# Soil Biota and Their Impact on Soil Health

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# Outline

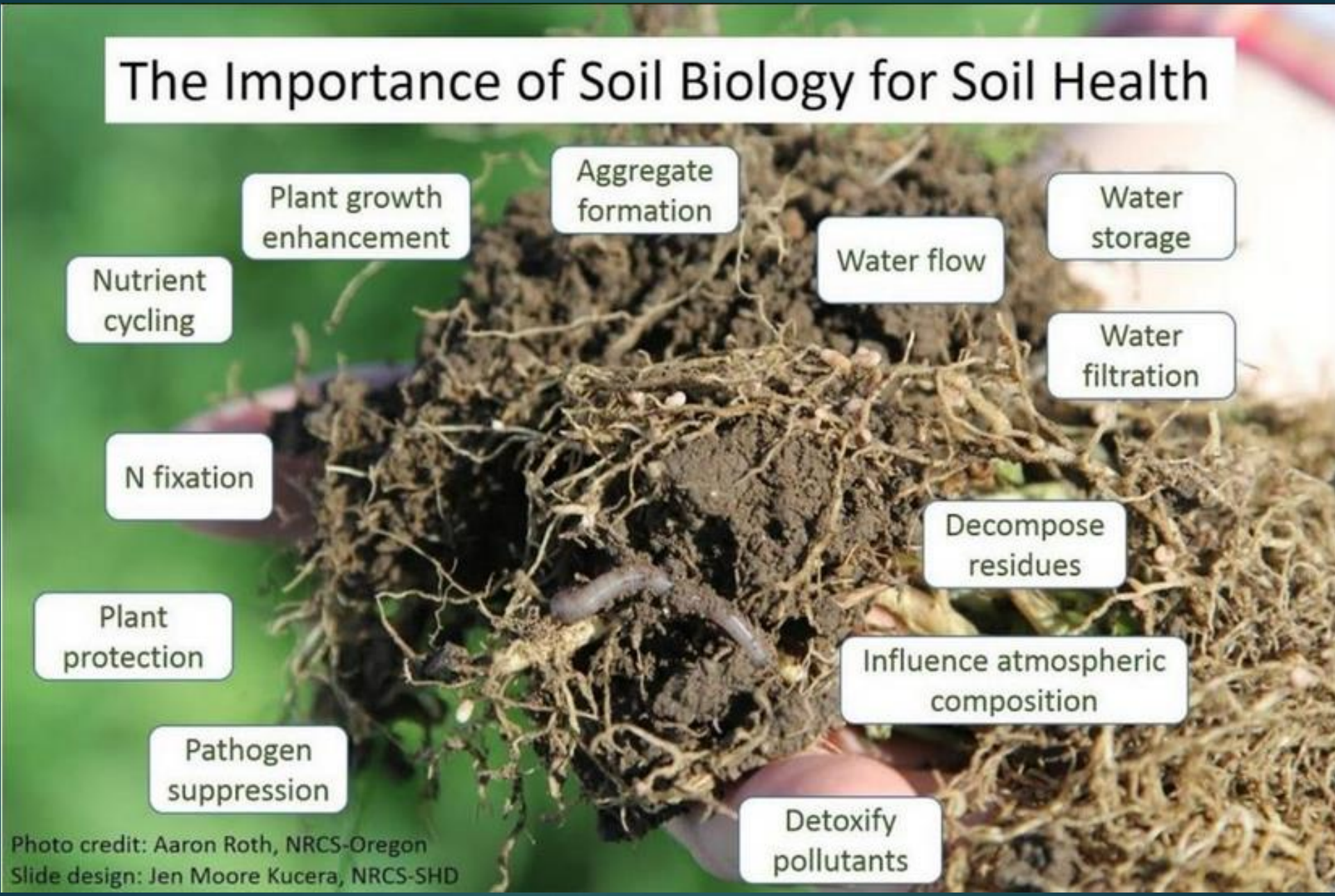
Importance of the soil biota

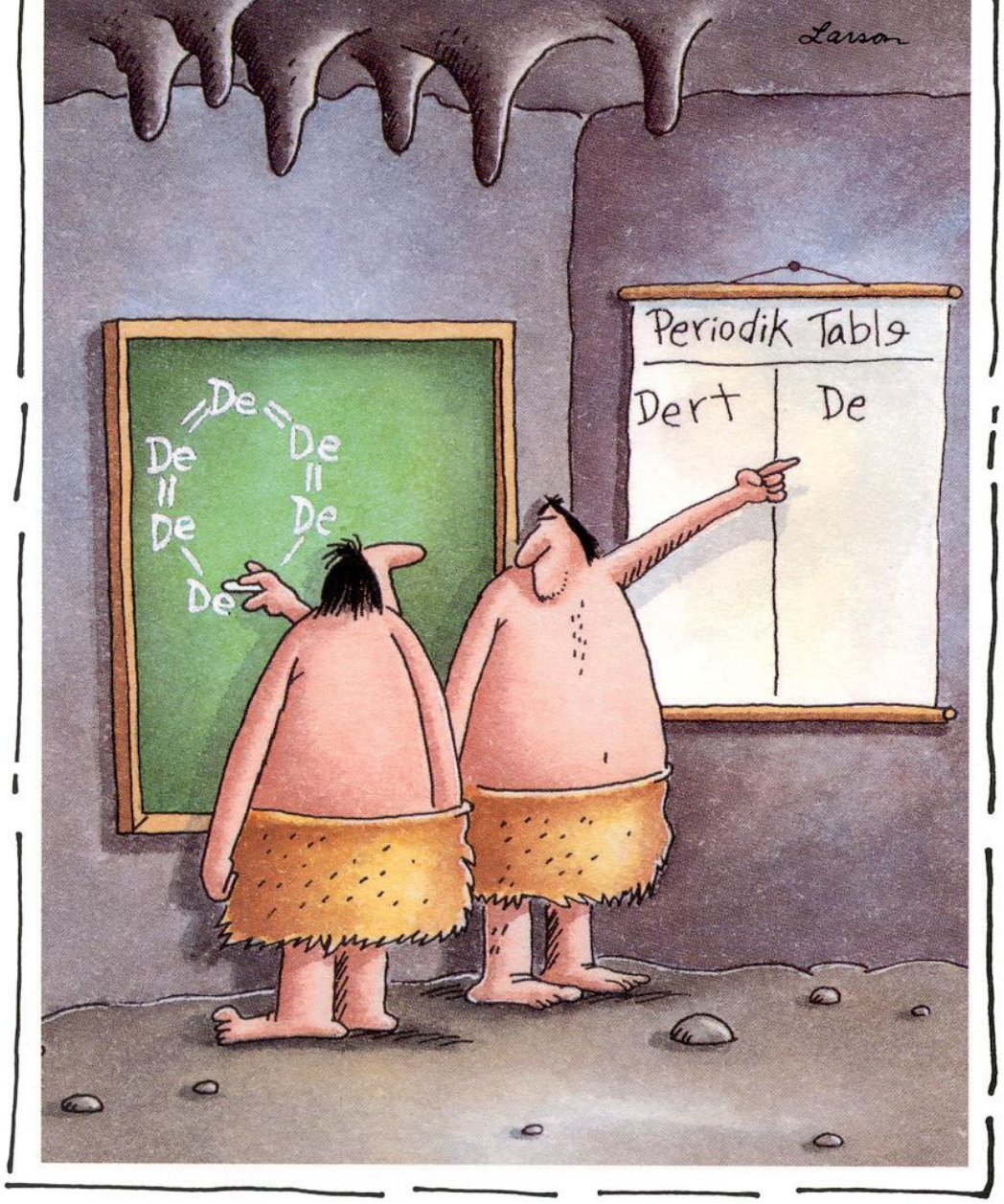
Energy and organic matter formation

Introduction to main groups of the soil biota

Hot spots of biological activity in soils

Summary


The Importance of Soil Biology for Soil Health
Plant growth enhancement
Aggregate formation
Water storage
Water flow
Nutrient cycling
Water filtration
N fixation
Decompose residues
Plant protection
Influence atmospheric composition
Pathogen suppression
Detoxify pollutants
Photo credit: Aaron Roth, NRCS-Oregon
Slide design: Jen Moore Kucera, NRCS-SHD




Early chemists describe the first dirt molecule.

# Energy

**Critical to microbial survival and function in the soil environment**

Gary Larson

# Biological activity
# Primary limiting factors

- Energy supply
  - light penetration for plants
  - substrate quality/availability for soil organisms
- Source of cell carbon
  - Carbon dioxide for plants
  - Organic carbon for most soil organisms

# Capture Energy & Fix C

+ $CO_2$
$H_2O$


$O_2$

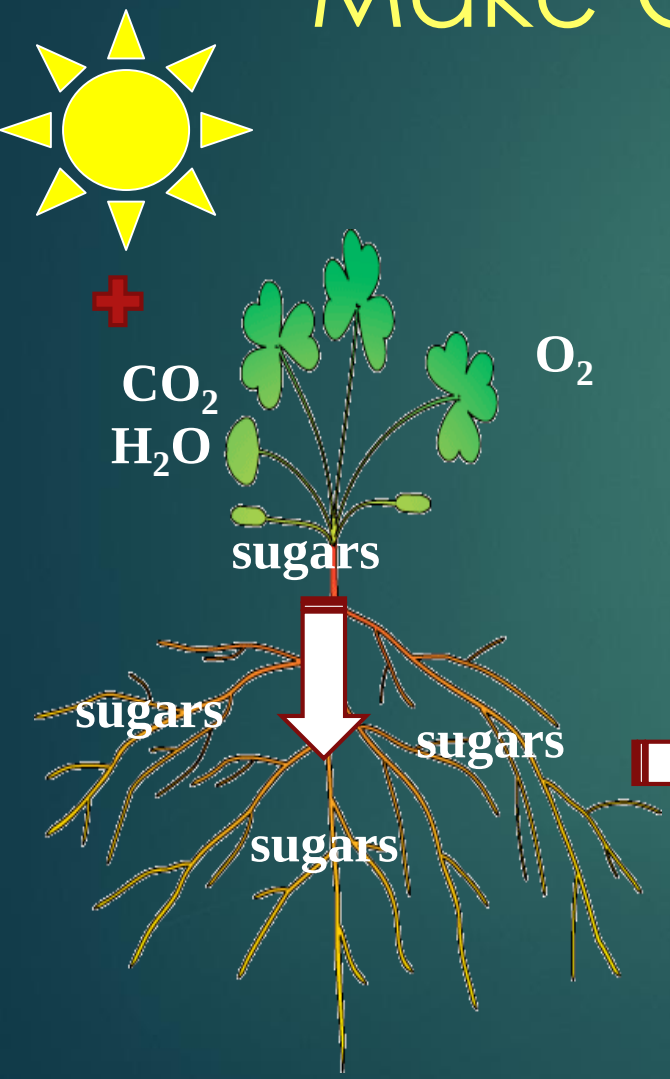
Photo: J. Moore Kucera, NRCS-SHD

# Capture Energy & Exude C

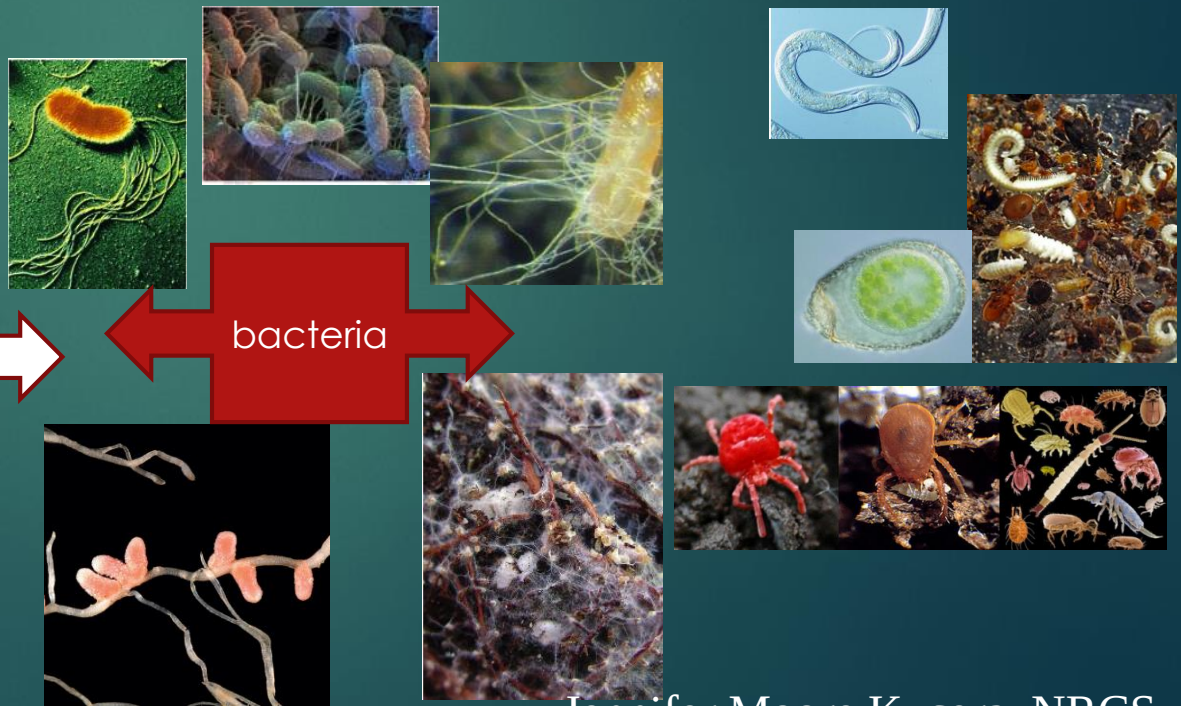

Photo source https://landinstitute.org/our-work/perennial-crops/global-inventory-project/

