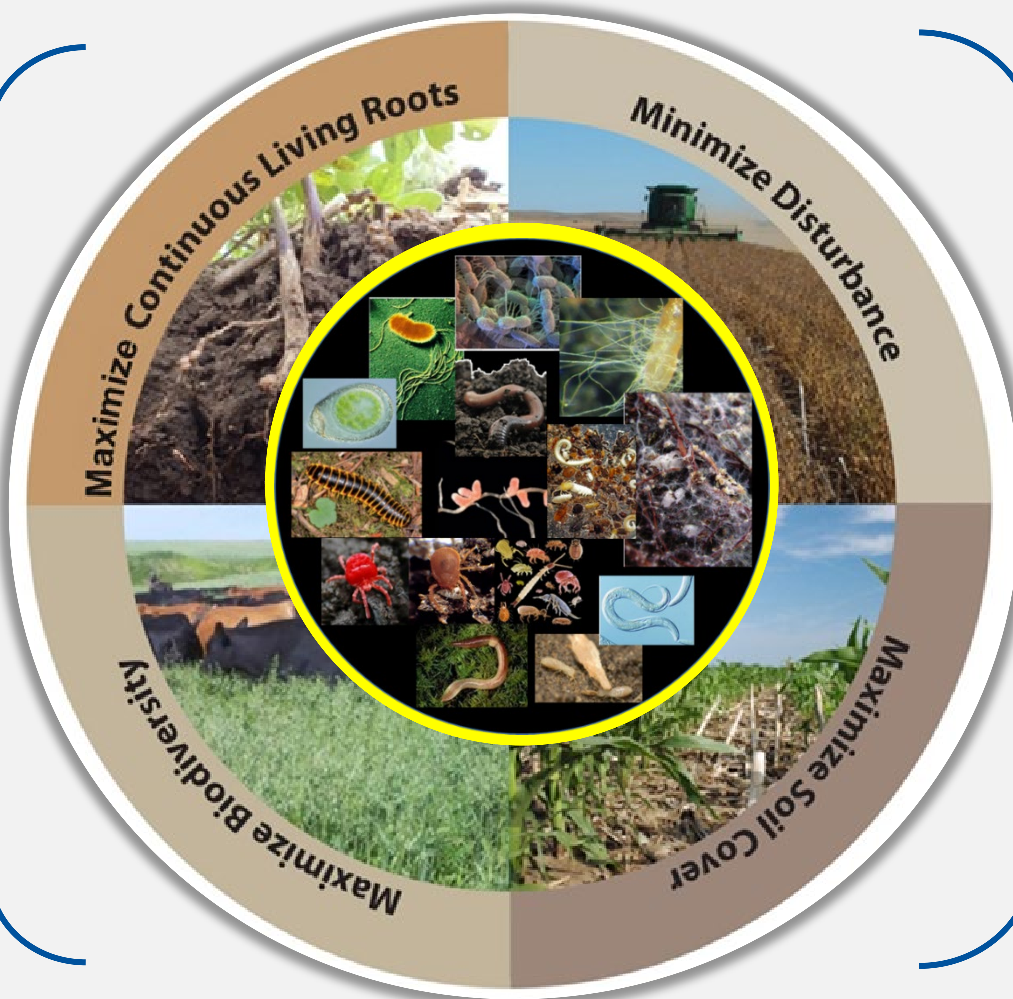
Managing for Soil Biology

Joe Williams
Soil Health Specialist
USDA NRCS
Soil Health Division

Soil Health Principles

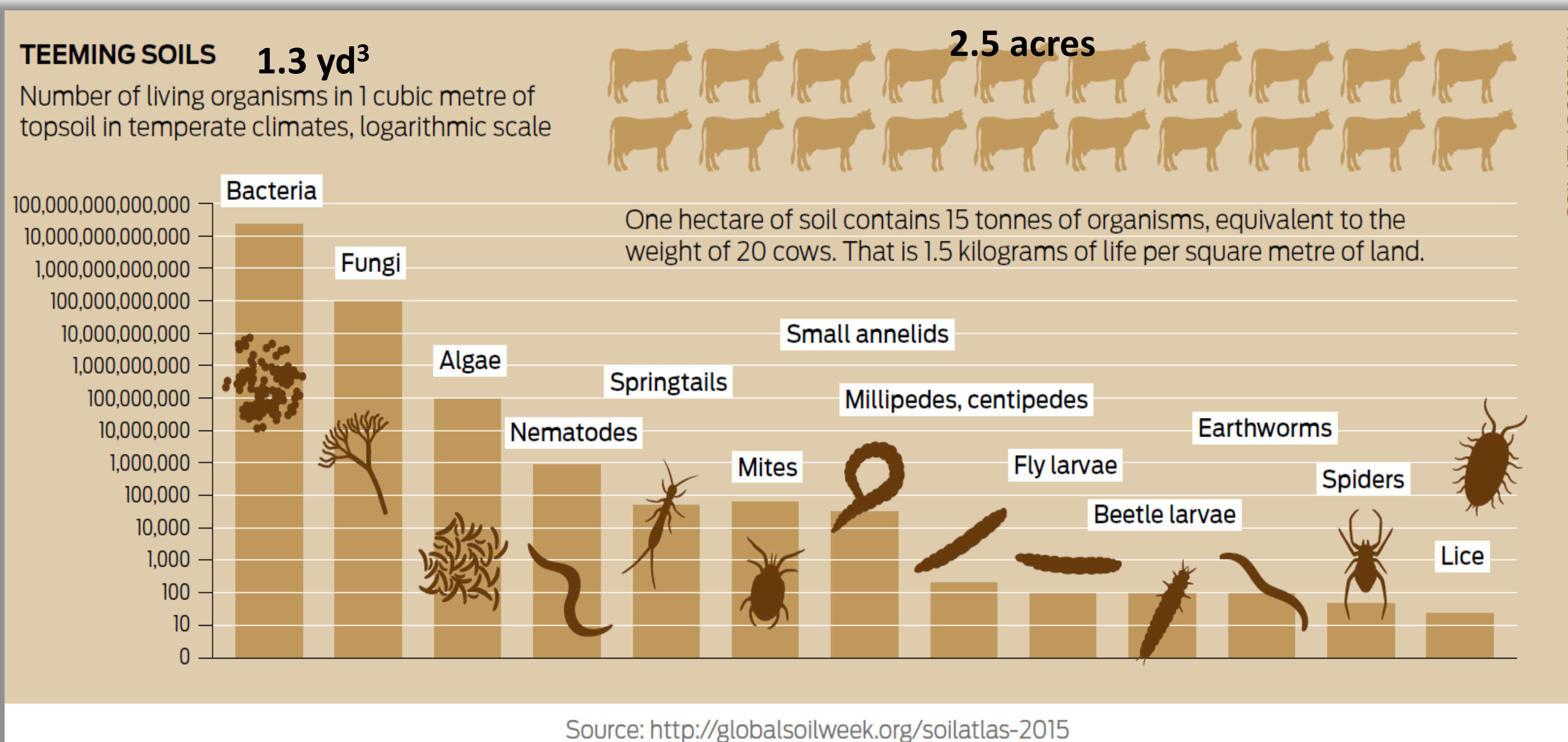


Feed & Fuel Soil Biology

Protect Soil Aggregates & Organic Matter

*Modified from USDA –NRCS-Principles for High Functioning Soils

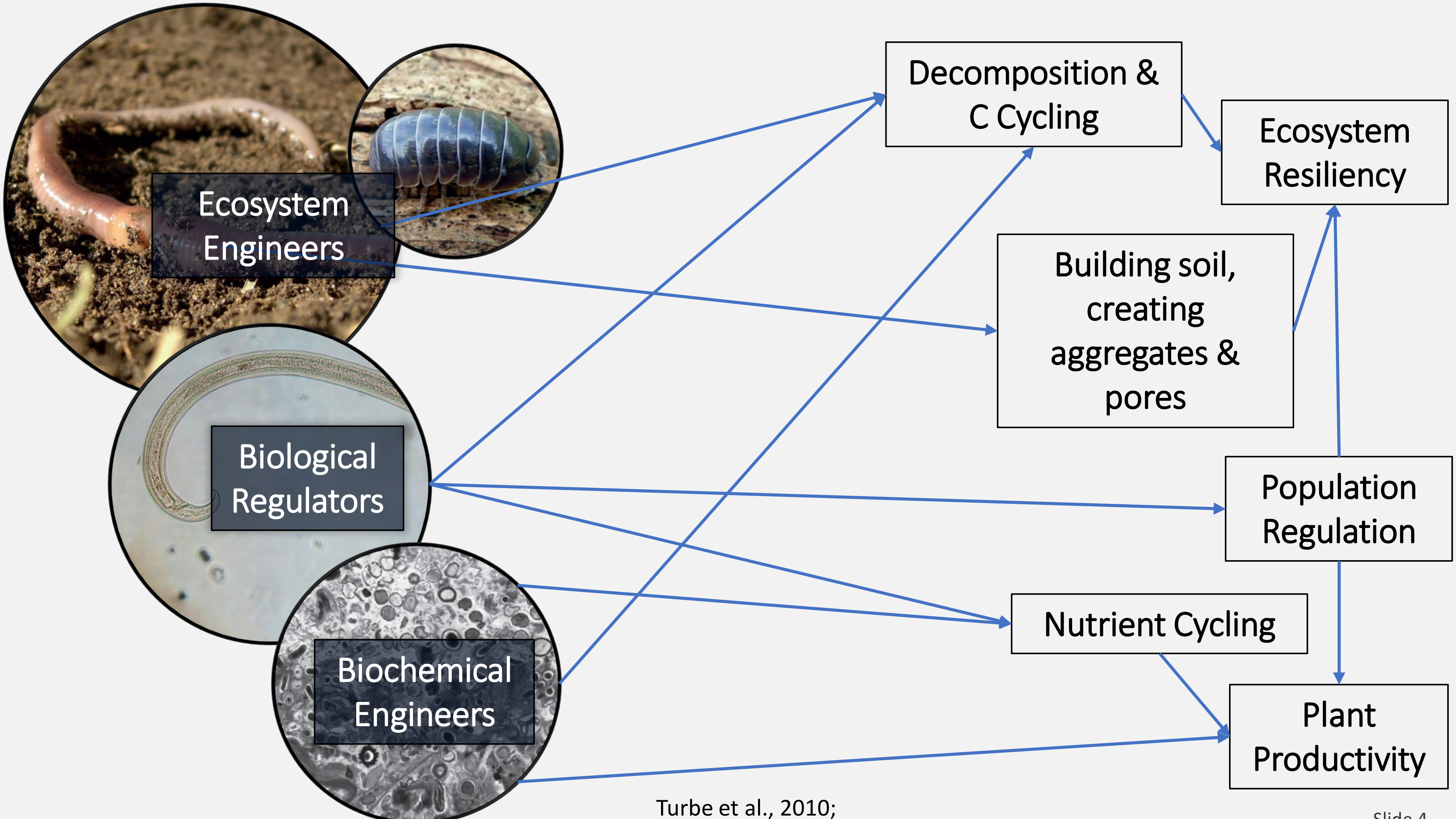
Soils Host Vast Numbers, Mass, and Diversity of Organisms



Source: http://globalsoilweek.org/soilatlas-2015

Soil Organisms
3 Functional Groups

Key Ecosystem Functions



Turbe et al., 2010;
Global Soil Biodiversity Atlas. 2016. Orgiazzi, Bardgett, Barrios et al.

