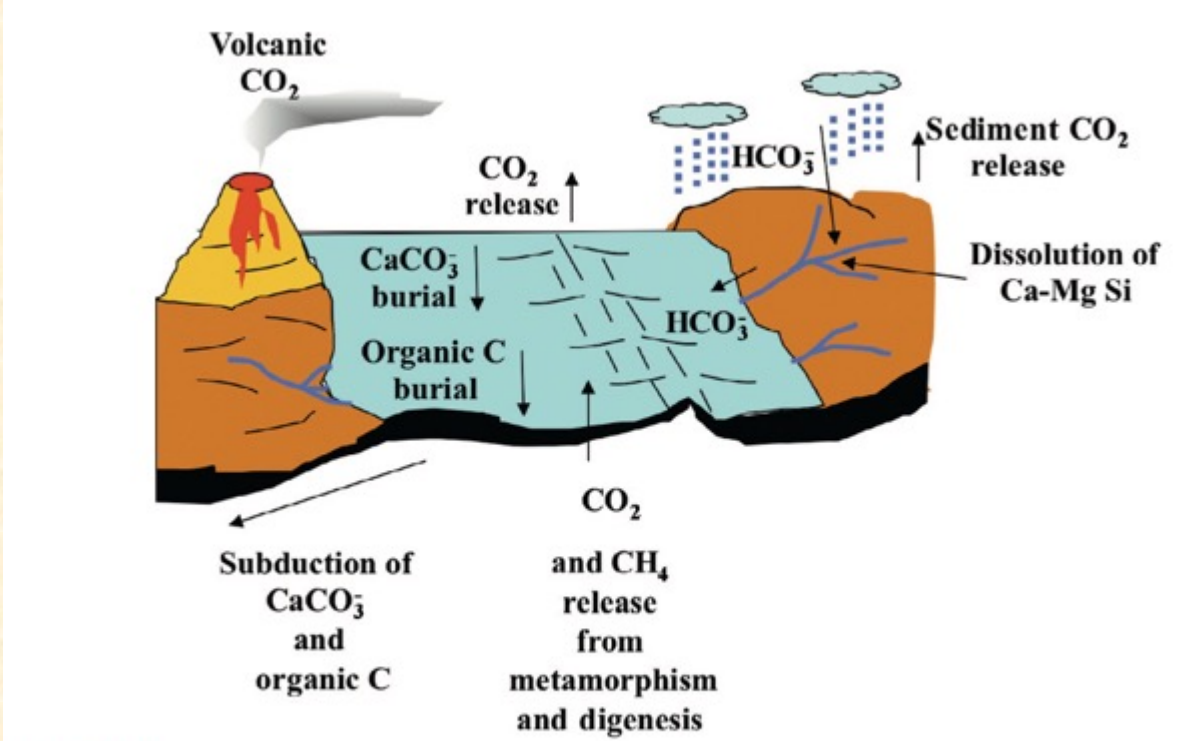
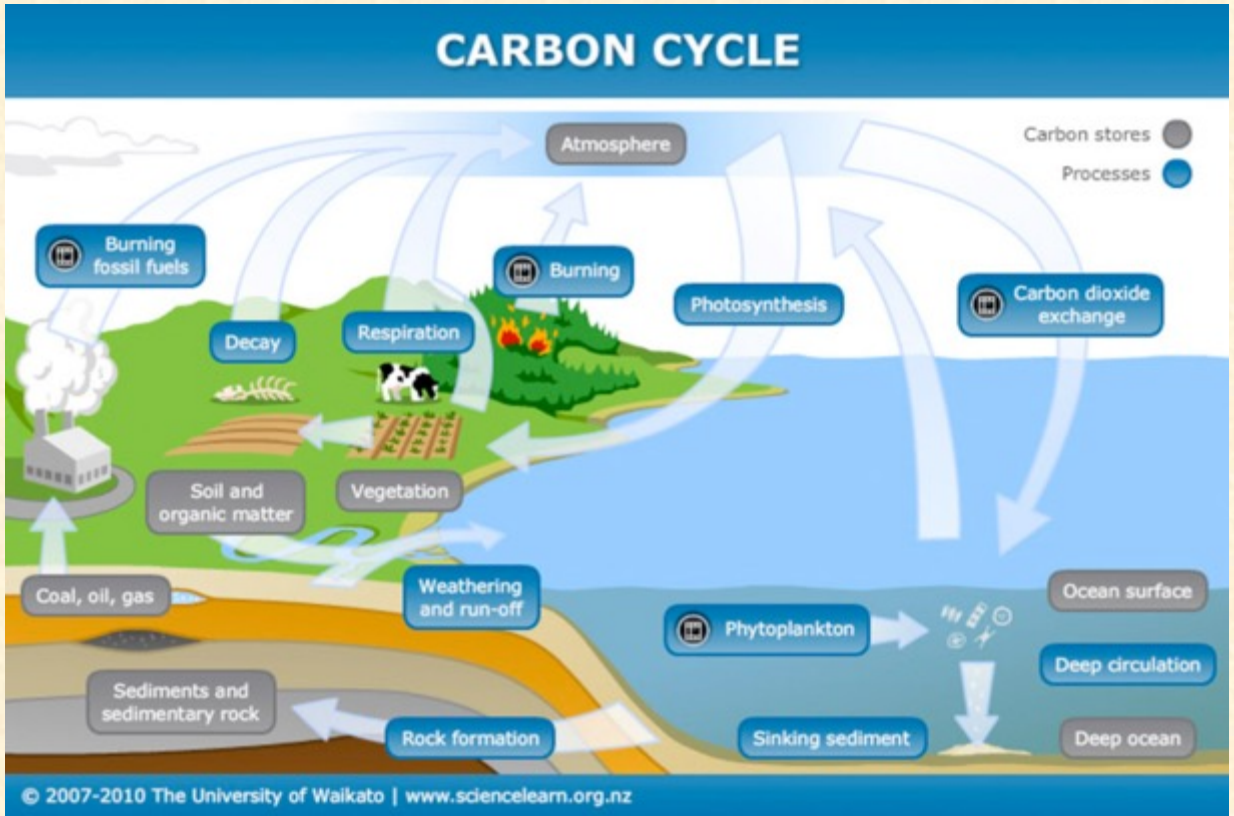


FIG. 12.1 The long-term C cycle.

(Horwath, 2015)

The Carbon Cycle - Biological

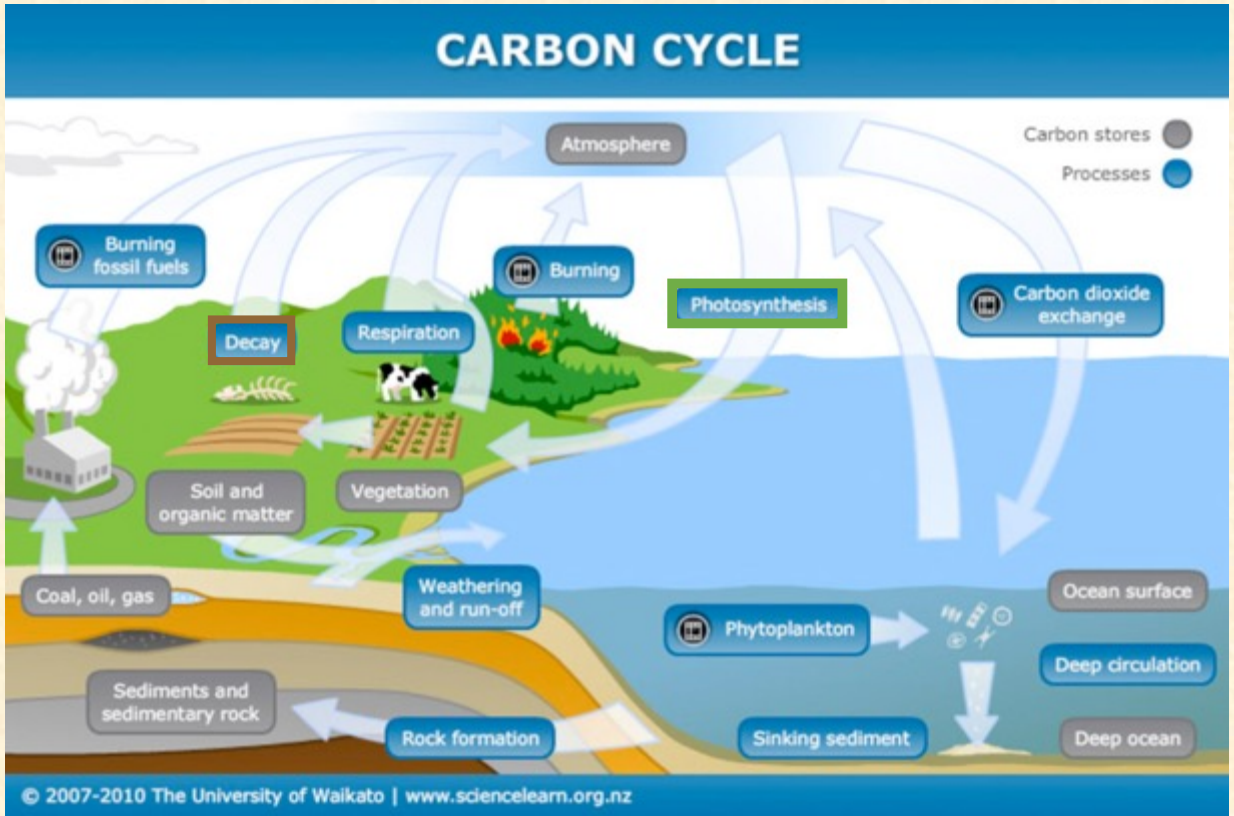
- The evolution of photosynthetic organisms profoundly altered the geologic C cycle: provided another sink for atmospheric CO_2



(Science Learning Hub, University of Waikato)

The Carbon Cycle - Biological

- The biological C cycle is characterized by the interaction of terrestrial & marine **photosynthesis** and **decomposition**