Jennifer Moore Kucera, NRCS

# Capture Solar Energy
# Make Organic Carbon

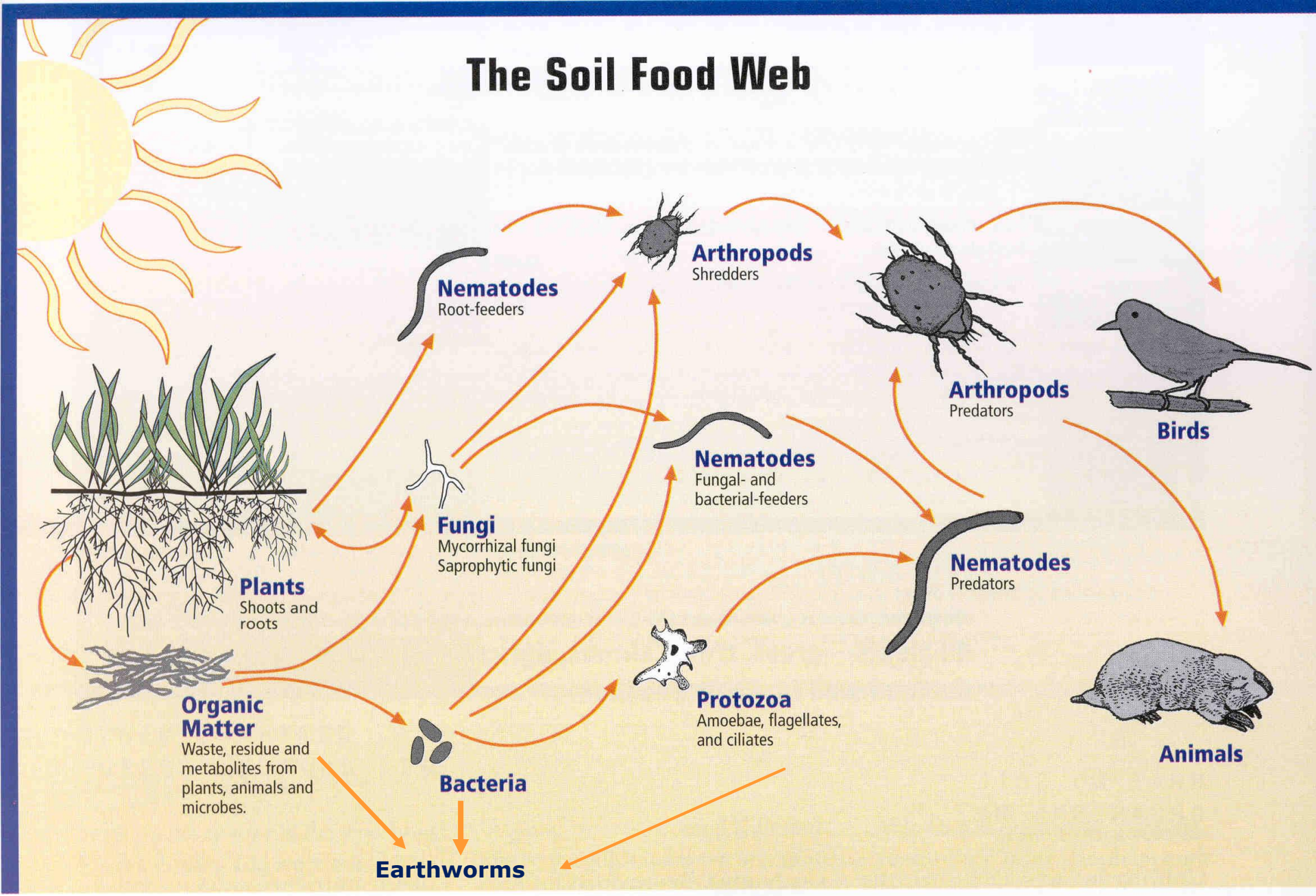



Creates a biological hot spot → Rhizosphere




Jennifer Moore Kucera, NRCS

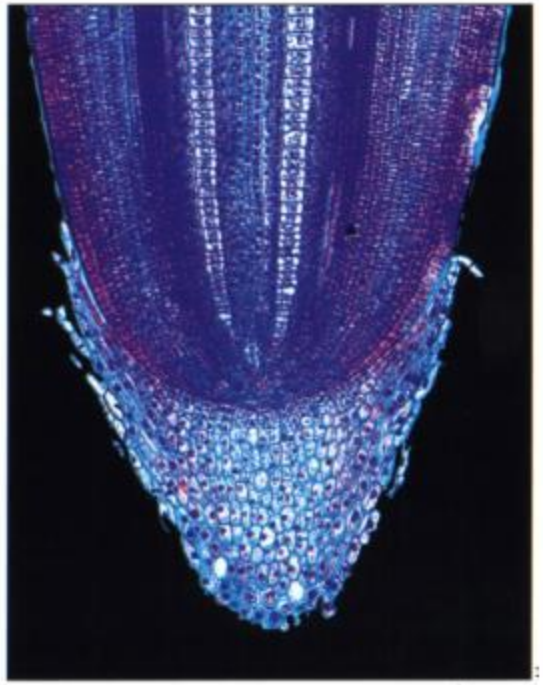
# The Soil Food Web



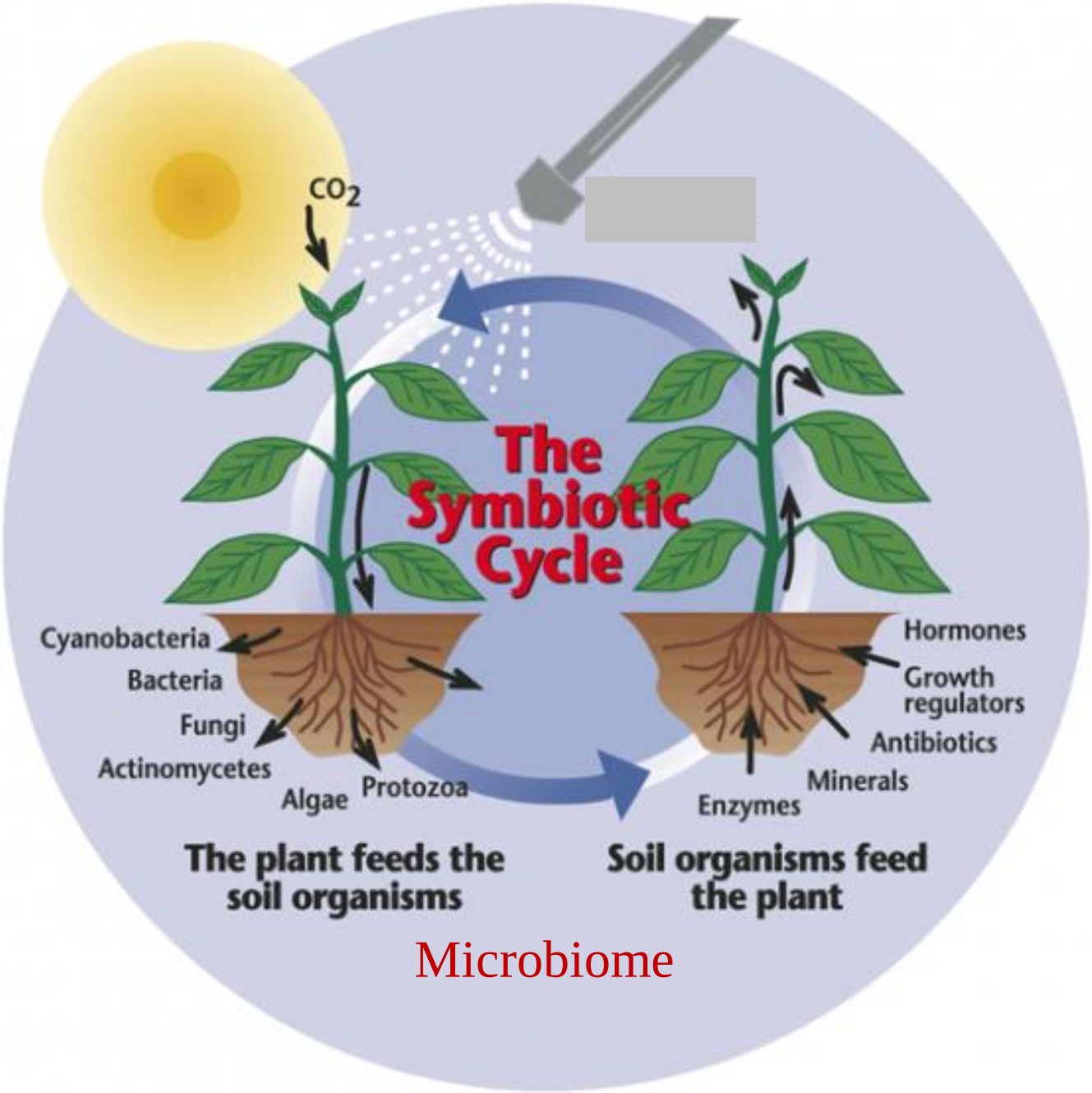

| First trophic level: | Second trophic level: | Third trophic level: | Fourth trophic level: | Fifth and higher trophic levels: |
|---|---|---|---|---|
| Photosynthesizers | Decomposers Mutualists<br>Pathogens, Parasites<br>Root-feeders | Shredders<br>Predators<br>Grazers | Higher level predators | Higher level predators |

