Linking Soil Biology to Soil Health

"In the end, we conserve only what we love.
We will love only what we understand.
We will understand only what we are taught."

~ Baba Dioum, Senegalese poet

Video

NEXT SLIDE - Video – Birth of an Earthworm

Video courtesy of Barry Fisher, NRCS-SHD

Last update: 1 August 2017

Birth of an Earthworm

Goals

By the end of this lesson, you will be able to:

- List at least six functions that soil microbes perform
- Define and describe the three broad functional groups used to categorize soil organisms and list a few key organisms for each group
- Identify and define biological hot spots in soil and key organisms living in each zone/sphere.
- Describe what a Tullgren/Berlese funnel is used for and how you might construct one.
- Describe how the soil health principles influence soil biology and soil function

What are Important Soil Functions?

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- Produce food, feed, fiber, biofuel feedstocks, and medicinal products
- Capture, filter, drain well, and store water
- Cycle and recycle nutrients
- Resilient to drought, temperature extremes, fire & floods
- Protect plants from pathogens and stress
- Detoxify pollutants
- Store C and modify release of gases (e.g., CO_2, CH_4, N_20)
- Stable, resist the erosive forces of wind and water

Which soil functions are strongly influenced by the actions of soil organisms?

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Which soil functions are strongly influenced by the actions of soil organisms?

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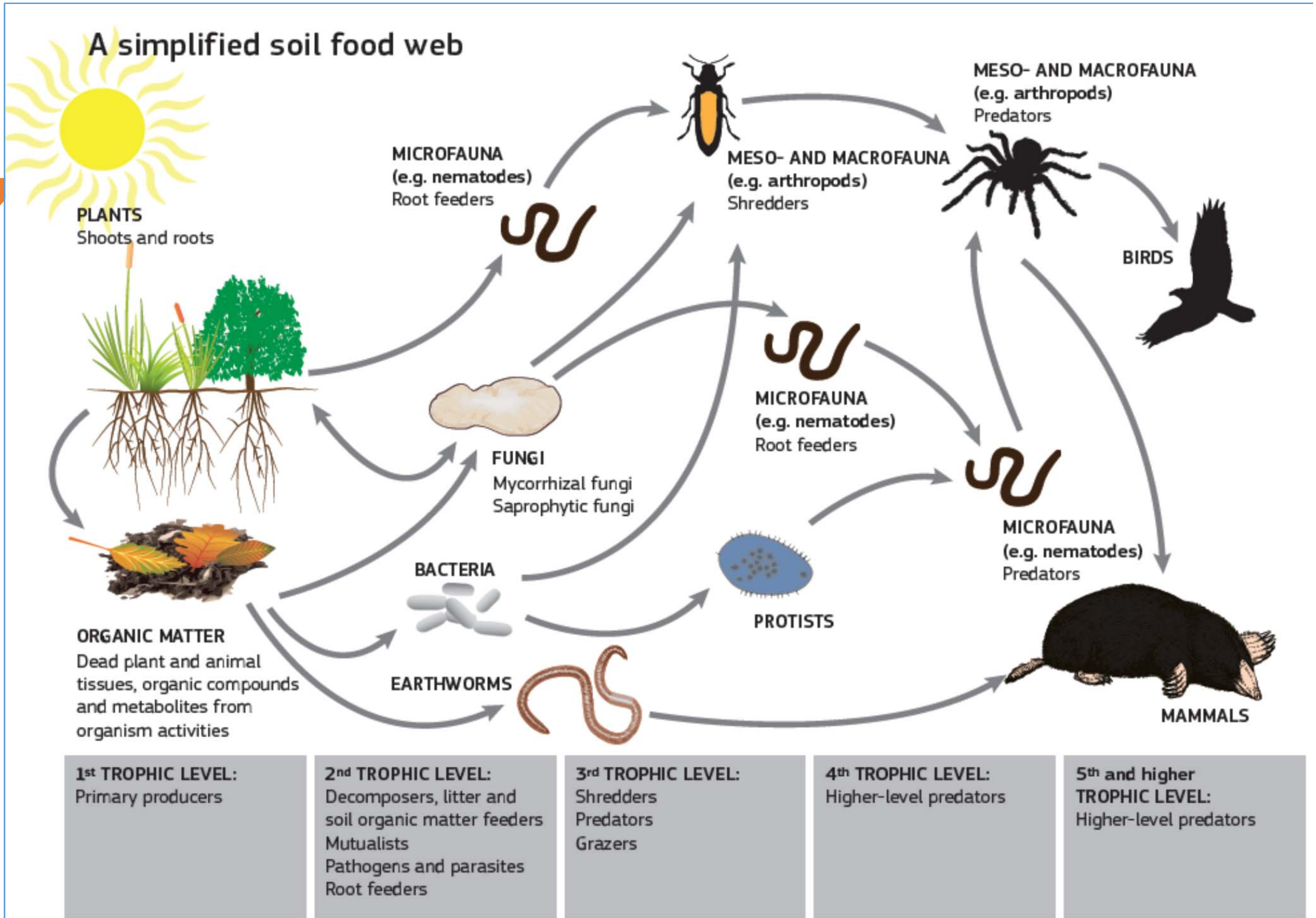
- ✓ Resilient to drought, te… …tremes, fire & floods
- ✓ Protect plants fr… …and stress
- ✓ Detoxify po…
- ✓ Store C and … release of gases (e.g., CO_2, CH_4, N_20)
- ✓ Stable, resist the erosive forces of wind and water

ALL OF THEM!

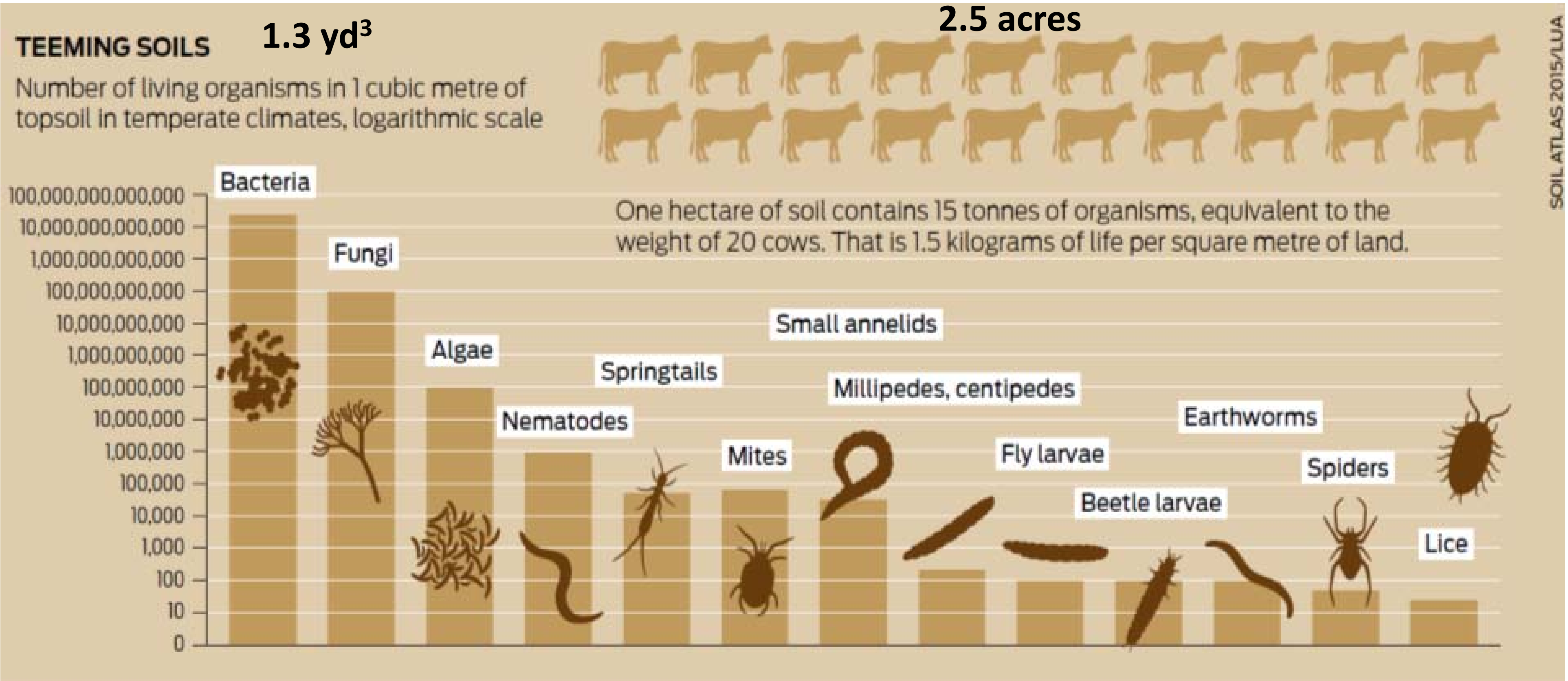
How Many Different Types of Soil Organisms Can you Name?