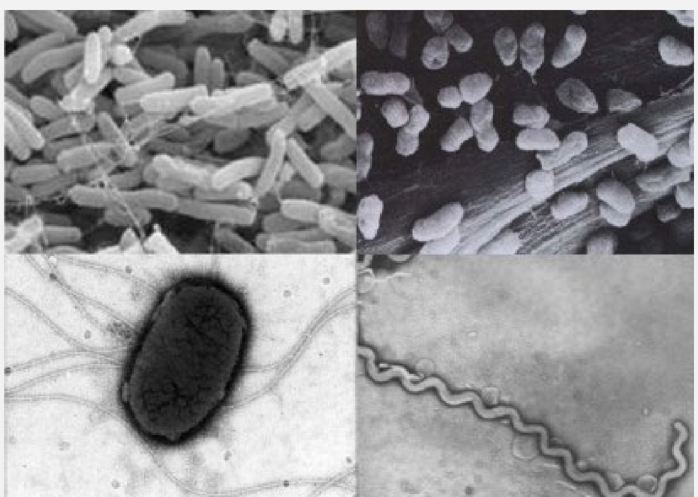
Ecosystem Engineers

Functional group	Function	Representative members
Ecosystem Engineers	Build pore networks and aggregates	Plant roots, earthworms, larger invertebrates (e.g., millipedes, centipedes, beetles)

Modified from Turbe et al., 2010; Images from: Orgiazzi, Bardgett, Barrios et al. 2016. Global Soil Biodiversity Atlas.

Chemical Processors (Engineers)

Functional group	Function	Representative members
Chemical Processors	Regulate 90% of energy flow in soil; Build soil organic matter & aggregates	Soil microbes (bacteria, fungi, protozoa)



Modified from Turbe et al., 2010; Images from: Orgiazzi, Bardgett, Barrios et al. 2016. Global Soil Biodiversity Atlas.

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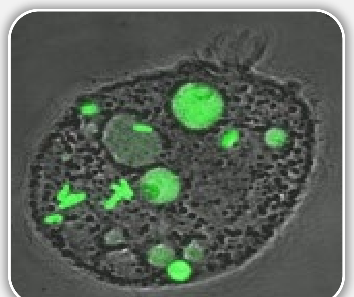
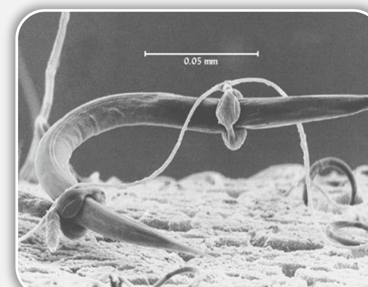
Biological Regulators

Functional group	Function	Representative members
Biological Regulators	Regulate populations of other soil organisms	Protozoa, nematodes, and other small invertebrates (e.g., springtails, mites but also microbes)



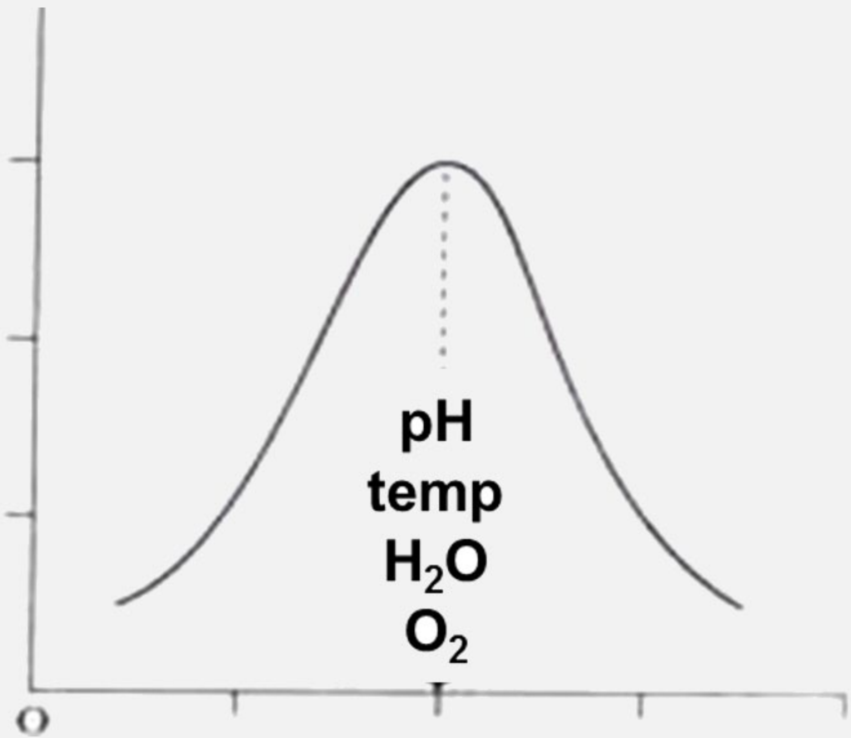




Modified from Turbe et al., 2010; Images from: Orgiazzi, Bardgett, Barrios et al. 2016. Global Soil Biodiversity Atlas.

Optimal Activity in Most Ag Systems Occurs When Conditions are ‘Just Right’

> 90% bacteria in soil are inactive!



Near neutral pH
Moderate temps
Moist conditions
Aerated
Abundant food (C)

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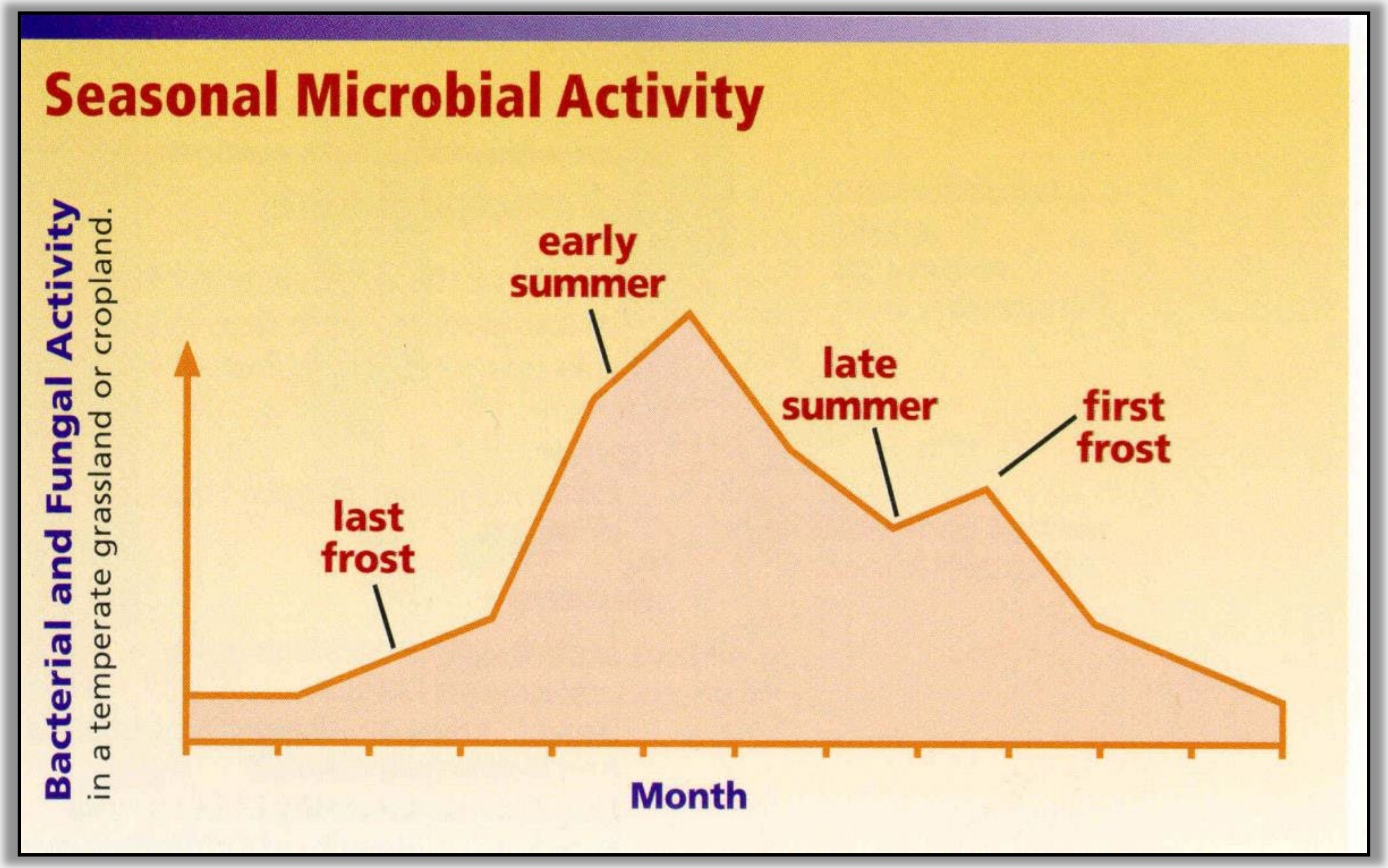
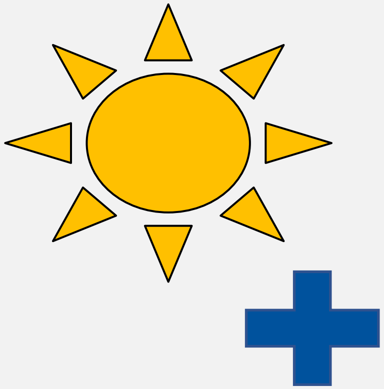
Seasonal Microbial Activity