# The Rhizosphere
## = a Carbon pump

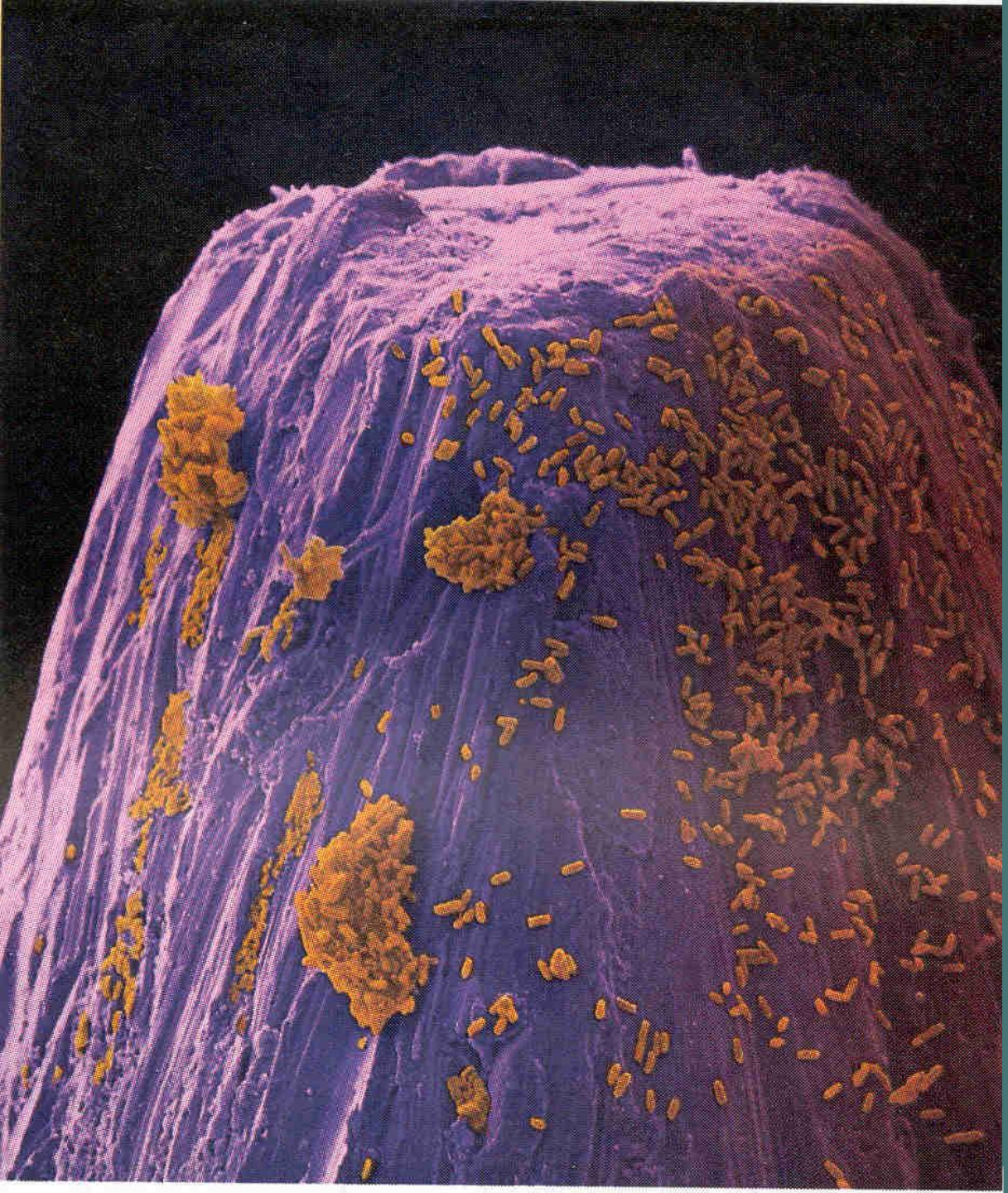
Exudates
Secretions
Lysates



Root exudates & chemical signals
stimulate microbes & predators


$CO_2$
The Symbiotic Cycle
Cyanobacteria
Bacteria
Fungi
Actinomycetes
Algae
Protozoa
Hormones
Growth regulators
Antibiotics
Minerals
Enzymes
The plant feeds the soil organisms
Soil organisms feed the plant

Microbiome



# Bacteria

Decompose OM

Release nutrients

Retain nutrients

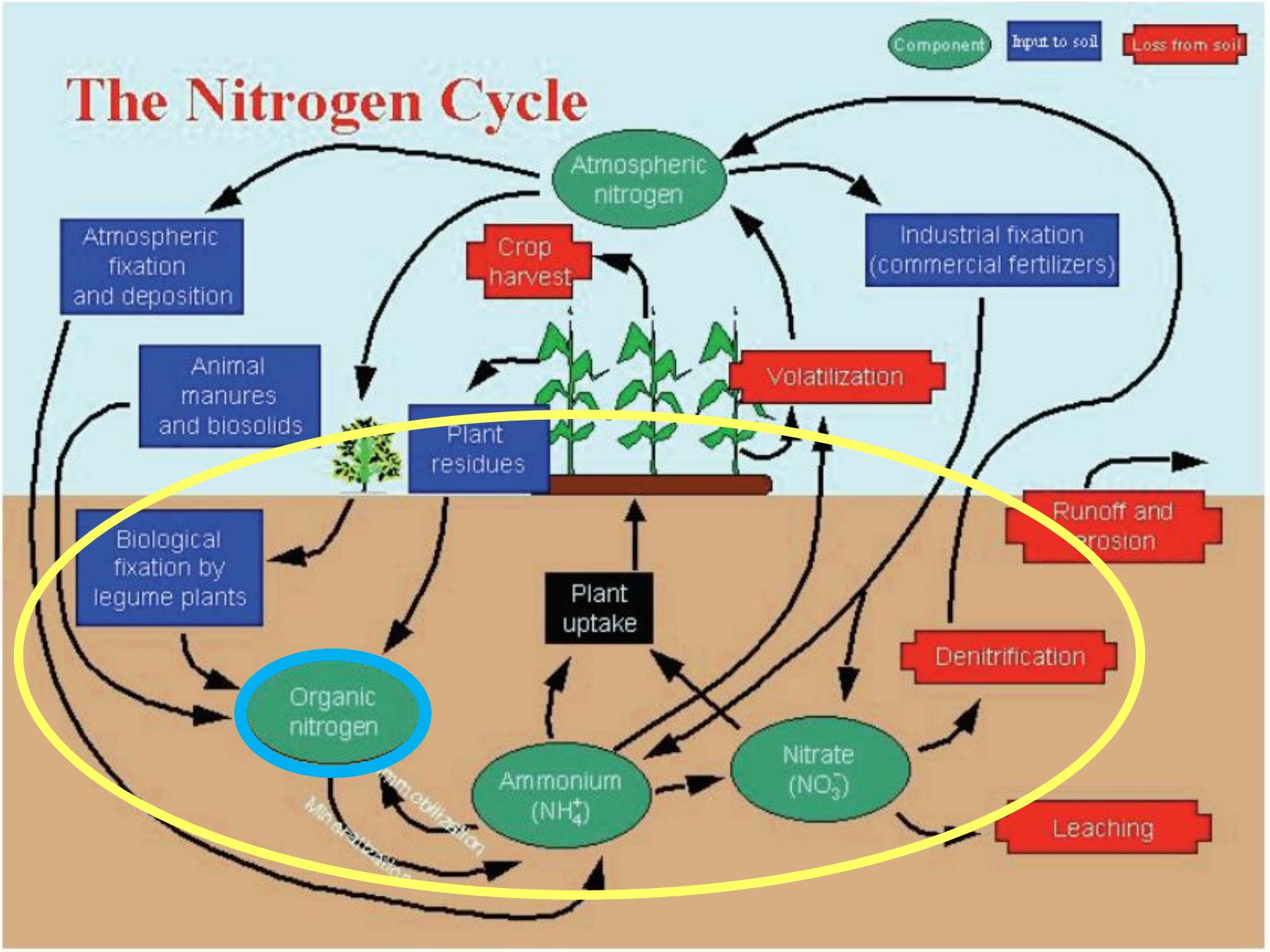
Control pathogens

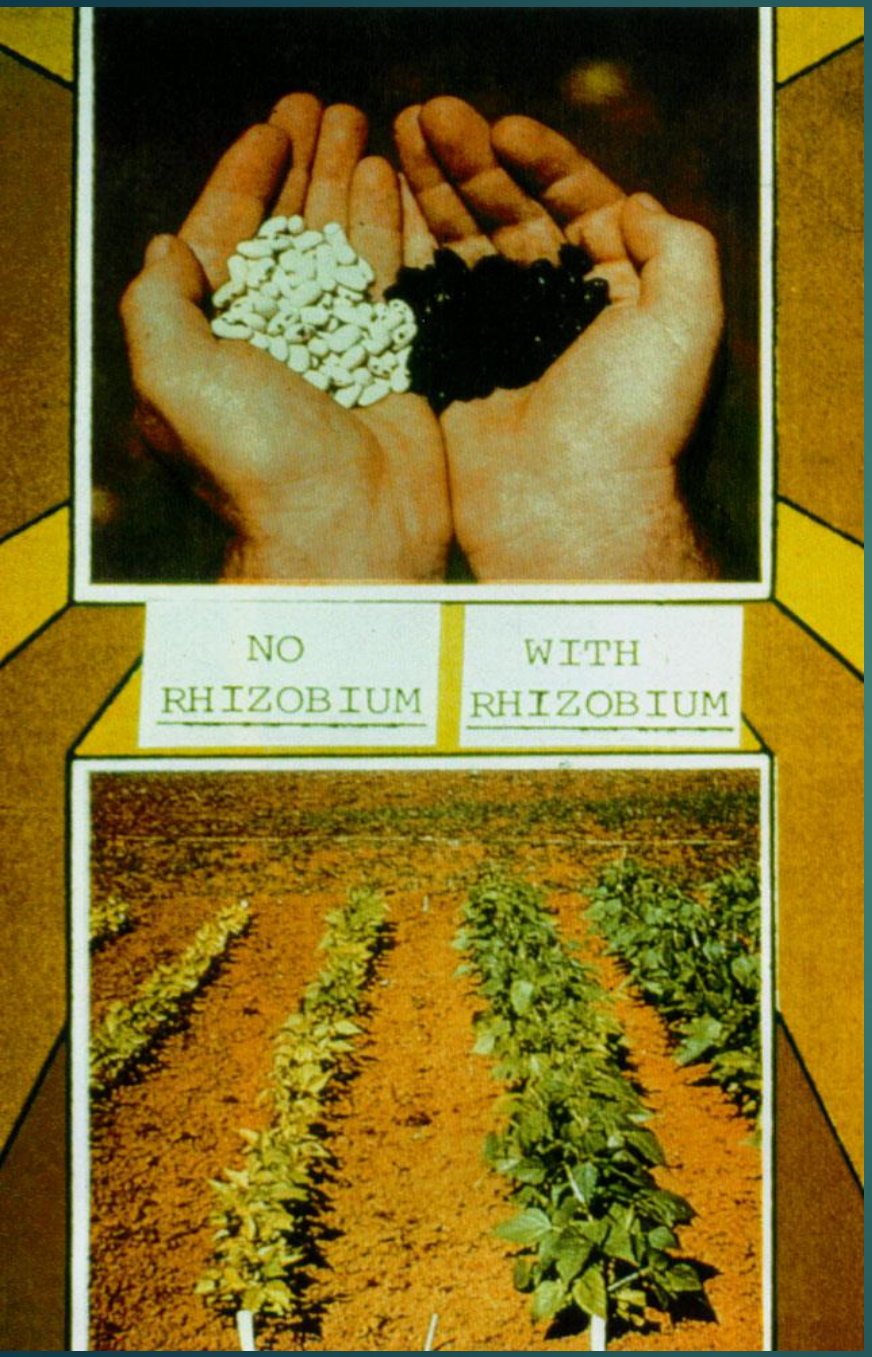
Are pathogens!

Solubilize P

Aggregate soil

Form soil organo-mineral association

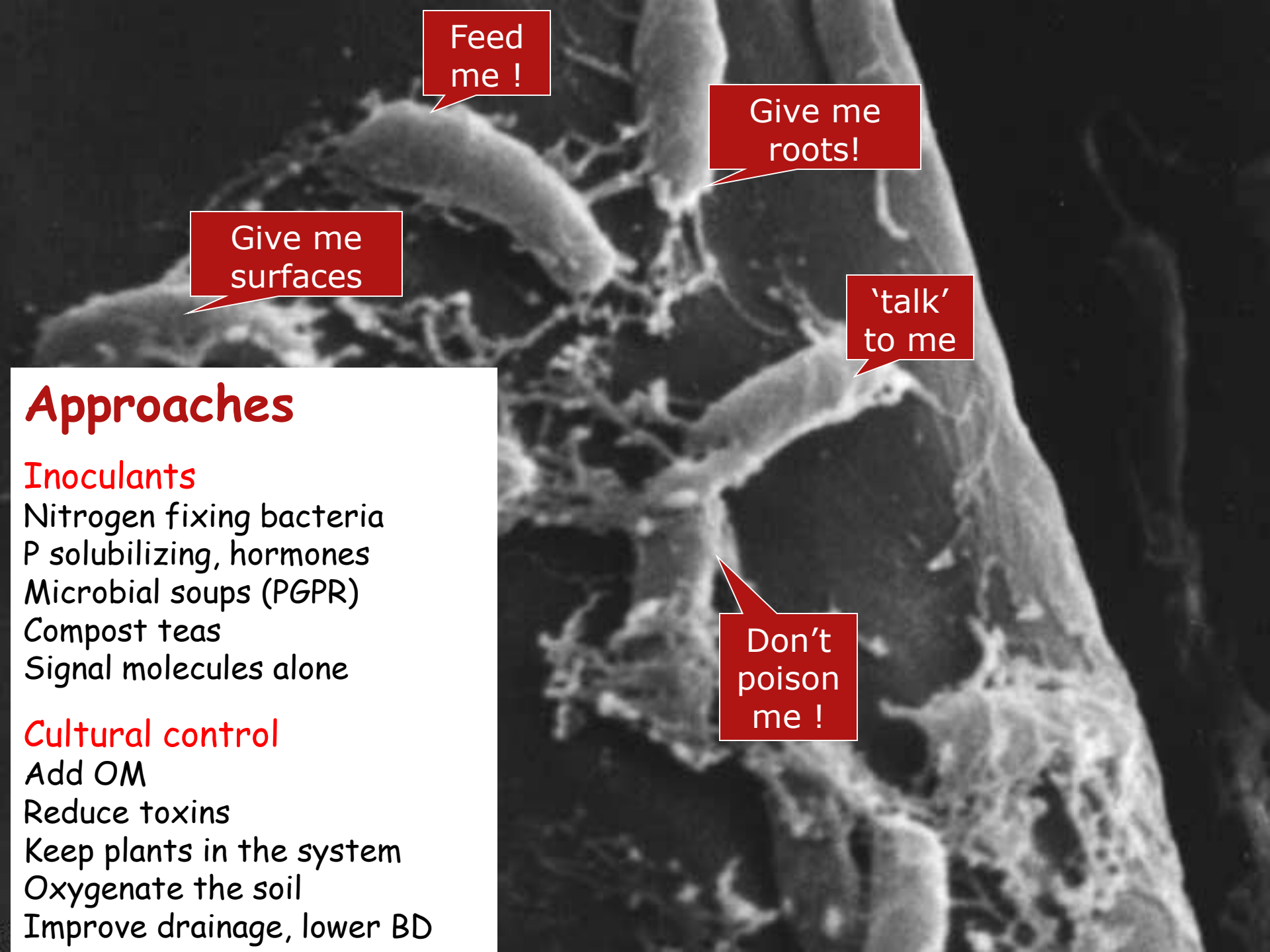

Component
Input to soil
Loss from soil
The Nitrogen Cycle
Atmospheric nitrogen
Atmospheric fixation and deposition
Crop harvest
Industrial fixation (commercial fertilizers)
Animal manures and biosolids
Volatilization
Plant residues
Biological fixation by legume plants
Runoff and erosion
Plant uptake
Denitrification
Organic nitrogen
Ammonium ($NH_4^+$)
Nitrate ($NO_3^-$)
Leaching