This simplified soil food web represents some of the possible feeding connections in a soil ecological community. The trophic level of an organism is the position it occupies in a food web. Soil formation parallels the development of a food soil web in that it is simple in the early stages and becomes complex during the mature stages of soil formation. (JRC)

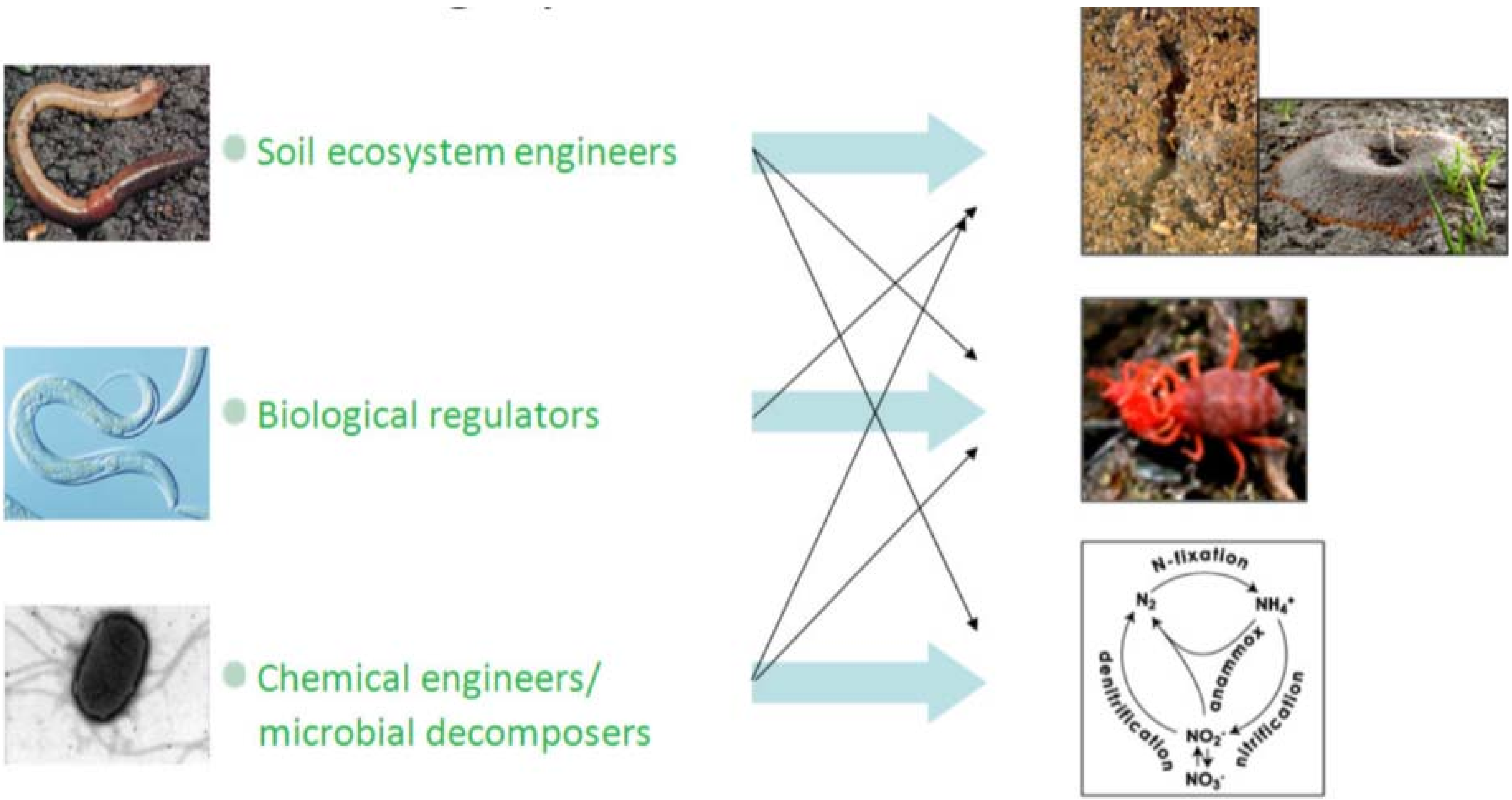
Global Soil Biodiversity Atlas. 2016. Orgiazzi, Bardgett, Barrios et al. Luxembourg, European Commission, Publications Office of the European Union**: 176p.**

Soils Host Vast Numbers & Mass of Organisms



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

Three Broad Functional Groups

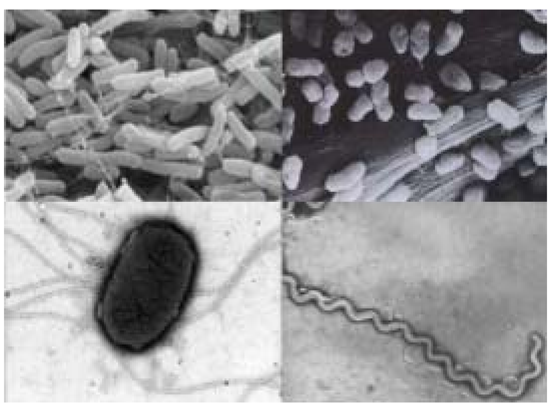


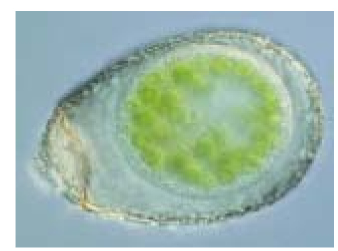
Turbe et al., 2010

Chemical Engineers

Regulate 90% of energy flow (Carbon / Photosynthesis) in soil

Functional group	Function	Representative members
Chemical Engineers	• Decompose Organic Matter • Keeps Nutrients in the Root Zone and Out of Water • Enhance Soil Structure by making some "glues" • Competes with Disease Causing Organisms • Filters and Degrades Pollutants • Actinobacteria (filamentous bacteria) – Soil Smell • Feed other members of the food web (Prey)	bacteria, archaea, fungi, protozoa

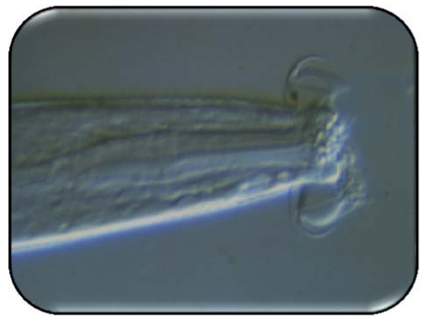




Turbe et al., 2010

Biological Regulators

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



File name: Arthrobotrys.jpg at 265K. (Also: F-4 at 1600KB shows whole Bug Biography)
Photo credit: George L. Barron, University of Guelph, Ontario.