Microbes are impacted by temp and moisture

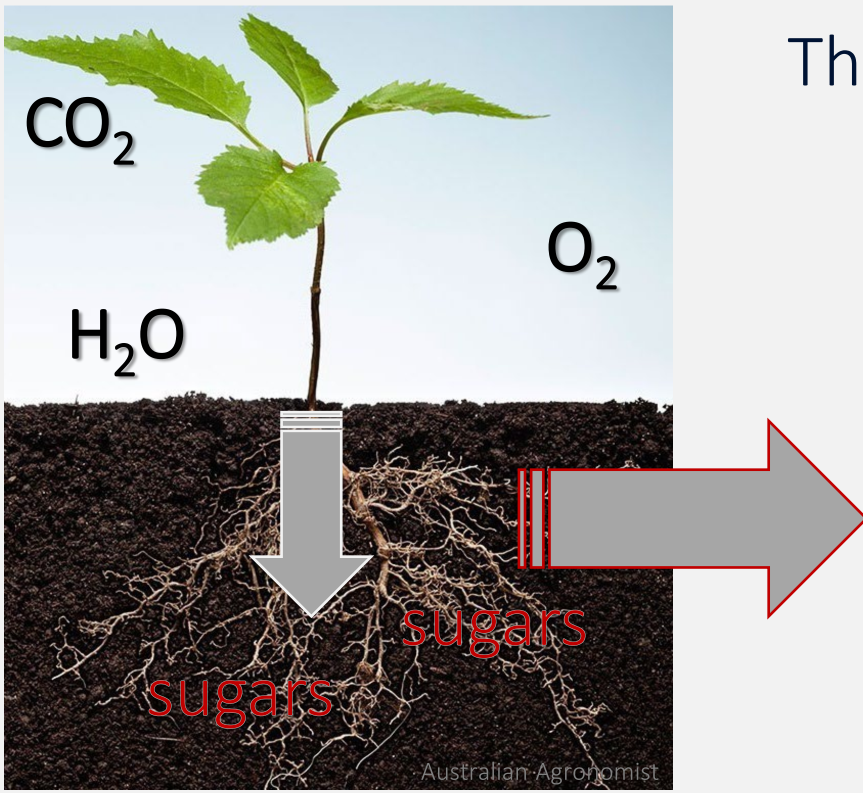


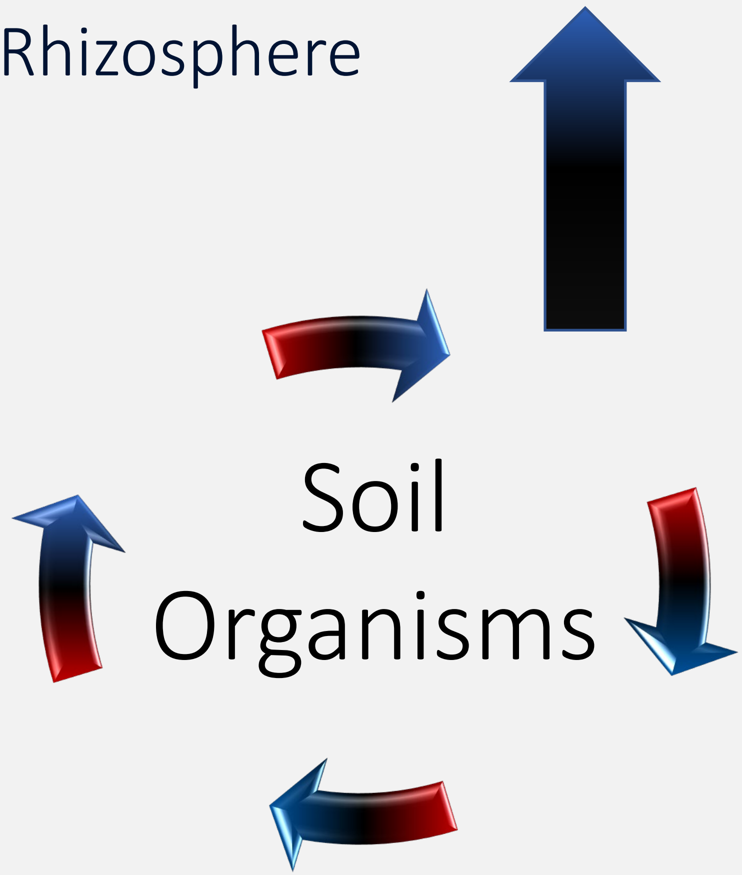


1. Capture Solar Energy
2. Make Organic Carbon

Creates a biological hot spot:

The Rhizosphere





Continuous Flow of C Drives System

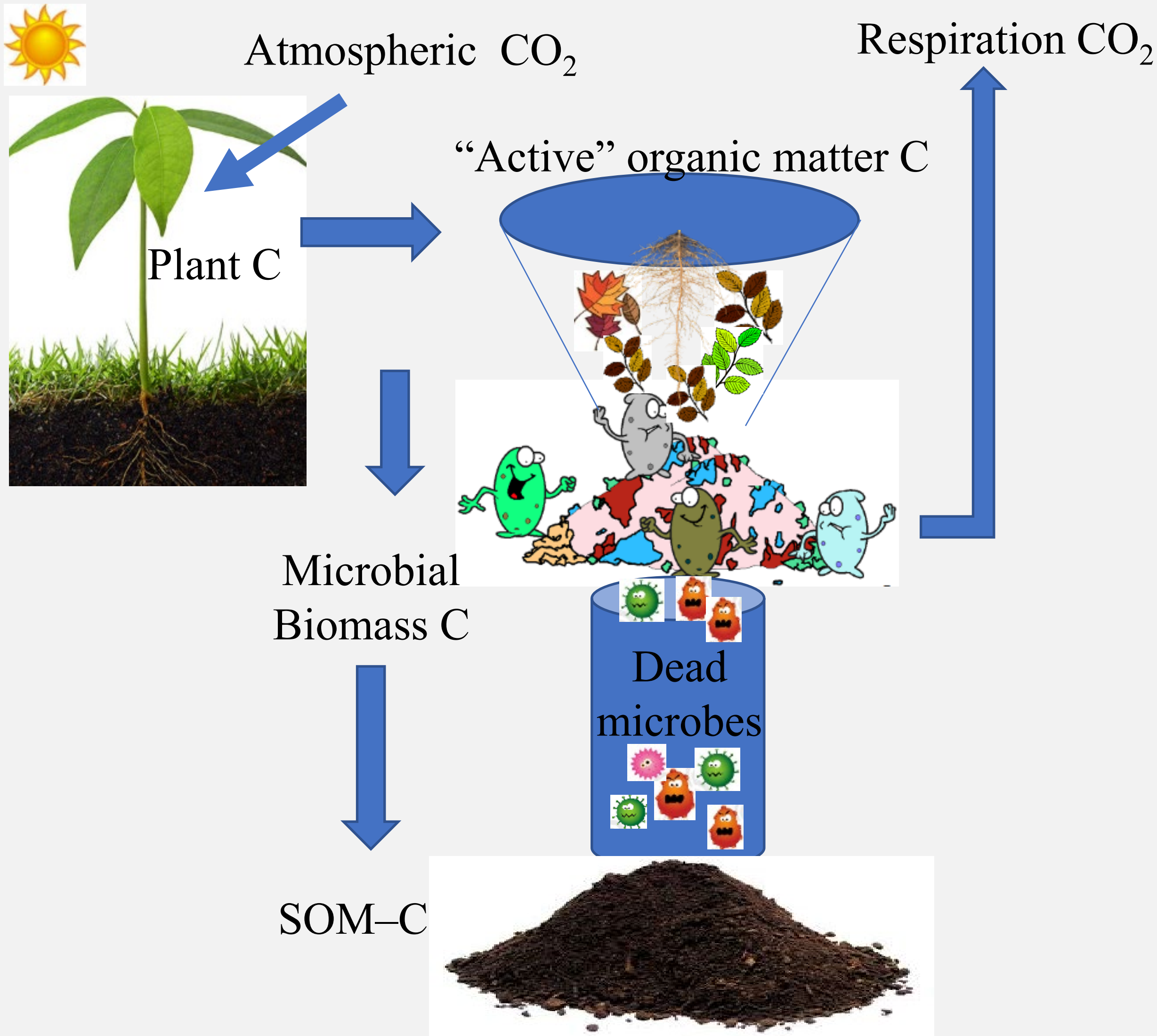
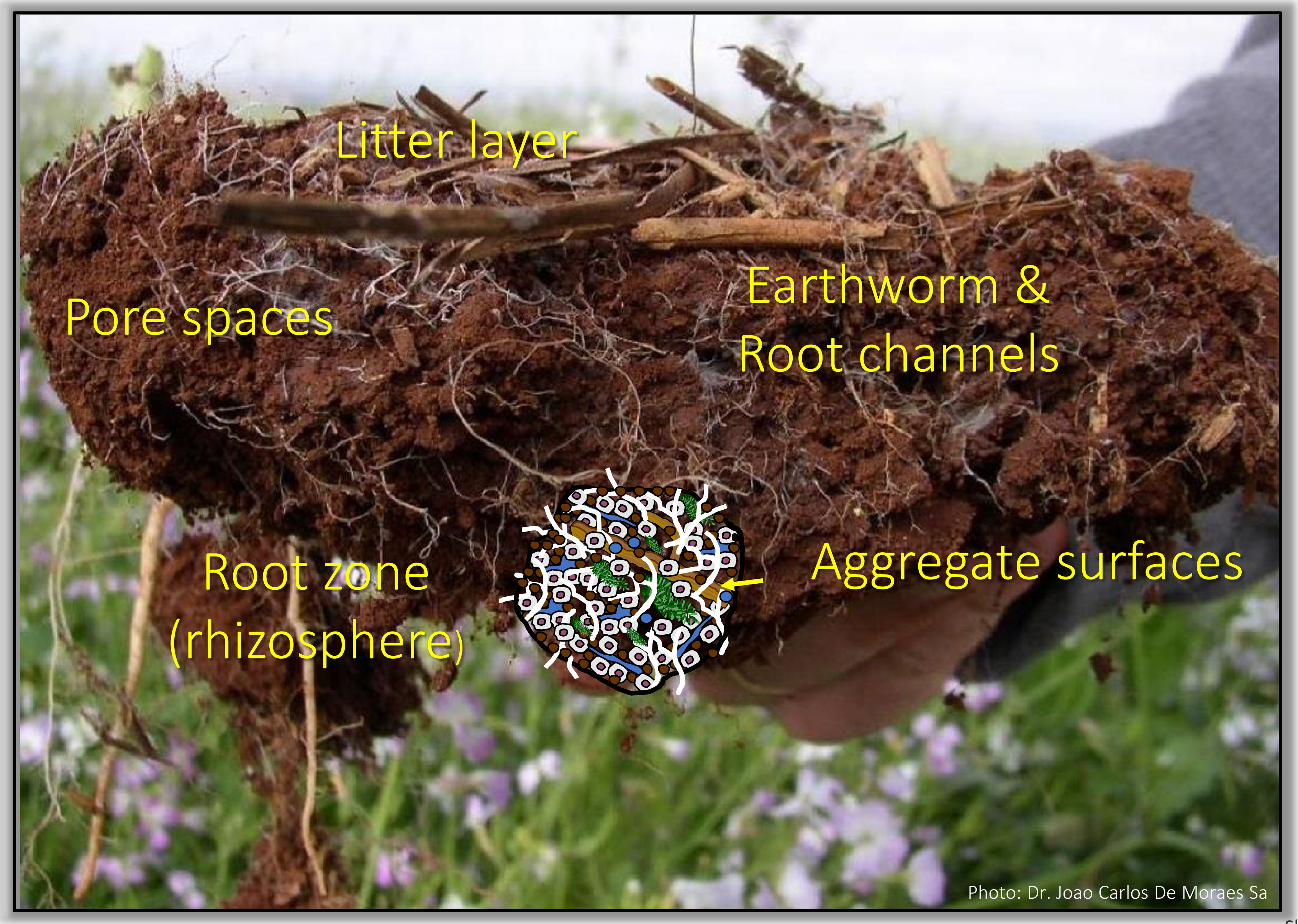