# Decades of success…

Legume/*Rhizobium* symbiosis

# Inoculation response



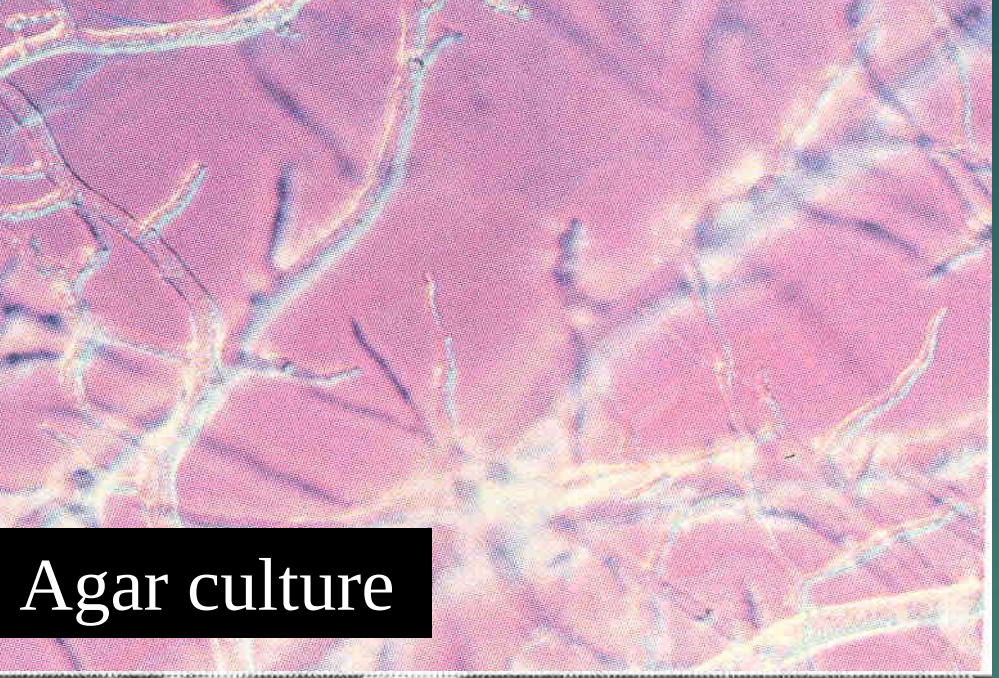

# Approaches

## Inoculants

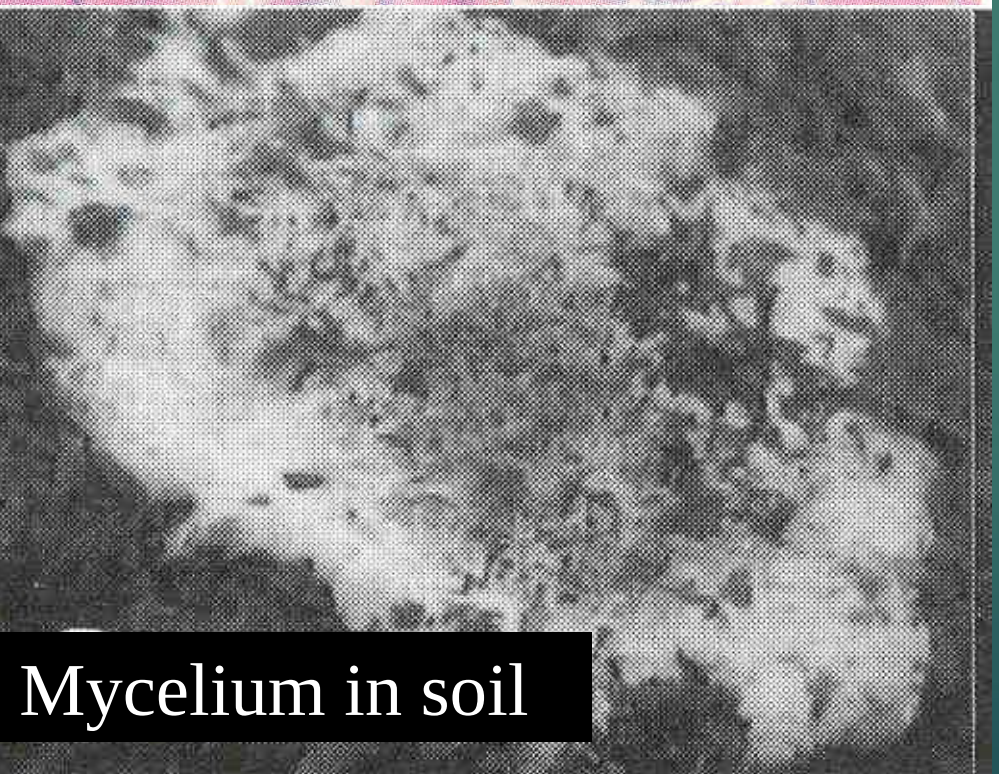
Nitrogen fixing bacteria
P solubilizing, hormones
Microbial soups (PGPR)
Compost teas
Signal molecules alone

## Cultural control

Add OM
Reduce toxins
Keep plants in the system
Oxygenate the soil
Improve drainage, lower BD



