United States Department of Agriculture

Soil Biology

Module 4

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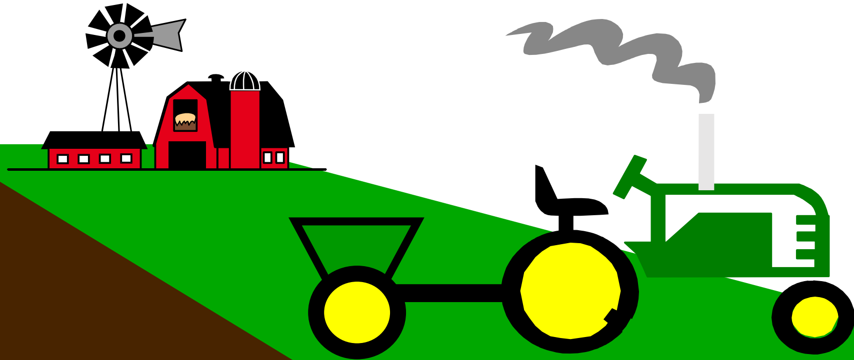
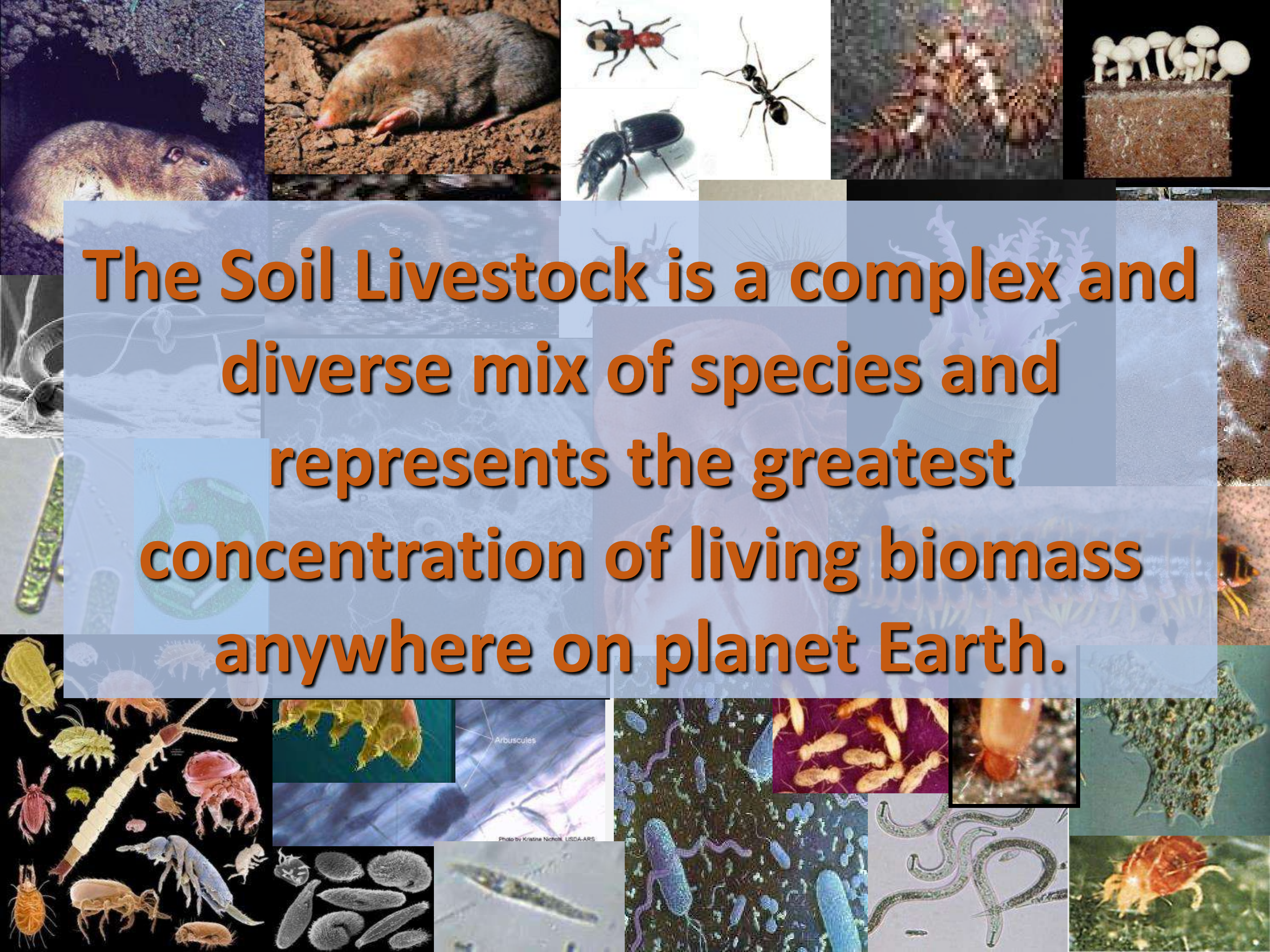
Soil Health Specialist

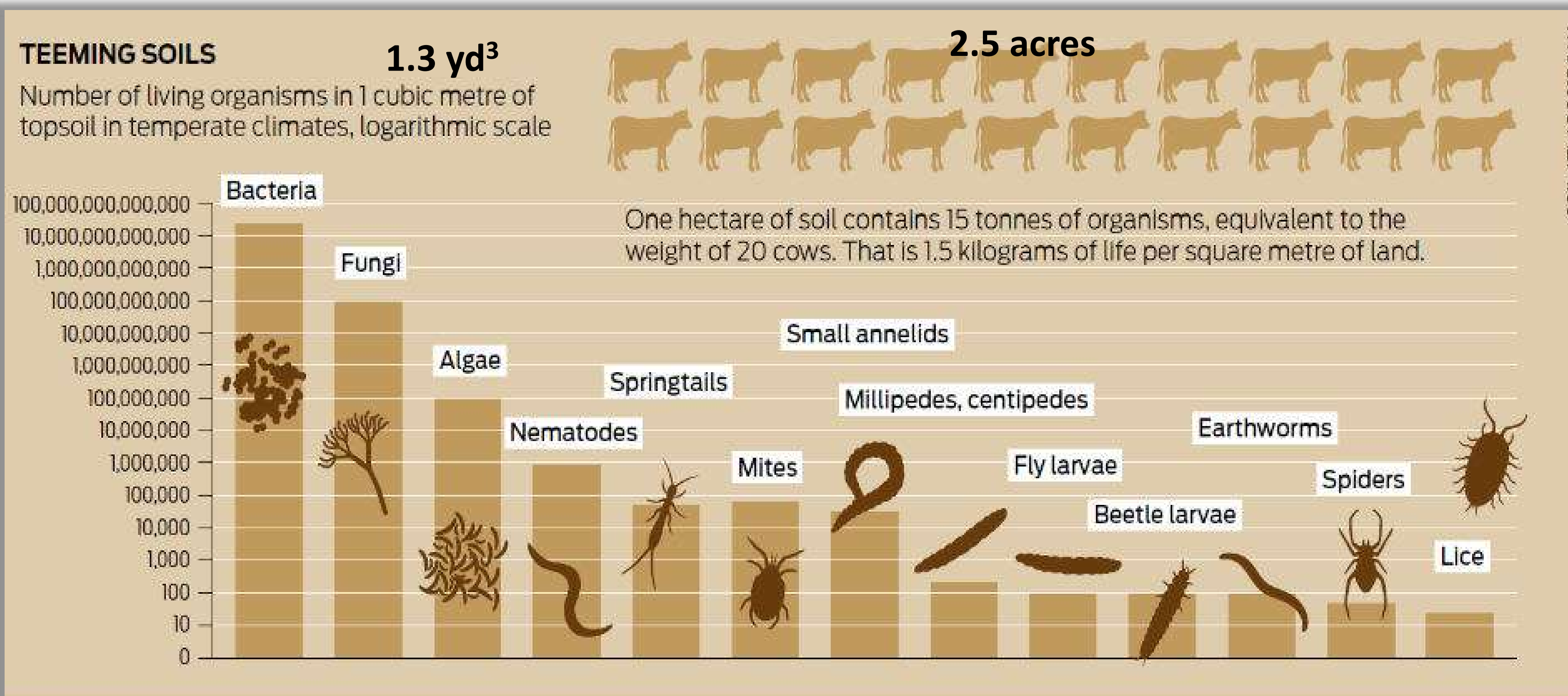


One of the largest ECOSYSTEMS in the world is right under our feet.



The Soil Livestock is a complex and diverse mix of species and represents the greatest concentration of living biomass anywhere on planet Earth.

Soils Host Vast Numbers, Mass, and Diversity of Organisms



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

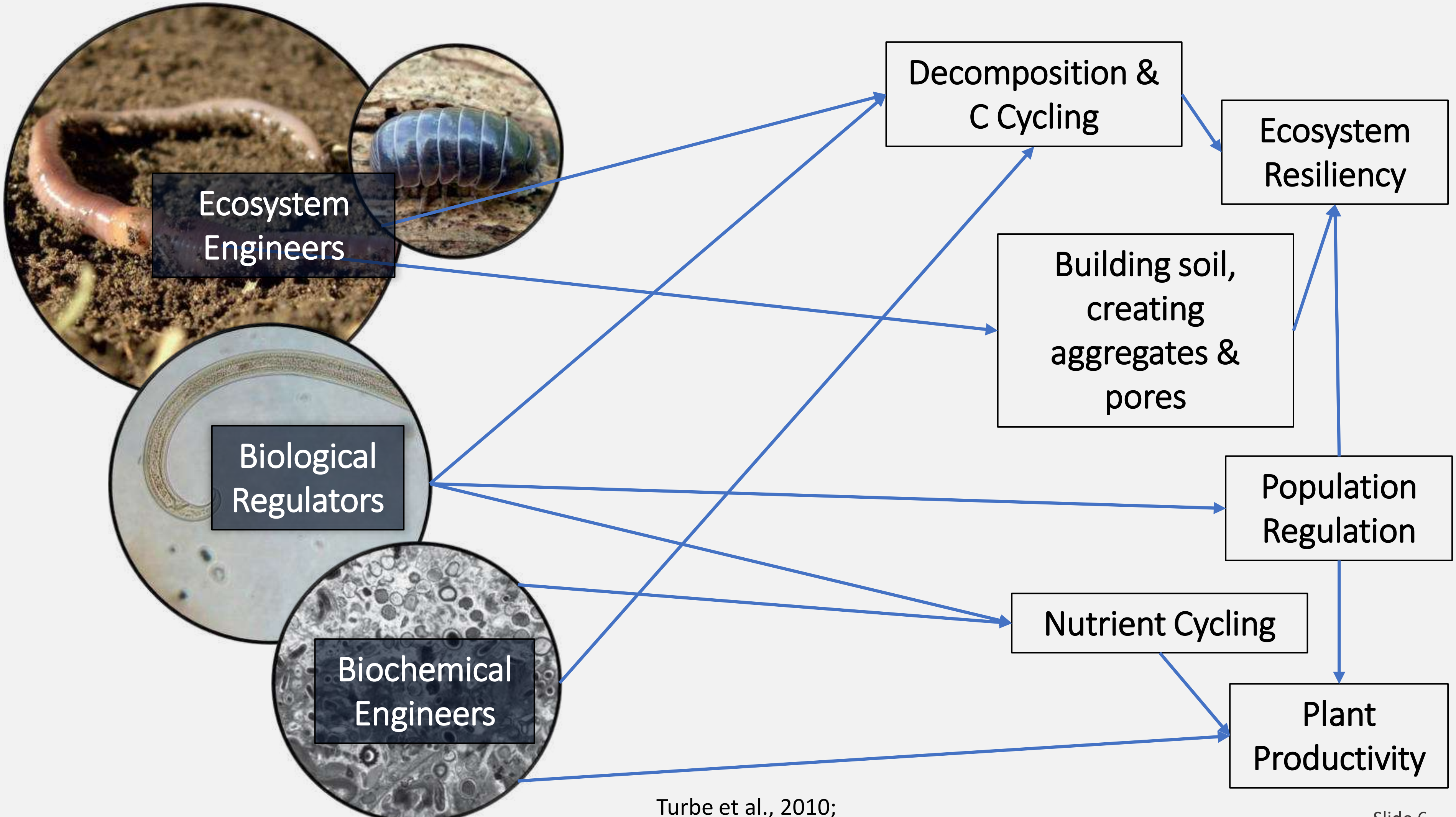
Abundance of Soil Organisms

Organism	Number per gram soil (~1 tsp)	Biomass[1] (lbs per acre 6”)
Earthworms	–	100 – 1,500
Mites	1-10	5 – 150
Nematodes	10 – 100	10 – 150
Protozoa	up to 100 thousand	20 – 200
Algae	up to 100 thousand	10 – 500
Fungi	up to 1 million	1,000 – 15,000
Actinomycetes	up to 100 million	400 – 5,000
Bacteria	up to 1 billion	400 – 5,000