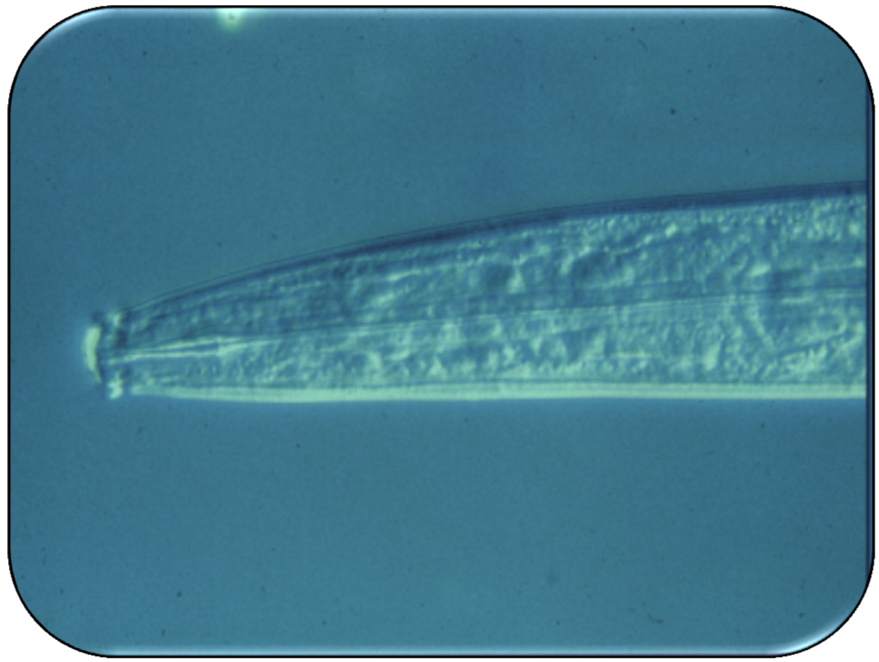
Turbe et al., 2010

Regulators and nutrient cycling

Nematodes – Services they provide

- Control disease
- Cycle nutrients
- Disperse bacteria & fungi

A bacteria-feeding nematode



A fungal-feeding nematode

Lasso fungus

Ecosystem Engineers

Functional group	Function	Representative members
Ecosystem Engineers	Build pore networks and aggregates Redistribute soil particles, microbes, & organic matter	Earthworms, and other larger invertebrates (e.g., millipedes, centipedes, beetles, caterpillars, scorpions)

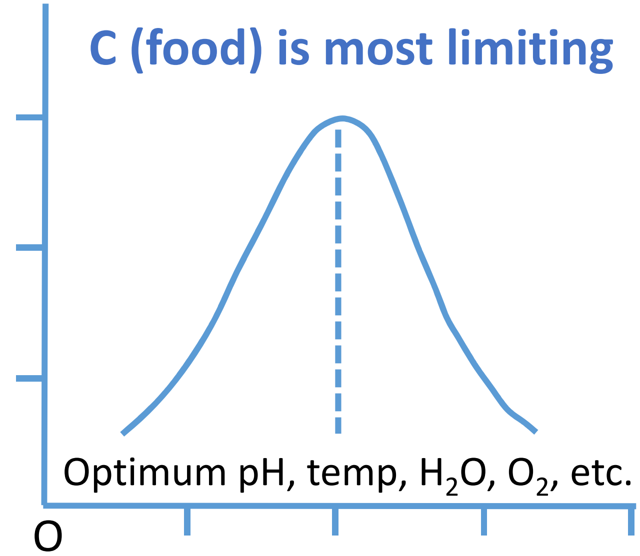
Turbe et al., 2010

What are the requirements of life and what makes soil living?

What are the requirements of life and what makes soil living?

Ecosystems that are naked, hungry, thirsty and running a fever!

Soil organisms are optimal under the following conditions:



- Near-neutral pH (6-7.5)
- Warm soil temps (60-90°F)
- Soil water at field capacity
- Good aeration (low bulk density)
- Abundant and diverse food sources
- Diverse soil pore sizes
- Minimal contaminants, salts

 http://googoogallerykids.blogspot.com/2011/02/obscure-scan-sunday-three-bears.html

Survival Strategies, Sleeping Beauty & Prince Charming

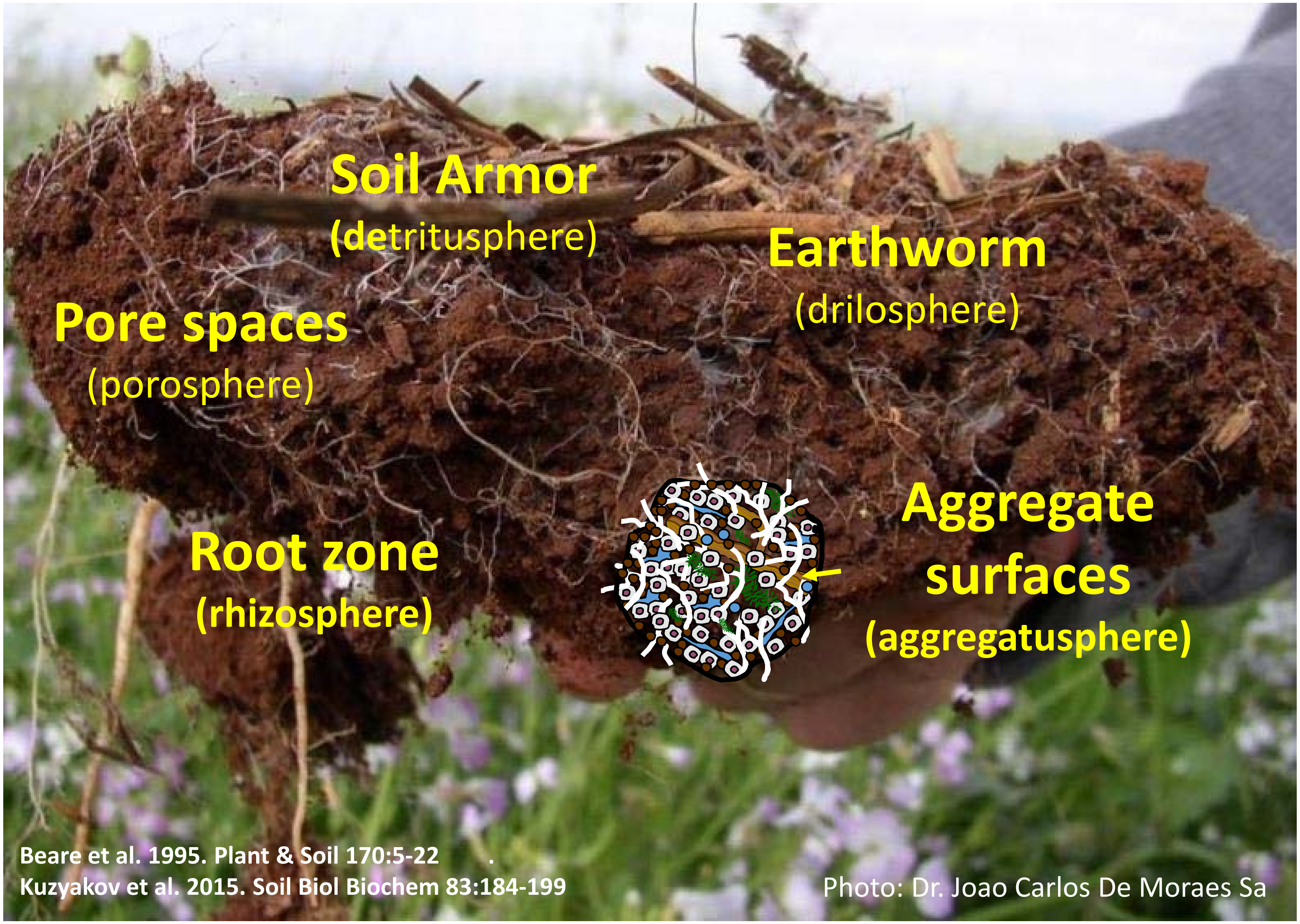

Cysts of nematodes; Turbe et al. 2010

- Enter long, resistant resting stages
- Majority of soil life are inactive
- Fungi, earthworms, nematodes, & other fauna act as 'Prince Charming'

Review Questions

- What are the three broad functional groups of soil organisms?
- Which functional group regulates 90% of the energy flow in soil and is important in decomposition and nutrient release?
- Which functional group involves the actions of protozoa and nematodes as they graze on bacteria, fungi?
- Which organism is a classic example of an ecosystem engineer?