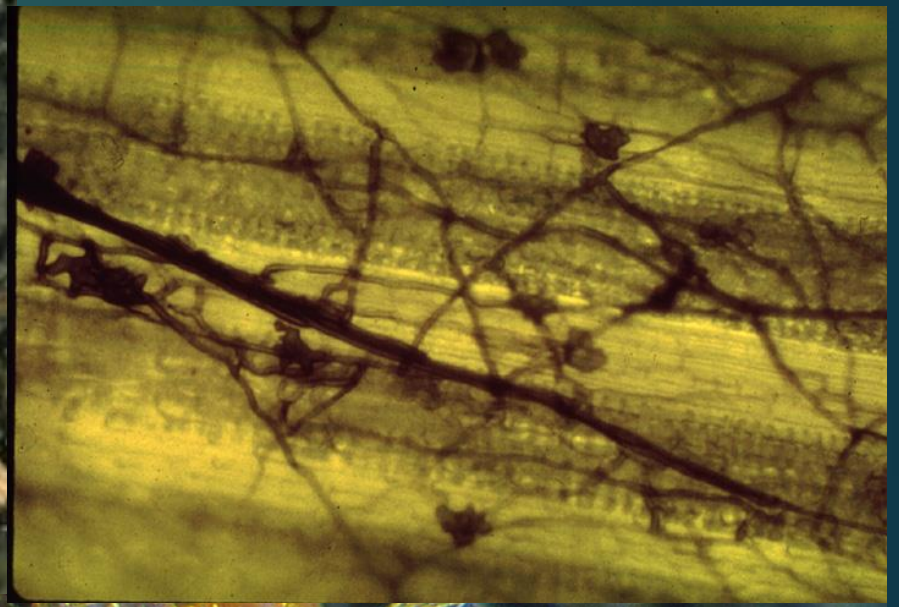
Agar culture

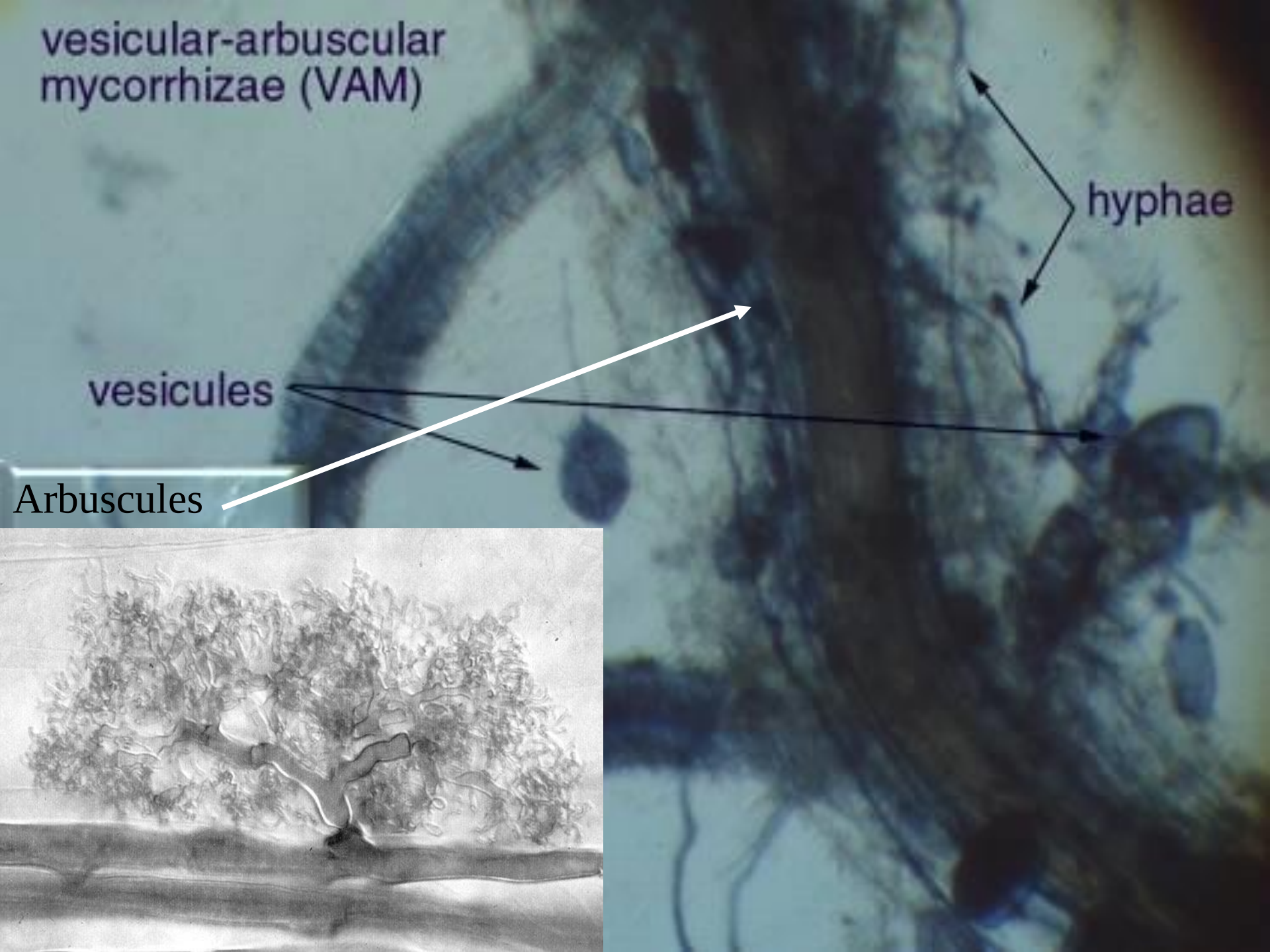


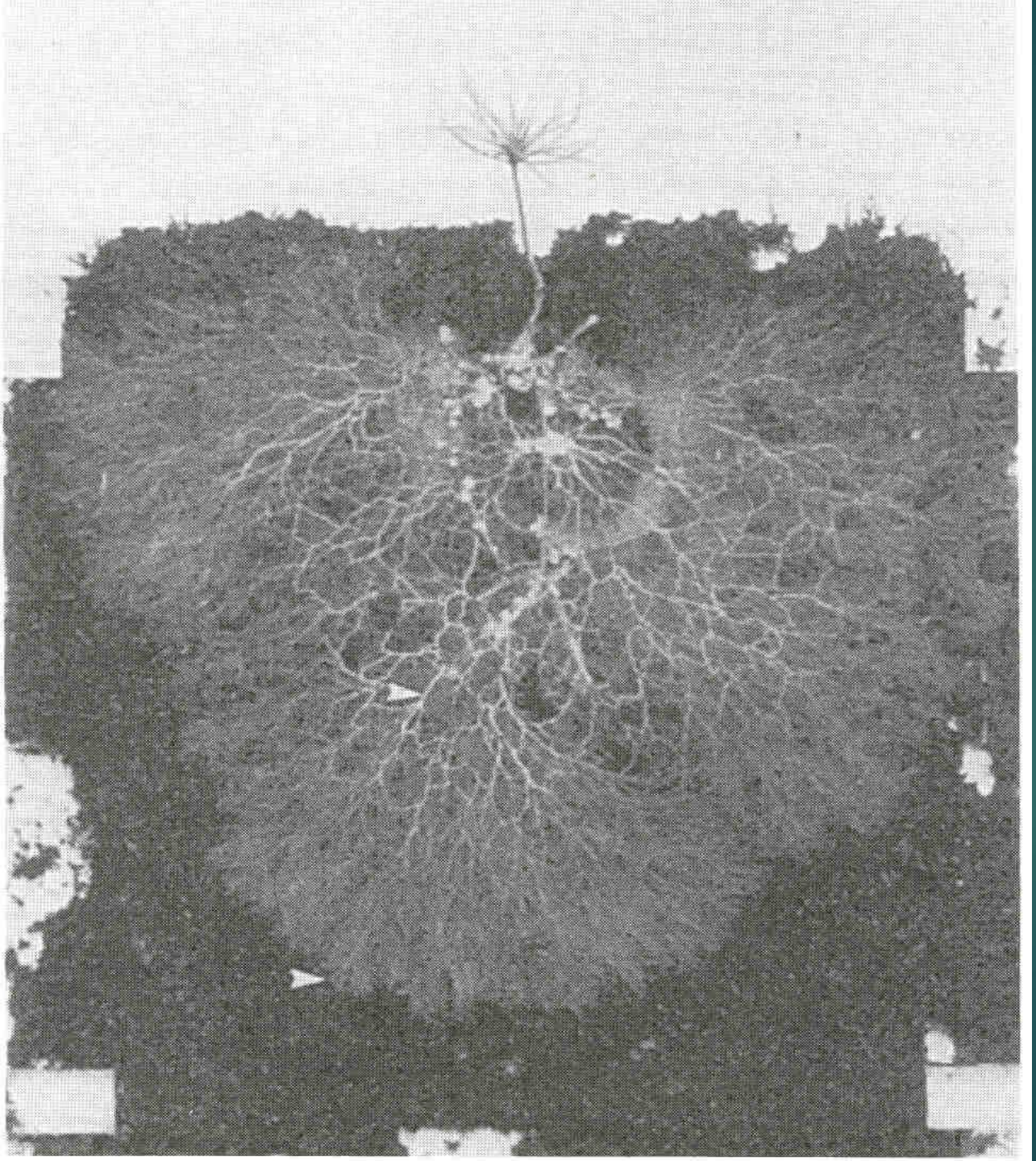
Mycelium in soil

# Fungi

- Decompose OM
- Mobilize P
- Control pathogens
- Promote plant growth
- Control insects
- Aggregate and stabilize soil