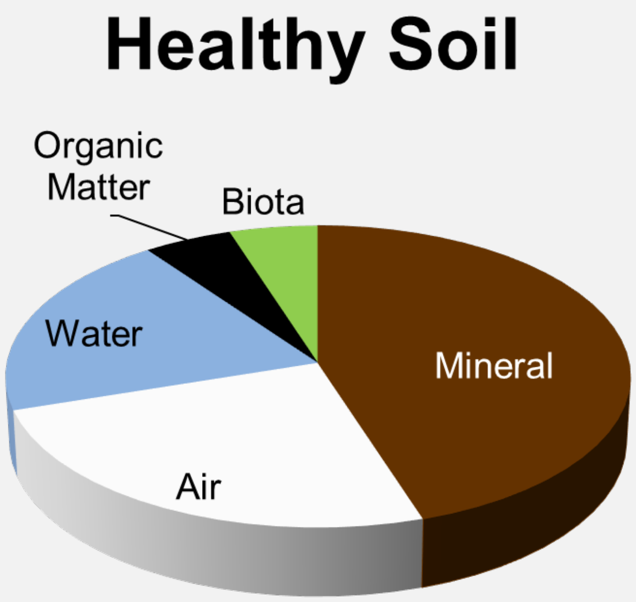
Image courtesy of Dr. Chenhui Li

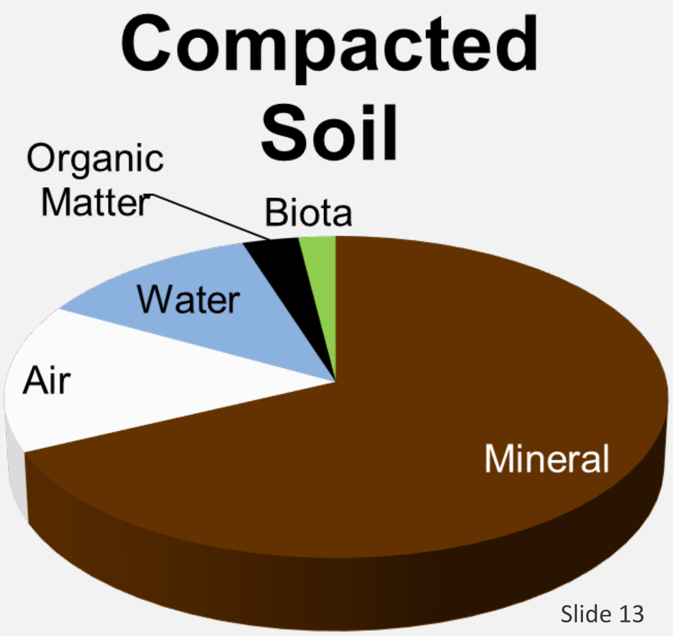
Biological Hot Spots



Hot Spot for Chemical Processors & Regulators in Pore Spaces

- Created via roots, organisms & SH management
- “Lungs & circulatory system”
- Air flow
- Water flow, storage, & availability
- Biological highways





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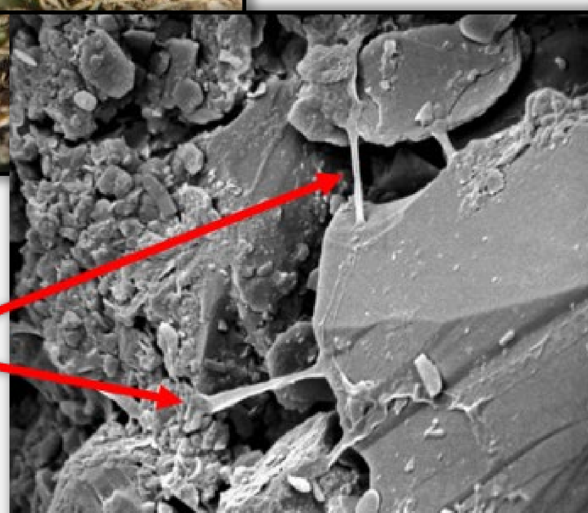
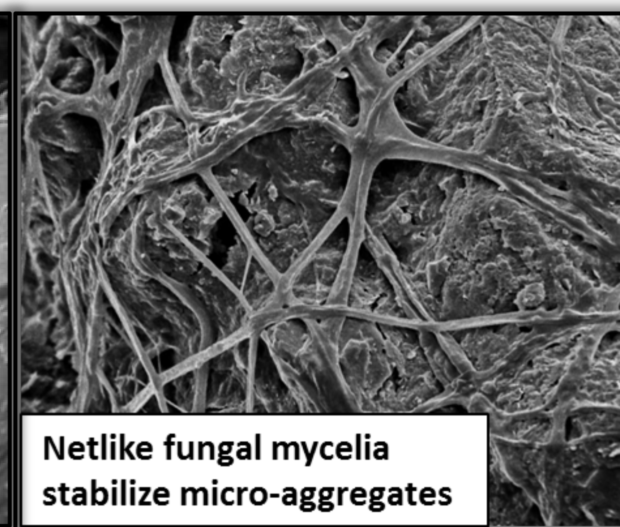
Soil Organisms Physically Stabilize Soil Aggregates

- Plant roots enmesh soil particles
- Earthworm casts
- Fungal and bacterial filaments physically enmesh soil particles

Stabilization of soil structure by actinomycete (bacterial) filaments





Netlike fungal mycelia stabilize micro-aggregates

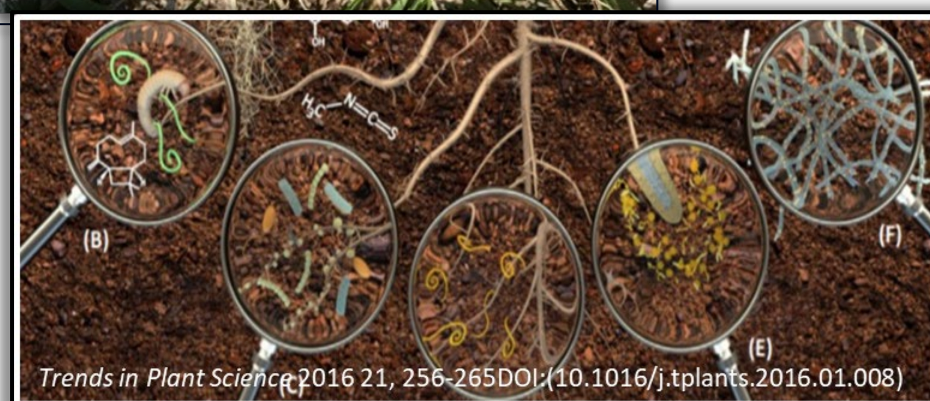
SEM photo source (accessed on 6/2/2016): Eickhorst, Thilo & Tippkoetter, Rolf. Micropedology – The hidden world of soils. University of Bremen, Germany. http://www.microped.uni-bremen.de

Hot Spot For Chemical Processors & Regulators - Rhizosphere

- Root exudates & chemical signals stimulates microbes & predators
  - Symbiosis
  - Protection
  - Chemical signaling
  - Nutrients
  - Resilience

Photo: J Moore Kucera, NRCS-SHD

Orgiazzi, Bardgett, Barrios et al., 2016. Global Soil Biodiversity Atlas.



Trends in Plant Science 2016 21, 256-265DOI:(10.1016/j.tplants.2016.01.008)

Root Zone (Rhizosphere): Key Organisms

Bacteria

- Most numerous
- 2-5% of SOM but responsible for 90% of energy flow
- 1 g can contain 10 million bacteria and one million species.
- 0.5-3 tons per acre (Killham 1994)

Fungi

- Saprophytic
- Mycorrhizae
- Pathogenic
- Up to 5 tons per acre

Protozoa & Nematodes

*Consume microbes and recycle nutrients to plant roots

Turbe et al 2010; Coleman & Crossley 1996; Nannipieri & Badalucco 2003; Global Soil Biodiversity Atlas. 2016. Orgiazzi, Bardgett, Barrios et al.

United States Department of Agriculture

Rhizosphere Key Organisms Mycorrhizae

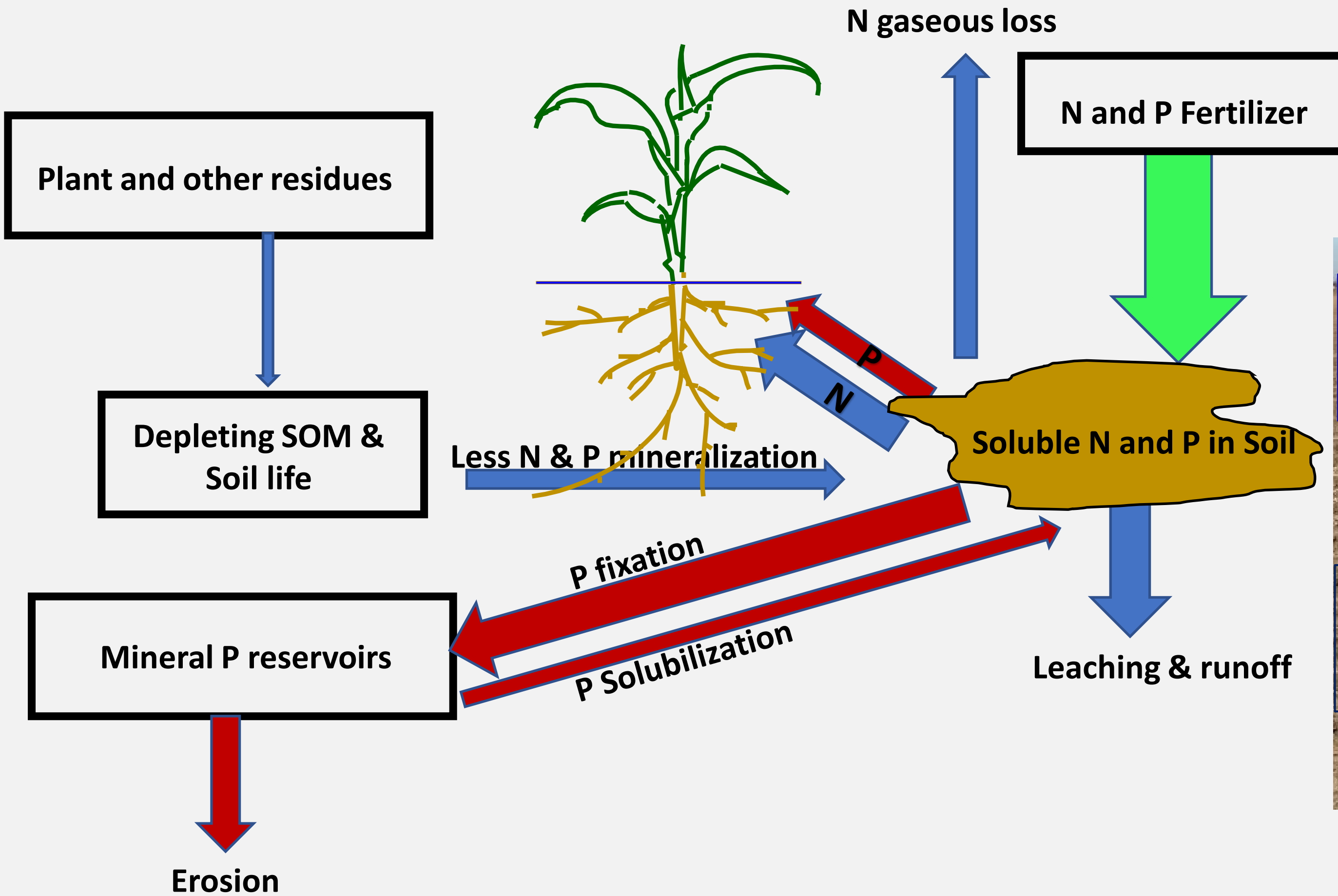
Mykós (fungus)- riza (root)