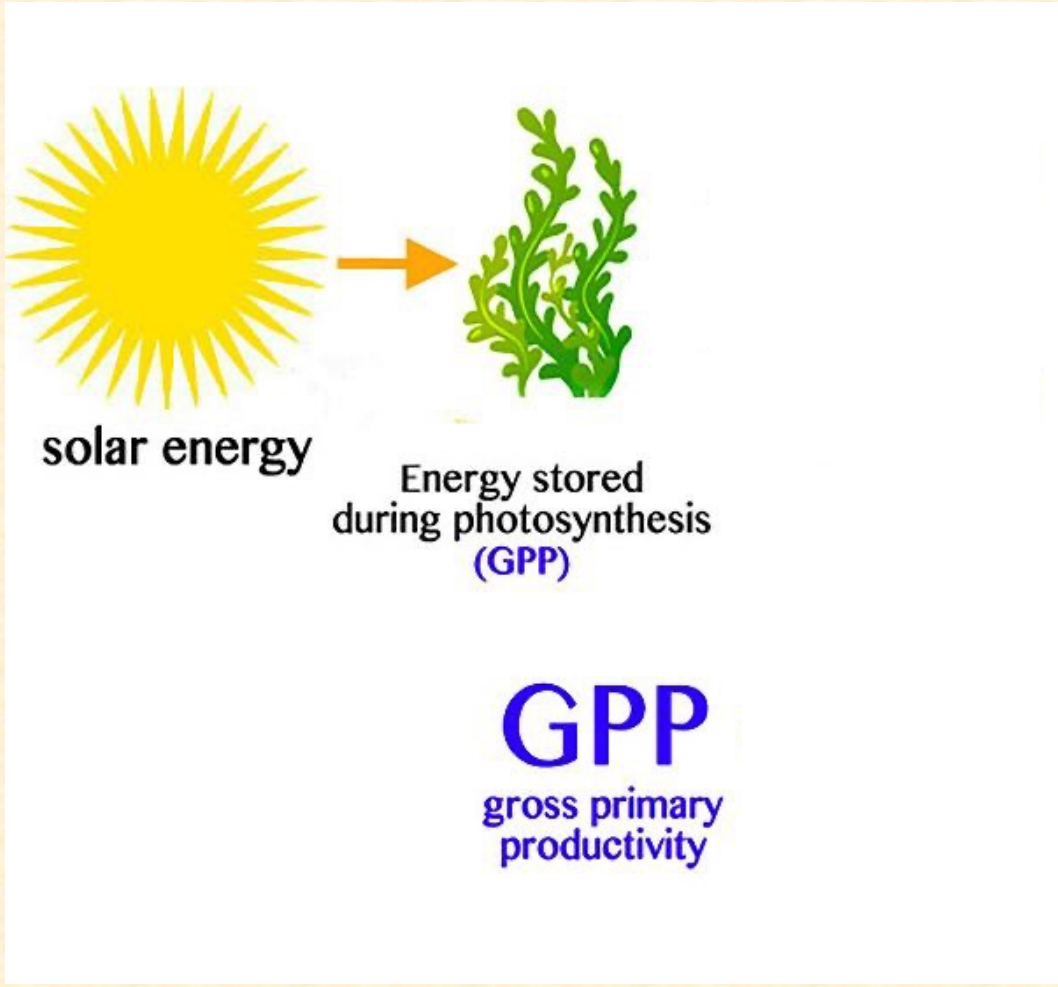


The biological C cycle is what we'll focus on today in agricultural systems

(Science Learning Hub, University of Waikato)

The Carbon Cycle - Biological

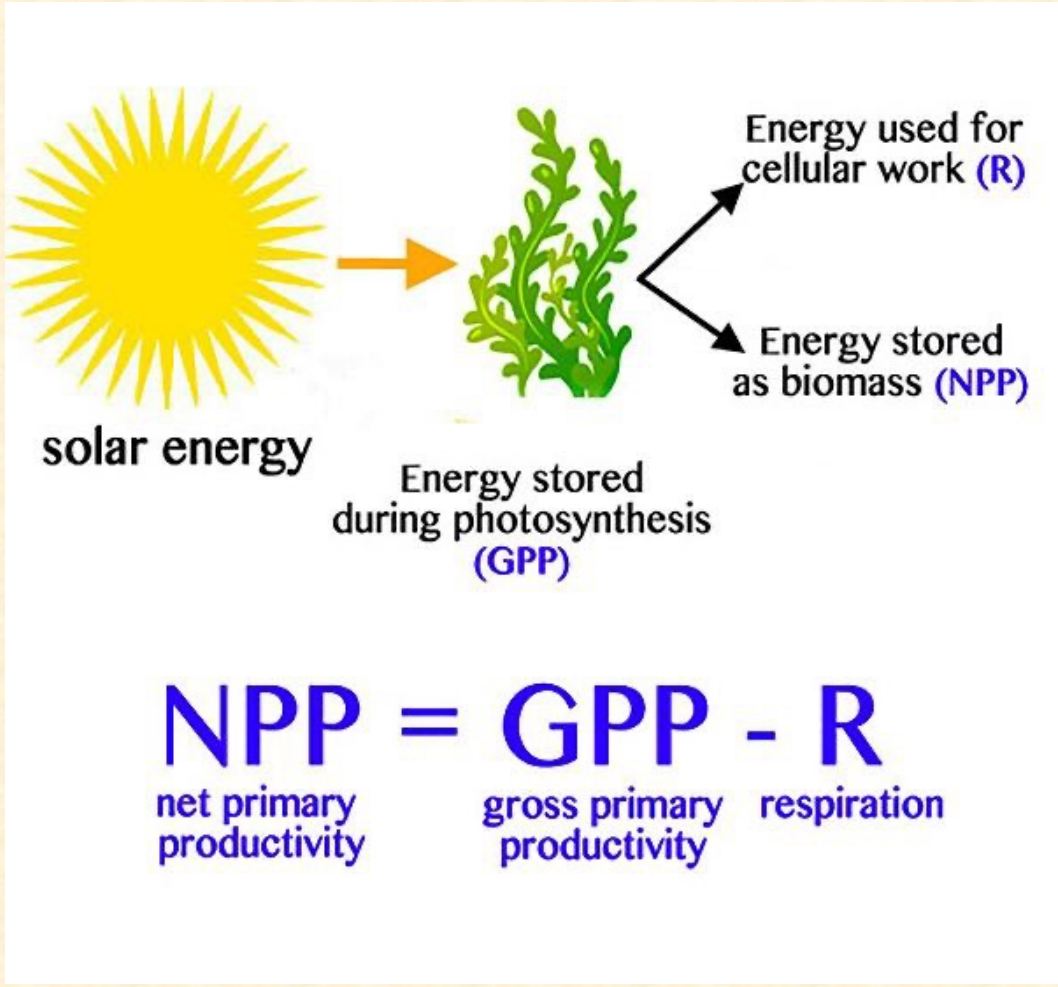
- Gross primary production (GPP): production of organic matter thru photosynthesis



(Biologyonline.com, Miami.edu)

The Carbon Cycle - Biological

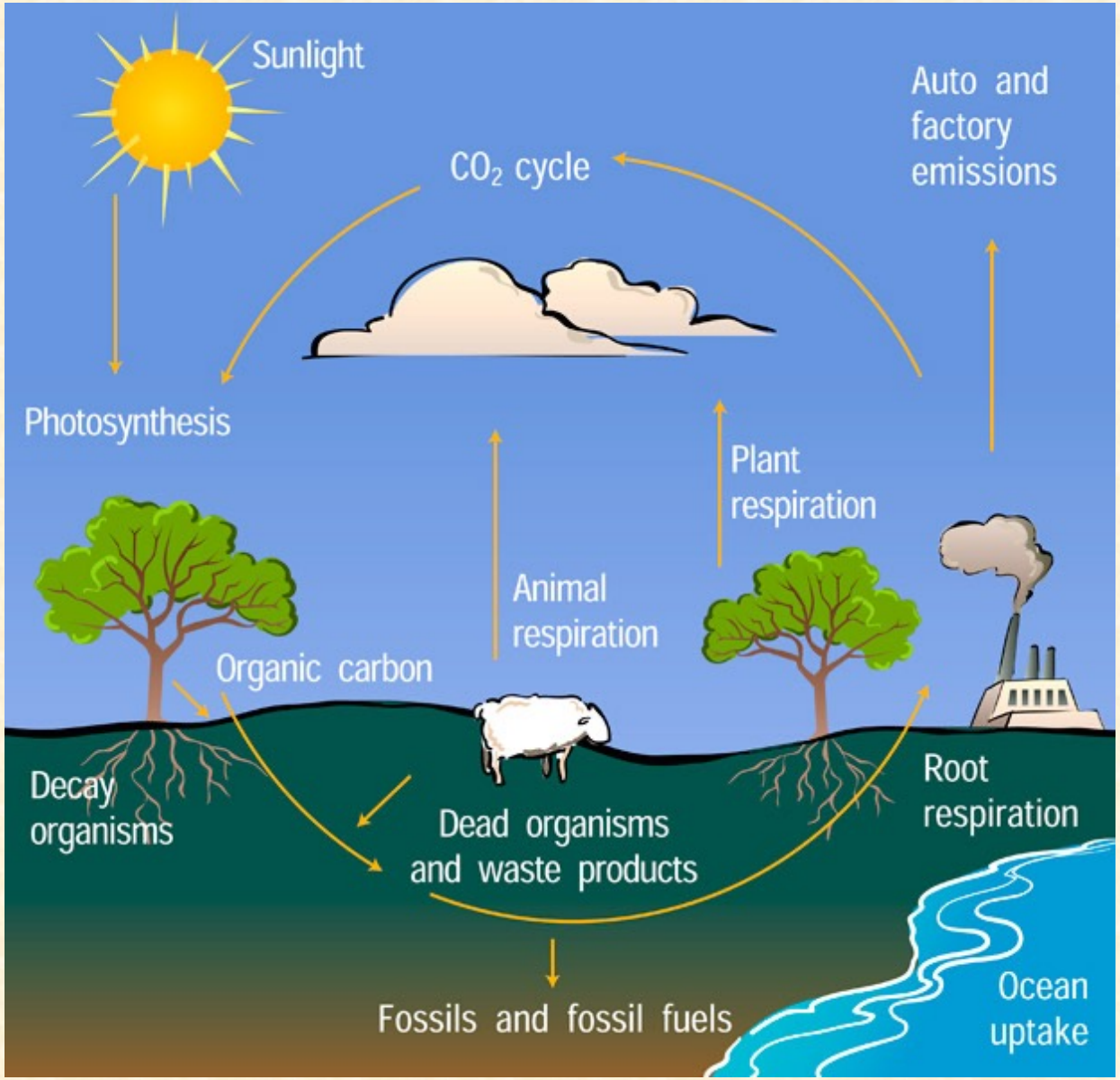
- Gross primary production (GPP): production of organic matter thru photosynthesis
- Net primary production (NPP): the carbon remaining after respiration in live & dead biomass
- This is the main process that most life on earth depends on as a source of chemical energy



(Biologyonline.com, Miami.edu)