[1] Biomass is the weight of living organisms

Soil Organisms
3 Functional Groups

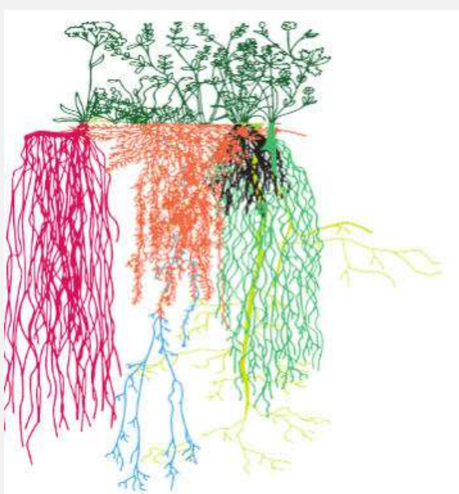
Key Ecosystem Functions



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

Ecosystem Engineers

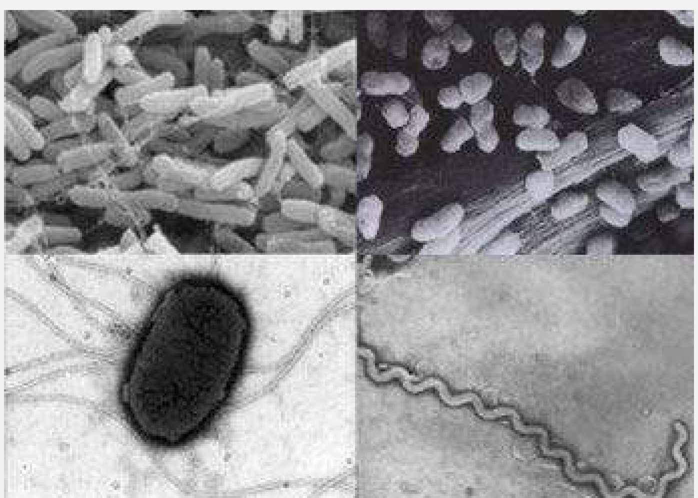
Functional group	Function	Representative members
Ecosystem Engineers	Build pore networks and aggregates	Plant roots, earthworms, larger invertebrates (e.g., millipedes, centipedes, beetles)




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

Chemical Processors (Engineers)

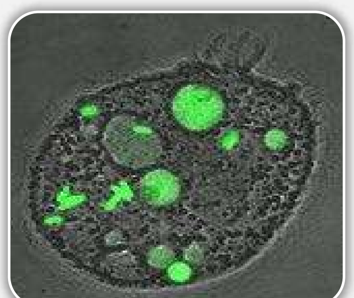
Functional group	Function	Representative members
Chemical Processors	Regulate 90% of energy flow in soil; Build soil organic matter & aggregates	Soil microbes (bacteria, fungi, protozoa)



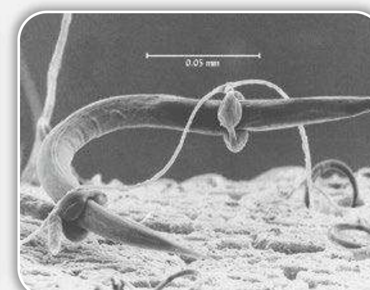
Modified from Turbe et al., 2010; Images from: Orgiazzi, Bardgett, Barrios et al. 2016. Global Soil Biodiversity Atlas.

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.

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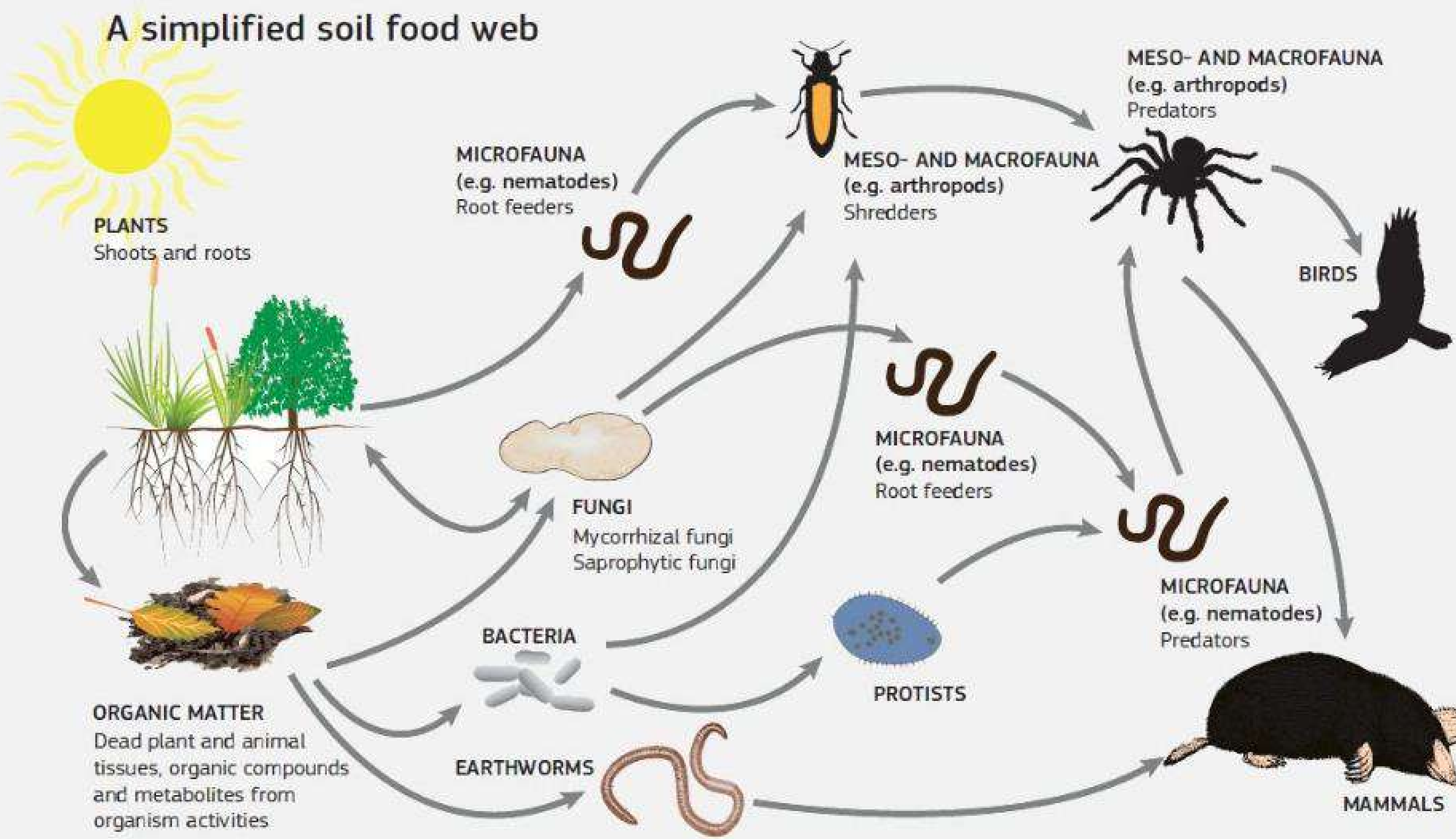
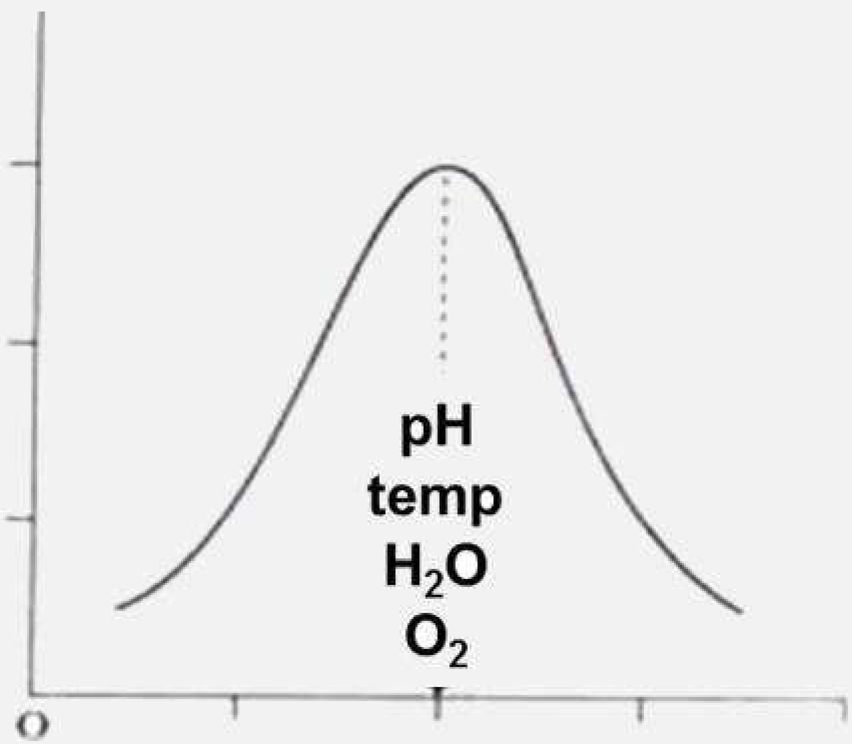


Global Soil Biodiversity Atlas. 2016. Orgiazzi, Bardgett, Barrios et al. Luxembourg, European Commission, Publications Office of the European Union: **176p.**

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

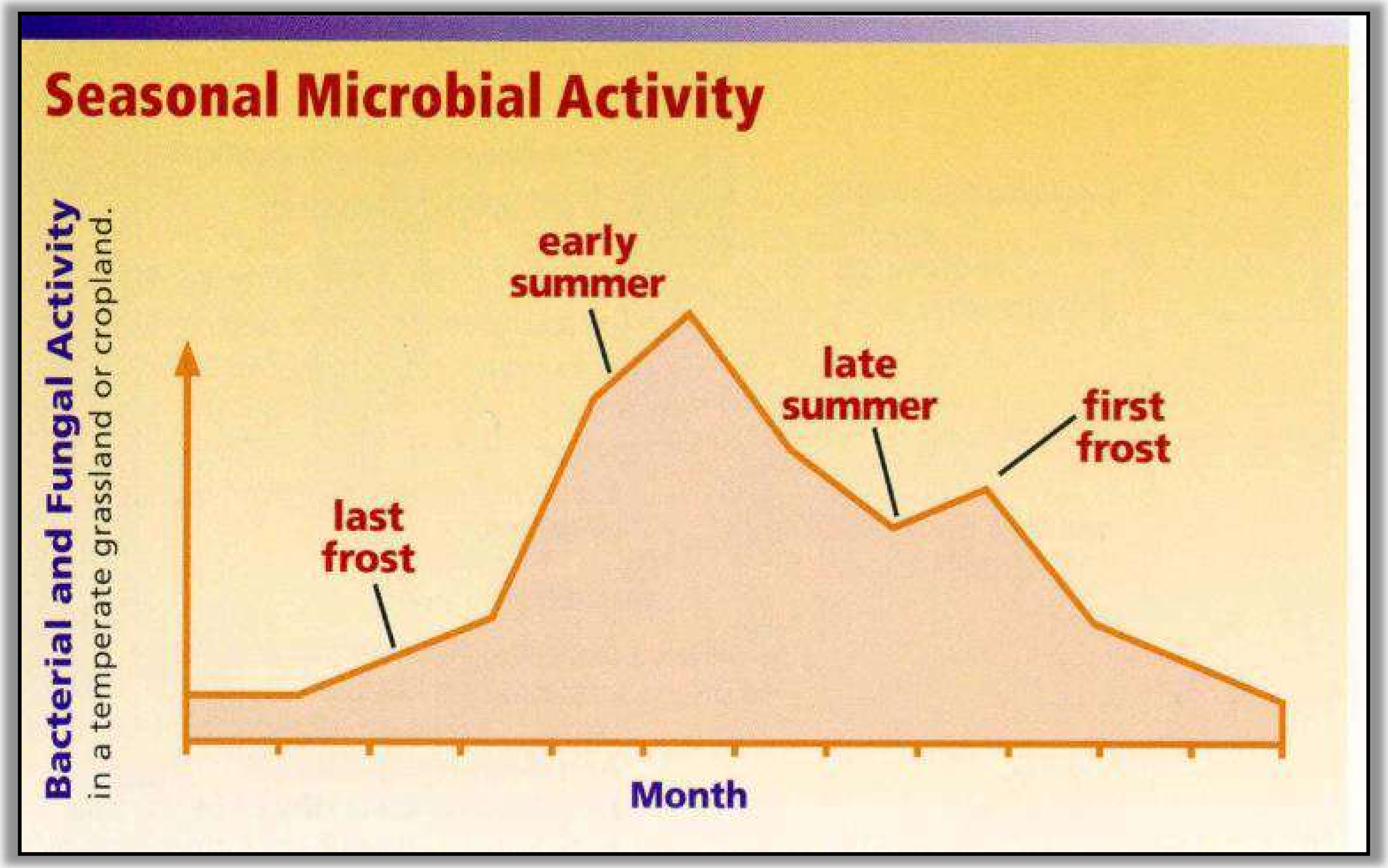
> 90% bacteria in soil are inactive!