vesicular-arbuscular
mycorrhizae (VAM)
hyphae
vesicules
Arbuscules



# Ectomycorrhiza

Extended hyphal network in pine

Paul and Clark, 1994

# Approaches

## Inoculants

ECM and AMF

*Trichoderma*

*Metarhizium, Beauvaria*

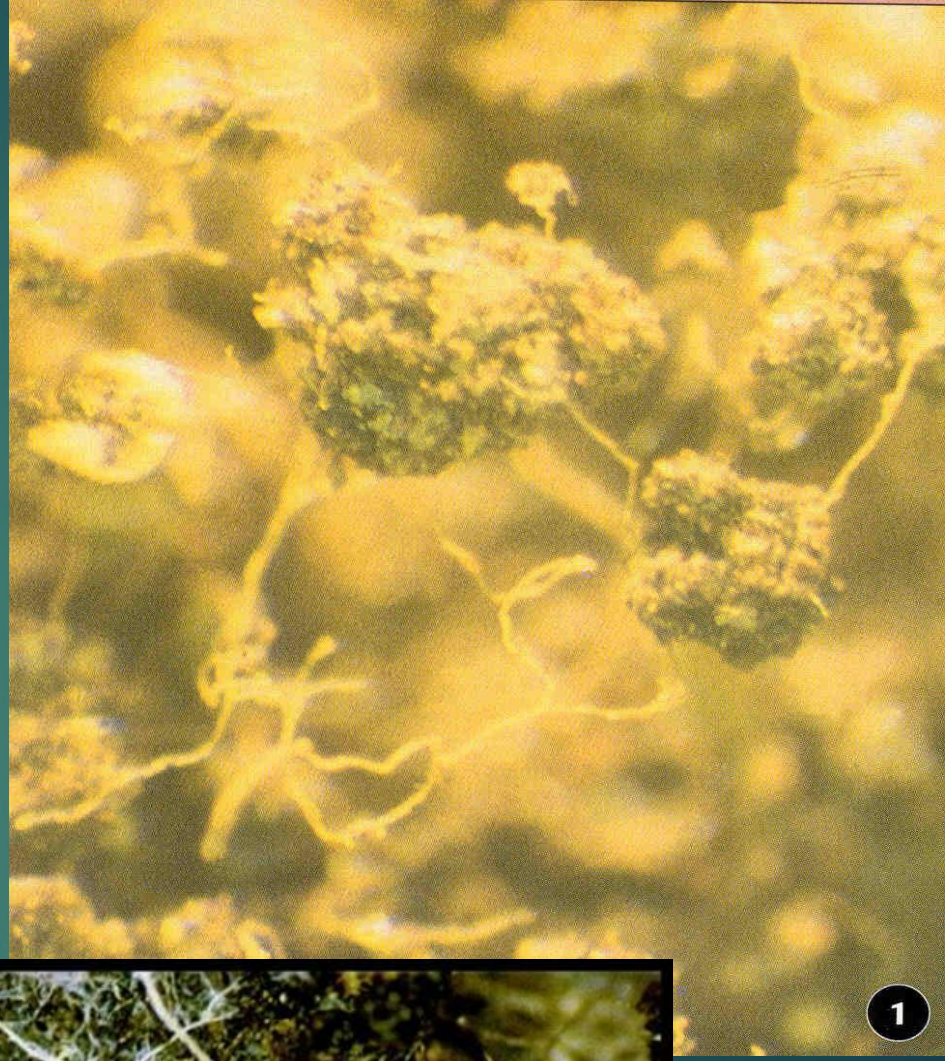
## Cultural control

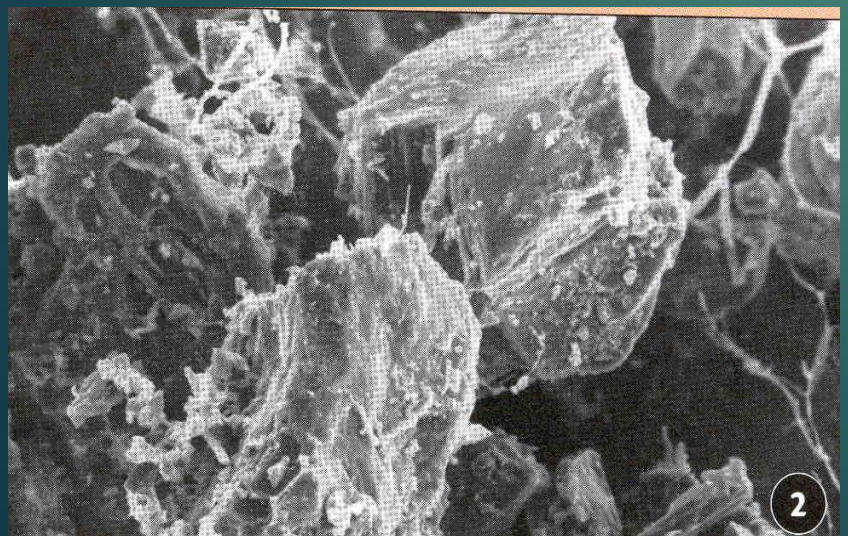
Reduce tillage

Add higher C/N OM

Reduce use of toxins

No bare fallows




# Earthworms

# Earthworms

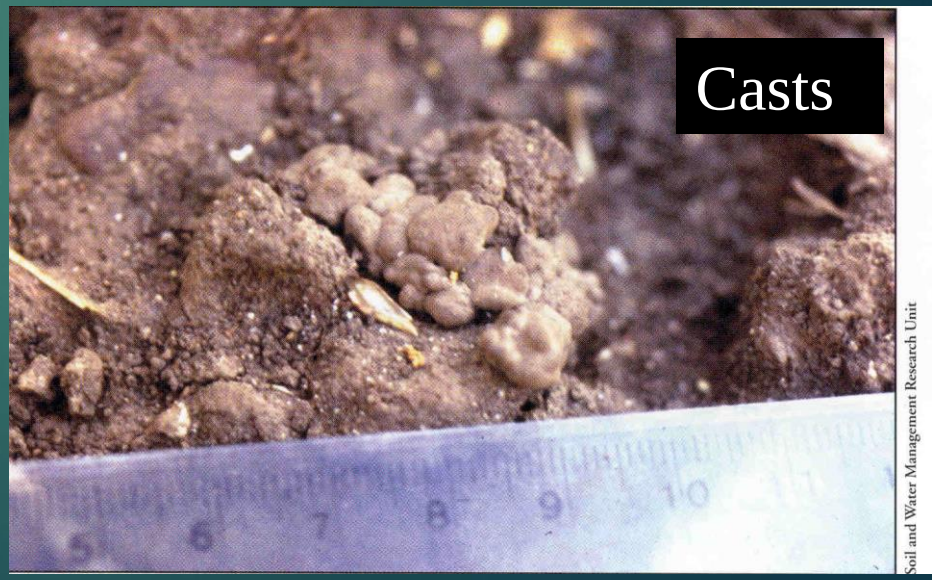
Stimulate microbial activity

Mix and aggregate soil

Increase infiltration, WHC

Provide channels for roots

Bury and shred plant residue

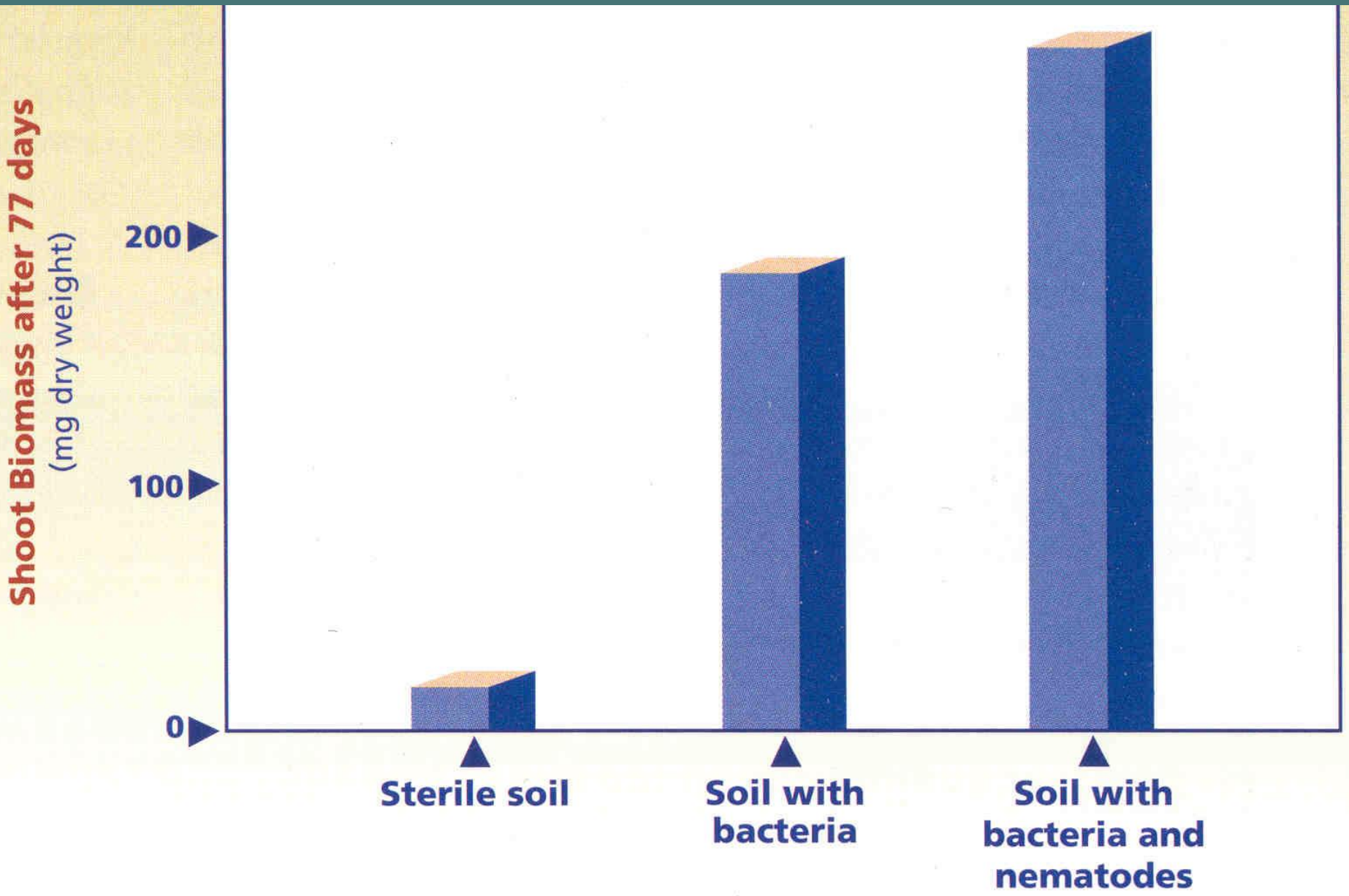




## Approaches

Cultural control

Reduce tillage, reduce use of chemicals, increase OM inputs

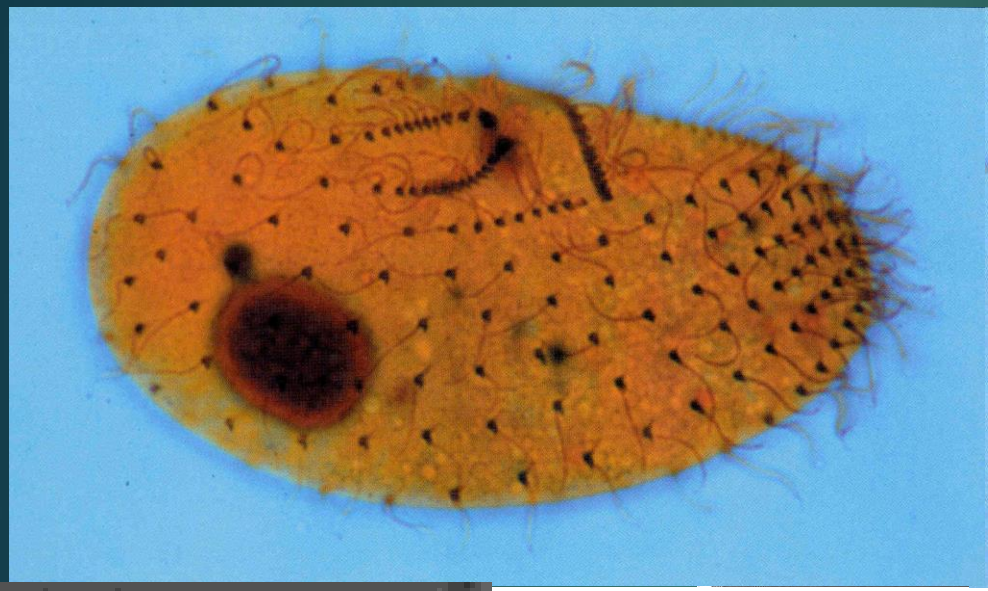
# A complex food web is needed for releasing mineral nutrients

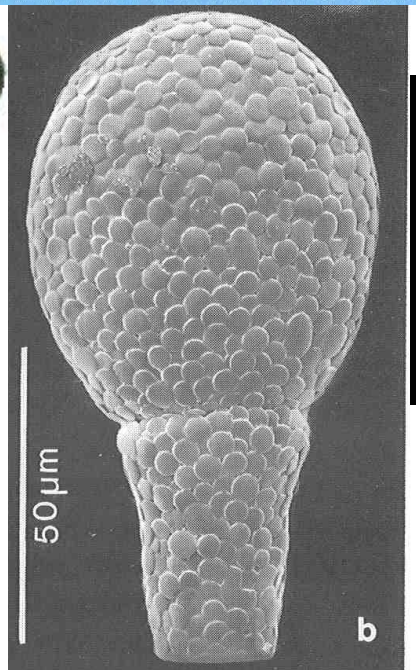


# Protozoa

Ciliates

Flagellates






Naked and testate amoebae

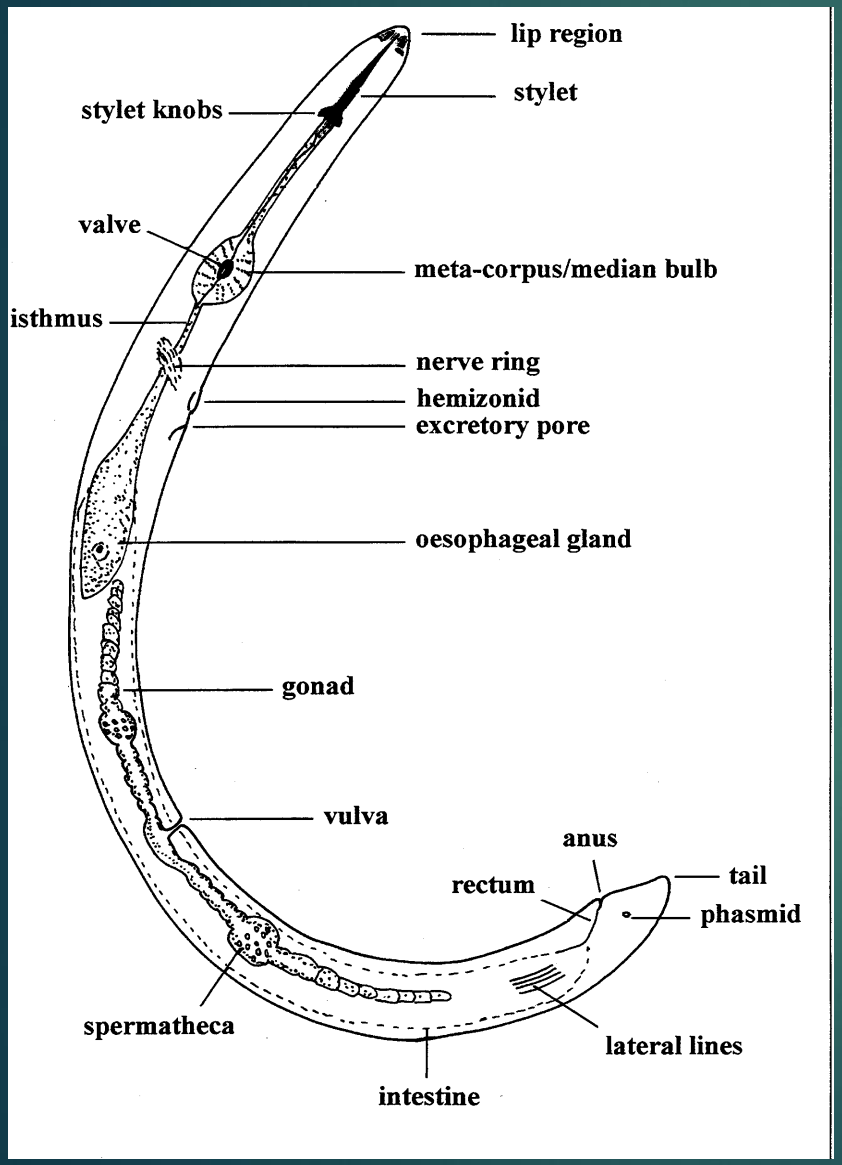
# Functional roles of protozoa

- Principal consumers of bacteria in soil
  - Regulate population size and composition
  - Accelerate turnover of soil biomass/OM
  - Maintain plant available N
  - Prevent pathogen establishment
- Indicator organisms for hazardous waste
- Food source for fungi, nematodes, others
- Cause disease (*Trypanosoma*) - parasites

# Carbon to nitrogen ratio

- C/N
- Used to estimate the likelihood of N mineralization from organic matter - < 20:1
- Used to understand the ratios of C and N required to satisfy metabolic needs
  - Bacteria  3:1
  - Fungi  15:1
  - Protozoa 10:1

# Soil Nematodes




- vermiform animals
- small (300-500 μm)
- ubiquitous in soil
- abundant
- water dependent
- diverse range of feeding strategies:
  - plant parasites
  - bacterial and fungal feeders
  - predators
  - omnivores

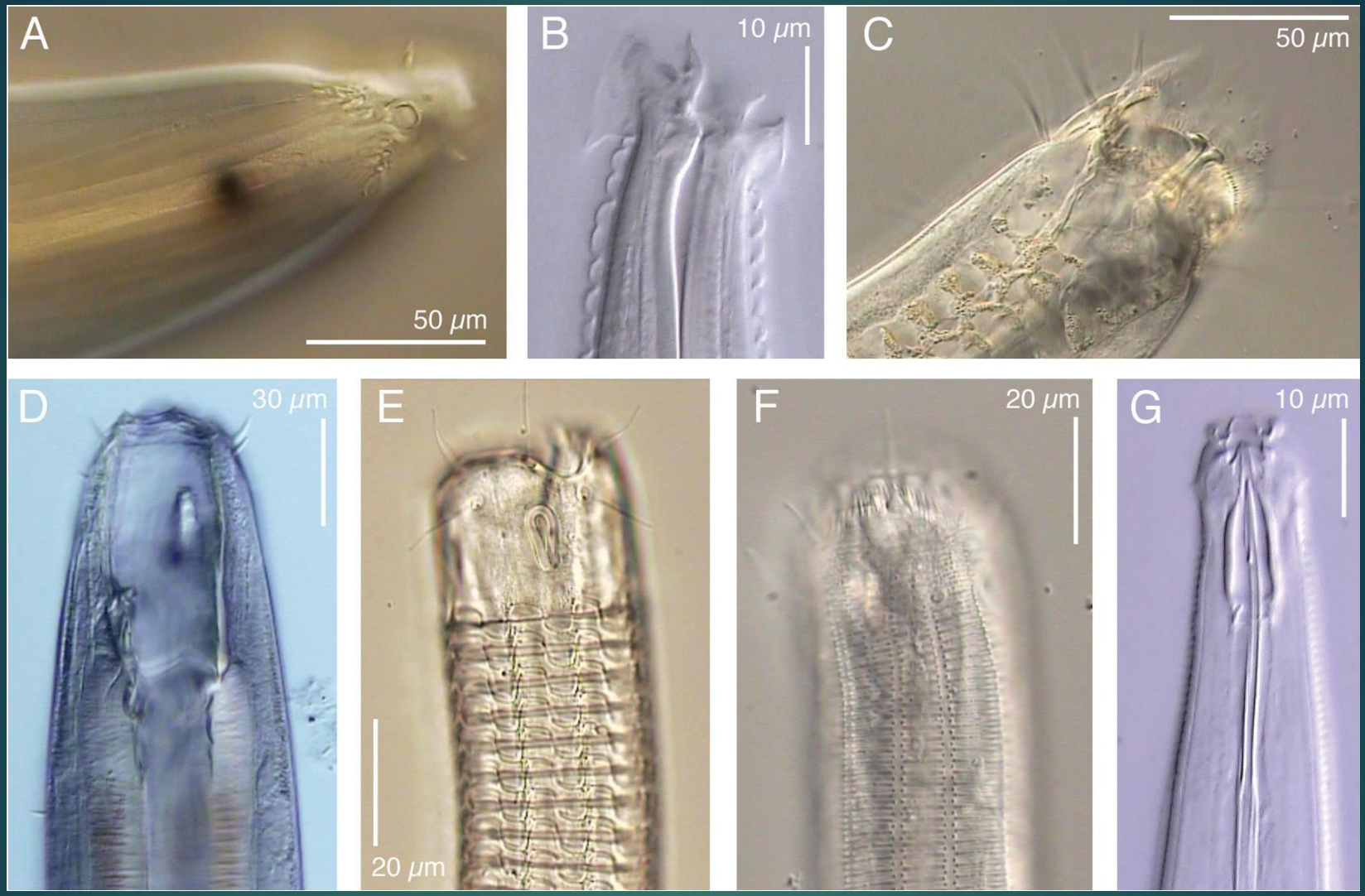



**Figure 1.** Examples of divergence in anterior morphology of some freeliving nematodes. A. *Thoracostoma* sp (Enoplina). B. *Acromoldavicus mojavicus* (Tylenchina: Cephalobomorpha). C. *Enoploides* sp. (Enoplina). D. *Pontonema* cf. *parpapilliferum* (Oncholaimina). E. *Ceramonema* sp. (Plectida). F. *Latronema* sp. (Chromadorida). G. *Actinca irmae* (Dorylaimida). Click on a picture to open a small video clip (200–600 Kb), or on a letter to open a large clip (2–5 Mb) of the depicted nematode. Use the left and right arrow keys on your keyboard to focus up and down. These clips were produced with Video Capture and Editing microscopy as described in De Ley & Bert (2002).