Biological Spheres of Influence of Soil Function



Detritusphere: Key Soil Organisms

Mesofauna (Biological regulators)

- Springtails (Collembola)
- Mites

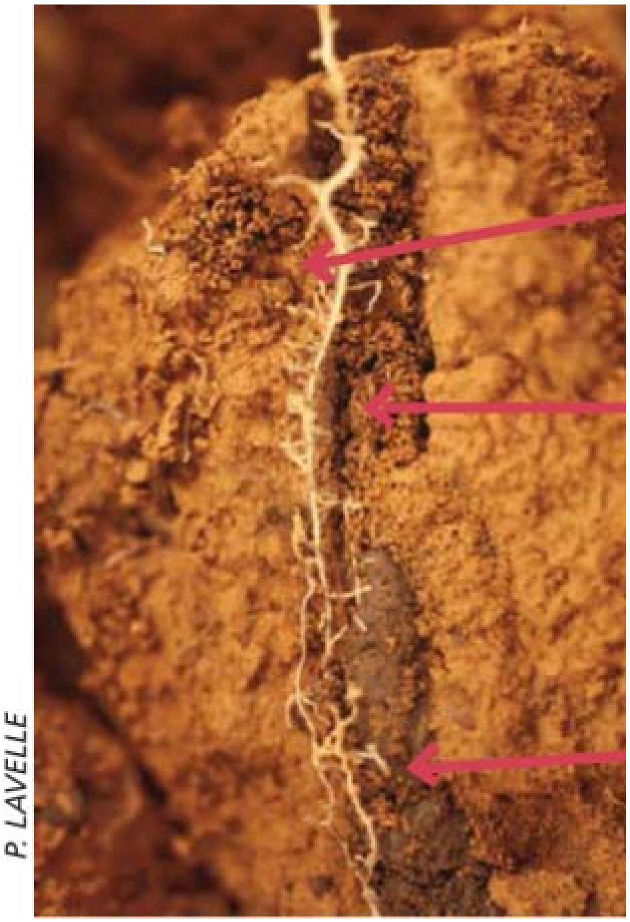
Macrofauna (ecosystem engineers)

- Earthworms, beetles, centipedes, ants, isopods

Earthworm Channels (Drilosphere)