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

Seasonal Microbial Activity

Microbes are impacted by temp and moisture



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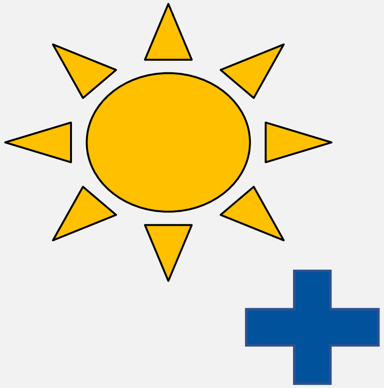
Soil Fauna Awaken Soil Microbes

15 week time lapse

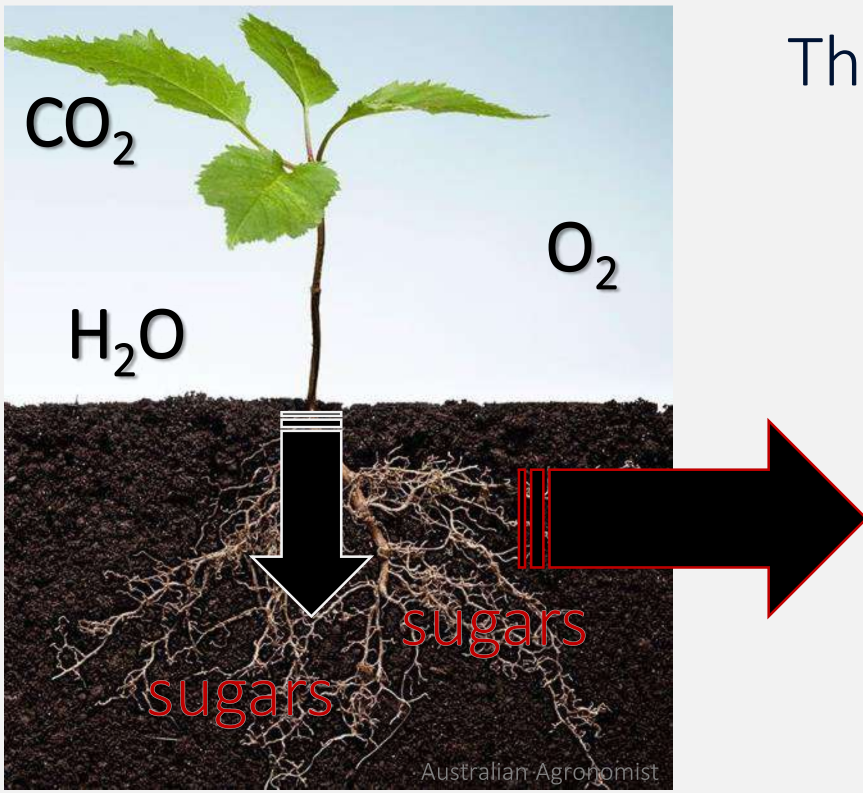
Made by: Wim van Egmond
https://vimeo.com/222168889

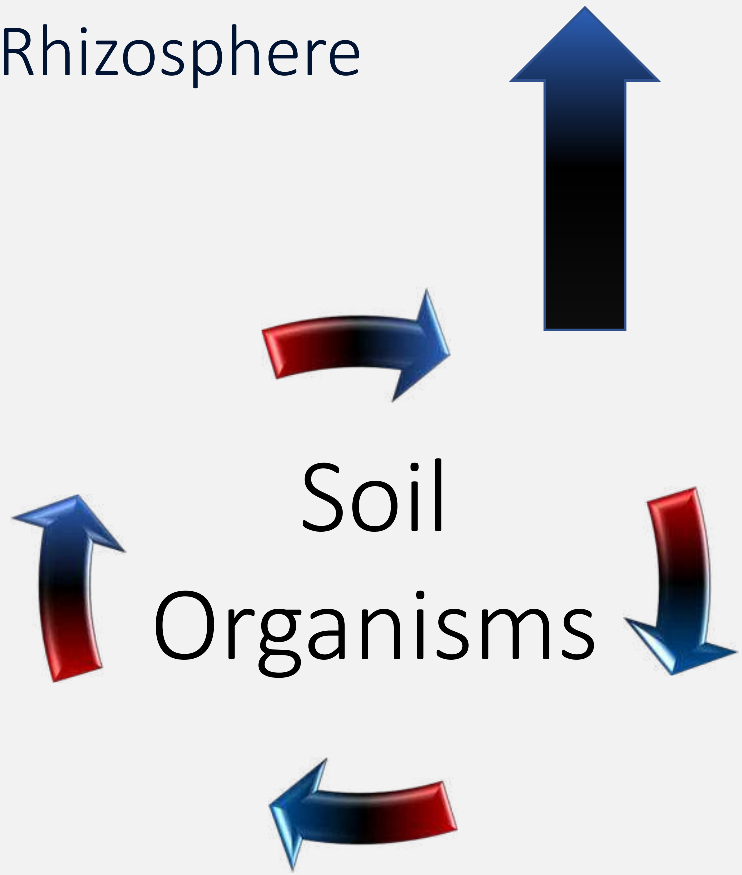


1. Capture Solar Energy
2. Make Organic Carbon

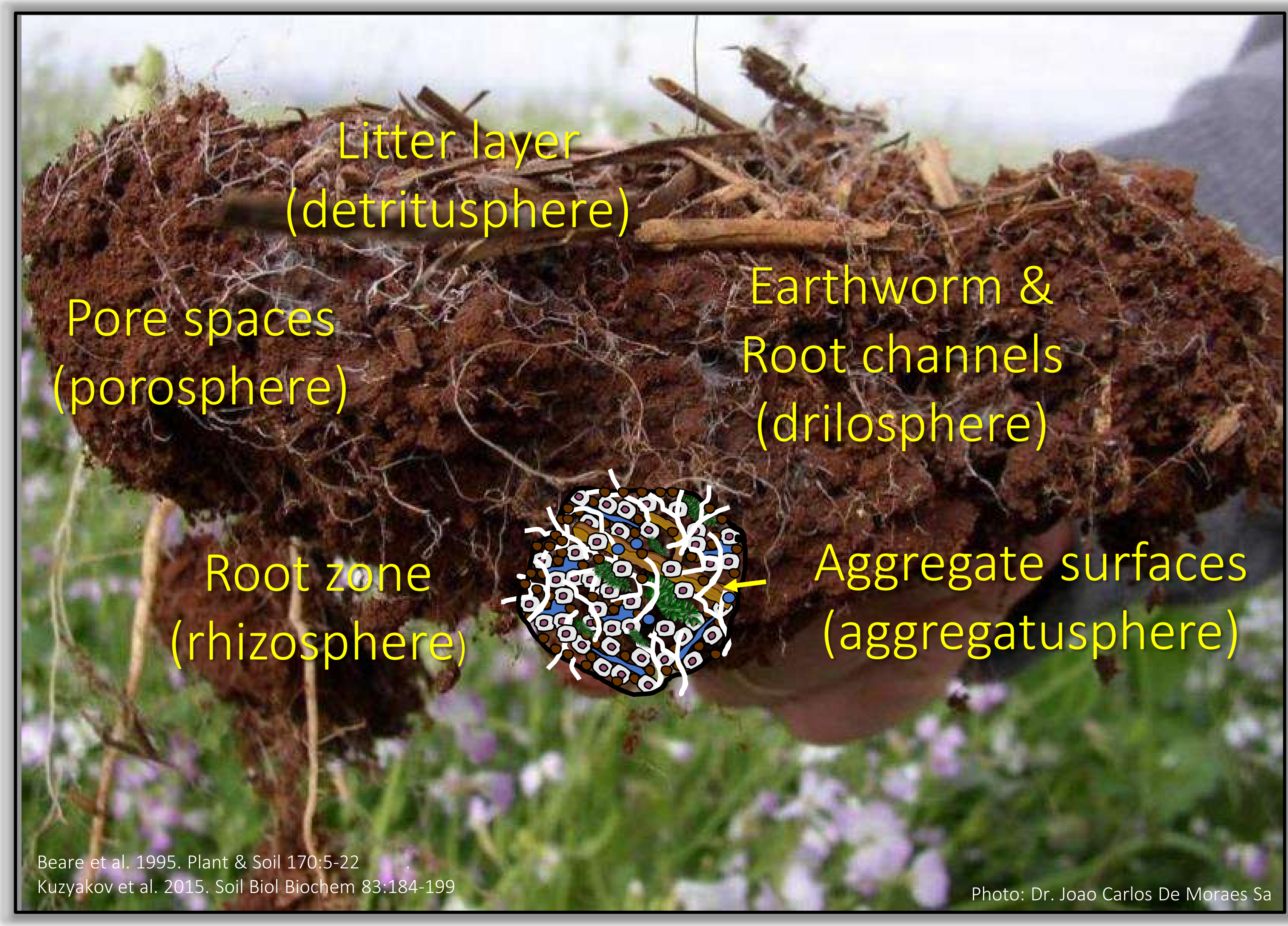
Creates a biological hot spot:

The Rhizosphere





Biological Hot Spots



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Hot Spot for Ecosystem Engineers
Detritusphere

Protects soil
Conserves soil temp & moisture
Carbon source for soil organisms

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

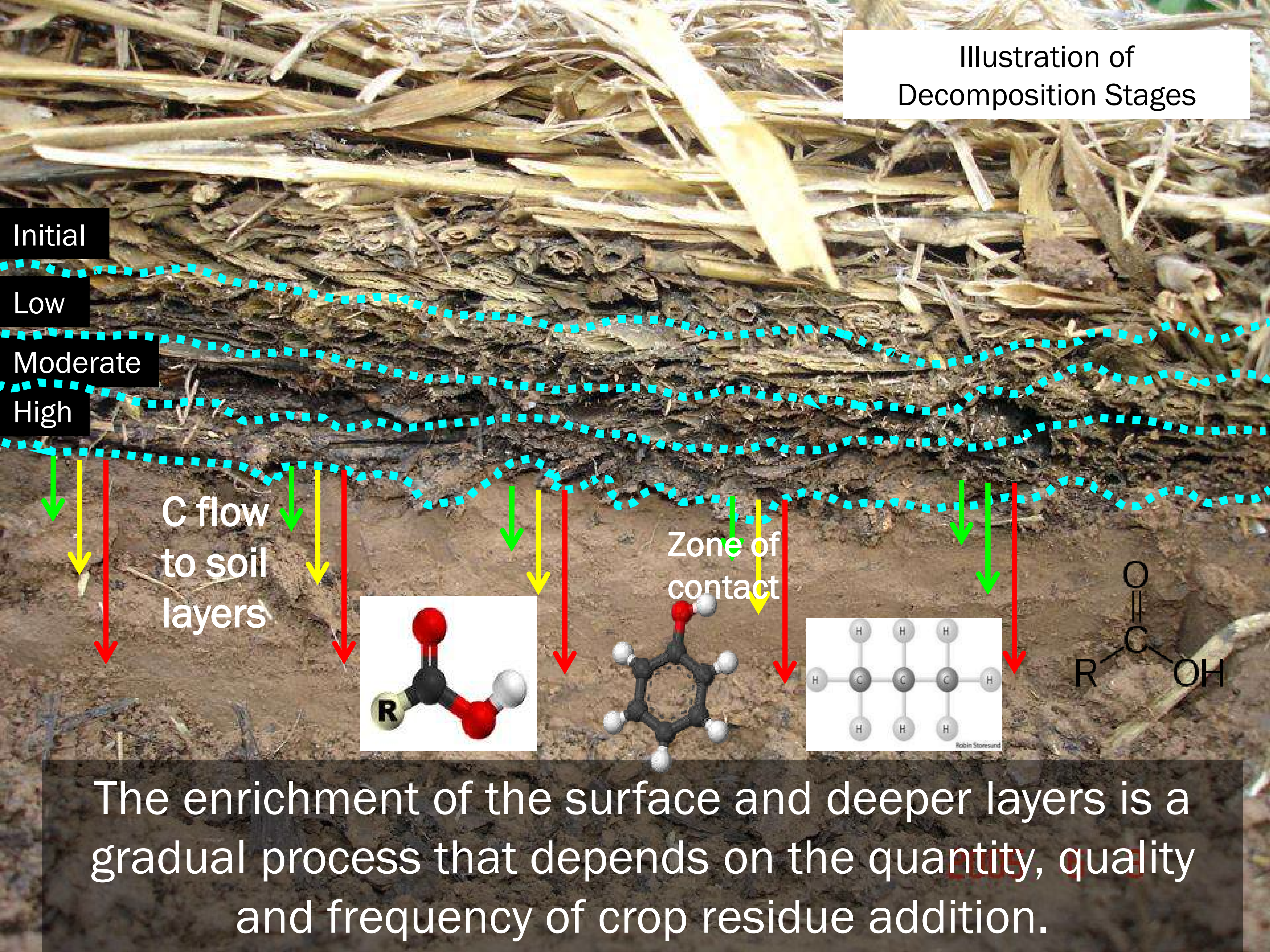
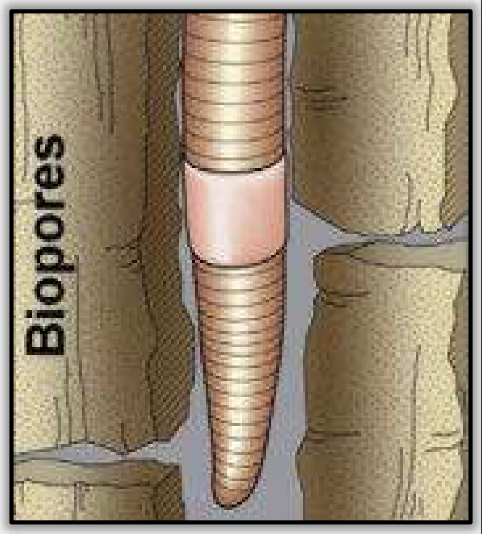


Illustration of Decomposition Stages
Initial
Low
Moderate
High
C flow to soil layers
Zone of contact
Robin Storesund
The enrichment of the surface and deeper layers is a gradual process that depends on the quantity, quality and frequency of crop residue addition.