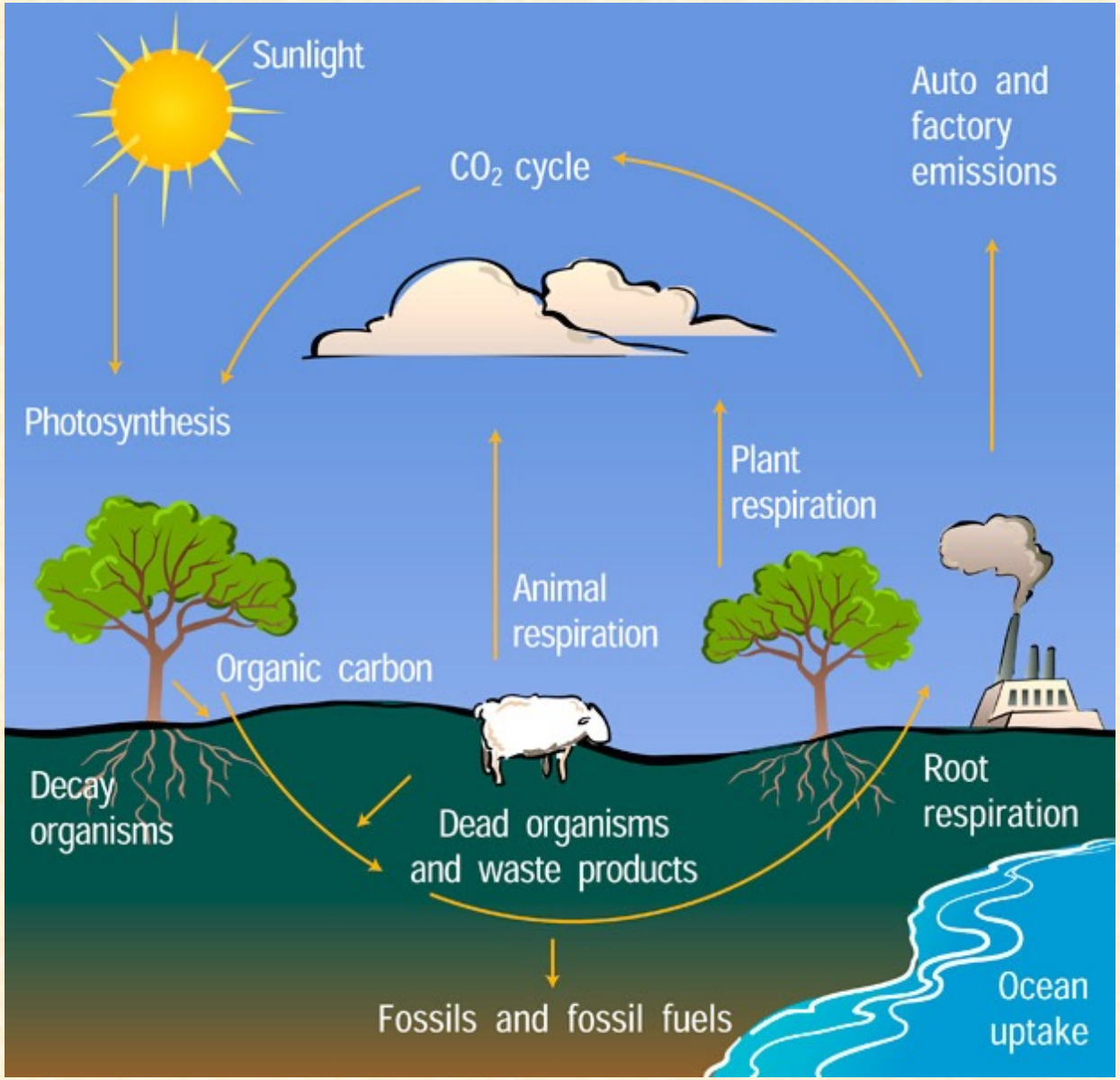
The Carbon Cycle

- Fluxes: flows of carbon
- Pools: reservoirs or storage of carbon in some amount



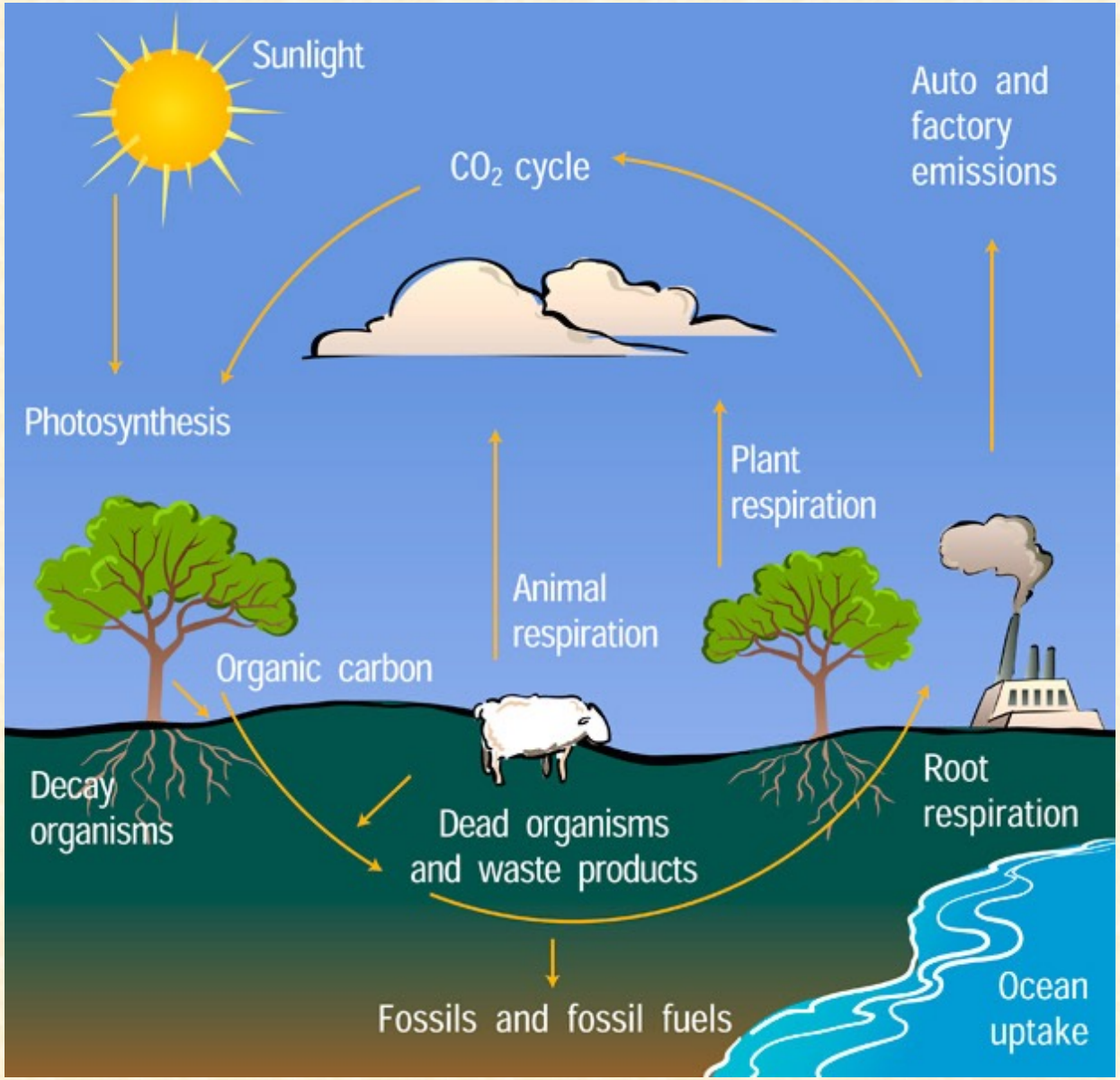
The Carbon Cycle

- Transformations: change in form of carbon through biogeochemical processes
- Stable carbon: more resistant to change & transformations
- Labile carbon: more available for microbial use & more responsive to changes