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

P. LAVELLE



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

Drilosphere: Key Soil Organisms earthworms, millipedes, ect

Relocate OM

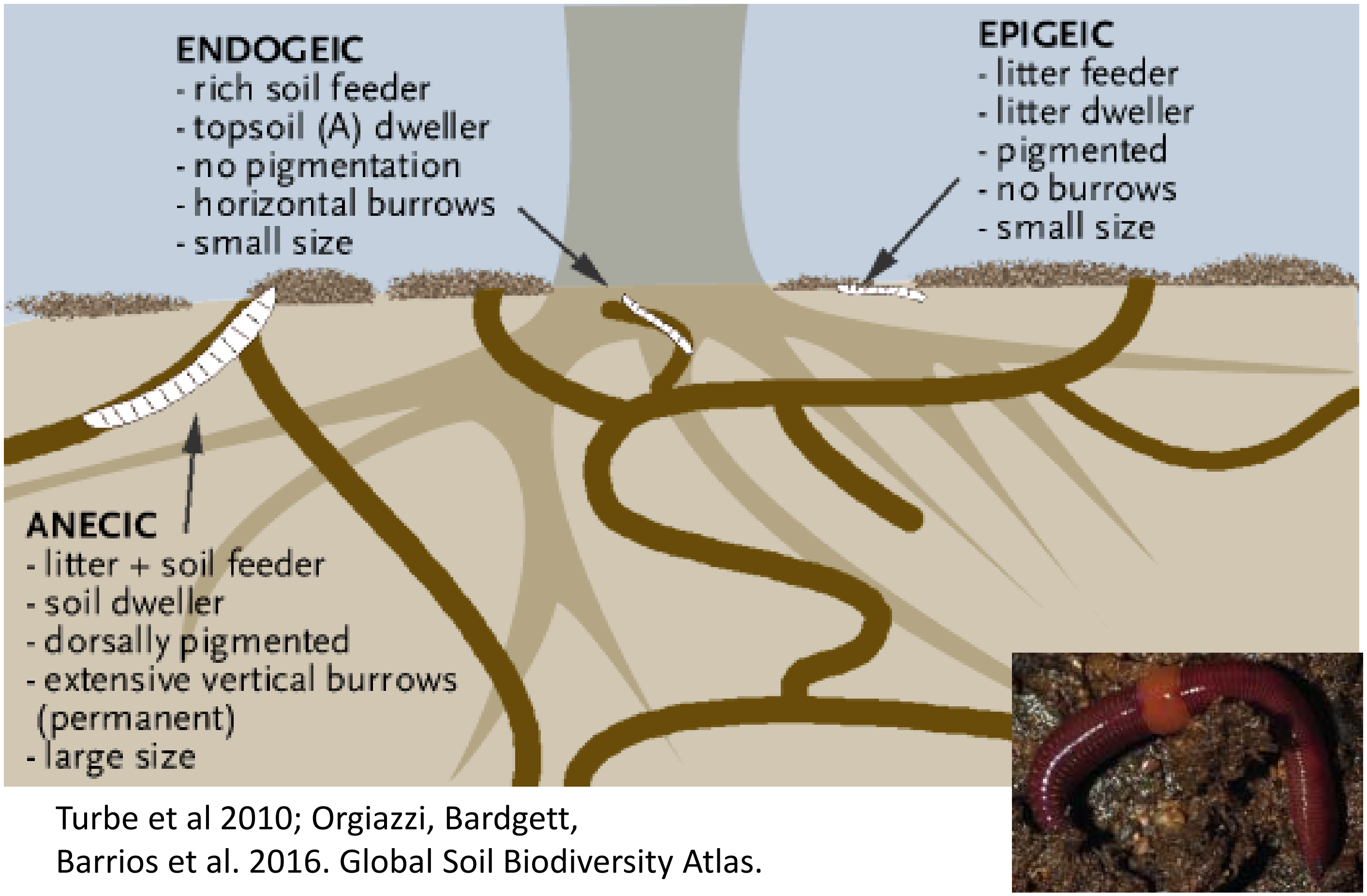
Move microbial community

Stable aggregates

Consume seeds

Large pores

Transport microbes

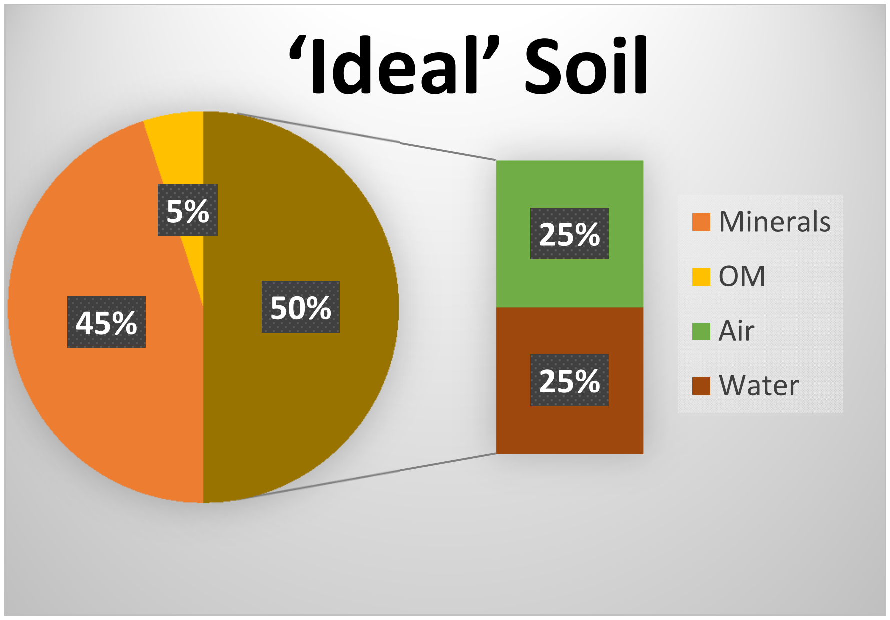


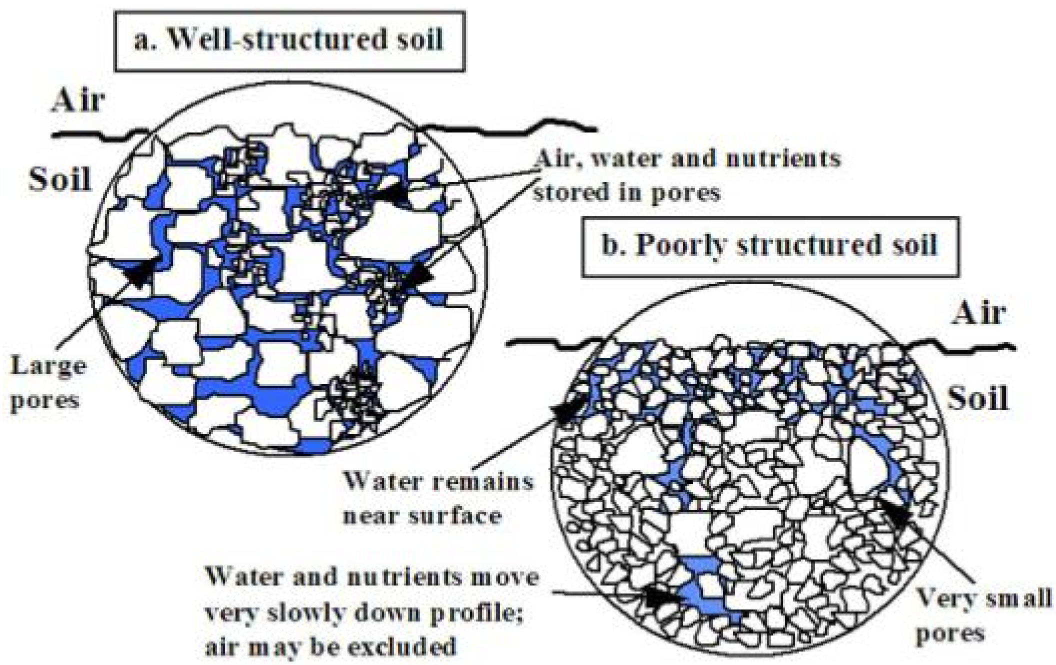
Turbe et al 2010; Orgiazzi, Bardgett, Barrios et al. 2016. Global Soil Biodiversity Atlas.


TOTAL VIDEO CONVERTER
HTTP://EFFECTMATRIX.COM

Pore Space (Porosphere)

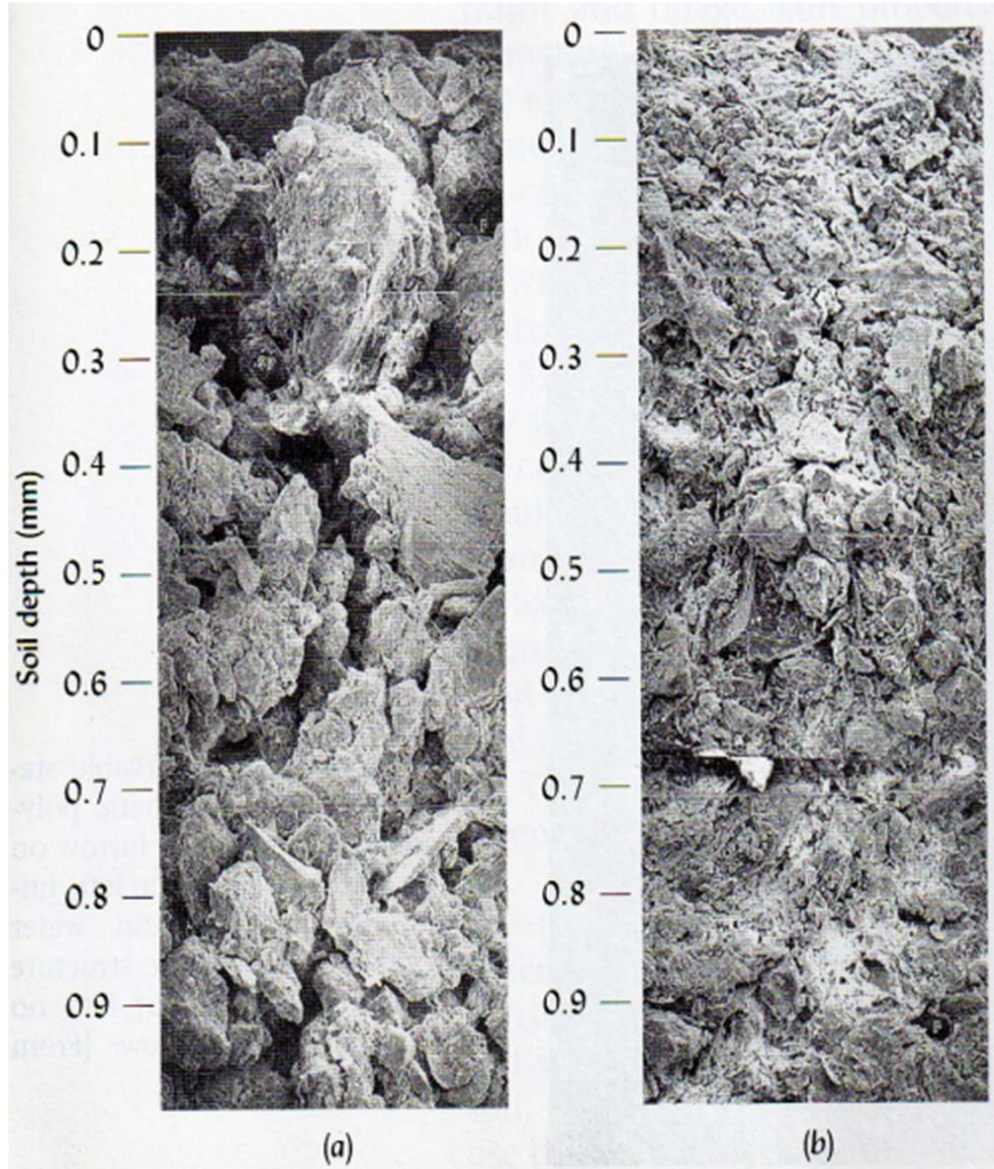
- "Lungs & circulatory system"
- Air flow
- Water flow, storage, & availability
- Biological highways





Pore Space (Porosphere)

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



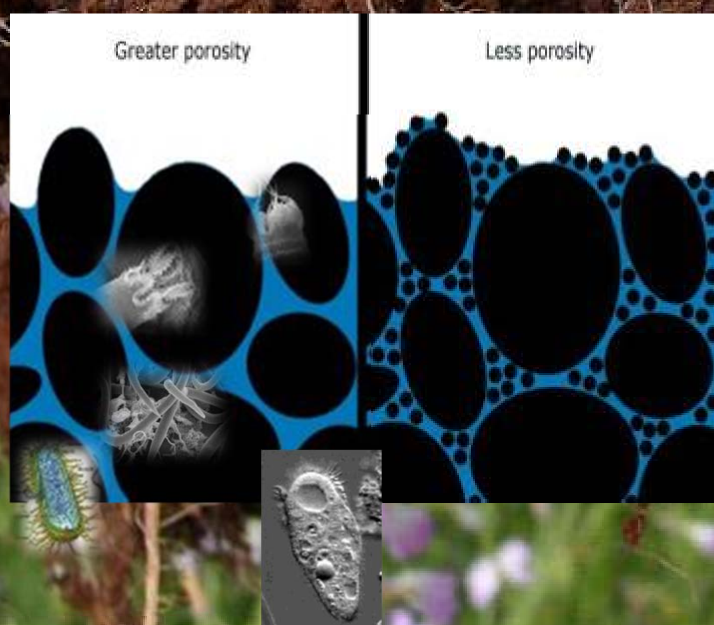
Nature and Properties of Soils 15th edition