Hot Spot for Ecosystem Engineers
Drilosphere

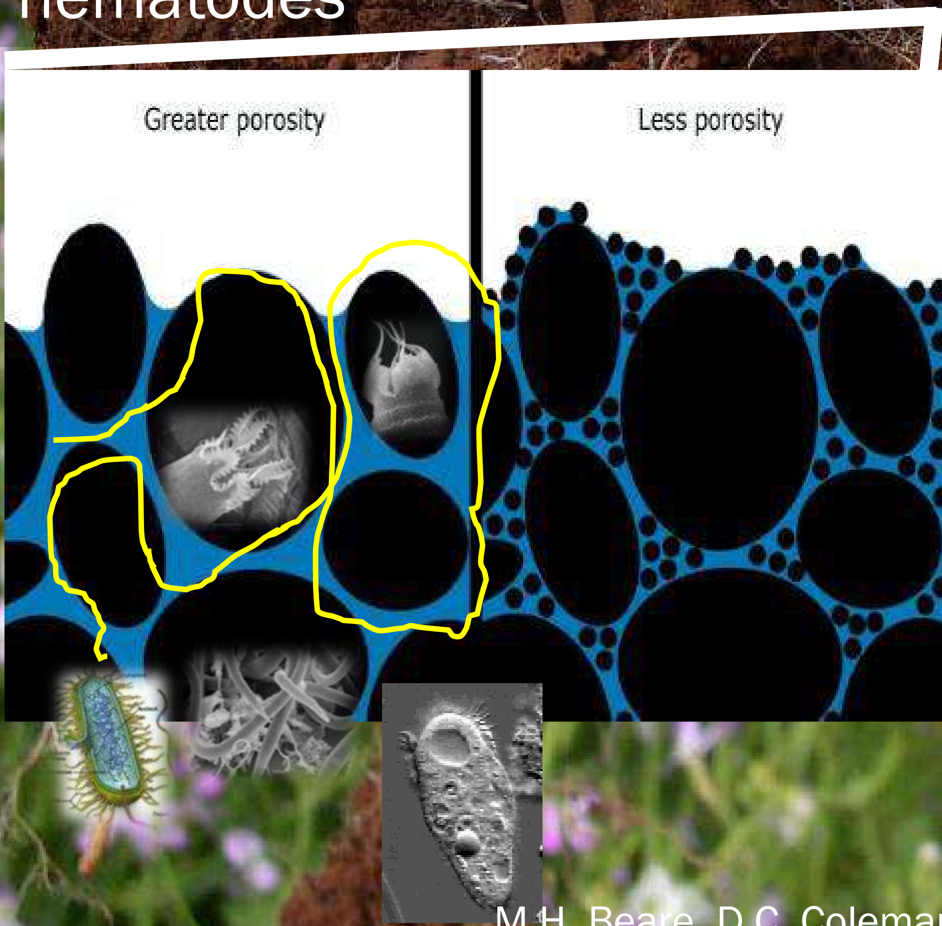


Mixes and moves residues
Large pores
Nutrient rich
Microbial enriched
Air and water flow
Roots grow & take advantage

Beare et al. 1995. Plant & Soil 170:5-22; Kuzyakov et al. 2015. Soil Biol Biochem 83:184-199

Porosphere: Arrangement of Solids and Voids

Primary an Aquatic Habitat (water films): for protozoa, bacteria, Mycorrhizae, and nematodes



The Lungs and circulatory system of the soil:

- Regulates water and air flow
- Impacts N, P Mineralization
- Impacts soil organism biomass and diversity
- Site of nutrient exchange
- Site of mycorrhizal entanglement and sequestration of water and nutrients
- Root interface
- Part of the water cycle

M.H. Beare, D.C. Coleman, D.A. Crossley Jr., P.F. Hendrix and E.P. Odum (1995)

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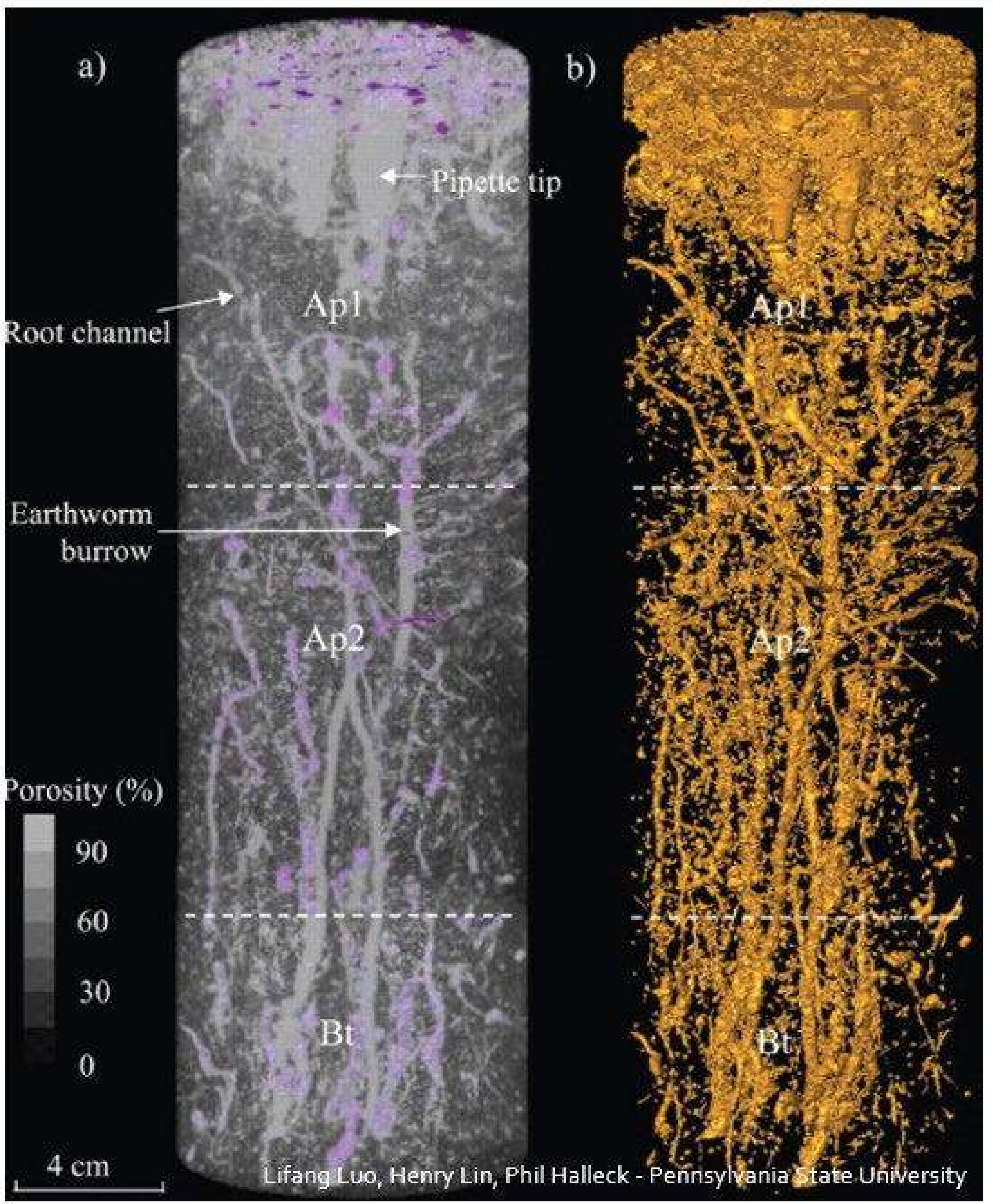


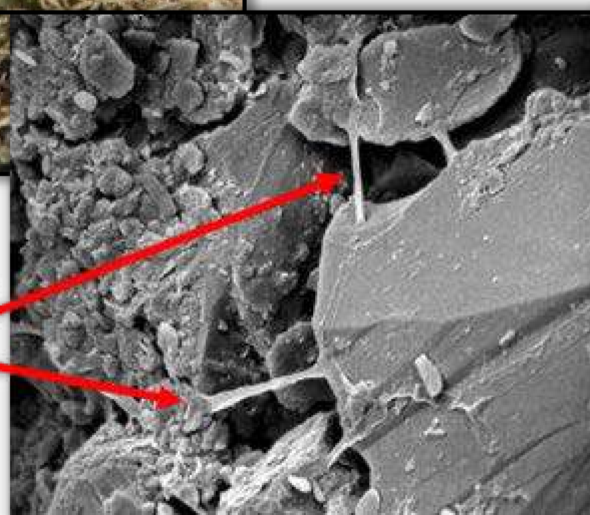
Aggregate Surfaces
Aggregatasphere

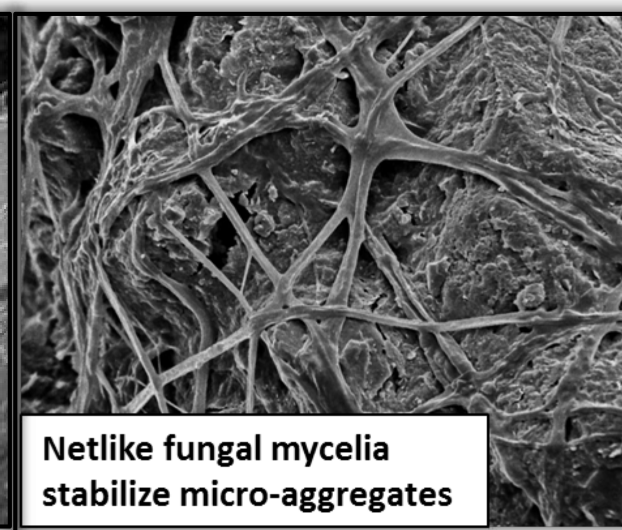
- Minerals and organic materials
- Creates stability and resists erosion
- Protects organic matter and microbes
- Supports porosphere
- Created by microbial glues, fungal hyphae, dead cells

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



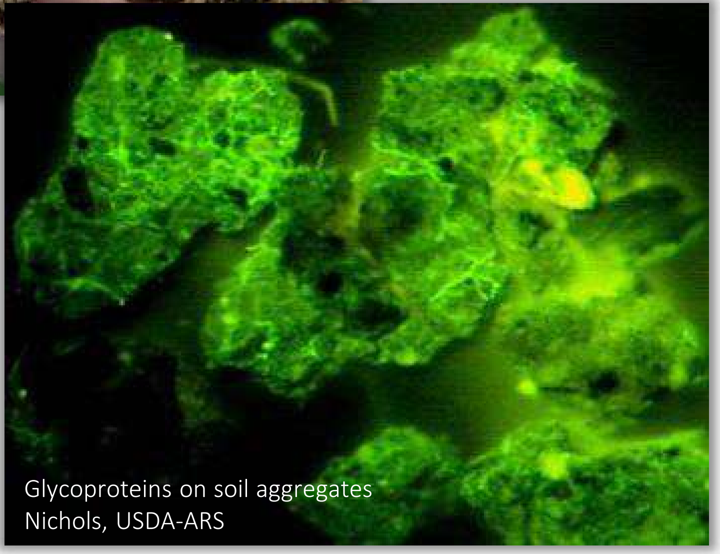


SEM photo source (accessed on 6/2/2016): Eickhorst, Thilo & Tippkoetter, Rolf. Micropedology – The hidden world of soils. University of Bremen, Germany. http://www.microped.uni-bremen.de

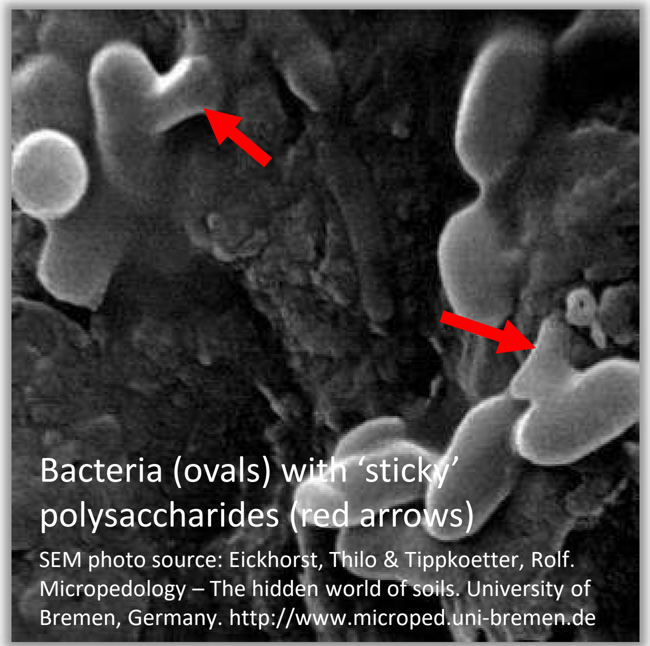
Soil Organisms Chemically Stabilize Soil Aggregates

- Polysaccharides released by bacteria bind particles
- Soil proteins and other biochemicals bind soil particles

Image source: Aaron Roth, NRCS-OR



Glycoproteins on soil aggregates
Nichols, USDA-ARS



Bacteria (ovals) with 'sticky' polysaccharides (red arrows)

SEM photo source: 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 stimulate microbes & predators
  - Symbiosis
  - Protection
  - Chemical signaling
  - Nutrients
  - Resilience

Bacteria are abundant around this root tip (the rhizosphere) where they decompose the plentiful simple organic substances. [No. 53 from *Soil Microbiology and Biochemistry Slide Set*. 1976. J.P. Martin, et al., eds. SSSA, Madison WI]

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Kingdoms of Organisms Living in the Soil

Taxonomy

- **Plantae** – plants
- **Animalia** – rodents, worms, insects, nematodes, and arthropods
- **Fungi** – molds, mushrooms, mycorrhizae
- **Protista** – ciliates, protozoa, amoebae
- **Monera** – bacteria, actinomycetes