# Functional roles of nematodes

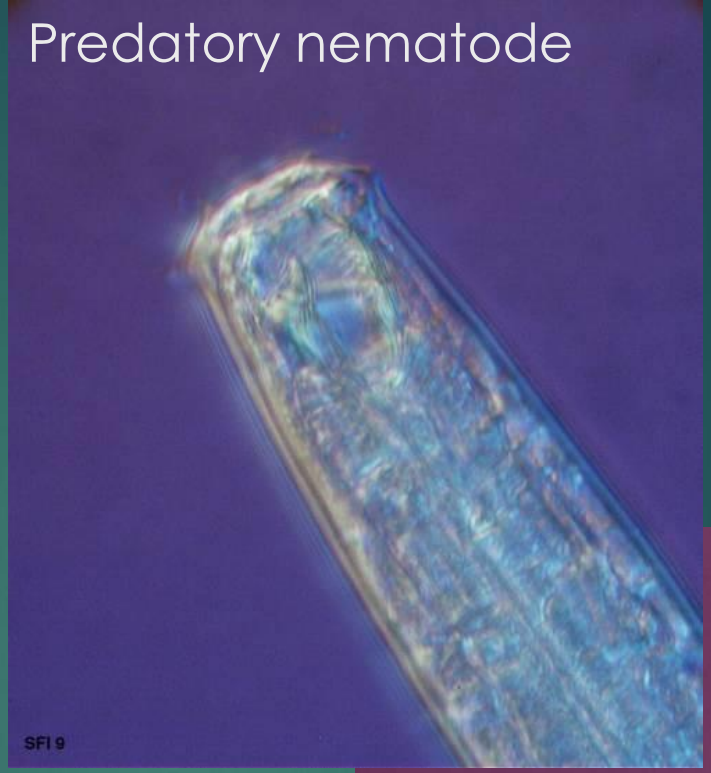
- Feed on bacteria, fungi and protozoa
  - Control bacterial numbers and population structure
  - Release large amounts of N while feeding and upon death
  - Help maintain plant available N
- Selective feeding influences
  - soil structure
  - C utilization rates
  - Types of substrates present in soil
- Plant and animal parasites

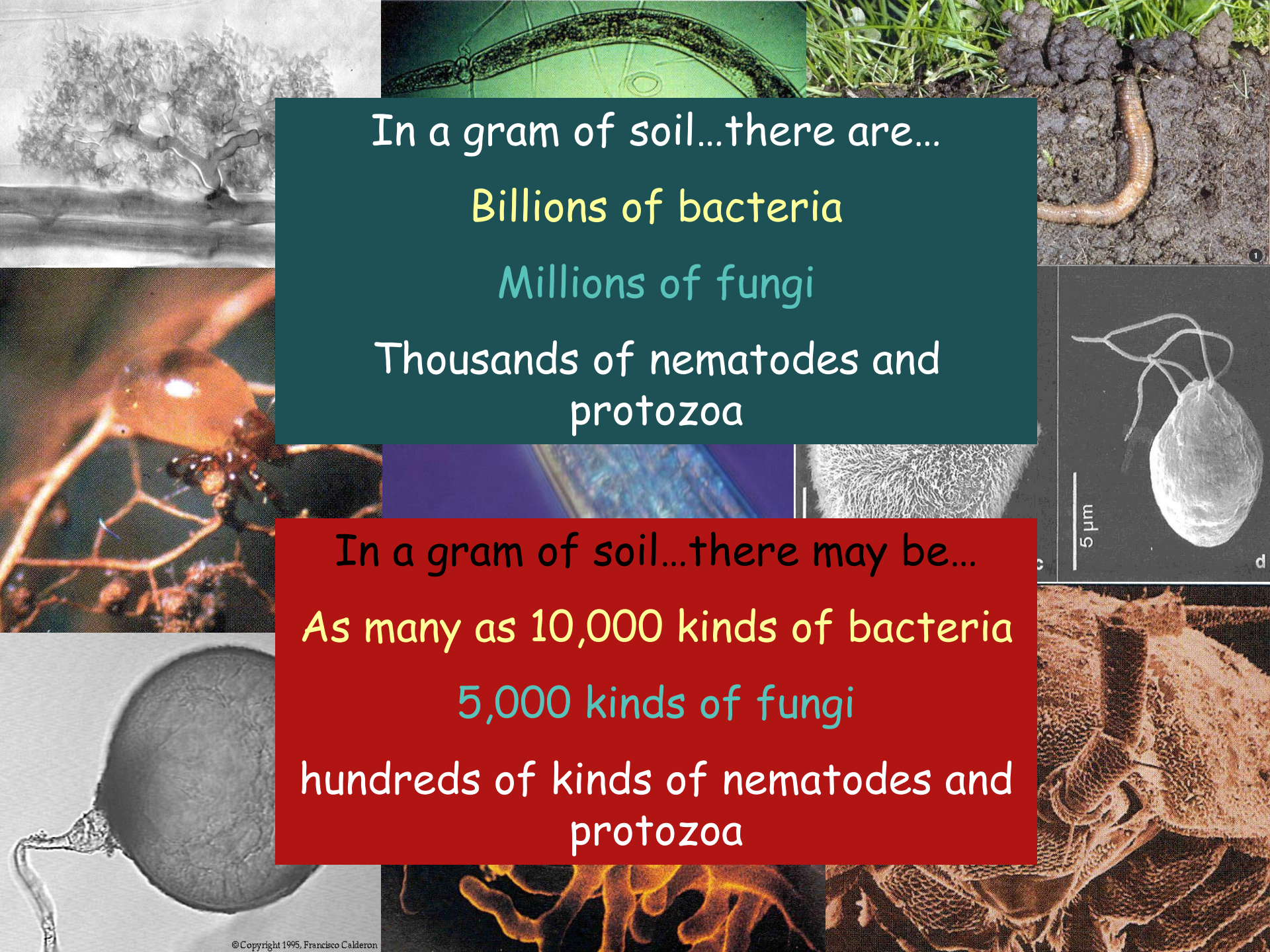
# Approaches

**Inoculants**
Entomopathogens

**Biocontrol**
Bacteria, viruses, microsporidia

**Cultural control**
Encourage diverse saprophytic food web





In a gram of soil…there are…
Billions of bacteria
Millions of fungi
Thousands of nematodes and protozoa
In a gram of soil…there may be…
As many as 10,000 kinds of bacteria
5,000 kinds of fungi
hundreds of kinds of nematodes and protozoa
5 µm
© Copyright 1995, Francisco Calderon