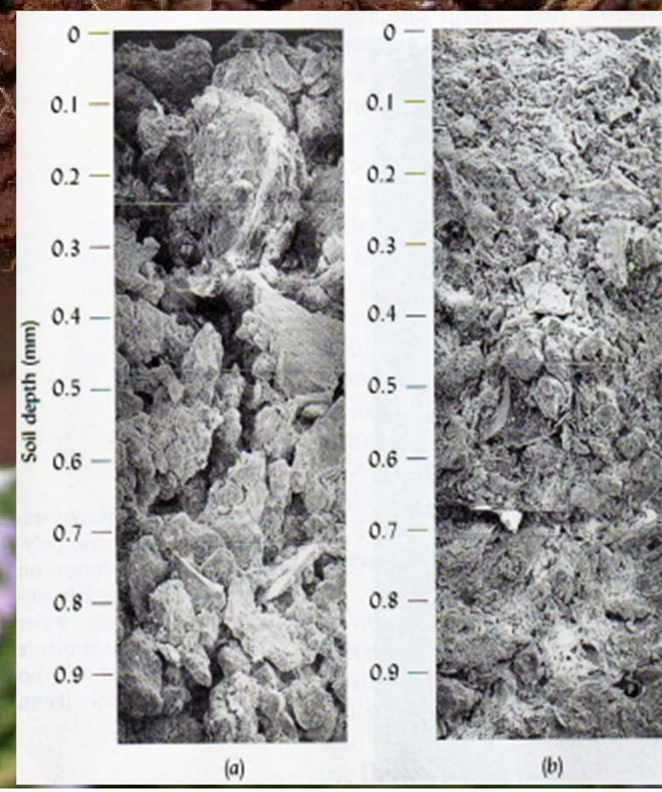
Primary an Aquatic Habitat (water films): for protozoa, bacteria, Mycorrhizae, and nematodes

Porosphere: Arrangement of Solids & Voids

The lungs and circulatory system of the soil:

- •Regulates water and air flow
- • Impacts N, P Mineralization
- •Impacts soil organism bio-mass 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)

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

Aggregatusphere : Influence of Soil Aggregates

Closed Habitat of Micropores

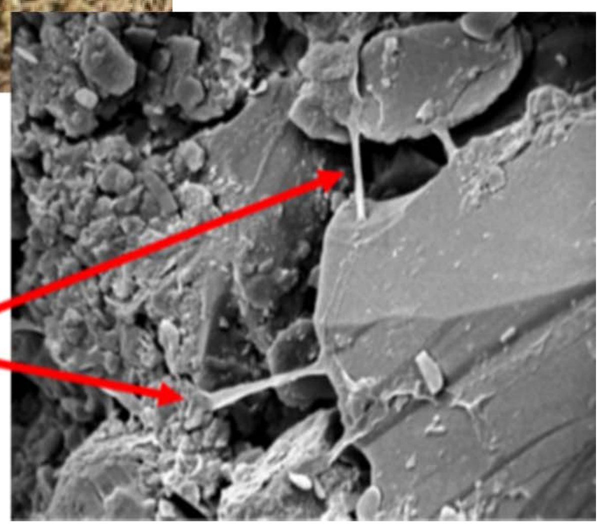
- Protects organic matter from decay
- Storage site for organic matter
- Habitat of Oligotrophic and Copiotrophic bacteria
- Protects and maintains the integrity of the porosphere

They are linked mainly by fungi hyphae, roots fibers, polysaccharides, Glomalin, rhizo-deposition, and aromatic humic materials

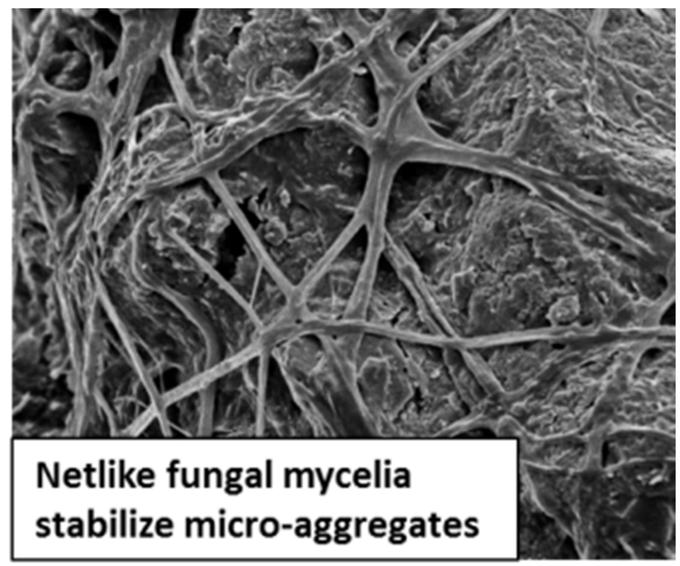
Beare, D.C. Coleman, D.A. Crossley Jr., P.F. Hendrix and E.P. Odum (1995)

Soil Organisms Physically Stabilize Soil Aggregates

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



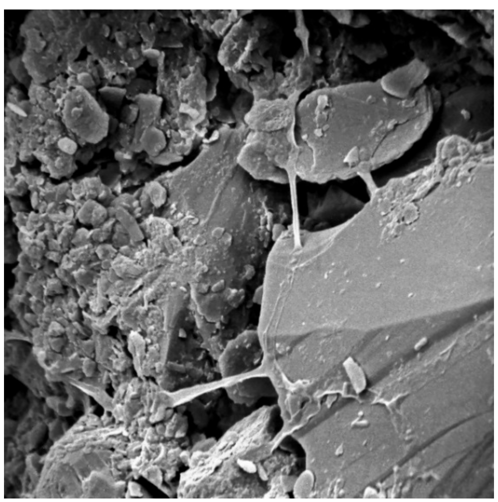
Stabilization of soil structure by actinomycete (bacterial) filaments



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, glomalin and other biochemicals bind soil particles



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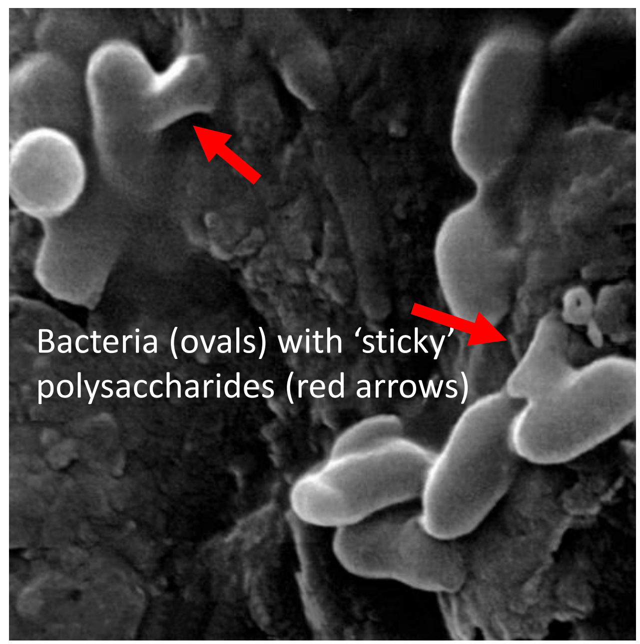
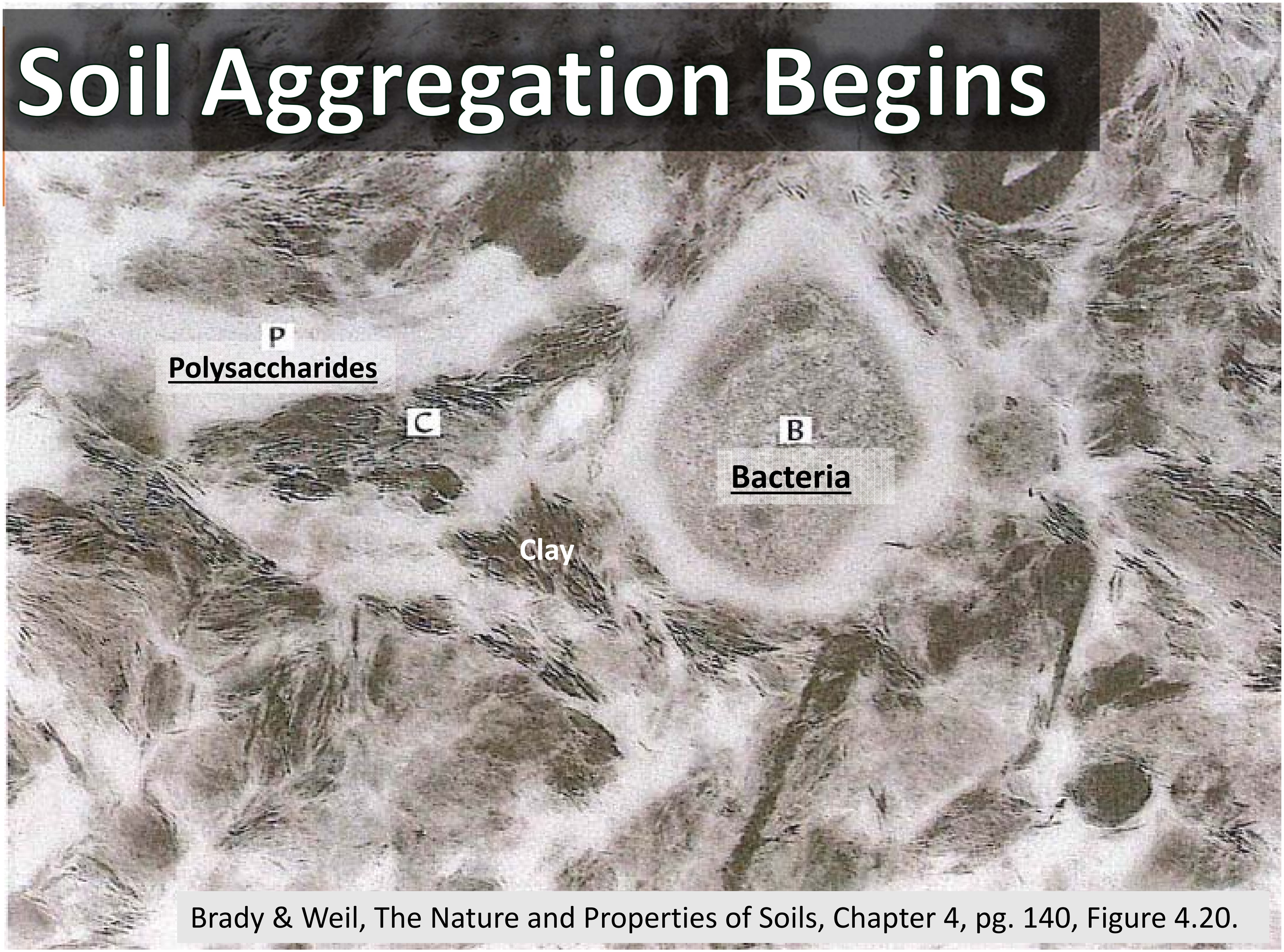