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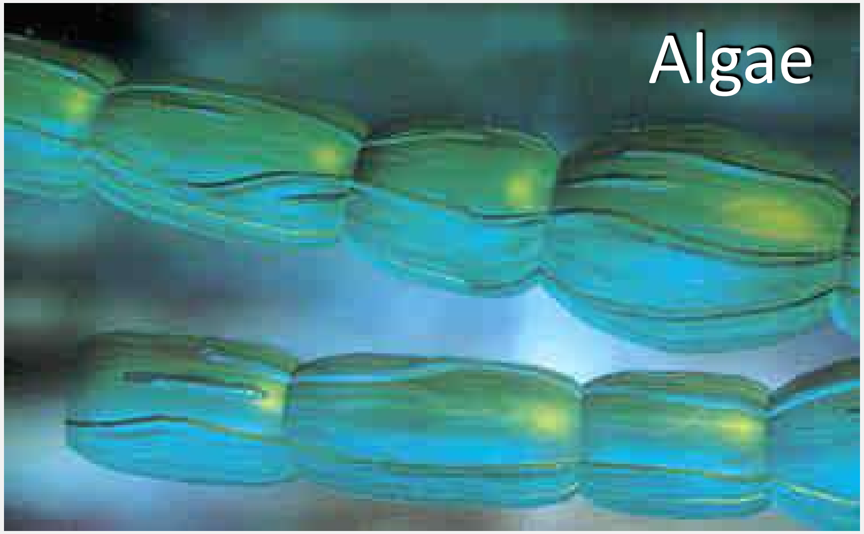
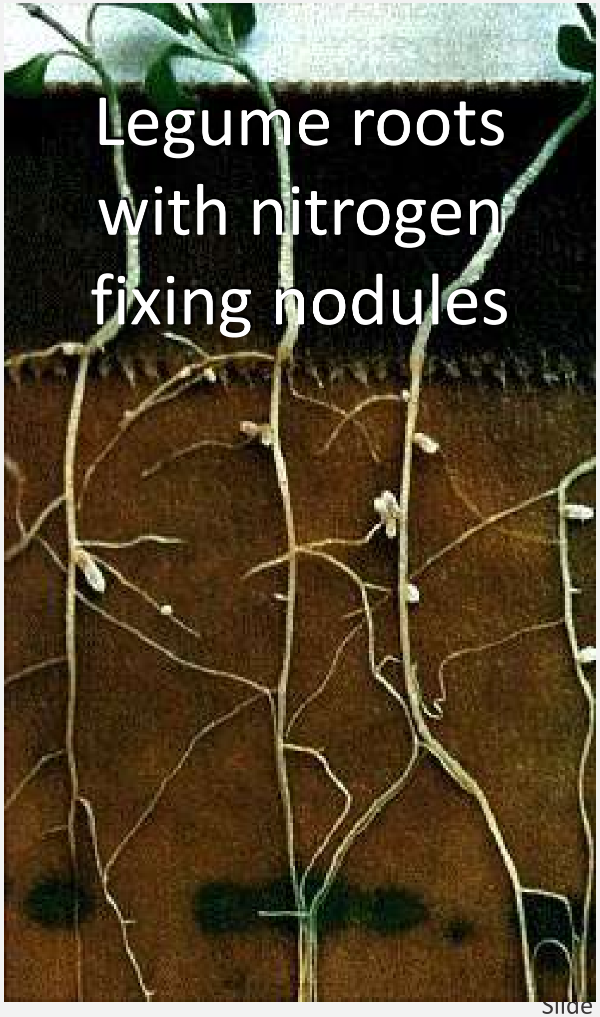
Plants

Plants – the primary producers

- Vascular Plants: roots of all crops and vegetable plants
- Algae





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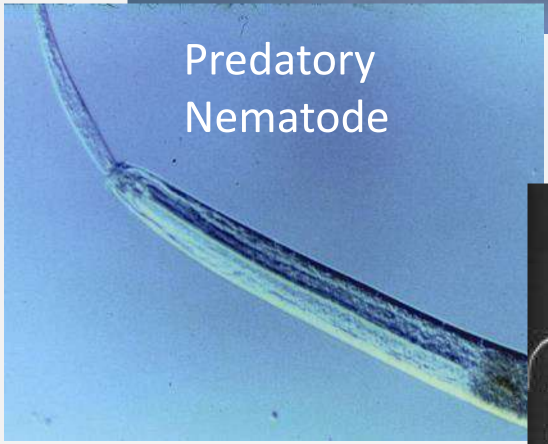
Animals

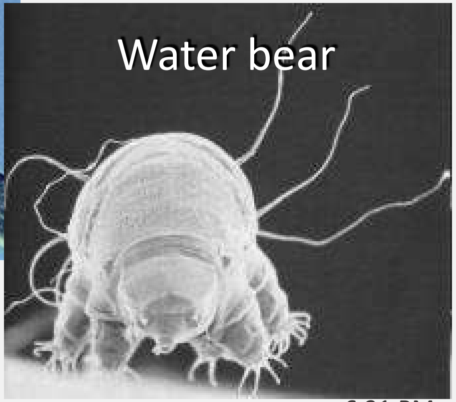
- Vertebrates: gophers, mice, voles, snakes
- Arthropods: spiders, ants, beetles, maggots
- Annelids: earthworms
- Mollusks: snails, slugs
- Nematodes

Parasitic nematodes in insect larvae

Mouth parts of bacteria-feeding nematode



Predatory Nematode



Water bear

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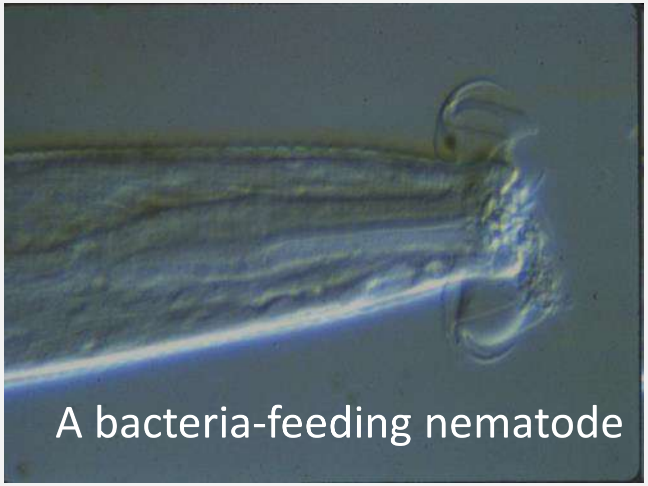
Animals – Nematodes

- Fungal feeders, bacteria feeders, root feeders, predators and omnivores
- Most are non-pathogenic
- An important part of the nitrogen cycle
- About 10-20 individuals/gram of soil
- Affected by management: pesticides, soil organic matter, tillage



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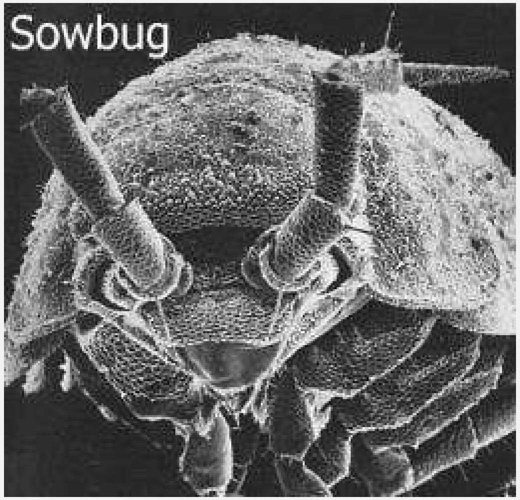
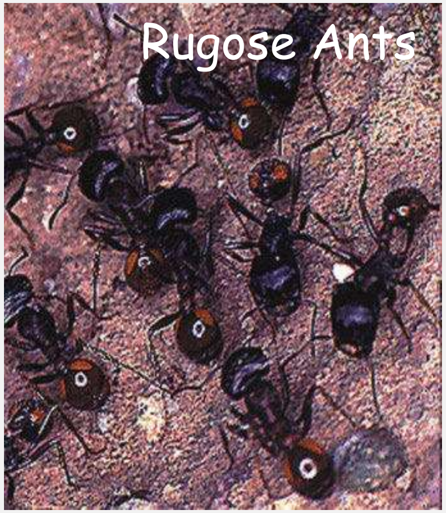
Animals – Microarthropods

- Mites, collembola (or springtails)
- Widths range from 0.1-2 mm
- Number from about 5-20 per gram of soil
- Decompose & shred organic matter
- Tillage and pesticides are harmful
- An important part of the nitrogen cycle

Animals – Arthropods

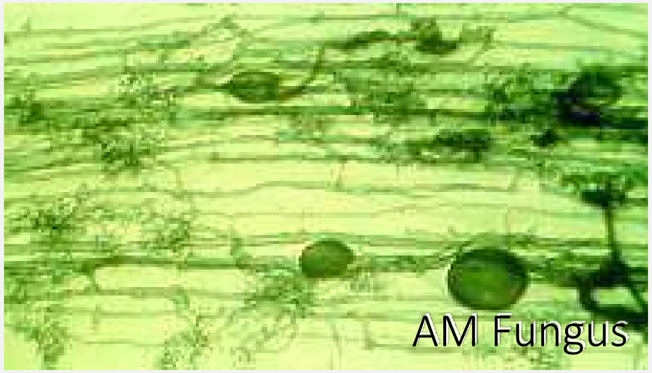




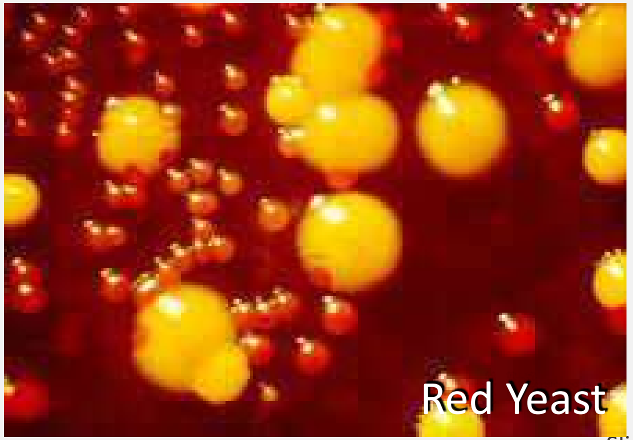
Animals – Earthworms

- ☐ Poor soils contain 250,000 earthworms per acre while good soils contain 1,750,000 per acre
- ☐ Good for nutrient cycling and stability functions
- ☐ Burrowing through lubricated tunnels forces air in and out of soil
- ☐ Earthworm casts contain 11% of the humus and 7X the nitrogen, 11X the phosphorus, and 9X the potash than surrounding soil

Fungi



- Decompose Organic Matter
- Glomalin Secretion which aids in developing soil structure
- Extract Nutrients
- Hold Nutrients



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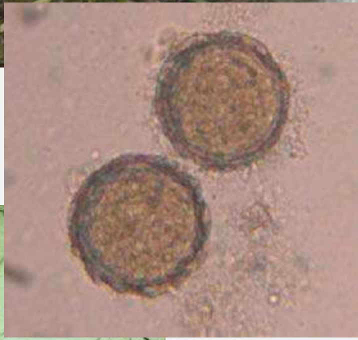
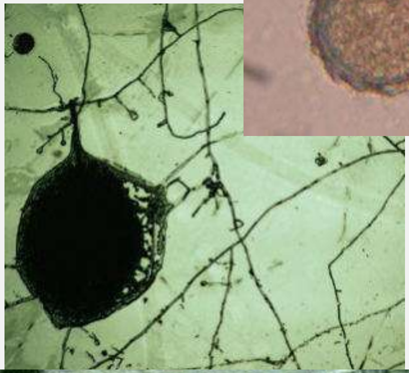
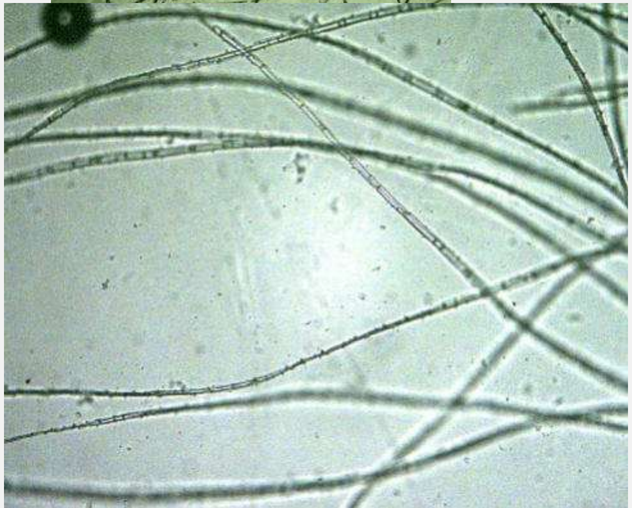
Fungi