Extension of Corn Root Surface Area through Mycorrhizal Fungi

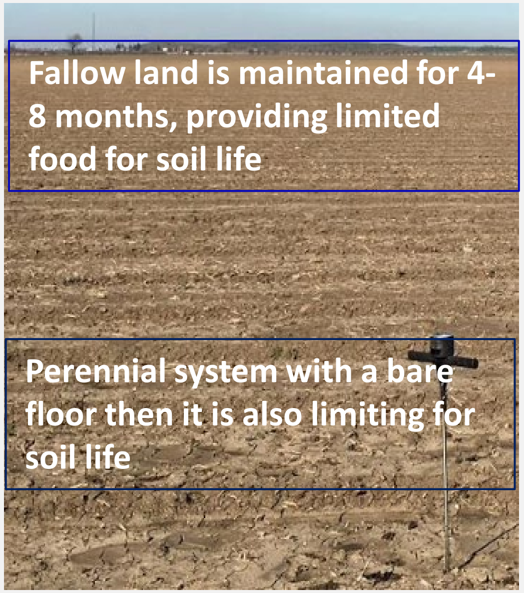
USDA-SARE

- Plants use 5-20% of C from photosynthesis to ‘feed’ fungi
- Fungi increase adsorptive root surface area at least 10x
- Fungi increase nutrient uptake especially P and Zn
- Fungi suppress pests and diseases
- Fungal networks build soil aggregates

Dominant Nutrient Management Strategy

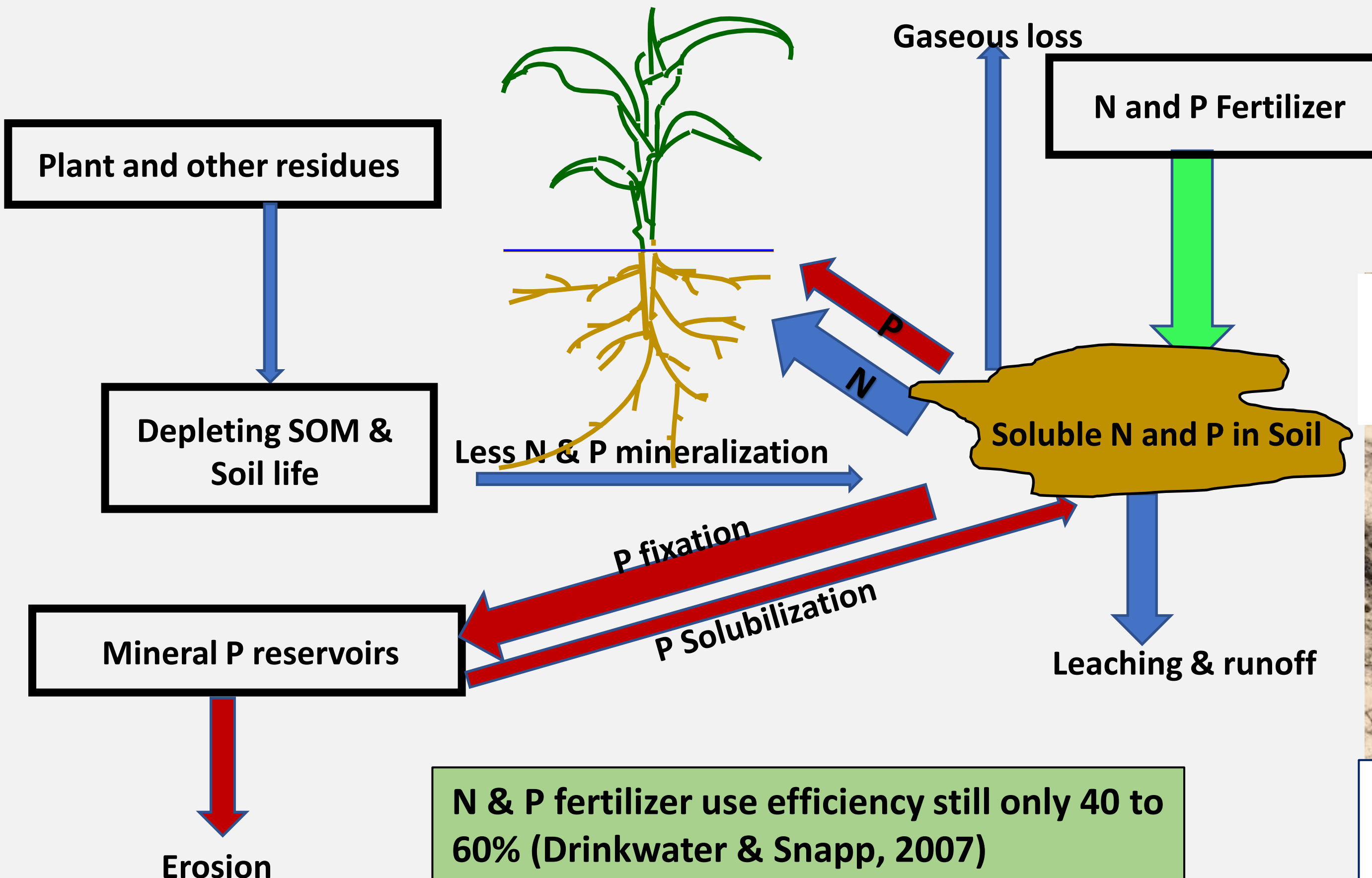


Plenty N & P are added to meet the yield goal. Soil with excess fertilizers is leaky



Adapted from Drinkwater & Snapp, 2007

The 4R Nutrient Management Strategy

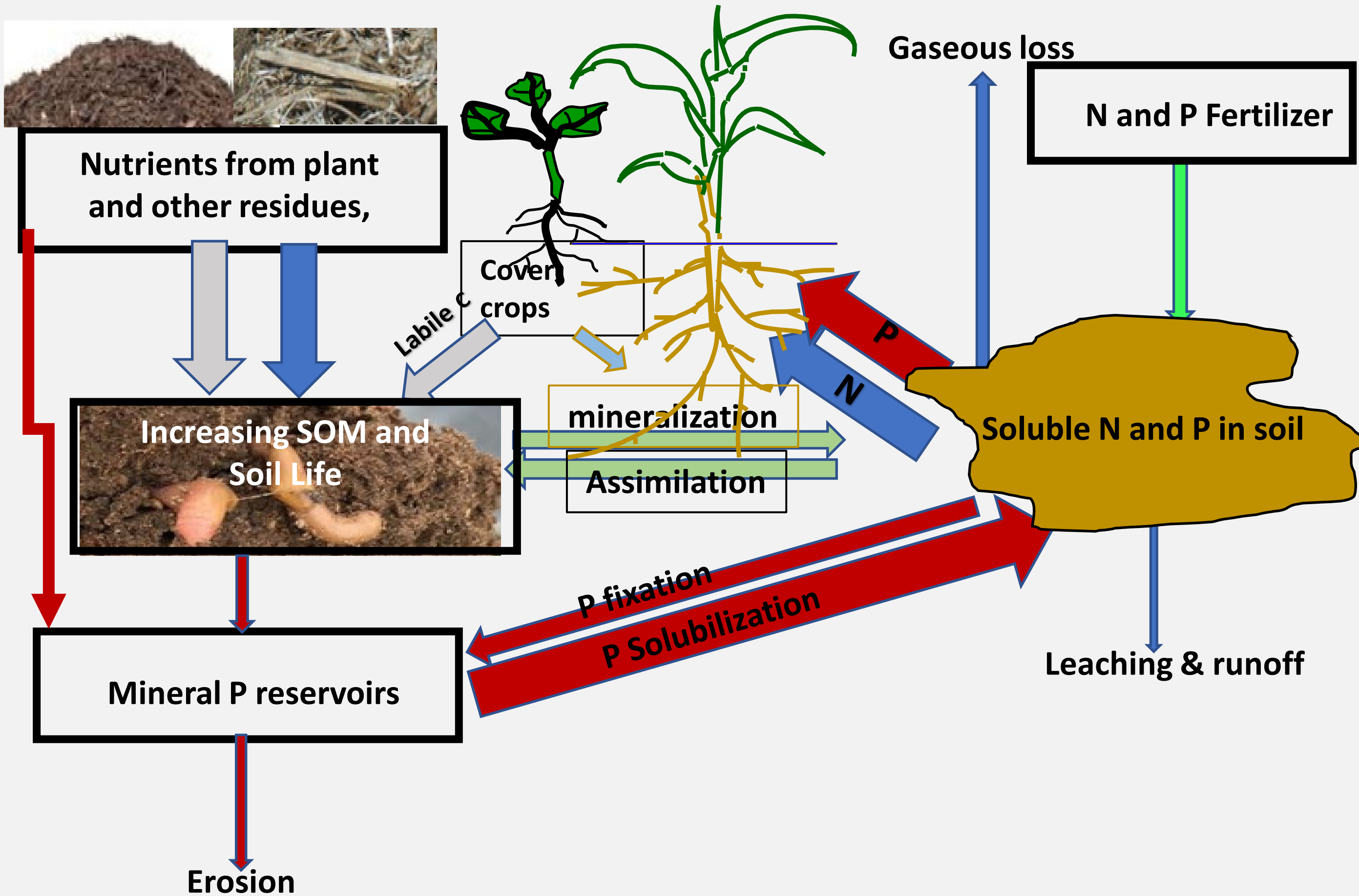


Side dressing, banding, fertigation, split application & nitrification inhibitors etc. increase the efficiency but do not eliminate nutrient losses

Fallow land is maintained for 4-8 months providing limiting food for soil life

Perennial system with a bare floor is also providing limiting food for soil life

Ecological Nutrient Management



Achieves high yields, minimizes fertilizer use, and reduces environment pollution

Soil reservoirs increase and are made more available by diverse inputs

Diverse inputs are residues, cover crops, compost, crop rotation, and slow release N

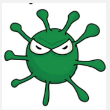
Minimize tillage to preserve residues & protect soil life that recycle nutrients

Measure all pools of N & P and apply 4R strategy to maximize the nutrient efficiency

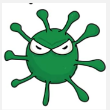
Adapted from Drinkwater & Snapp, 2007

Mineralization Vs. Immobilization

Mineralization:

Organic N +  → NH_4/NO_3

Immobilization is the reverse of mineralization.