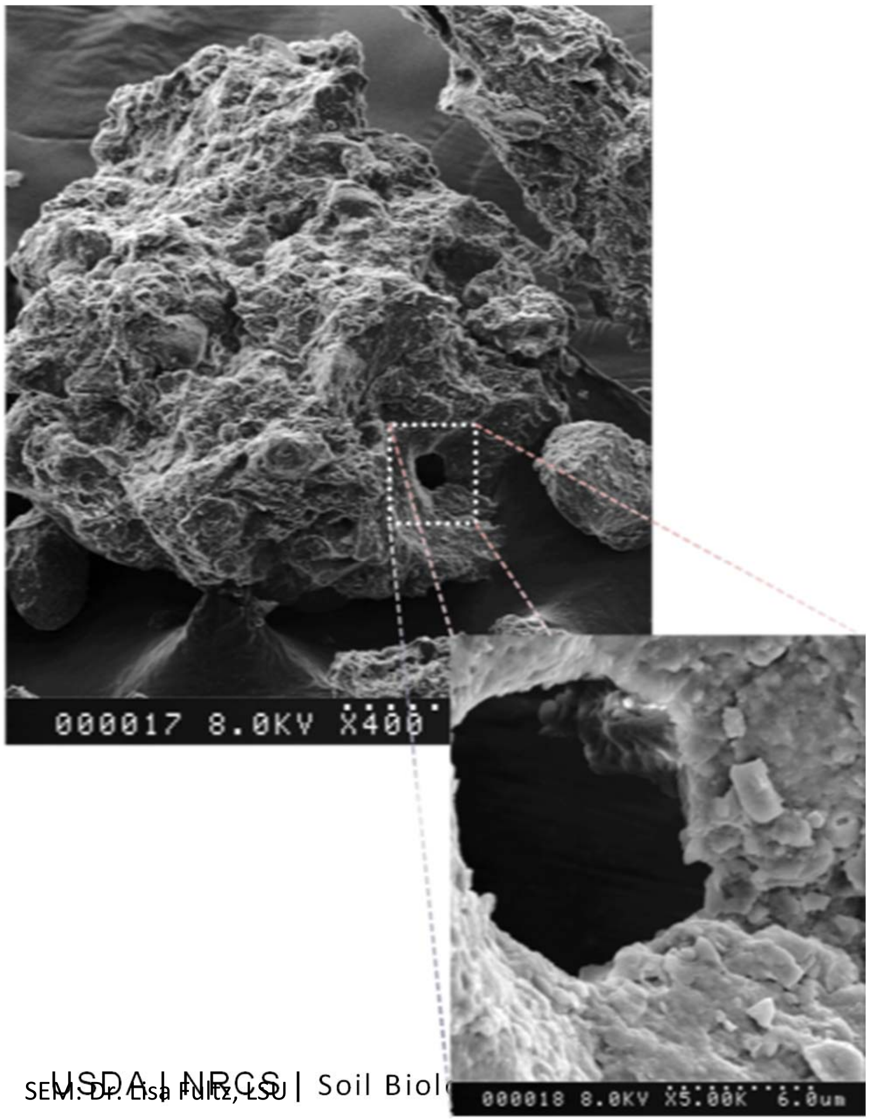
SEM photo source: Eickhorst, Thilo & Tippkoetter, Rolf. Micropedology – The hidden world of soils. University of Bremen, Germany. http://www.microped.uni-bremen.de

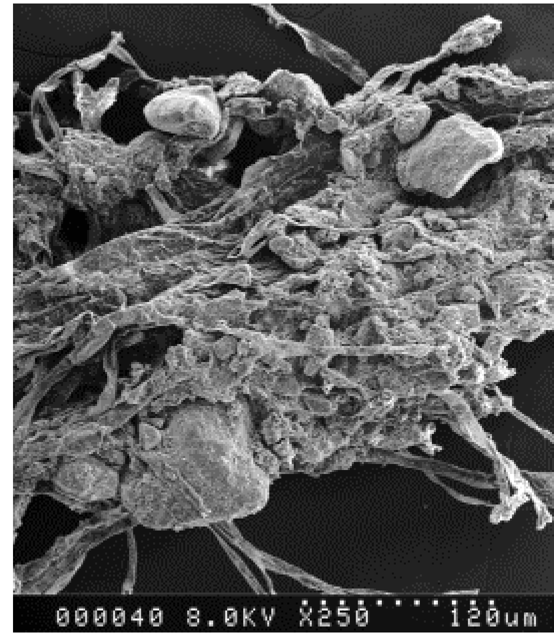
Soil Aggregation Begins



Brady & Weil, The Nature and Properties of Soils, Chapter 4, pg. 140, Figure 4.20.

Importance of Stable Aggregate: Field/Microbe Scale





- Ultimate ‘home’ of soil microbes (spaces in between)
- Increases pore space and sizes of space (decrease density and compaction)
- Large pores important for infiltration, drainage, aeration
- Small pores important for water storage and protection of organic matter and microbes

SEM: Dr. Lisa Fultz, LSU

Soil around the Root (Rhizosphere)

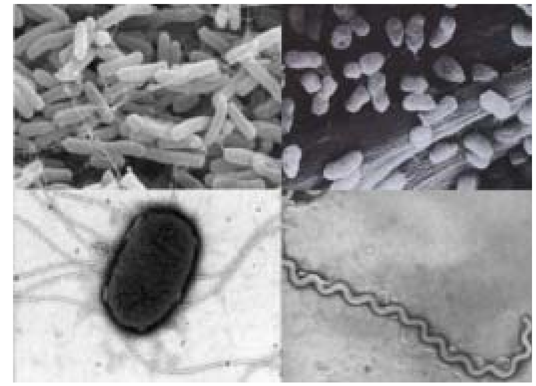
- Root exudates & chemical signals stimulates microbes & predators
  - Symbiosis
  - Protection
  - Nutrients
  - Resilience