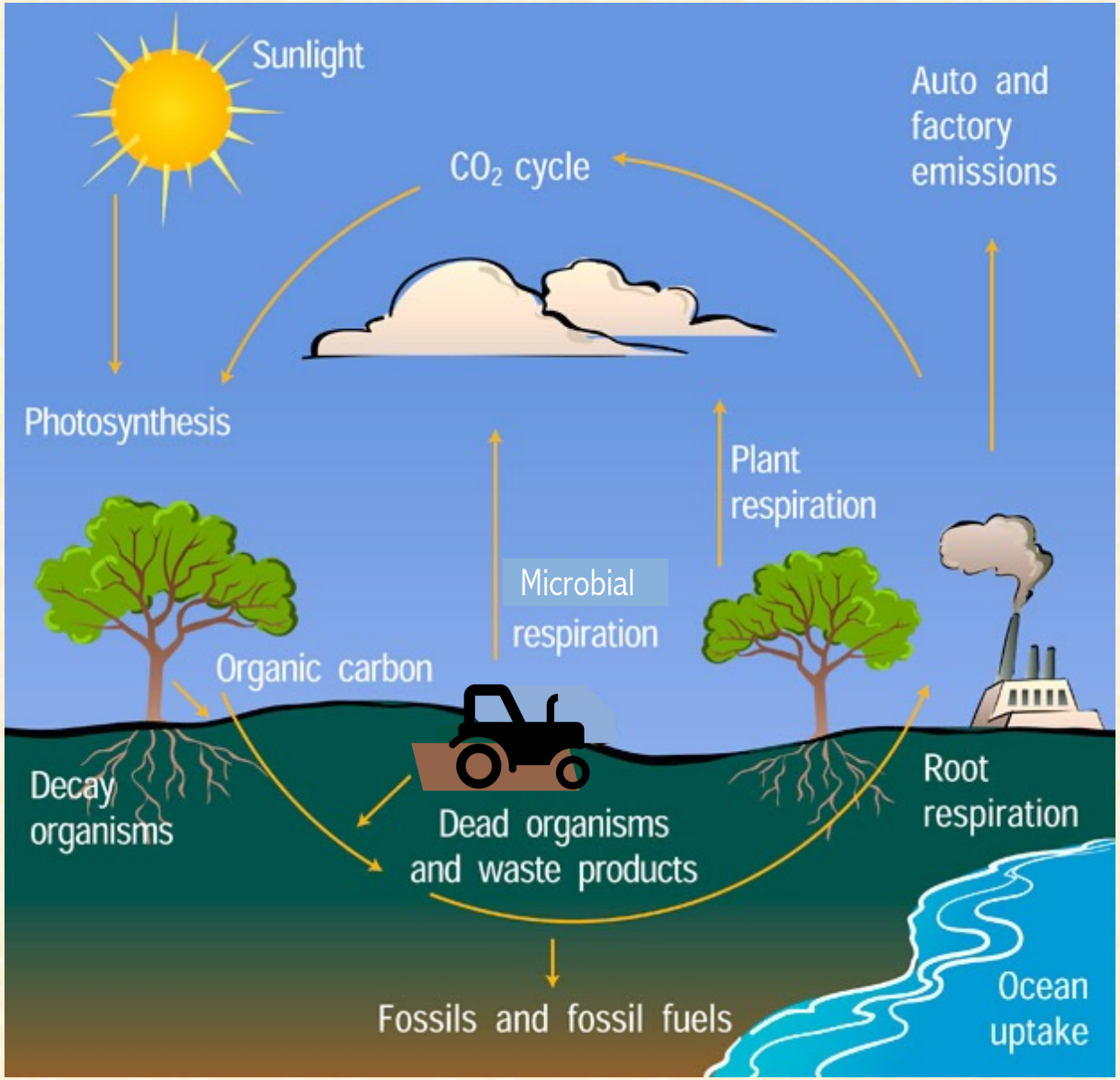
The Carbon Cycle

- Carbon is not static!
- Even the stable pools can be disrupted



The Carbon Cycle

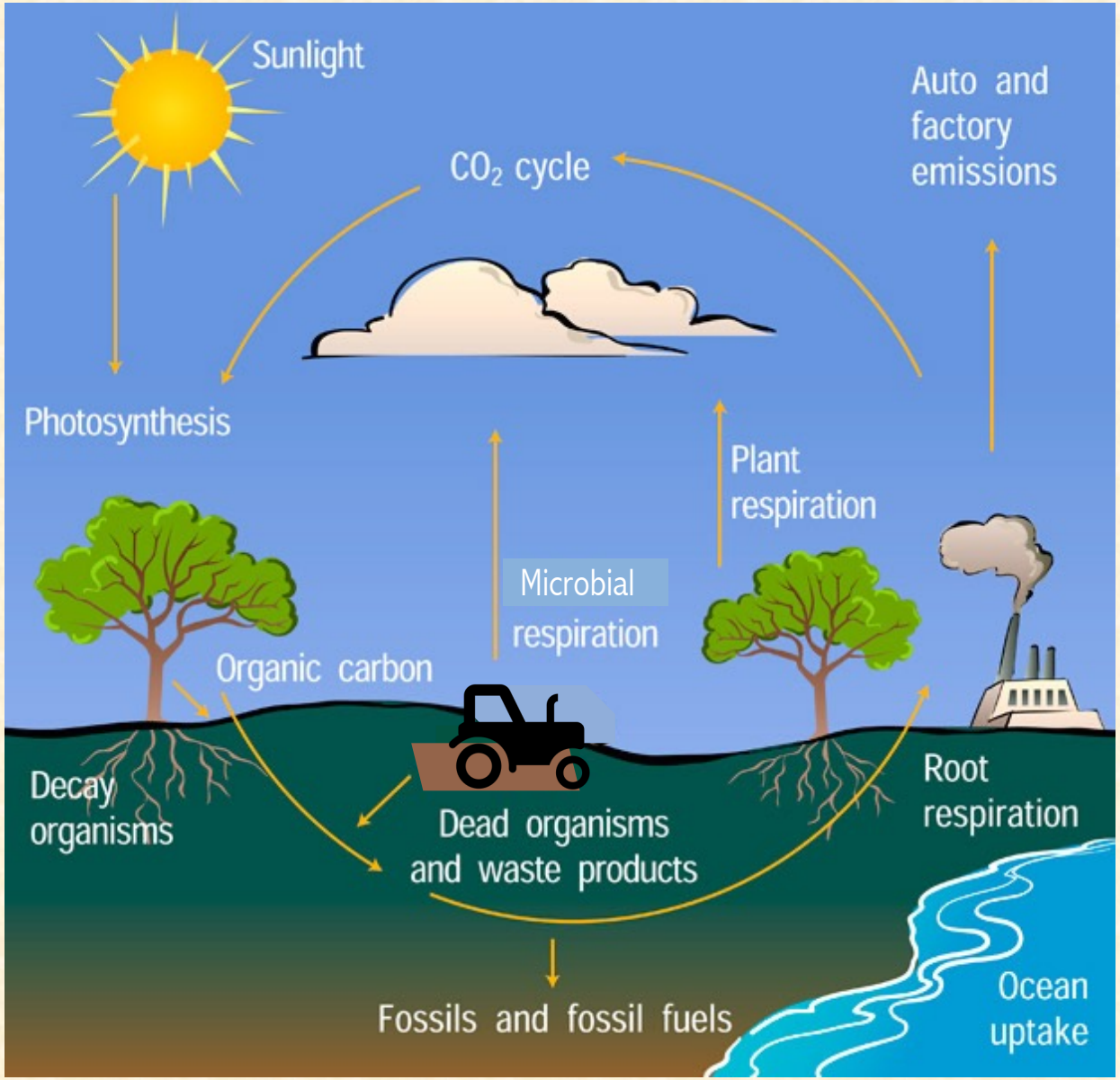
- Soil disturbance (such as tillage)
  - Makes more carbon available for microbes to access & decompose
  - Leads to microbial activity & CO_2 release
  - Acts like a valve for soil carbon



The Carbon Cycle

Sometimes tillage can be very useful

- to break up hardpan
- improve infiltration
- prepare bed for planting
- weed management

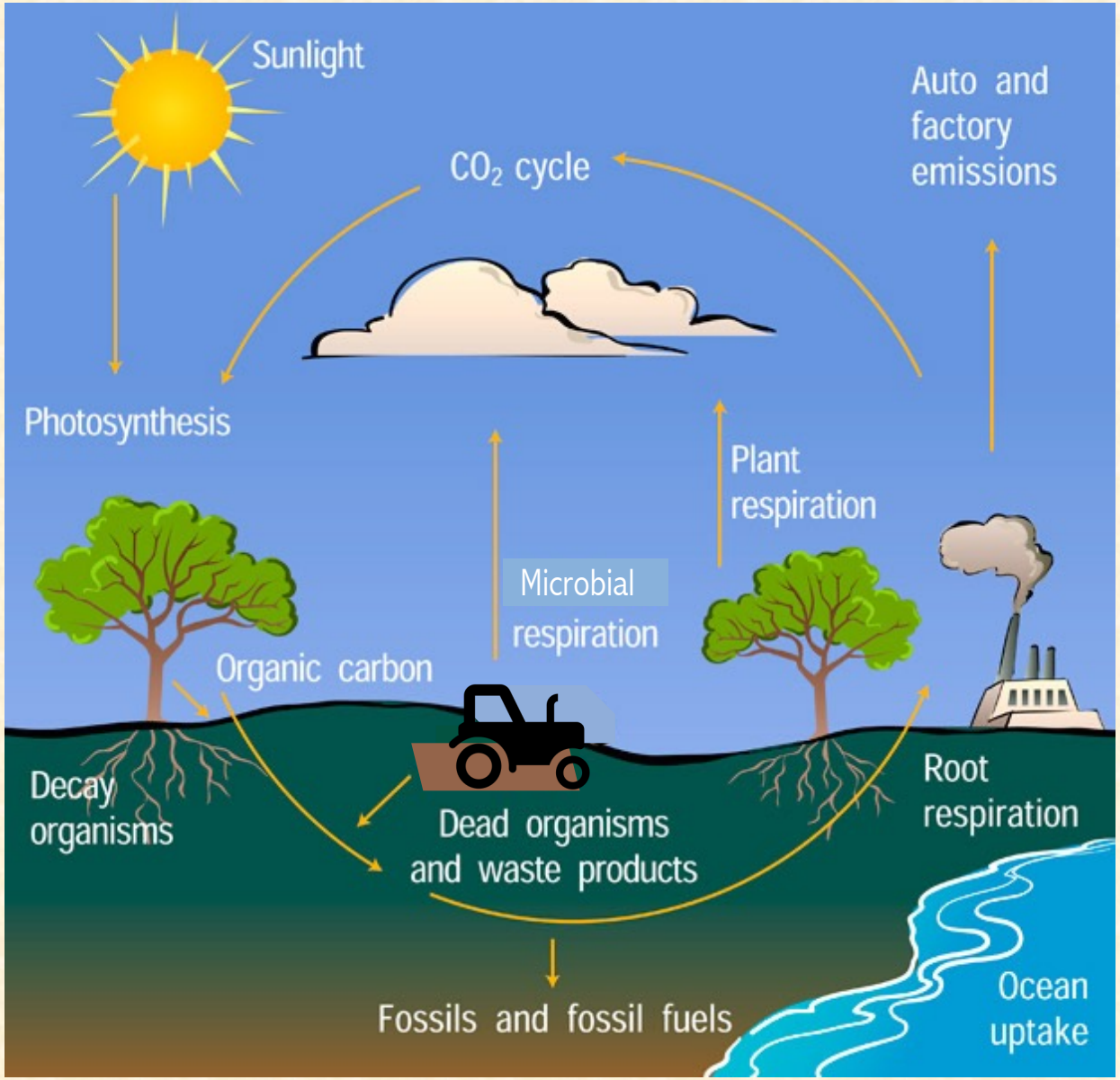


The Carbon Cycle

Sometimes tillage can be very useful

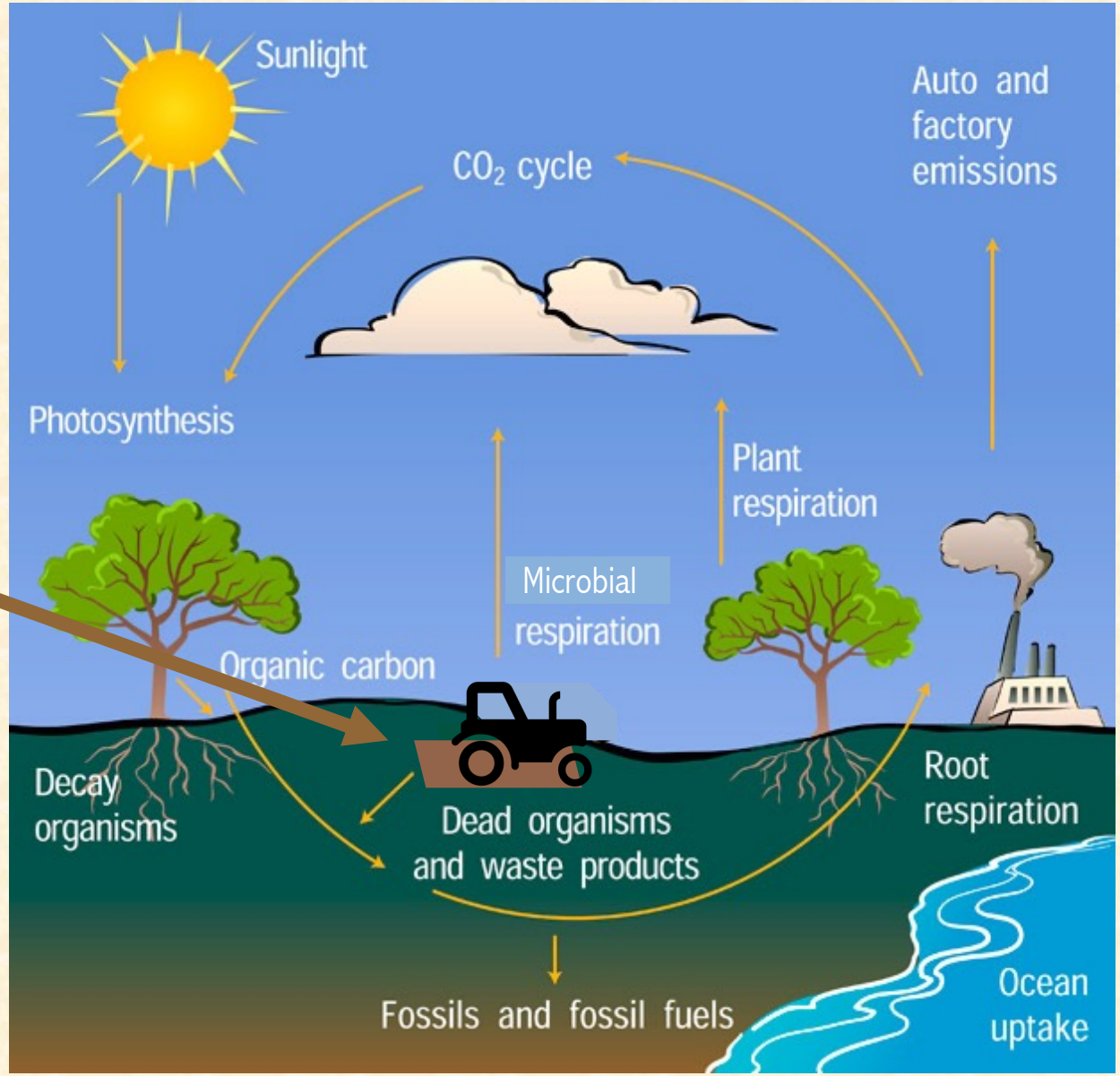
...just be strategic and consider:

- frequency
- depth
- implements
- compaction from equipment
- erosion risk
- etc.



The Carbon Cycle

Now we'll zoom in to the soil!