NH_4/NO_3 +  → Organic N

Johnson et al. 2005, Cornell University

United States Department of Agriculture

Biological Hot Spots to Optimize Function

Litter Layer

Photo source: NRCS

Root/Worm Channels

Photo source: P. Lavelle; J Moore-Kucera

Aggregate Surfaces

Photo source: J Moore-Kucera

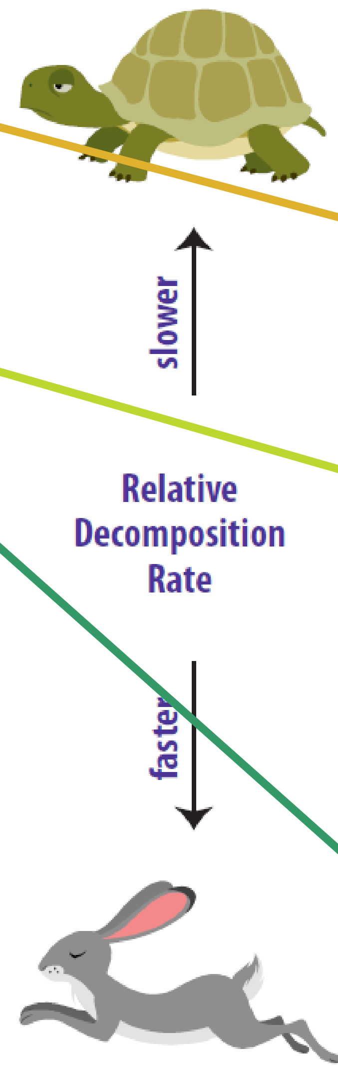
Pore Space

Photo source: Barry Fisher, NRCS

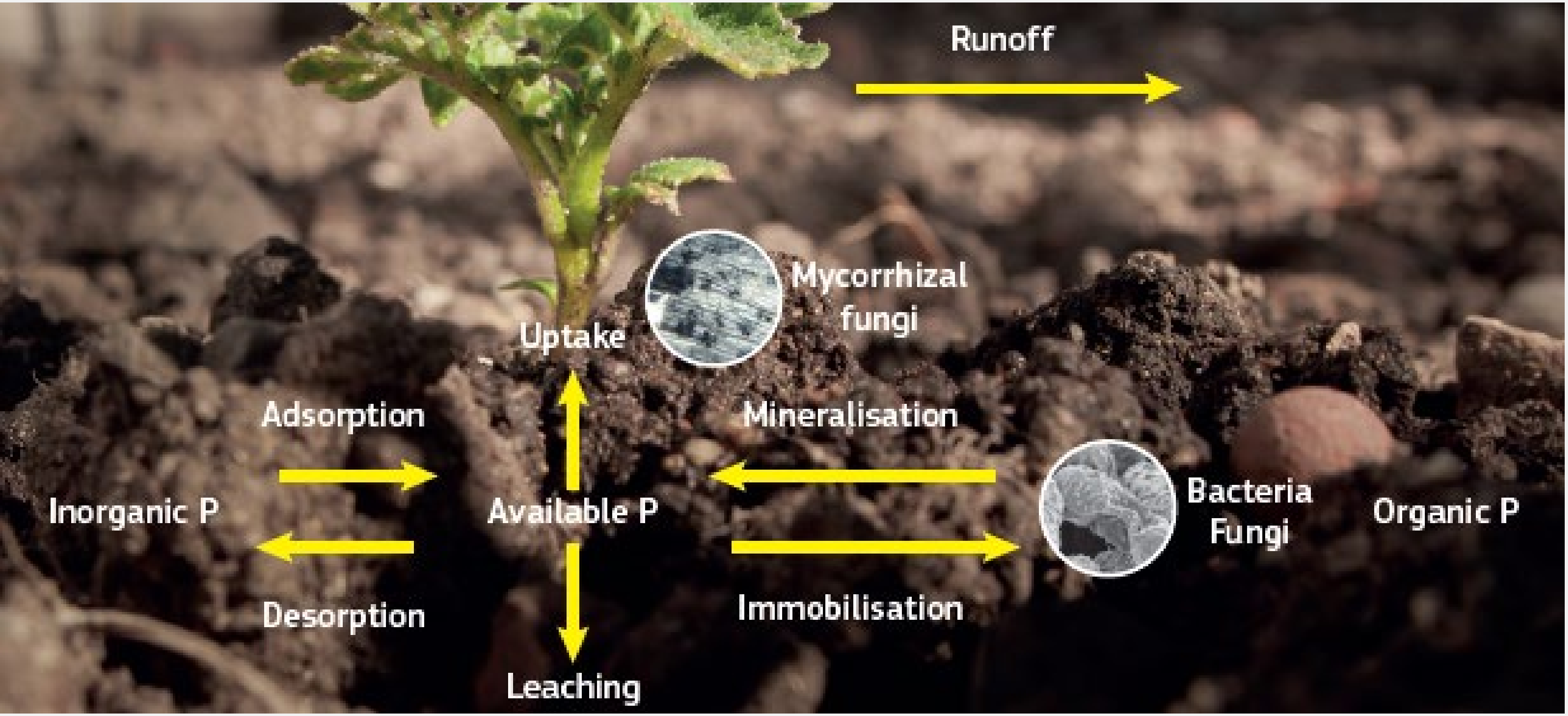
Root cartoon and organism images: Orgiazzi , Bardgett, Barrios et al. 2016. Global Soil Biodiversity Atlas.; Slide design by J Moore-Kucera

C:N ratio in Cover Crops (Nutrients Availability & Decomposition Rate)

Material	C:N Ratio
rye straw	82:1
wheat straw	80:1
oat straw	70:1
corn stover	57:1
rye cover crop (anthesis)	37:1
pea straw	29:1
rye cover crop (vegetative)	26:1
mature alfalfa hay	25:1
Ideal Microbial Diet	**24:1**
rotted barnyard manure	20:1
legume hay	17:1
beef manure	17:1
young alfalfa hay	13:1
hairy vetch cover crop	11:1
soil microbes (average)	8:1

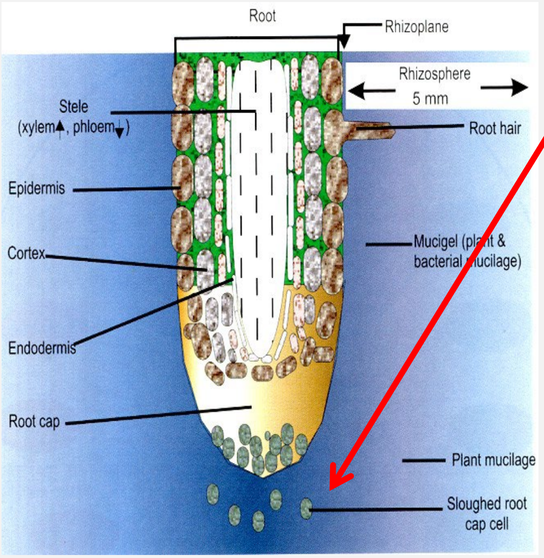


Biology and the Phosphorus Cycle

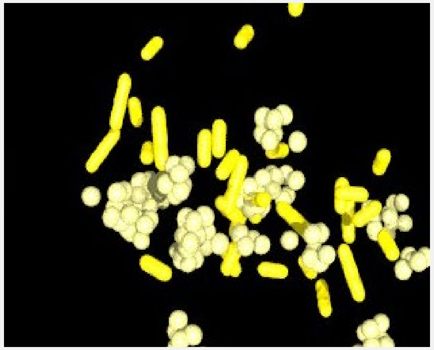


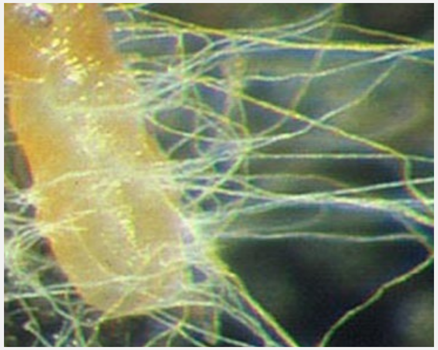
Top: Global Soil Biodiversity Atlas, p.105: Simplified phosphorus (P) cycle in the soil. The regulation of soil P cycling is influenced by microorganisms (e.g. bacteria and fungi). (DG, JRC)

Plant Roots Attract Microbes

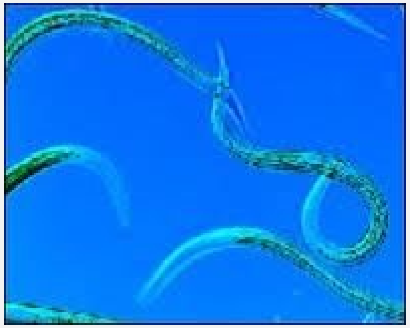


Exudates: carbohydrates and proteins secreted by roots; attract bacteria which nematodes & protozoa consume, which mineralize nutrients for plants.