# Functional roles of soil fauna

Shred organic material

Stimulate microbial activity

Mix microbes with their food

Mineralize plant nutrients

Enhance soil aggregation

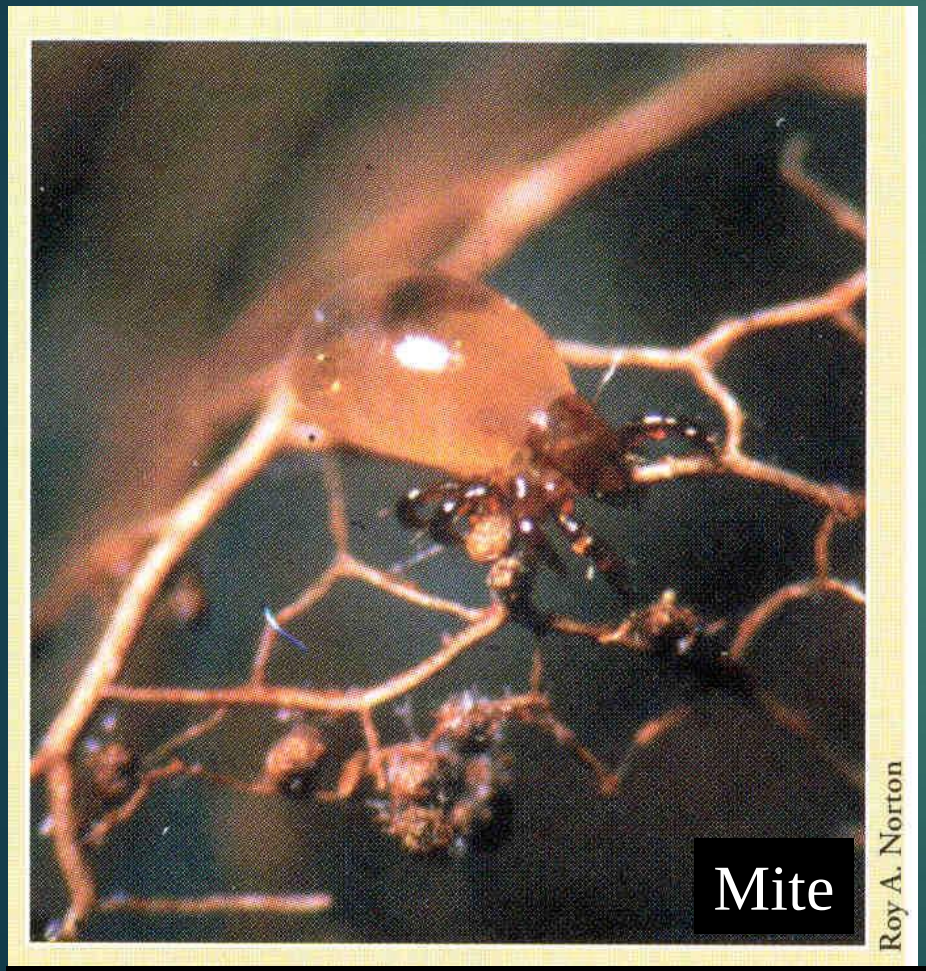
Burrow

Control pests

May also be pests

# Shredders

Dung beetle




Mite


Sow bug

# Fungal and litter grazers


# Herbivores


Symphylan

Mole cricket

# Soil predators

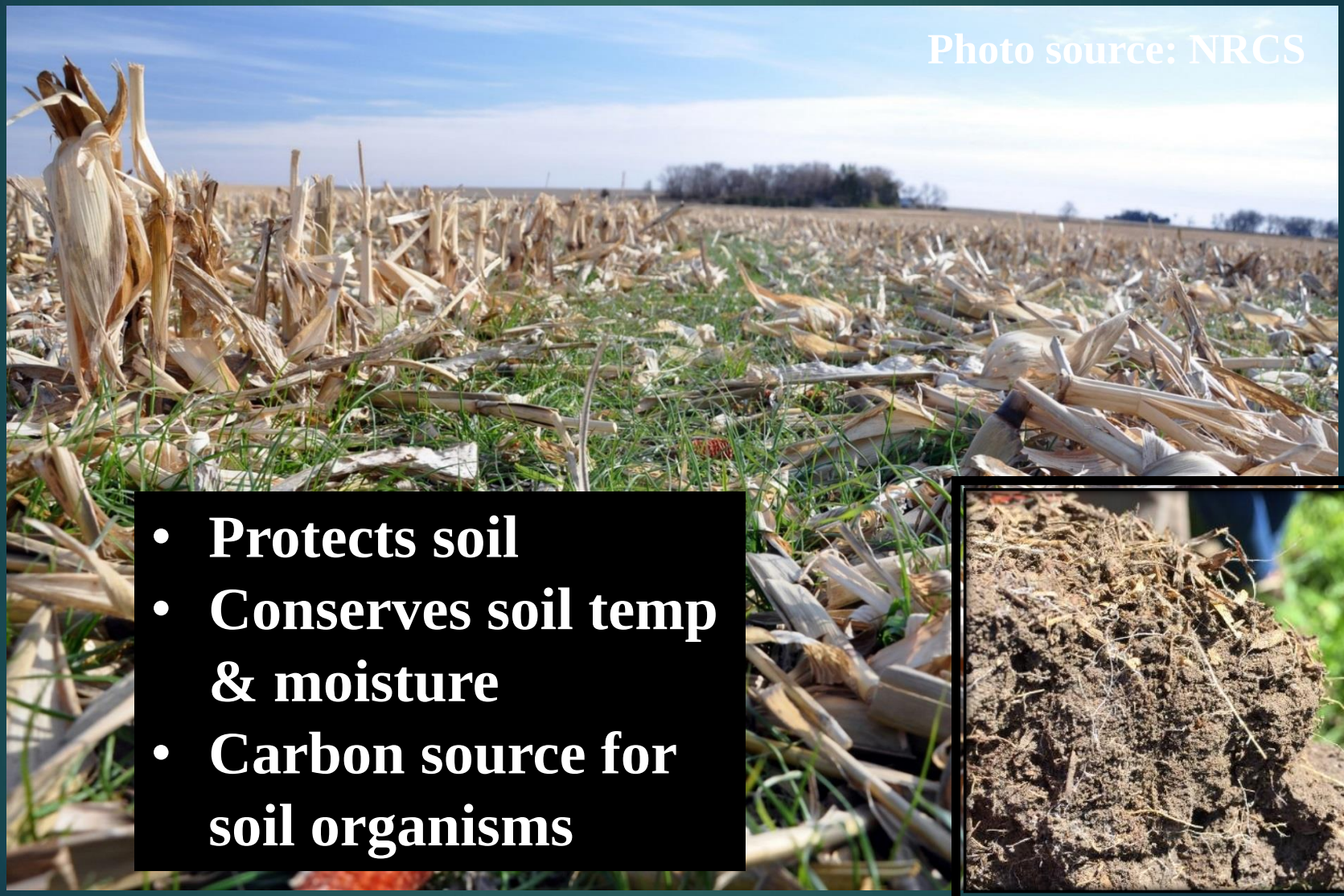
Psuedoscorpion

Wolf spider

Harvester ants

# Control crop pests

# Litter Layer (Detritusphere)




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



**Photo: J Moore Kucera NRCS**

# Detritusphere: Key Soil Organisms

**Mesofauna (Biological regulators)**

- Springtails (Collembola)
- Mites

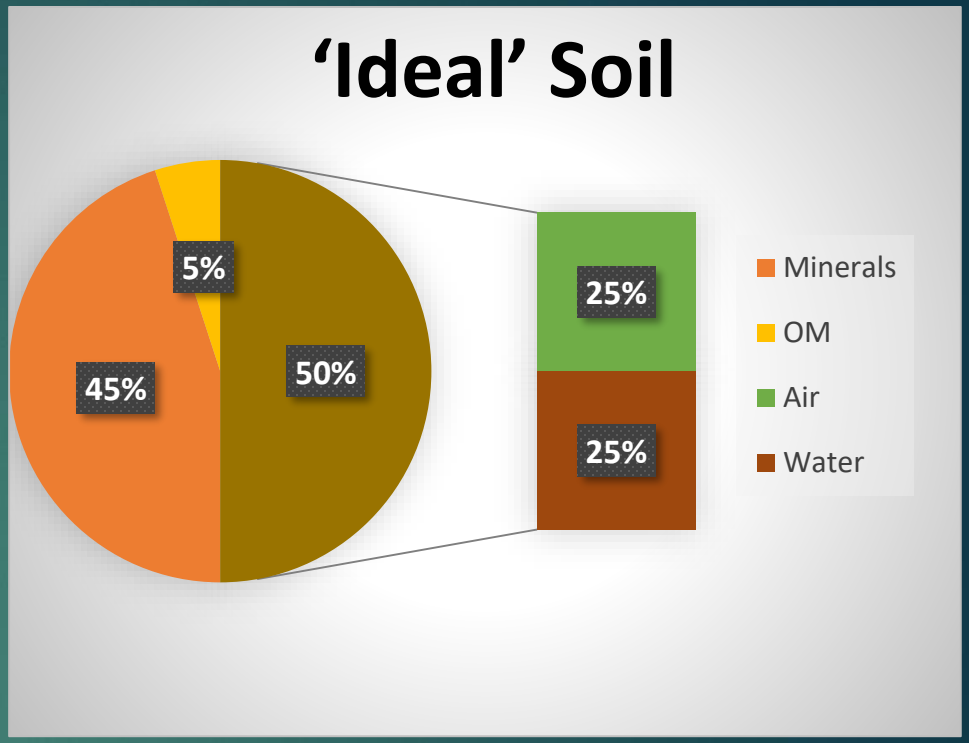
**Macrofauna (ecosystem engineers)**

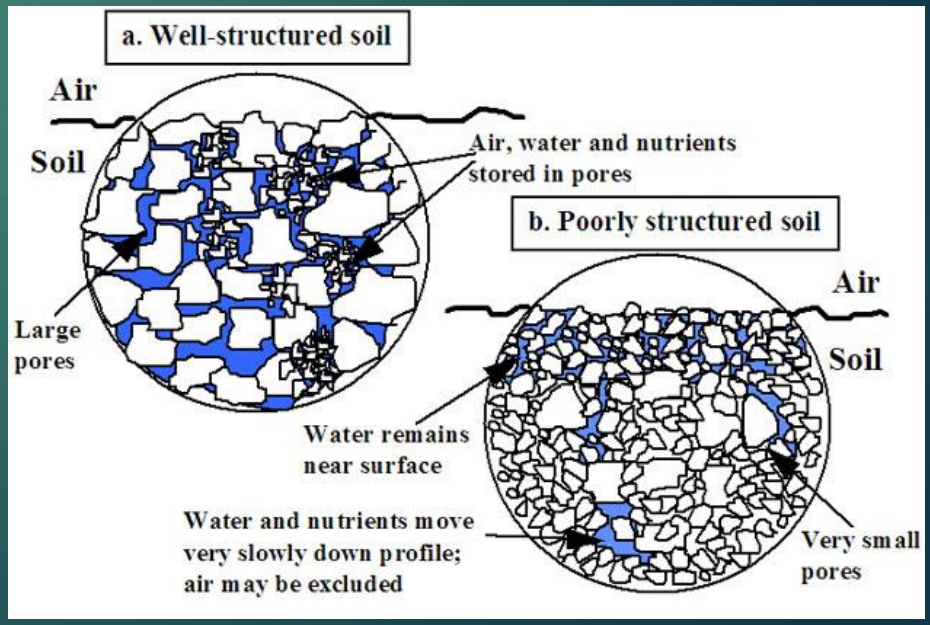
- Earthworms, beetles, centipedes, ants, isopods

Jennifer Moore Kucera, NRCS

# Pore Space (Porosphere)

- "Lungs & circulatory system"
- Air flow
- Water flow, storage, & availability
- Biological highways

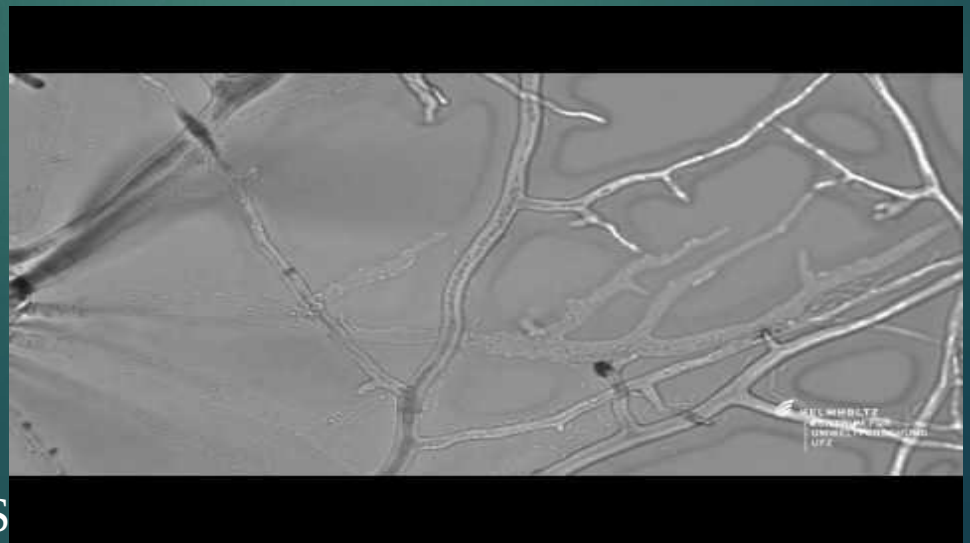



Jennifer Moore Kucera, NRCS

# Pore Space (Porosphere)

- Organisms that colonize depend on size and resources
- Many move through soil via connected pores
- Nematodes and protozoa common if prey are present (e.g., bacteria, fungi, etc.)



Jennifer Moore Kucera, NRCS

# Aggregate Surfaces (Aggregatusphere)

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

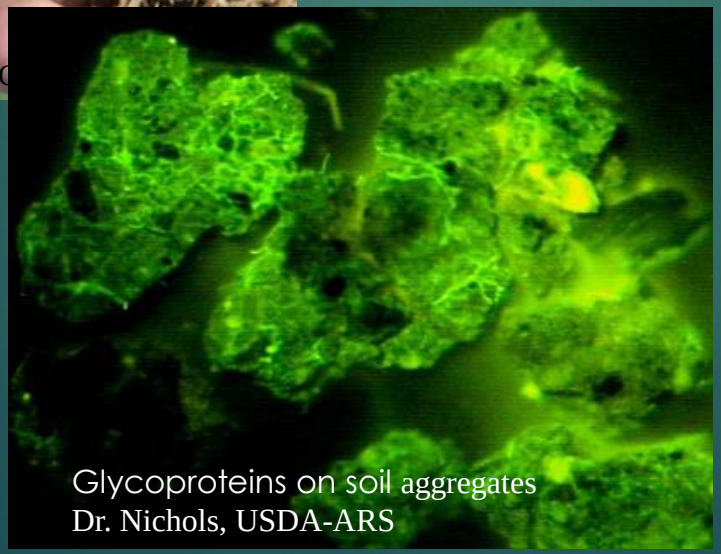
Photo: J Moore Kucera, NRCS-SHD
Soil Health Training, Pullman, WA, 2017

Jennifer Moore Kucera, NRCS

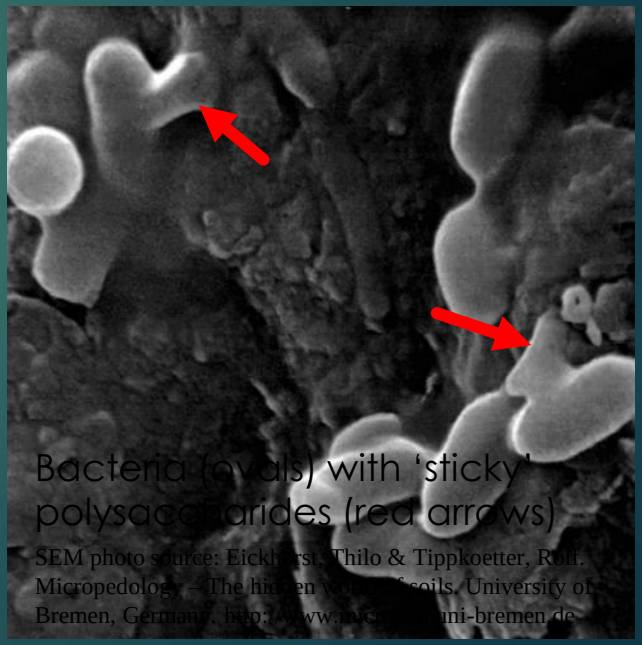
# Soil Organisms Chemically Stabilize Soil Aggregates

Image source: Aaron Roth, NRC

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



Glycoproteins on soil aggregates
Dr. 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.[illegible].uni-bremen.de

Jennifer Moore Kucera, NRCS

# Microbial activity rates

- chemical factors
  - pH, moisture, $O_2$, $CO_2$, inorganic nutrients
- physical factors
  - texture, porosity, compaction, bulk density, temperature
- biological factors
  - competition, predation, allellopathy

# Key Biological Processes in Healthy Soil

- *Organic matter* decomposition/accumulation
- Nutrient transformations & availability
- Disease, disease suppression
- Well-supported microbial community, beneficials, producing plant growth promoting compounds
- Immobilization of toxins

# Roots are excellent indicators of soil health

- Poor drainage
- Poor nutrient availability
- Severe compaction
- Pathogen infections
  - *Rhizoctonia*
  - *Pythium*
  - Root-knot nematodes

# Summary

Soil is a highly complex and dynamic living system

Need organic inputs for energy to drive the system

Sensitive to tillage, pesticides, and other toxins

Increasing nutrient availability and plant productivity depends on maintaining a healthy soil food web