The Carbon Cycle

Soil Continuum Model

Soil Aggregates

Mineral Surfaces

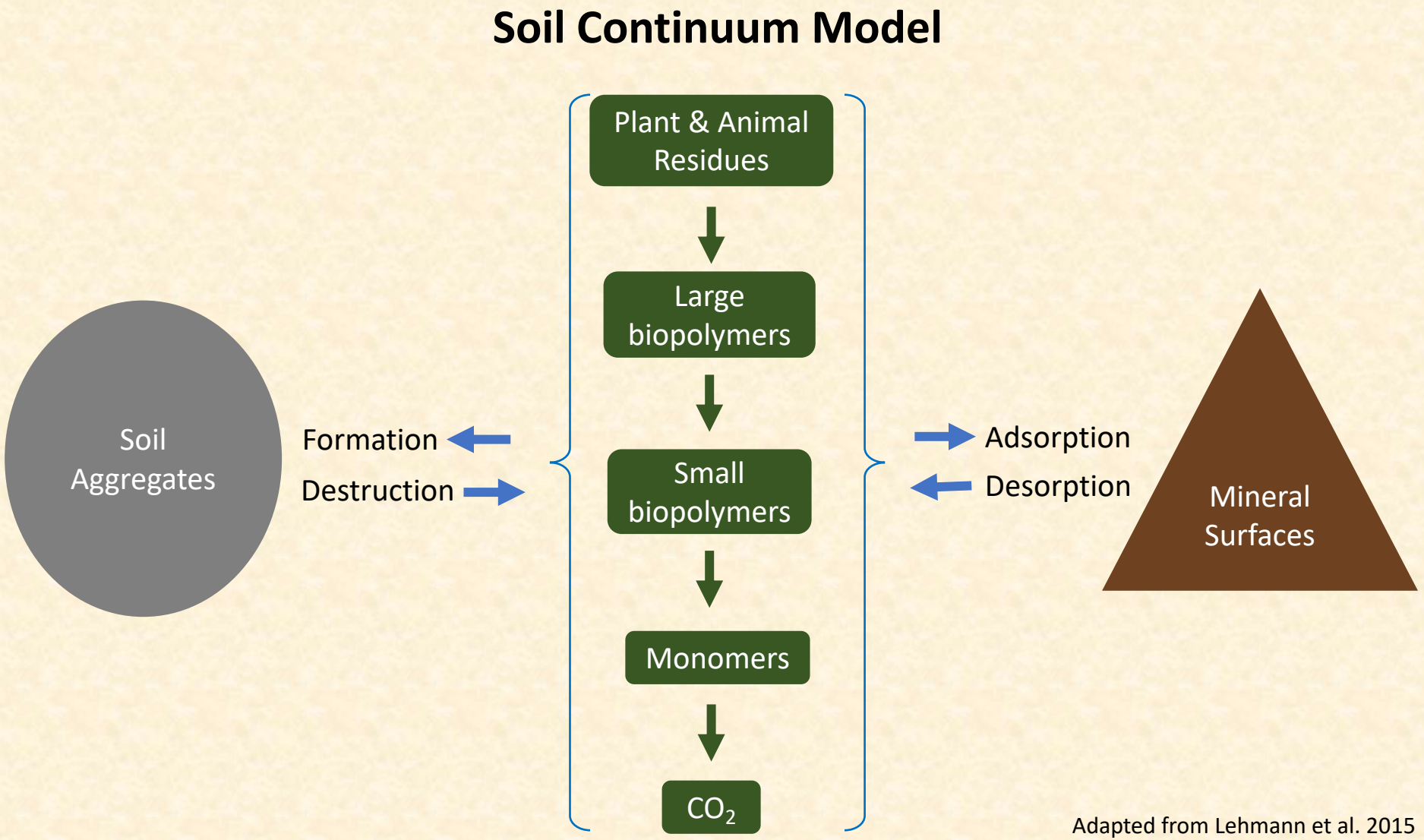
The Carbon Cycle

Soil Continuum Model

The Carbon Cycle

Soil Continuum Model

The Carbon Cycle



Adapted from Lehmann et al. 2015

Soil Organic Matter (SOM)

- Residual compounds & the organic structures remaining after decomposition
- Anything in the soil that used to be alive
- Formation & decay of SOM is an essential ecosystem process

(FAO)

SOM & SOC

- Soil Organic Matter (SOM): any material in soil originally produced by living organisms

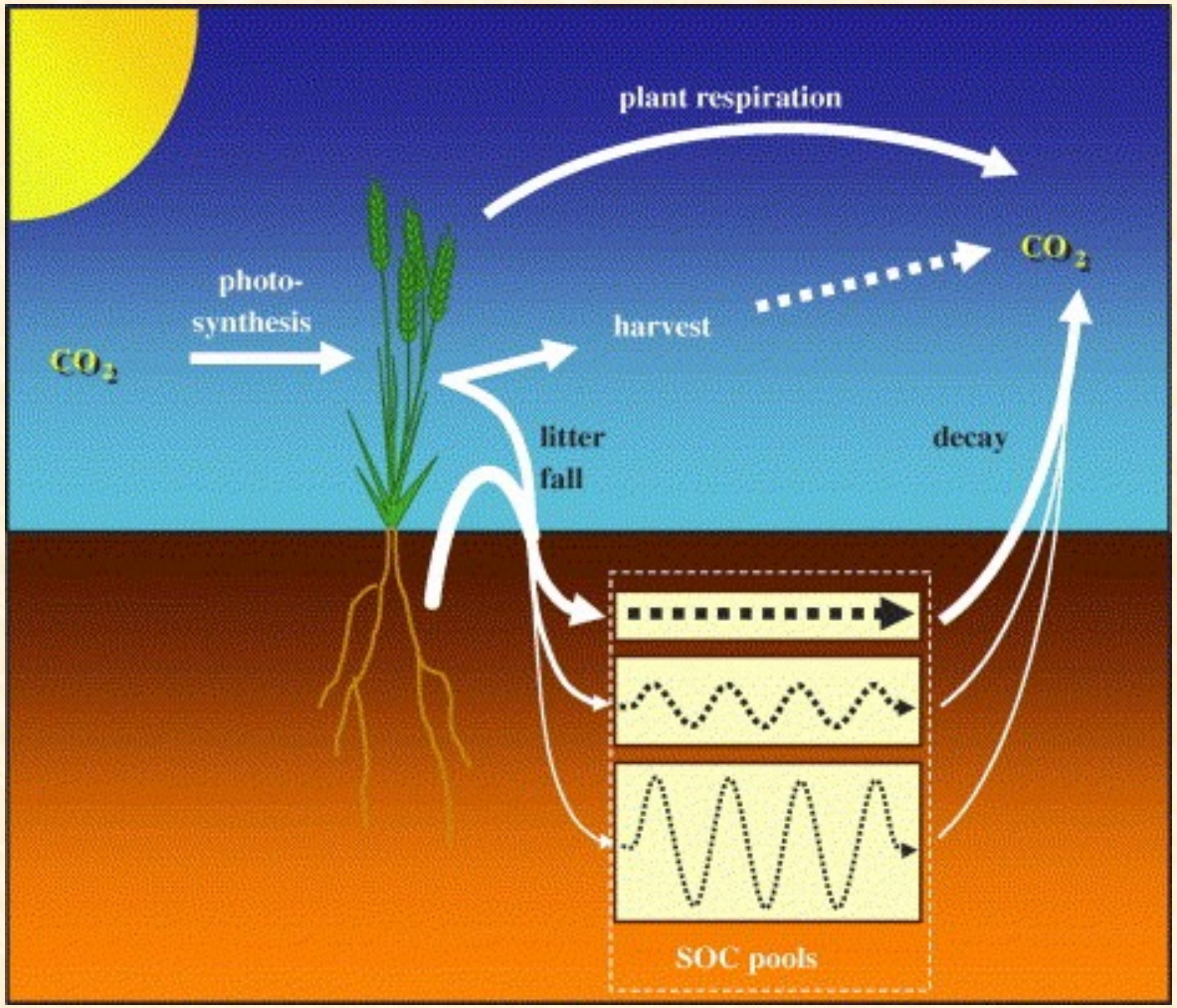
- Soil Organic Carbon (SOC): the carbon component of organic compounds in soil
  - Labs use SOC to estimate SOM

Soil Organic Matter

- Darker soil color indicates higher SOM
- SOM can come from:
  - Surface-applied organic matter amendments
  - Root exudates (carbon)
  - Microbial byproducts
- Lighter soil color farther down suggests relatively less SOM

The Carbon Cycle

- Soil carbon dilemma:
  - You need microbial activity to increase SOM
  - Microbial activity → respiration
  - Can't get around microbial respiration (aka some CO_2 loss to the atmosphere)



(Janzen et al. 2006)