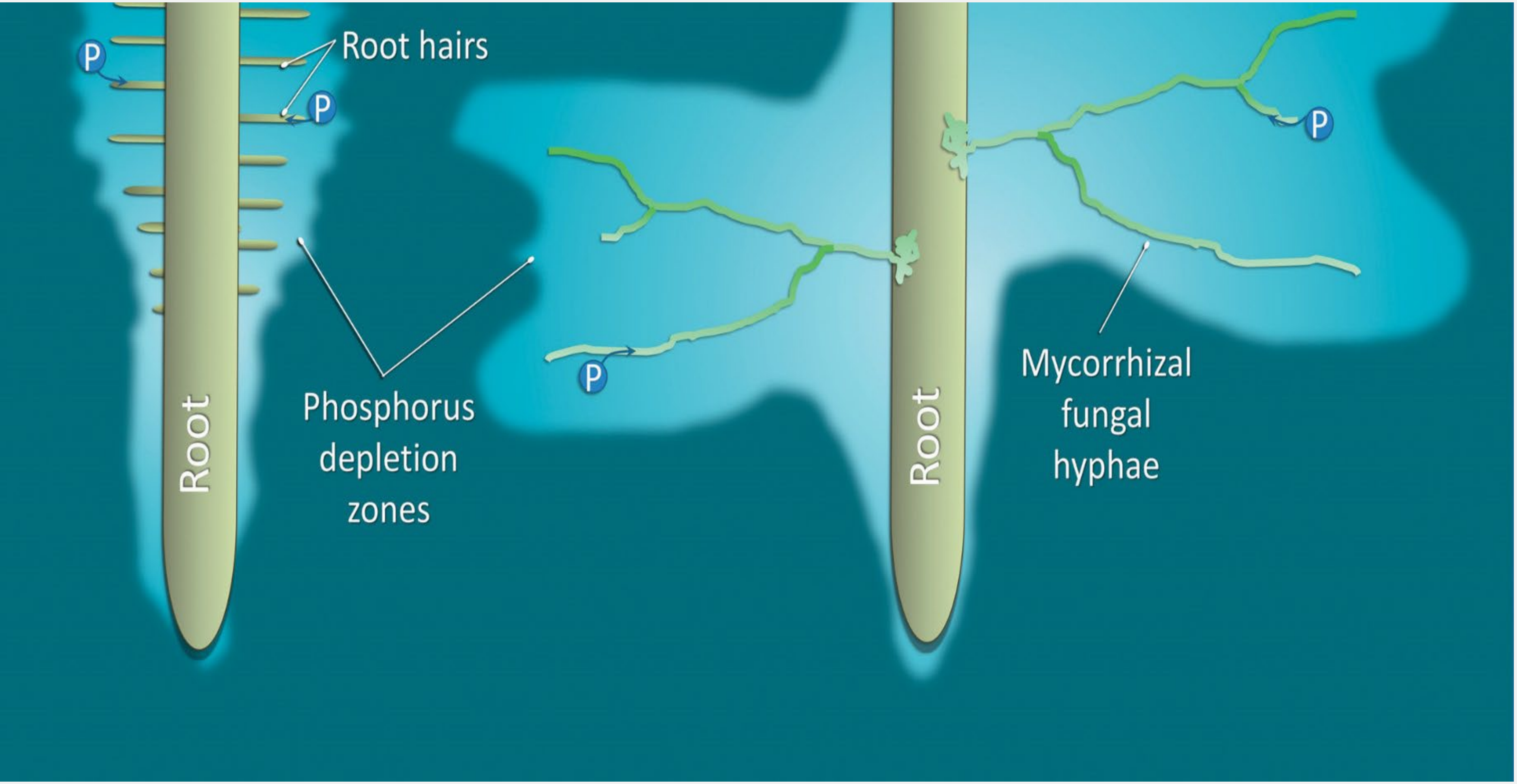


Bacteria and fungi are like little fertilizer bags



Nematodes and protozoa consume microbes and excrete plant available nutrients

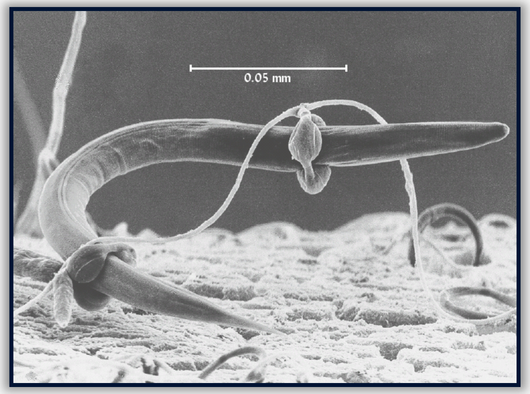
Benefits of AM Association



Weil and Brady, The Nature and Properties of Soils, 15th ed.

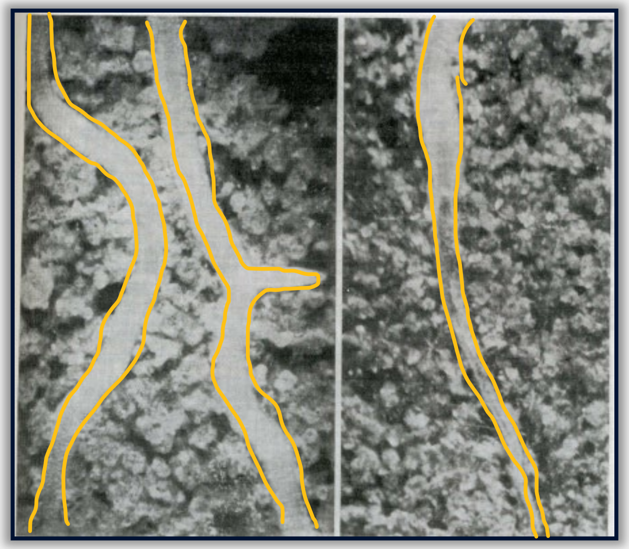
Belowground Competition

Nematode-trapping Fungi



Vampyrellids (protist) eating a fungal root pathogen involved in take-all disease

Protection from *Rhizoctonia solani*

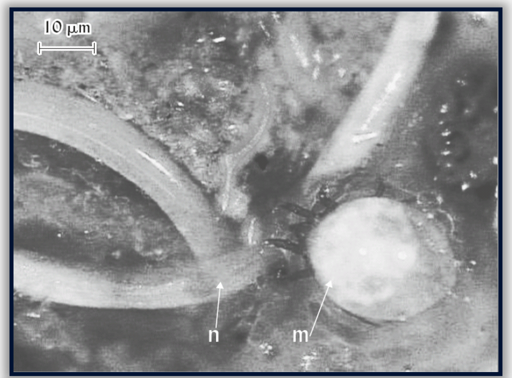


Roots with springtails

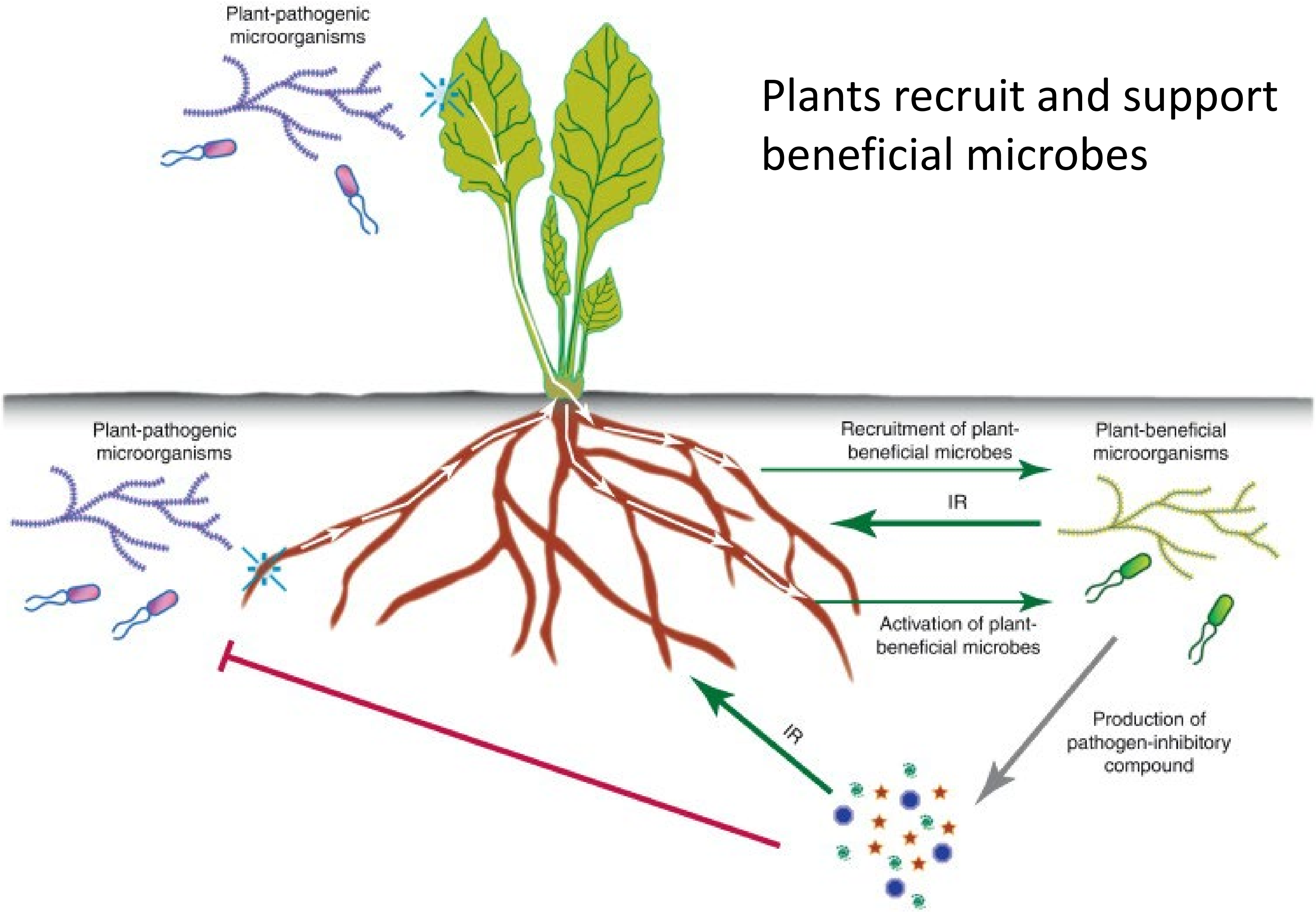
Roots without springtails

A single protozoan can eat billions of bacteria each day!