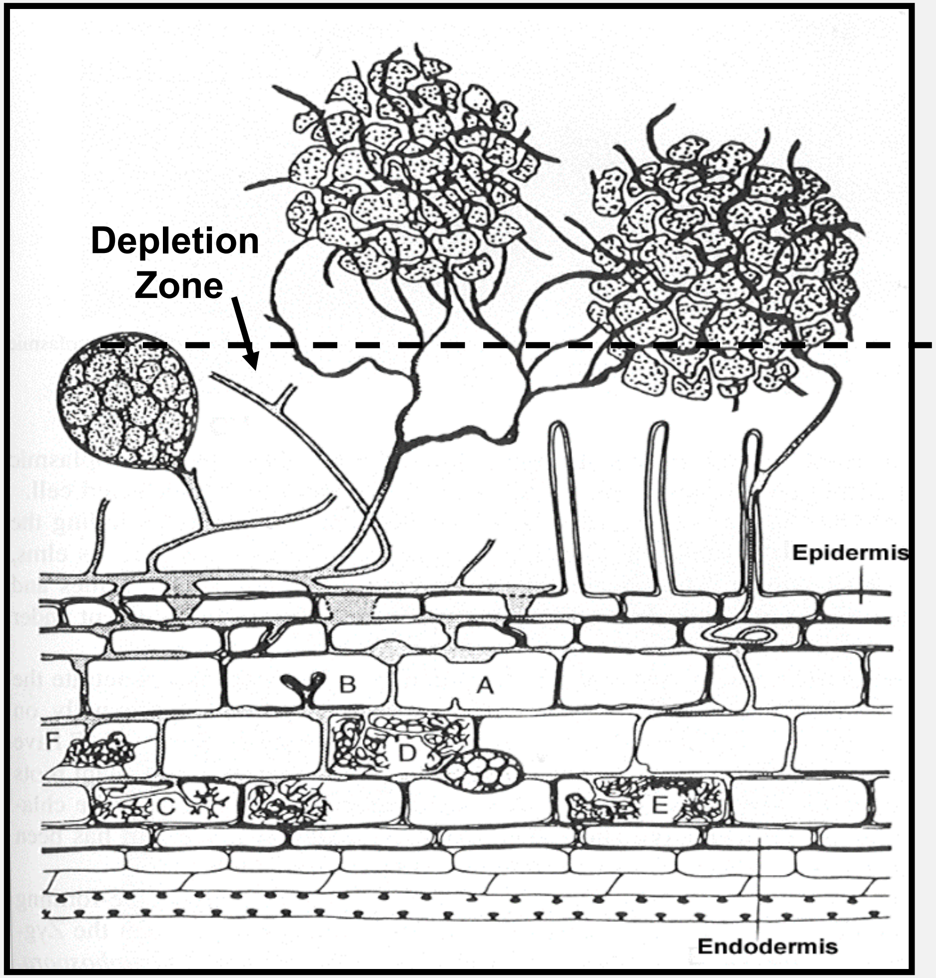
- Up to 3,000 species in cultivated soil
- Three main types: parasites, saprophytes and mutualists
- Parasites attack foliar and root plant material, other fungi, nematodes and micro and macroarthropods
- Saprophytes feed on organic matter that is difficult to breakdown, such as crop residue
- Store nitrogen in hyphal bodies and release nitrogen by decomposition

Mutualistic Fungi:

Arbuscular Mycorrhizal Fungi

- Mutualists can obtain nutrients (primarily P, but also Cu and Zn) from beyond the depletion zone around roots
  - Grow about 1 to 2 inches out into the soil (about 100 meters of fungal hyphae per gram of soil)
- Usually broad host range
- Little known physiology, ecology, etc.
- Low numbers can stress plant
- Affected by:
  - Rotation including cover crops
  - Fallow
  - Flooding
- Create mycorrhizosphere in soil
  - Assist with nutrient cycling
  - Form soil aggregates



Mycorrhizal Fungi

Plant/Fungi Symbiosis

- Plants supply fungi with sugars (energy)
- Fungal hyphae grow 5-10 cm beyond plant roots
  - Extend to soil pores to large for root hairs
  - Increase plant nutrient supply, especially phosphorus
  - Increase plant water supply

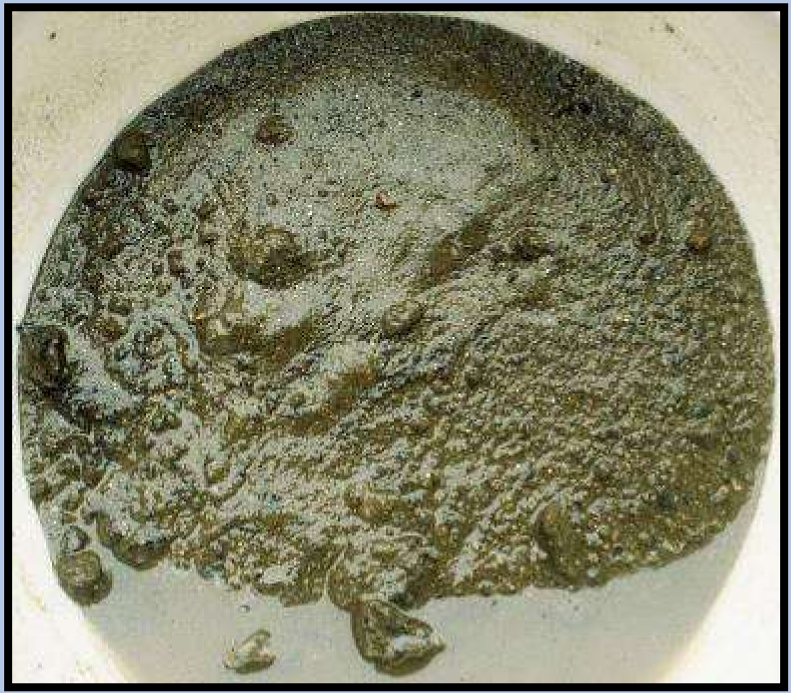
Growth of Douglas Fir Seedlings

No mycorrhizal fungi

With mycorrhizal fungi

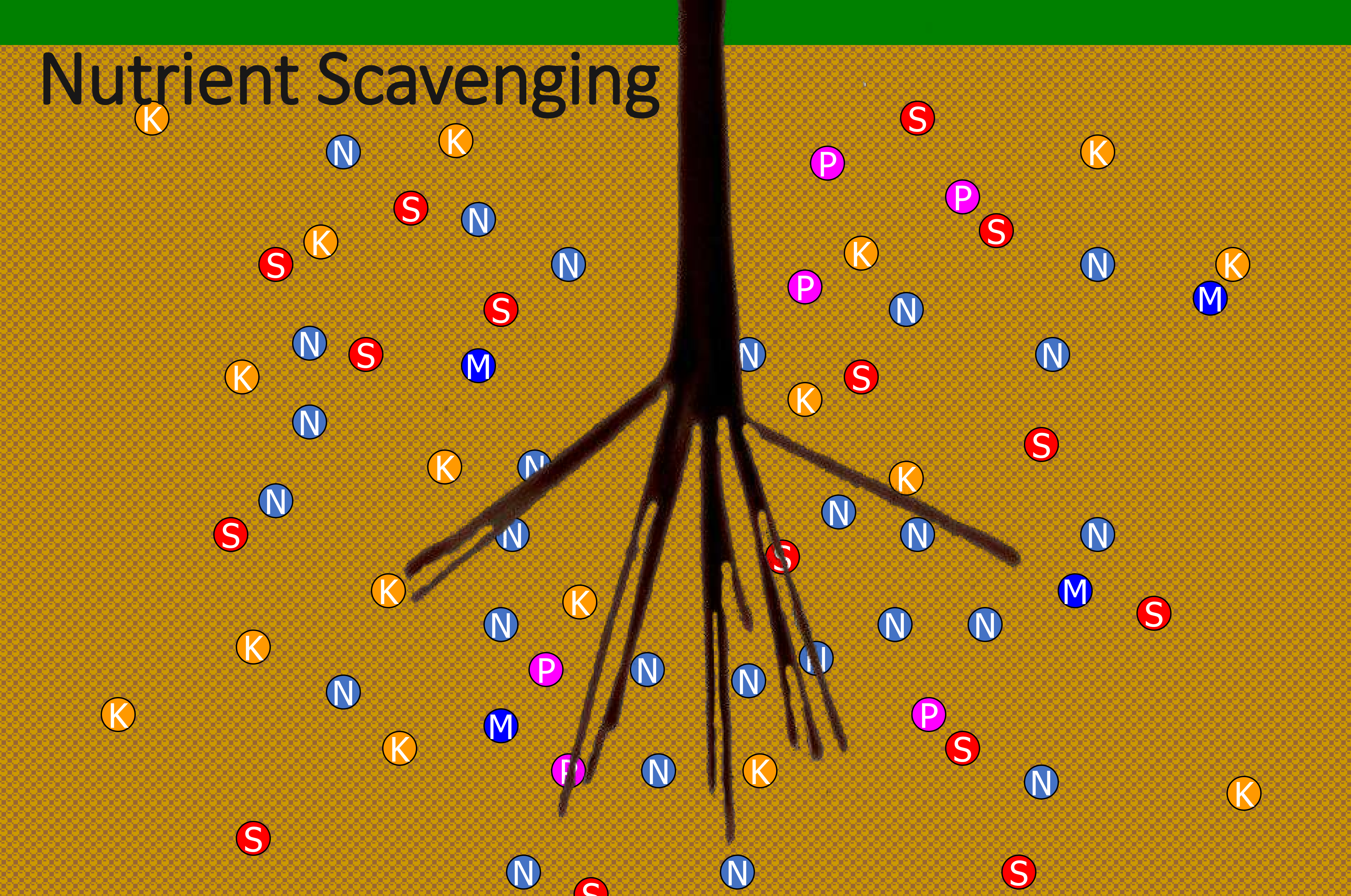
Mycorrhizal Fungi

Soil Structure Benefit



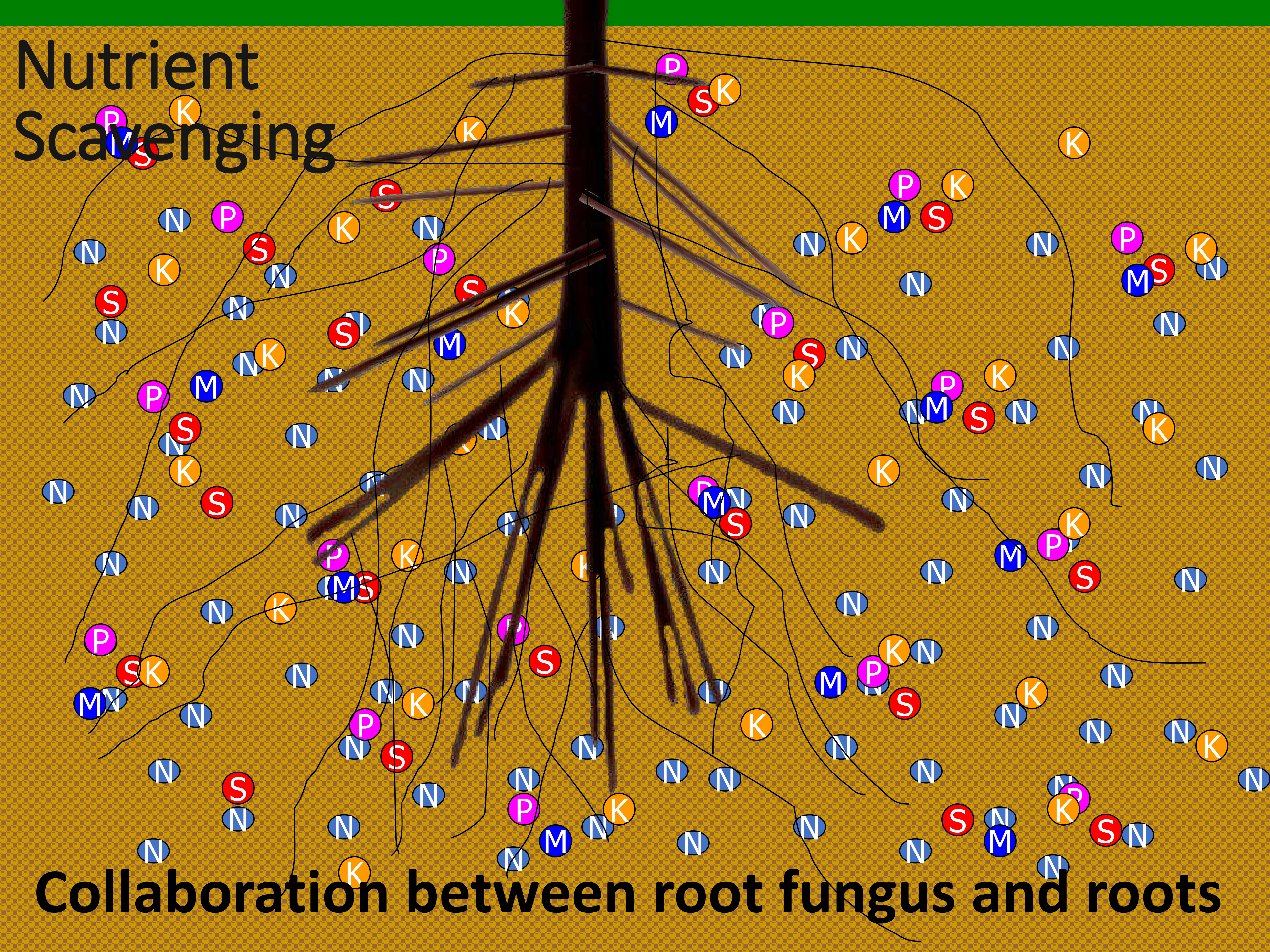
- Mycorrhizal Fungi Present
  - Soil Structure Stabilized and Strengthened
  - Structure is Maintained When Immersed in Water
- Mycorrhizal Fungi Absent
  - Soil Structure is Weak
  - Structure is Not Maintained When Immersed in Water

Nutrient Scavenging



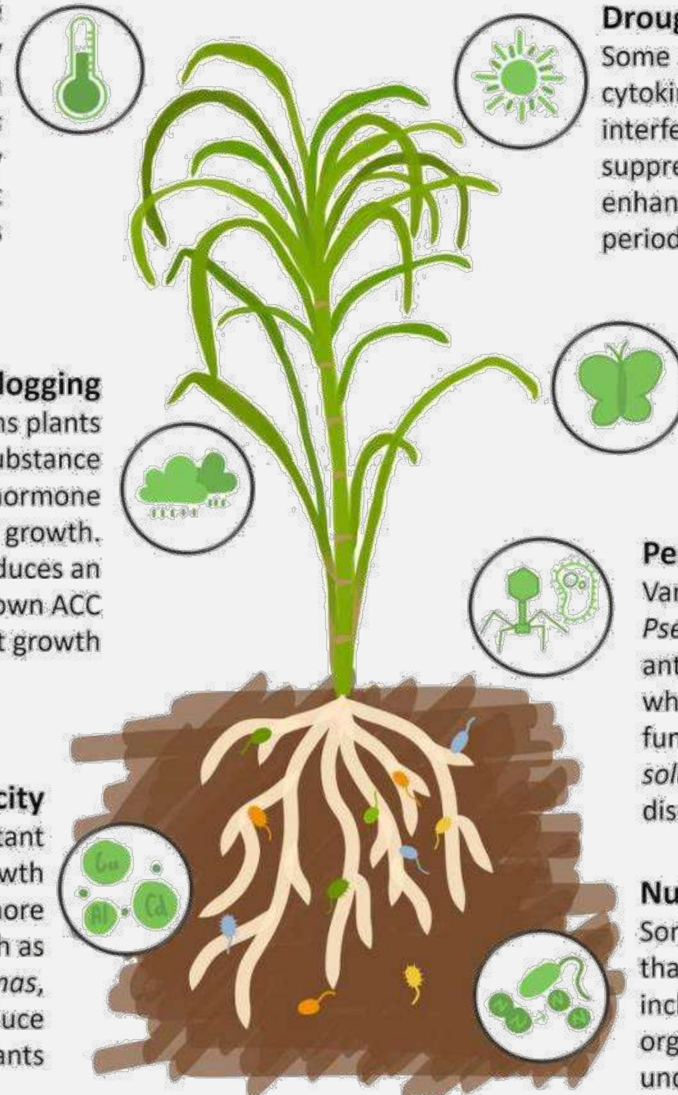
Plant roots are not very efficient at absorbing moisture & nutrients.