The Carbon Cycle

ELSEVIER

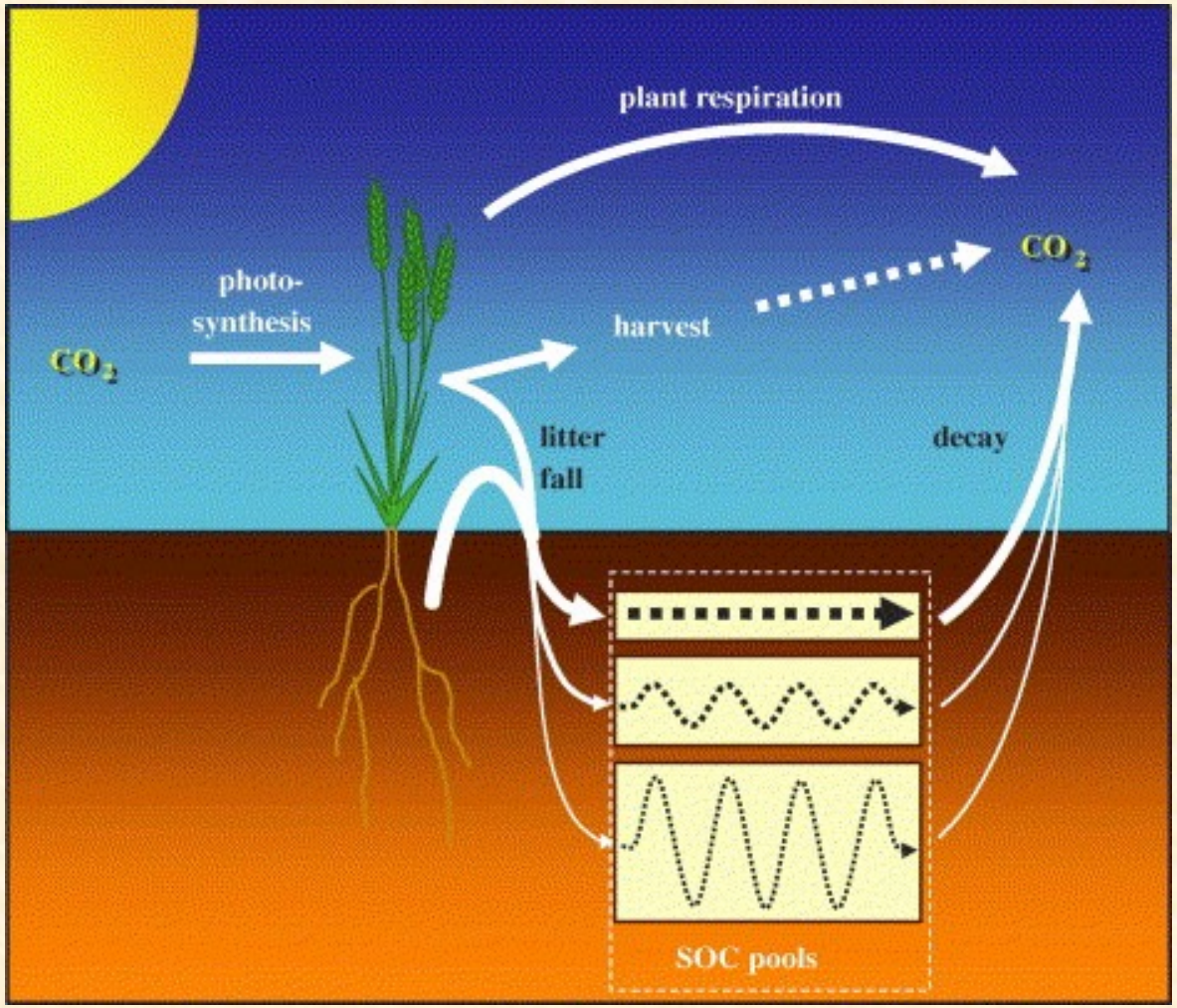
Soil Biology and Biochemistry

Volume 38, Issue 3, March 2006, Pages 419-424

Points of view

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

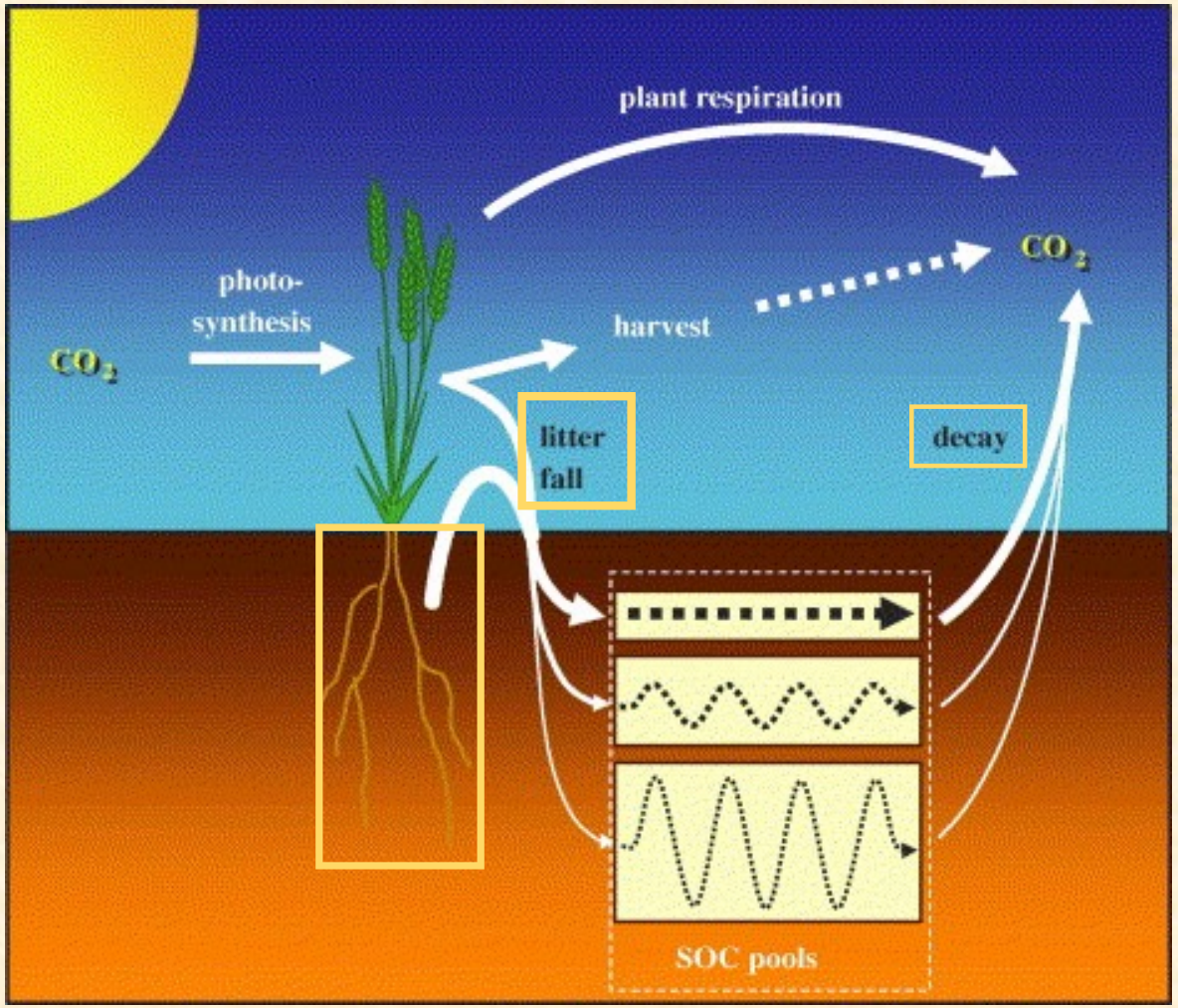
H.H. Janzen



(Janzen et al. 2006)

The Carbon Cycle

- We can manage some things:
  - Keep plant residues on ground, repetitive & diverse OMA inputs
  - Slow decay (low disturbance)
  - Keep living roots in soil: they release C exudates



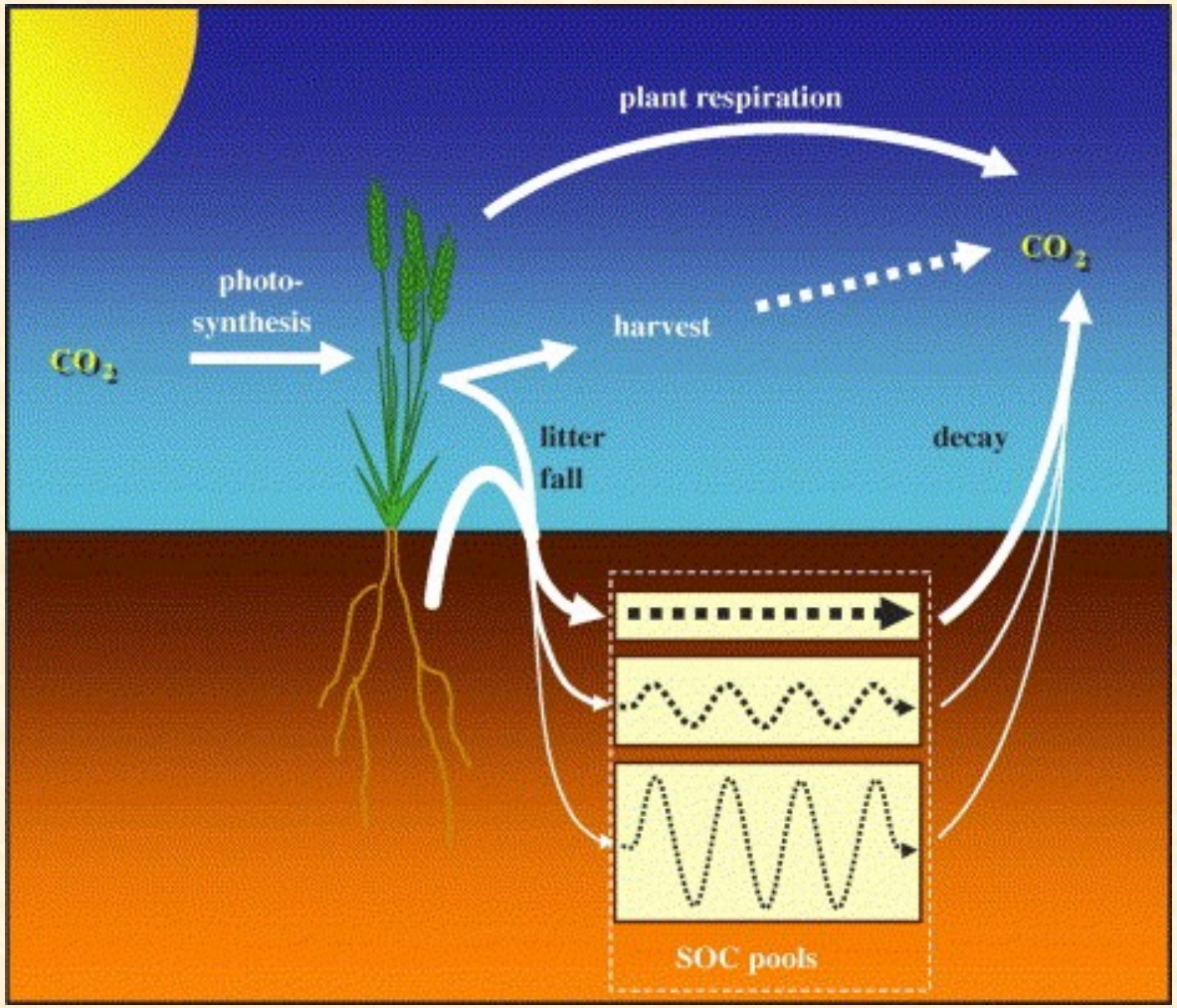
(Janzen et al. 2006)

The Carbon Cycle

"Soil organic matter is far more than a potential tank for impounding excess CO_2;

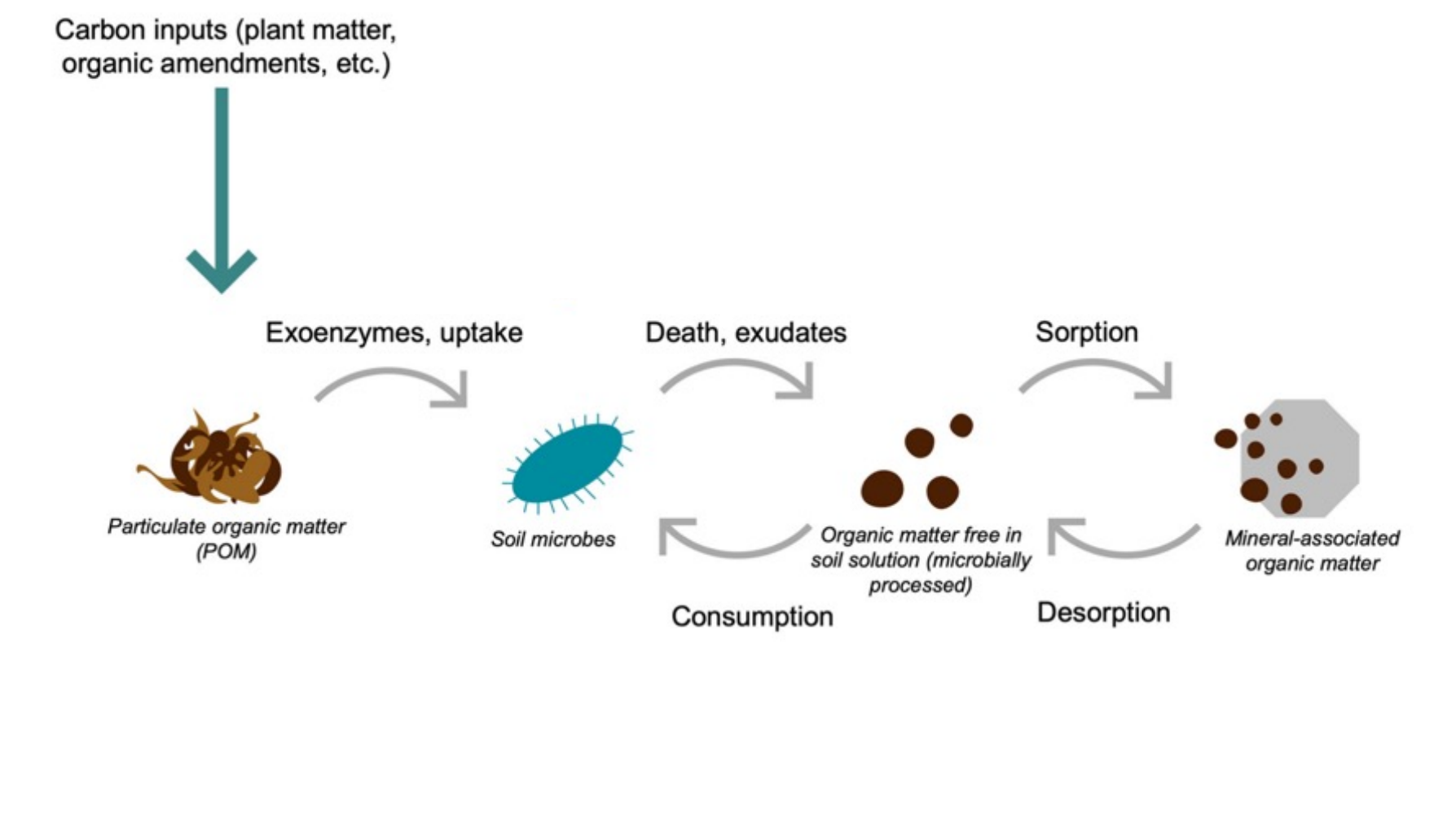
it is a relentless flow of C atoms, through a myriad of streams–some fast, some slow—wending their way through the ecosystem, driving biotic processes along the way."