Mite preying on a nematode

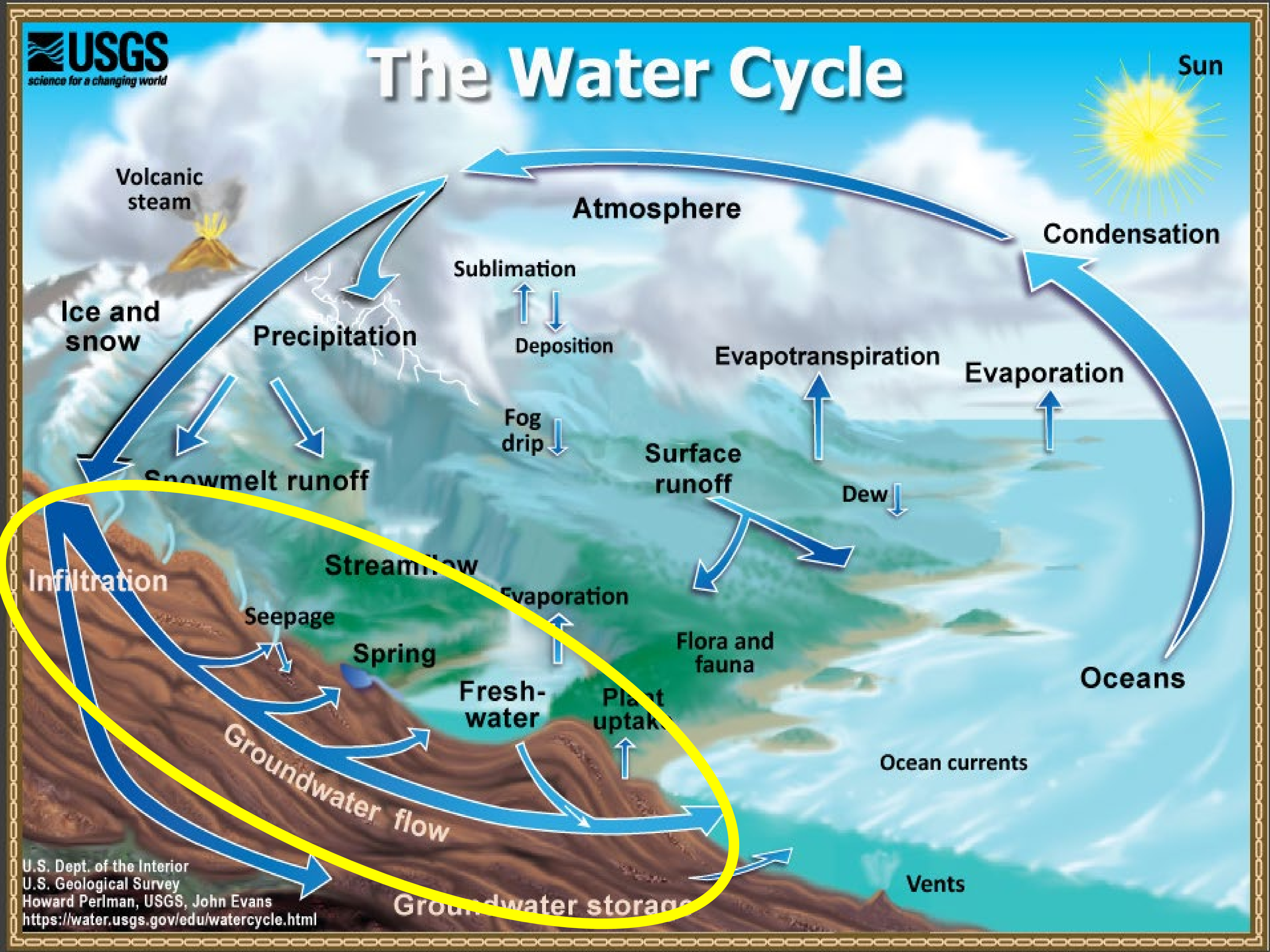


Soybean cyst nematode parasitized by the fungus *Hirsutella minnesotensis*



Plants recruit and support beneficial microbes

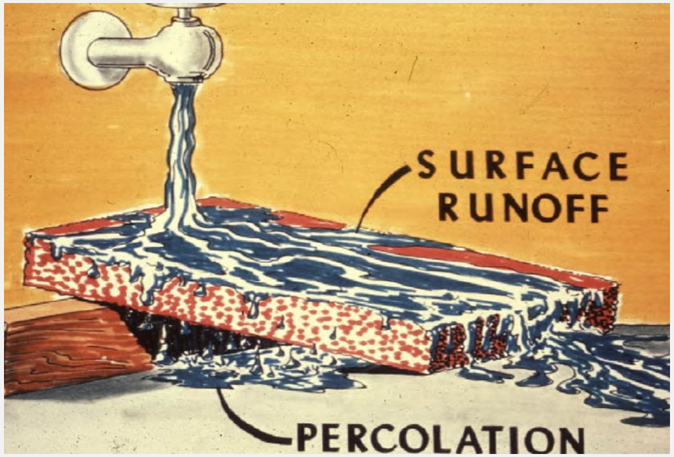
Berendsen, et al., 2012. Trends in Plant Science. 17(8)



USGS
science for a changing world
The Water Cycle
Sun
Volcanic steam
Atmosphere
Condensation
Sublimation
Deposition
Ice and snow
Precipitation
Evapotranspiration
Evaporation
Fog drip
Surface runoff
Snowmelt runoff
Dew
Streamflow
Infiltration
Evaporation
Seepage
Spring
Flora and fauna
Fresh-water
Plant uptake
Oceans
Groundwater flow
Ocean currents
Vents
Groundwater storage
U.S. Dept. of the Interior
U.S. Geological Survey
Howard Perlman, USGS, John Evans
https://water.usgs.gov/edu/watercycle.html

Aggregate stability & Water Cycling

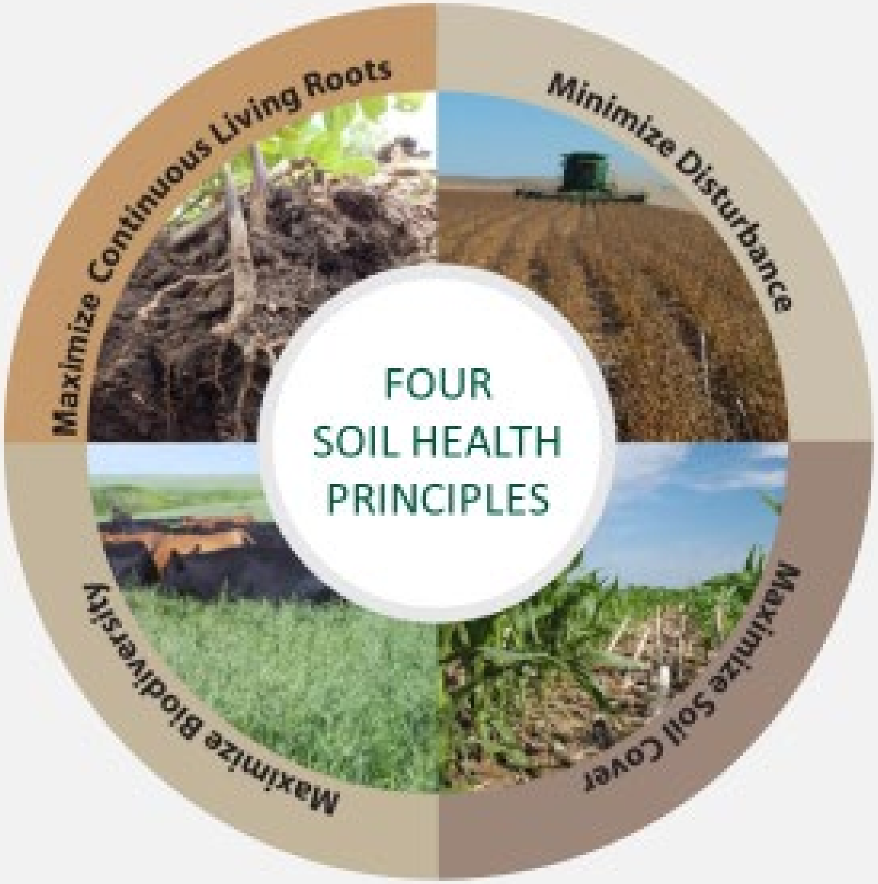
- Soil-atmosphere interface controls infiltration, one of the most critical moments in the water cycle.
- Soil aggregate instability leads to soil pore plugging, ponding, runoff and water quality problems.
- Soil aggregate stability supports infiltration, and soil profile storage and groundwater recharge.



What do Soil Organisms Need?

- How can we feed belowground life?
  - Choose practices that provide diverse, near continuous inputs and build reserves (SOM)
- How can we provide & protect habitat?
  - Choose practices that minimize disturbance of habitat (aggregates) and food sources (SOM + residue)
  - Choose practices that support a stable habitat from major swings in temperature, water, & chemistry

The 4 Principles that Conserve the Soil Ecosystem



1. Minimize Disturbance
2. Maximize Living Cover
3. Maximize Biodiversity
4. Maximize Continuous Living Roots

Soil Health Principles to Support High Functioning Soils

Feed

Fuel Soil Biology
Improve Resilience
Improve SOM

Protect

Soil Aggregates
Organism Habitat
SOM

USDA United States Department of Agriculture

How Soil Health Principles Support Soil Function – FEED

- Stimulate below-ground diversity
- Increase SOM
- Improve nutrient cycling
- Enhance plant growth
- Break pest cycles
- Increase predator & pollinator populations

How Do We Maximize Living Roots?

- Grow crops in the off-season
- Avoid fallow & ↓ re-cropping interval
- ↑ time in perennial crops
- Manage rotations & forage height

What Practices?

- Conservation Crop Rotation (328)
- Conservation Cover (327)
- Cover Crop (340)
- Forage & Biomass Planting (512)
- Prescribed Grazing (528)

How Do We Maximize Biodiversity?

- Grow diverse cover crops & legumes
- ↑ diversity of crop rotations
- Integrate livestock & graze cover crops
- ↑ time in diverse perennial crops

What Practices?

- Conservation Crop Rotation (328)
- Conservation Cover (327)
- Cover Crop (340)
- Forage & Biomass Planting (512)
- IPM (595)
- Prescribed Grazing (528)

How Soil Health Principles Support Soil function – PROTECT

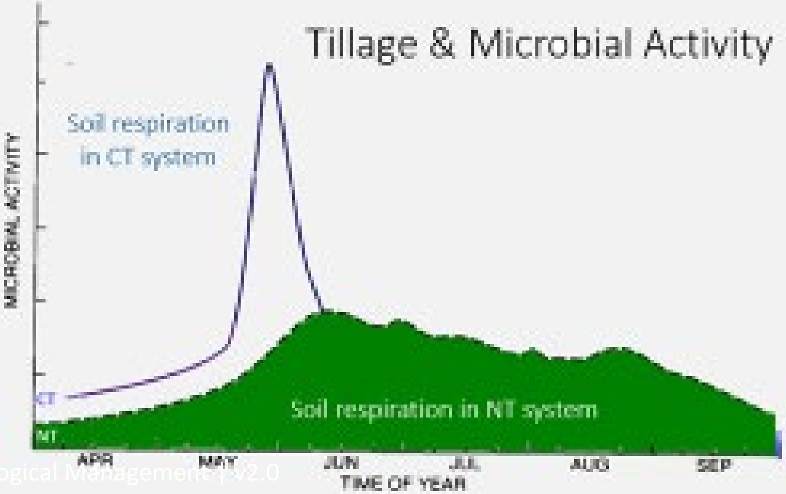
- Maintain stable aggregates
- Manage erosion
- Buffer temperature
- Reduce evaporation
- Maintain soil organic matter

United States Department of Agriculture

What Practices Minimize Disturbance?

Photo: Echo –Y Farms

- Residue & Tillage Mgmt. (329/345)
- Conservation Cover (327)
- Nutrient Mgmt. (590)
- IPM (595)
- Prescribed Grazing (528)



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Why Maximize Soil Cover?

- ↓ Erosion
- ↑ Infiltration
- ↓ Evaporation
- Moderate Soil Temp
- Habitat for Soil Organisms ↑
- Food for Biota ↑
- Mitigate Compaction from Machines & Livestock

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How Can the Soil Microbiome be Manipulated?

- Select different plant species, varieties, or control at various plant stages (e.g., crop rotation, cover crop selection, planting timing and termination)
- Fertilization (4 R's)
- Soil amendments, including biologicals (promise but fraught with issues)
- Manage the environment to minimize stress (e.g., pathogens, drought, temperature extremes, etc.)
    - Temperature
    - Moisture
    - Maximize presence and duration of hot spots

Summary: Managing for Soil Biology

- Most ag soils are carbon depleted
- Disturbances destroys habitat and hyphal networks
- Bare, fallow fields provide little protection, no C
- Agrichemicals have mixed effects
- Many fertilizer concentrations too high for symbiosis
- Manage for hot spots
- Support biology to build aggregates and create pore space
- Protect the habitat
- Feed the soil so it can feed us
- Optimize biological nutrient cycling
- Optimize plant-microbe interactions for plant defense optimization

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