Nutrient Scavenging



Collaboration between root fungus and roots

Microbes help Plants Deal with Stress



Temperature
Some soil microbes are very tolerant to harsh environments. *Pseudomonas putida* can significantly enhance growth of wheat under heat stress

Waterlogging
Under stressful conditions plants produce the chemical substance ACC, a precursor to the hormone ethylene which stunts plant growth. Bacterium *Serratia* produces an enzyme that breaks down ACC which results in better plant growth

Soil toxicity
Some salt or heavy metal resistant microbes can enhance plant growth and survivability. Siderophore producing bacteria, such as *Microbacterium* and *Pseudomonas*, can bind heavy metals and reduce toxicity to plants

Drought
Some *Bacillus subtilis* strains produce cytokinin, a plant hormone that interferes with drought induced suppression of shoot growth thereby enhancing plant growth throughout periods of drought

Insects
Many *Pseudomonas* and *Bacillus* isolates have insecticidal activity and can prime plants against insect attack

Pests and pathogens
Various bacteria including *Pseudomonas fluorescens*, produce antibiotic compounds like pyrrolnitrin, which confers resistance to various fungal pathogens such as *Rhizoctonia solani* which causes damping-off disease in cotton

Nutrient limitation
Some microbes can access nutrients that are unavailable to plants including atmospheric nitrogen and organic phosphorus. The best understood example is the rhizobia-legume symbiosis

Image: Mrs. Shelby Berg, Ph.D. candidate, The University of Queensland; http://www.uq.edu.au/research/impact/stories/promoting-plant-probiotics/

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THE NOBEL CONFERENCE
GUSTAVUS ADOLPHUS COLLEGE

"'Subiyay spoke of the ancient story of the Tree People that tells how the trees have much to teach us about their diversity and symbiotic nature. Under the forest floor there is an intricate and vast system of roots and fungi that keeps the forest strong. The story captures an important teaching for building alliances, communal strength, diversity and roles each member has in the web of the whole community. Together we are stronger."

Quote source: http://www.swinomish-nsn.gov/climate_change/Docs/SITC_CC_AdaptationActionPlan_complete

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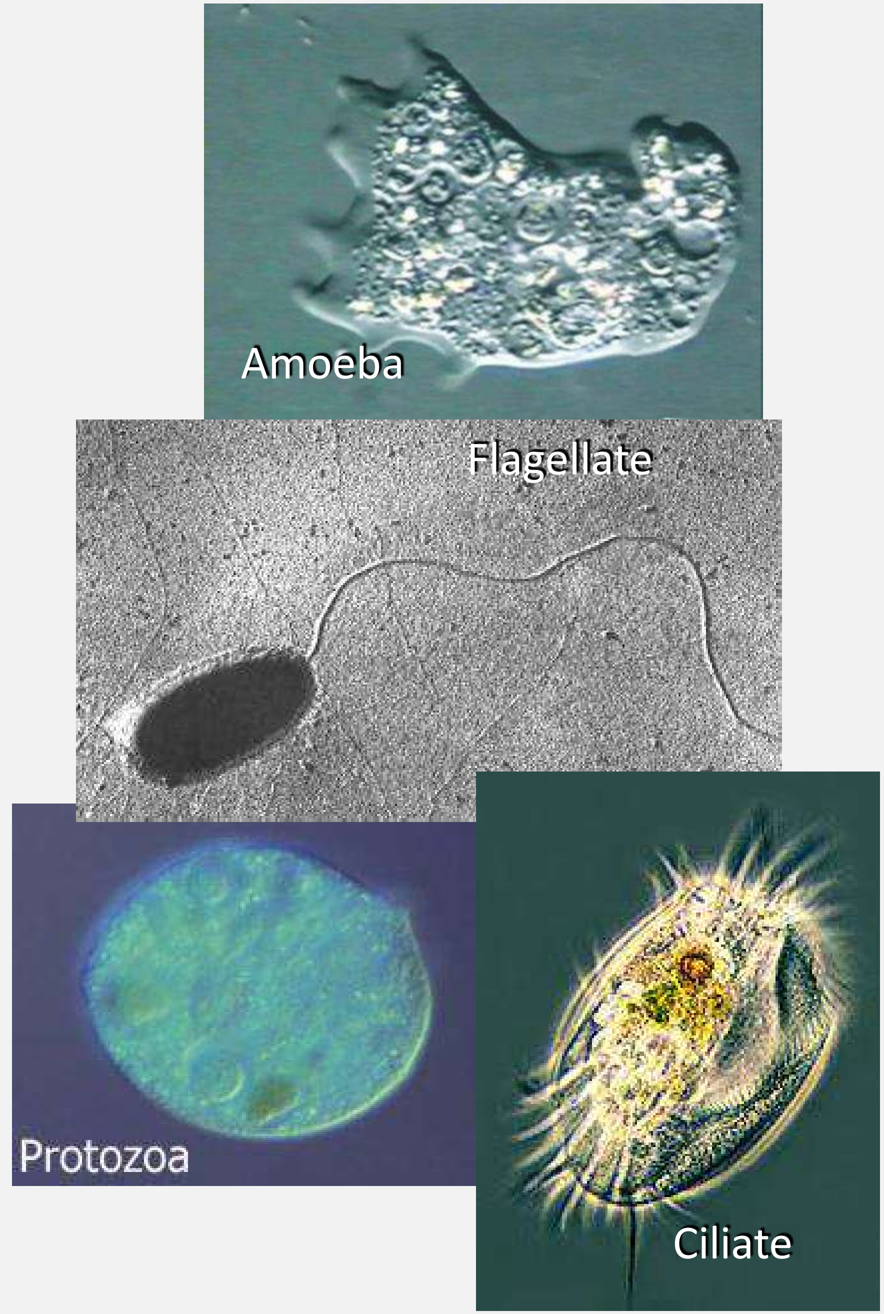
Protozoa

- Protozoa include: amoebae, ciliates, flagellates
- Consume and regulate populations of: bacteria, fungi, and algae
- Are an important part of the nitrogen cycle
- Number in the thousands per gram of soil
- Food source themselves



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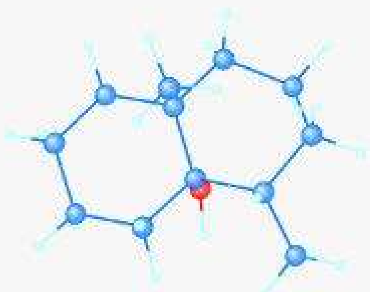
Monera – Actinomycetes

Geosmin



https://pubchem.ncbi.nlm.nih.gov/compound/geosmin#section=2D-Structure

Organic Matter Decomposition

Everyone is involved

- Earthworms
  - Mix fresh organic materials into the soil
  - Brings organic matter into contact with soil microorganisms

- **Soil Insects and Other Arthropods**
  - Shred fresh organic material into smaller particles
  - Allow soil microbes to access all parts of the organic residue

Organic Matter Decomposition

Everyone is involved

- Protists and nematodes;

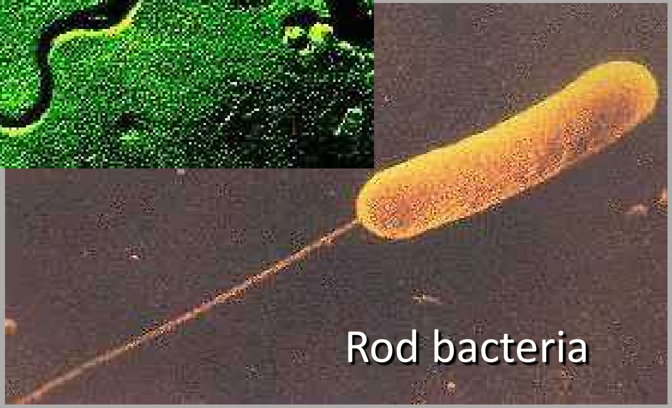
  "the predators"

  - Feed on the primary decomposers (bacteria, fungi, actinomycetes)
  - Release nutrients (nitrogen) contained in the bodies of the primary decomposers

Organic Matter Decomposition

Everyone is involved

- Bacteria
  - Population increases rapidly when organic matter is added to soil
  - Quickly degrade simple compounds - sugars, proteins, amino acids
  - Have a harder time degrading cellulose, lignin, starch
  - Cannot get at easily degradable molecules that are protected



Organic Matter Decomposition

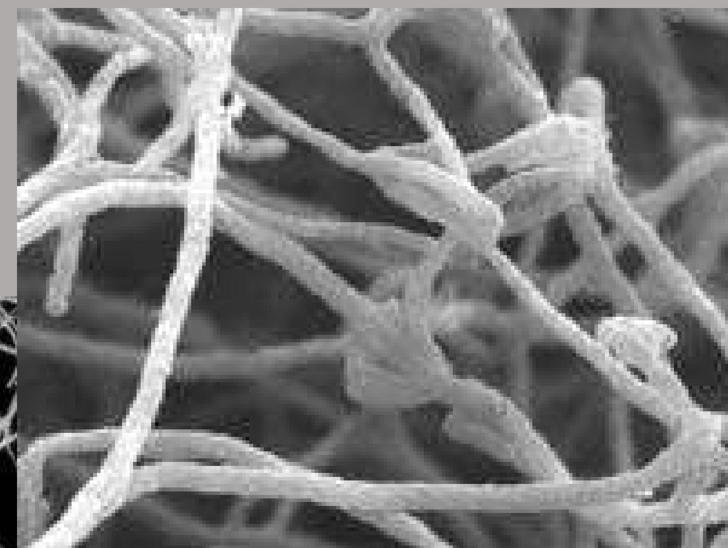
Everyone is involved

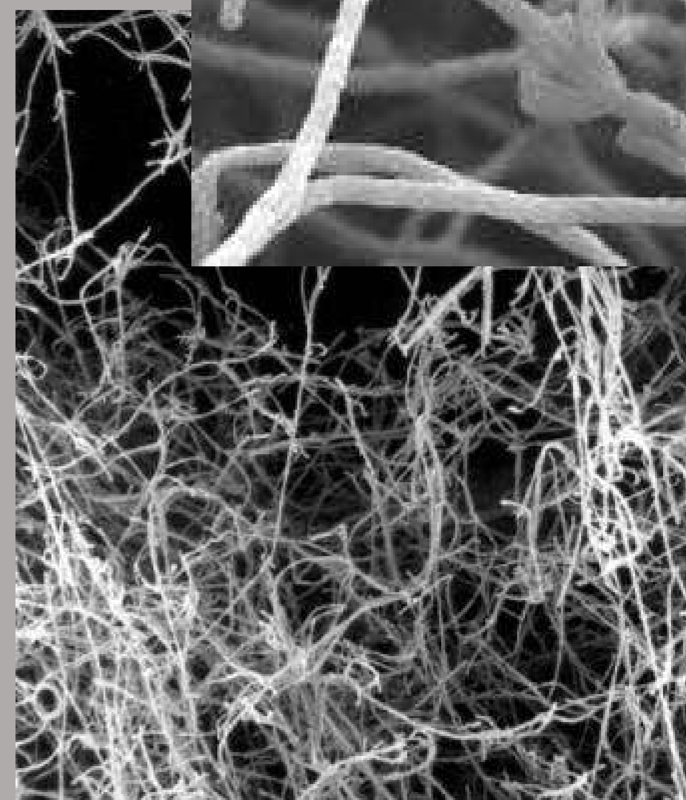
- Fungi
  - Grow more slowly and efficiently than bacteria when organic matter is added to soil
  - Able to degrade complex organic molecules such as cellulose, lignin, starch
  - Give other soil microorganisms access to simpler molecules that were protected by cellulose or lignin