--H.H. Janzen, 2006



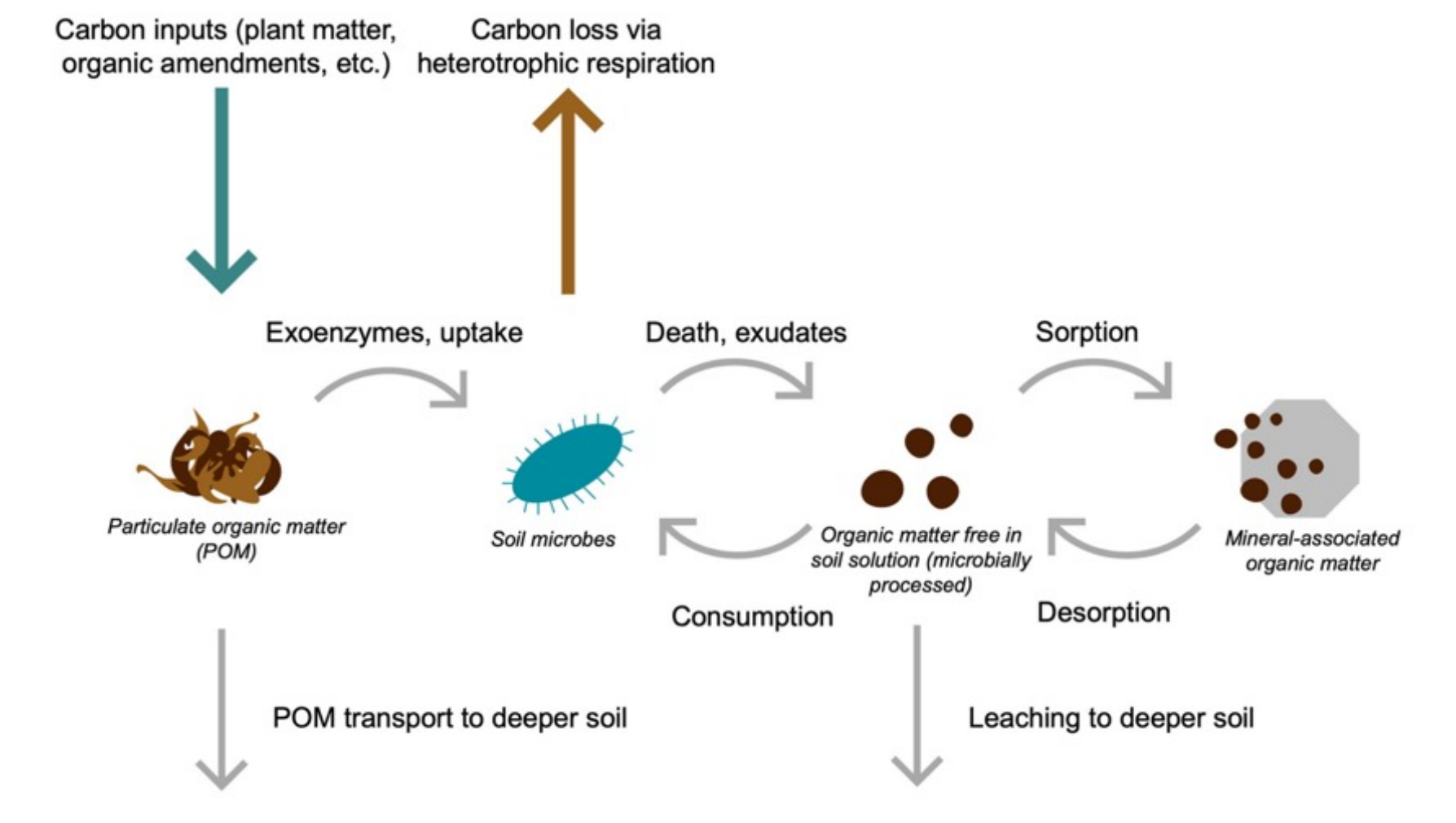
(Janzen et al. 2006)

Soil Biological Indicators



(Dynarski et al. 2020)

Soil Biological Indicators



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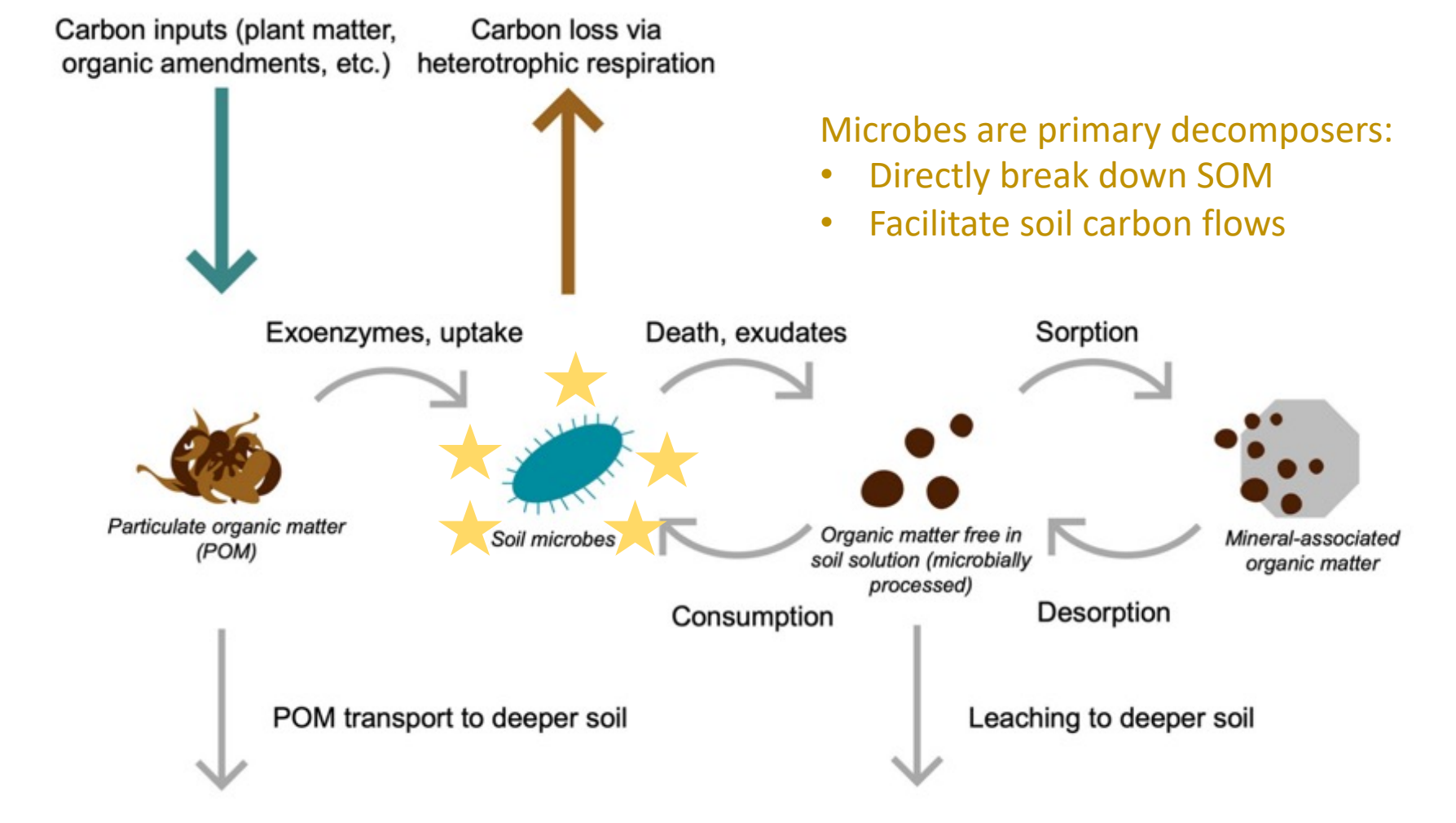
Soil Biological Indicators

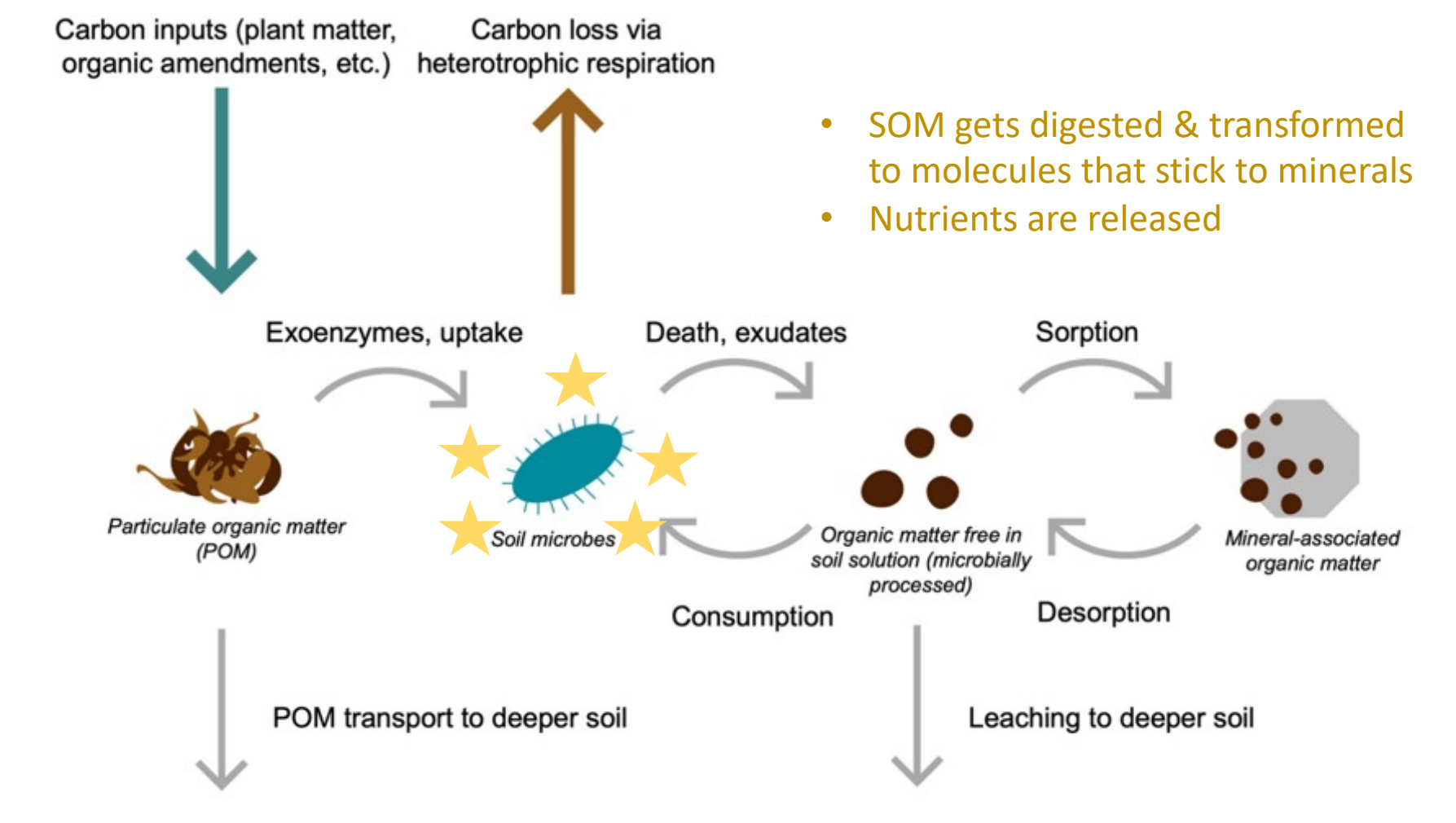


Microbes are primary decomposers:

- Directly break down SOM
- Facilitate soil carbon flows

(Dynarski et al. 2020)

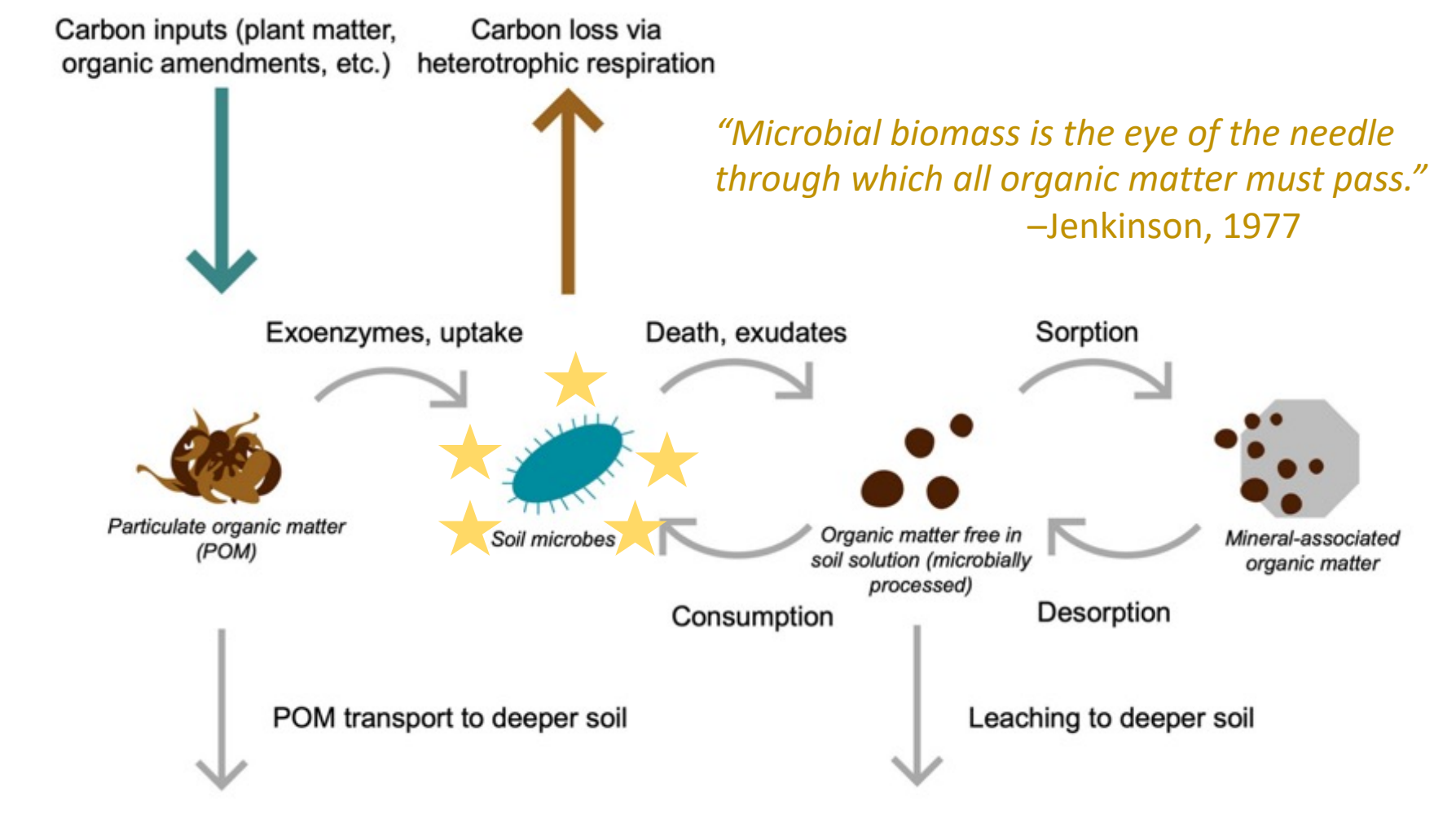
Soil Biological Indicators



- SOM gets digested & transformed to molecules that stick to minerals
- Nutrients are released

(Dynarski et al. 2020)

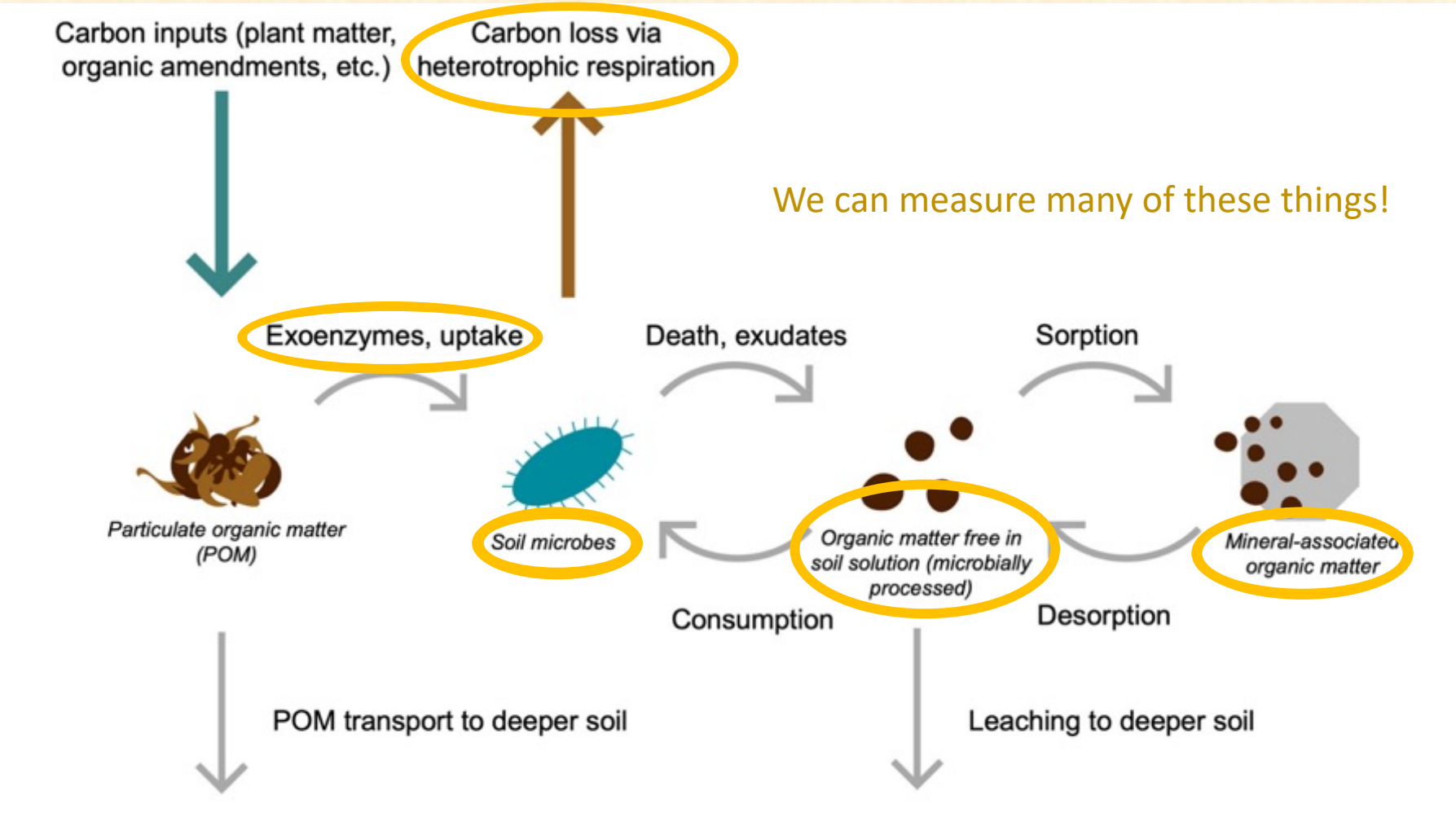
Soil Biological Indicators



"Microbial biomass is the eye of the needle through which all organic matter must pass."
–Jenkinson, 1977

(Dynarski et al. 2020)

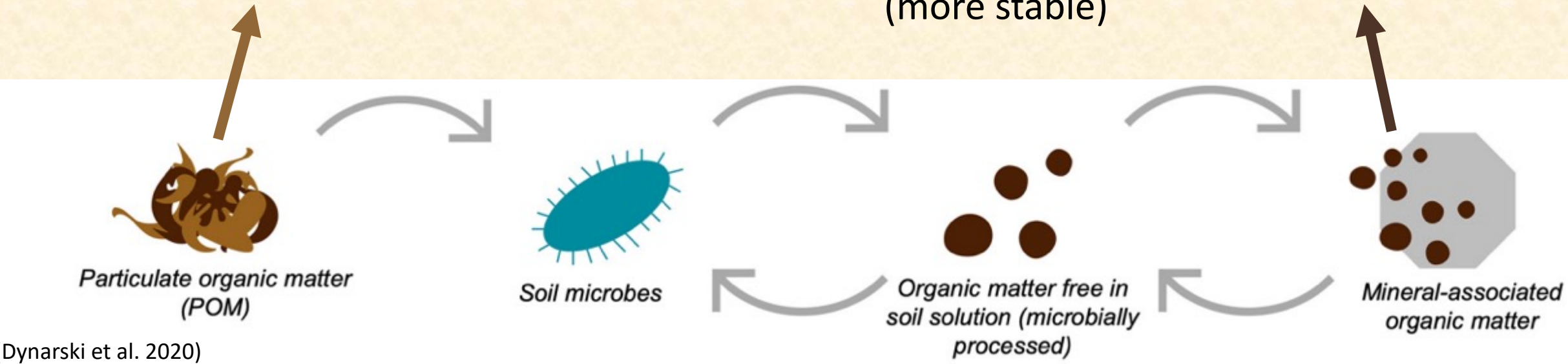
Soil Biological Indicators



(Dynarski et al. 2020)

Different Forms of Carbon

- Particulate Organic Matter (POM):
  - Somewhat broken-down SOM
- Mineral-Associated Organic Matter (MAOM):
  - Smaller molecular weight, microbially processed compounds that are stuck to the surfaces of mineral particles (more stable)



(Dynarski et al. 2020)