Organic Matter Decomposition

Everyone is involved

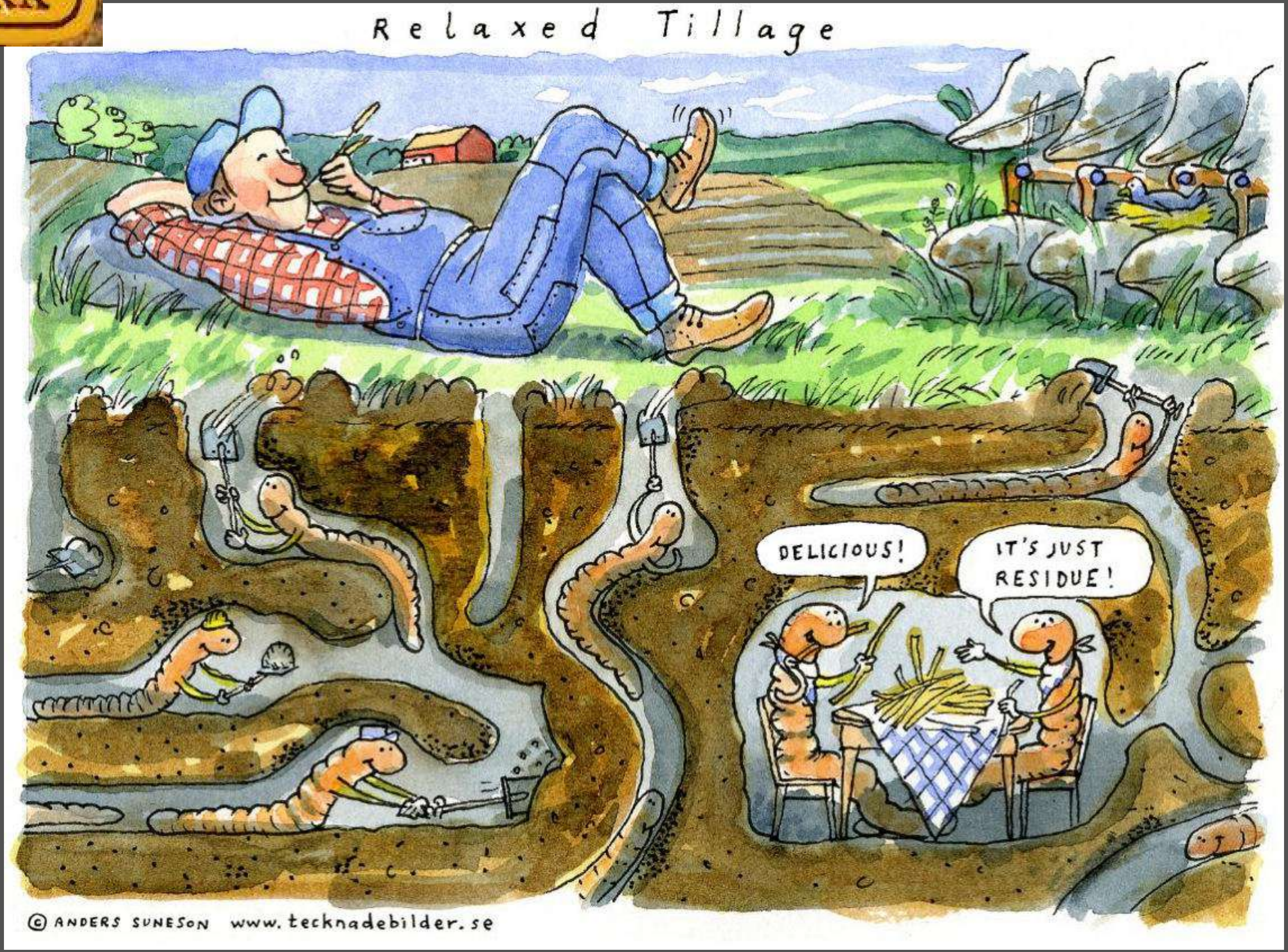
- Actinomycetes
  - The cleanup crew
  - Become dominant in the final stages of decomposition
  - Attack the highly complex and decay resistant compounds
    - Cellulose
    - Chitin (insect shells)
    - Lignin





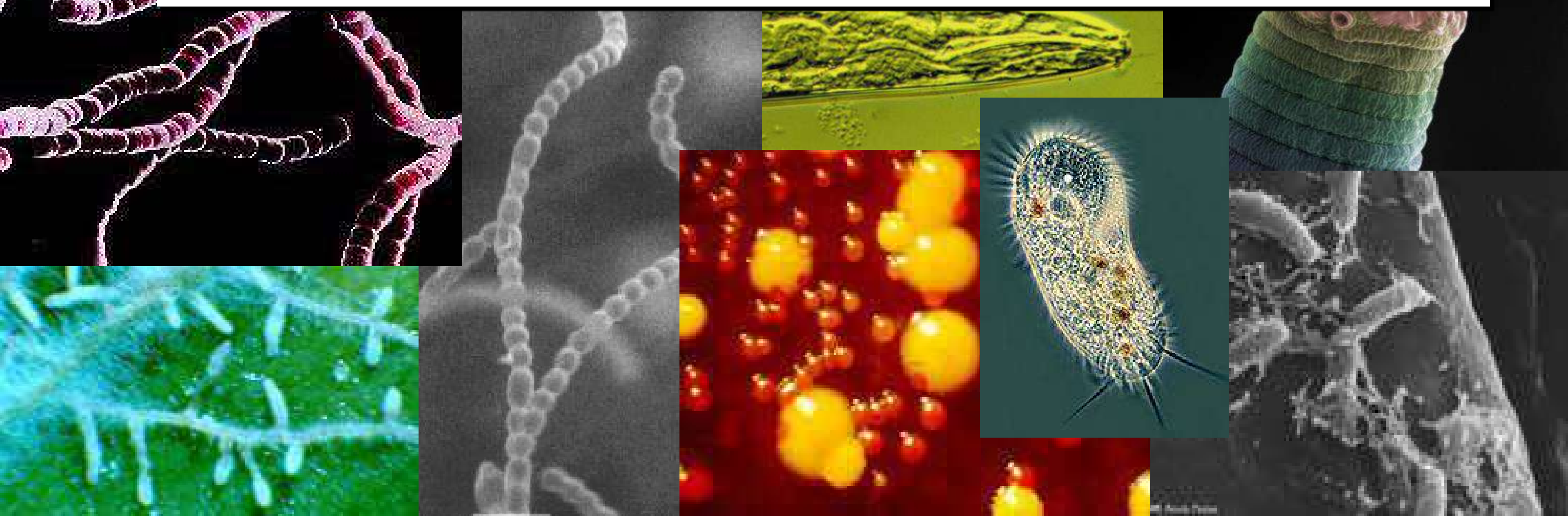
Biological tillage by soil fauna has to replace “iron tillage”!

– Rolf Derpsch



Benefits of Diversity

- ☐ Ecosystem Stability: Soil has several ways to accomplish the same function (system redundancy)
- ☐ Ecosystem Resilience: Soil has the ability to bounce back from a severe disturbance

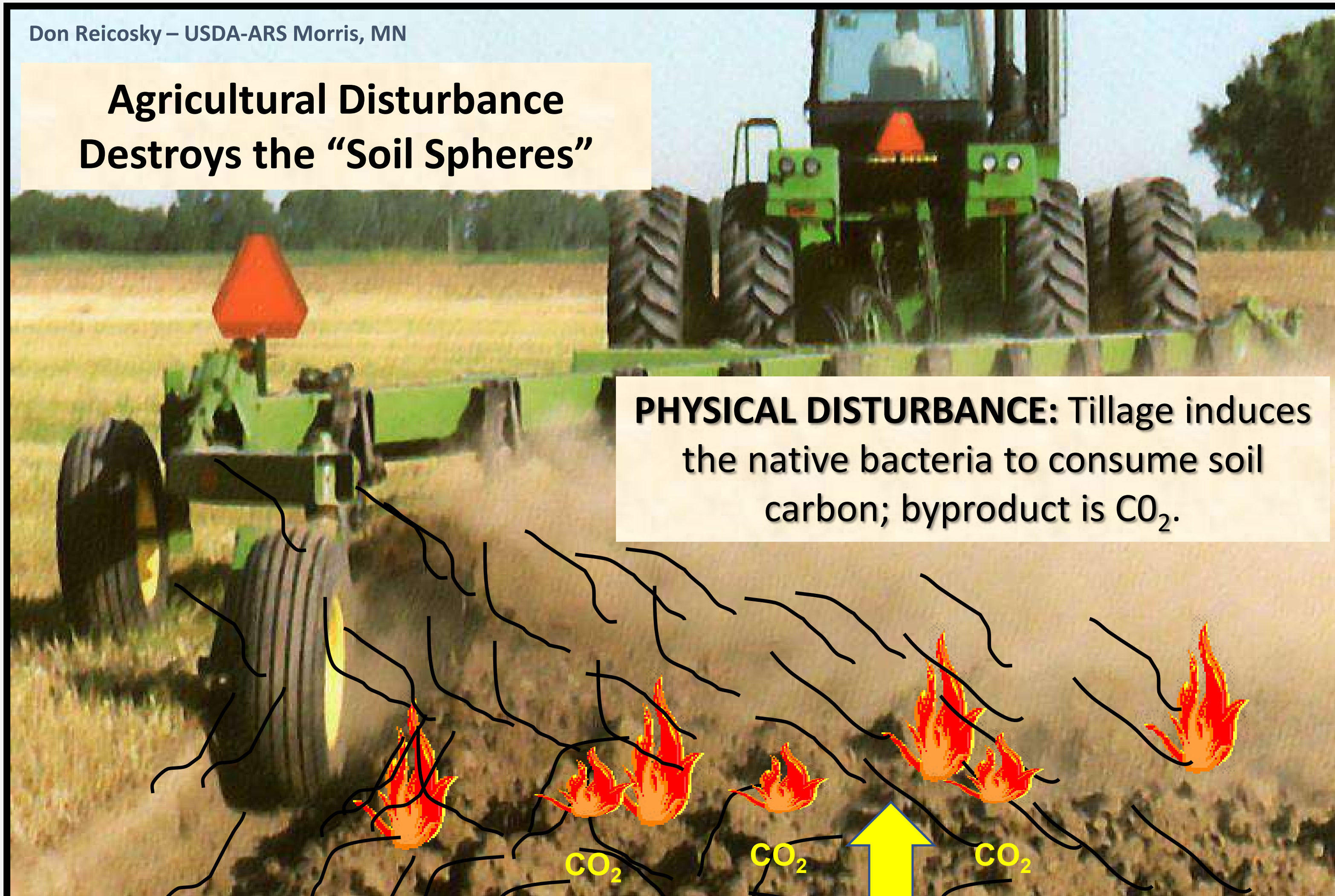


How Can the Soil Microbiome be Manipulated?

- 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

United States Department of Agriculture

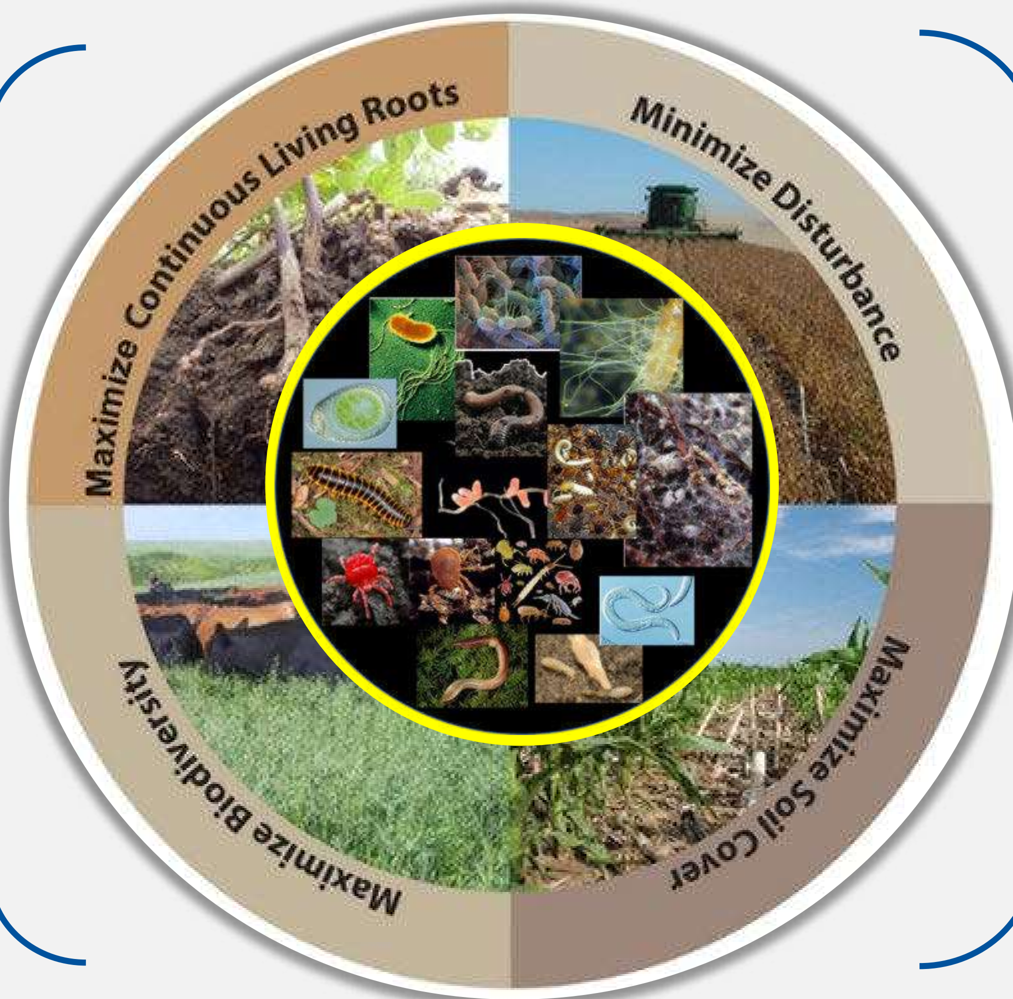
Agricultural Disturbance Destroys the "Soil Spheres"



Loss of SOM as CO_2

Soil Health Principles

[Feed](#) & Fuel Soil Biology



[Protect](#) Soil Aggregates & Organic Matter

*Modified from USDA –NRCS-Principles for High Functioning

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

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

Polling Questions