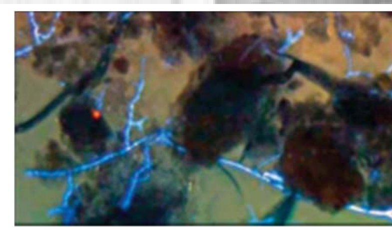

Photo: Marlon Winger

Pea -rhizosphere

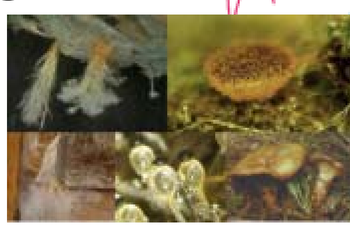
Root Zone (Rhizosphere): Key Organisms

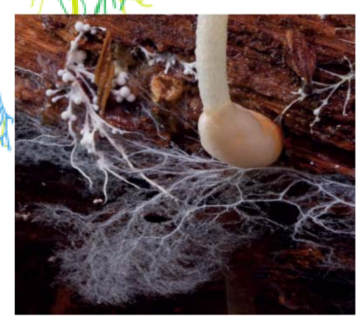
- Plant roots stimulate microbes
- Microbes: fungi, bacteria, protozoa, nematodes
- Symbiosis
- Chemical signaling
- Nutrient cycling

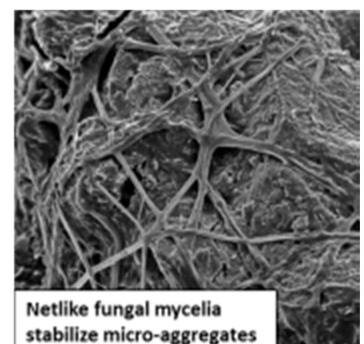




http://www.soilquality.org.au/factsheets/soil-biological-fertility







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

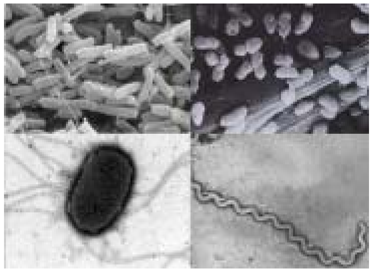
Rhizosphere: Key Organisms

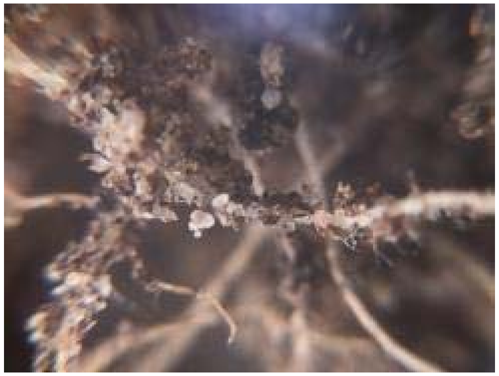
Bacteria

- Most numerous
- 2-5% of SOM but responsible for 90% of energy flow (Carbon)
  - 1 g can contain 10 million with 100s to 1000s of different species
  - 0.5-3 tons per acre (Killham 1994)

Fungi

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



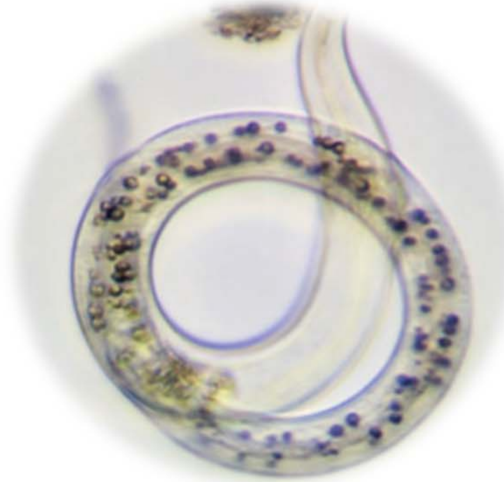


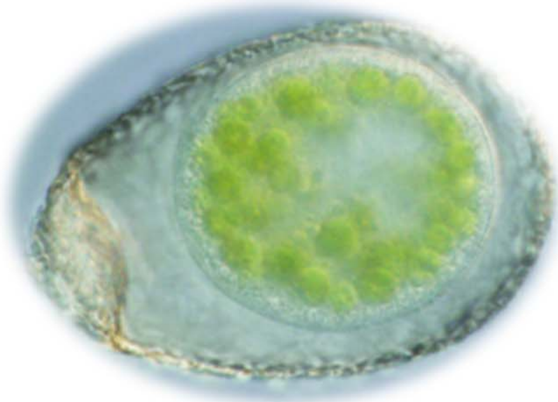
Turbe et al 2010; Coleman & Crossley 1996; Nannipieri & Badalucco 2003; Global Soil Biodiversity Atlas. 2016. Orgiazzi, Bardgett, Barrios et al.

Rhizosphere: Key Organisms

Nematodes and Protozoa

- Feed on a wide diversity of organisms
- Key in N and P cycling
- Some are pathogenic
- Also common in porosphere





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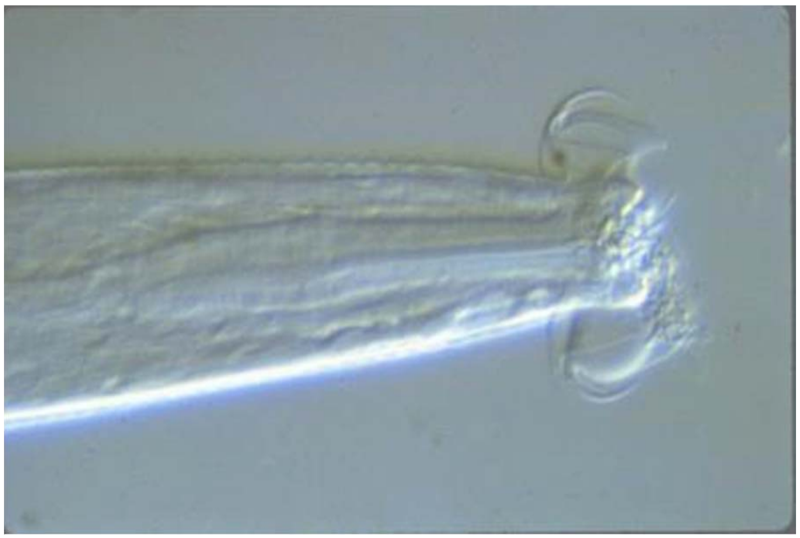
Bacteria Feeding Nematode



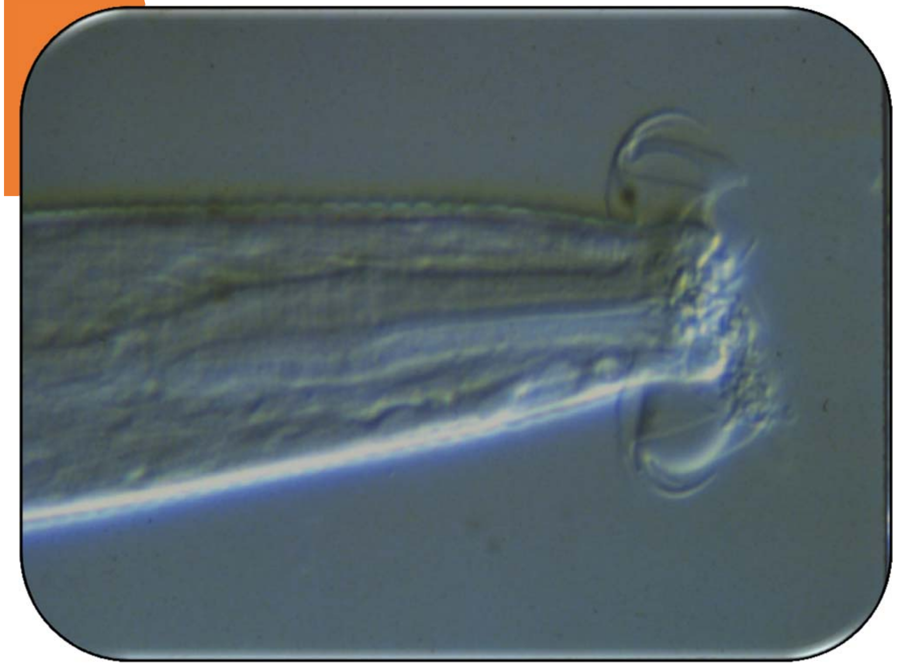
•Bacteria are high in protein that in turn is high in nitrogen.

• When nematodes like this eat bacteria they digest the protein and convert it to nitrogen which is excreted as a body waste product back into the soil in a form that becomes available to plants.

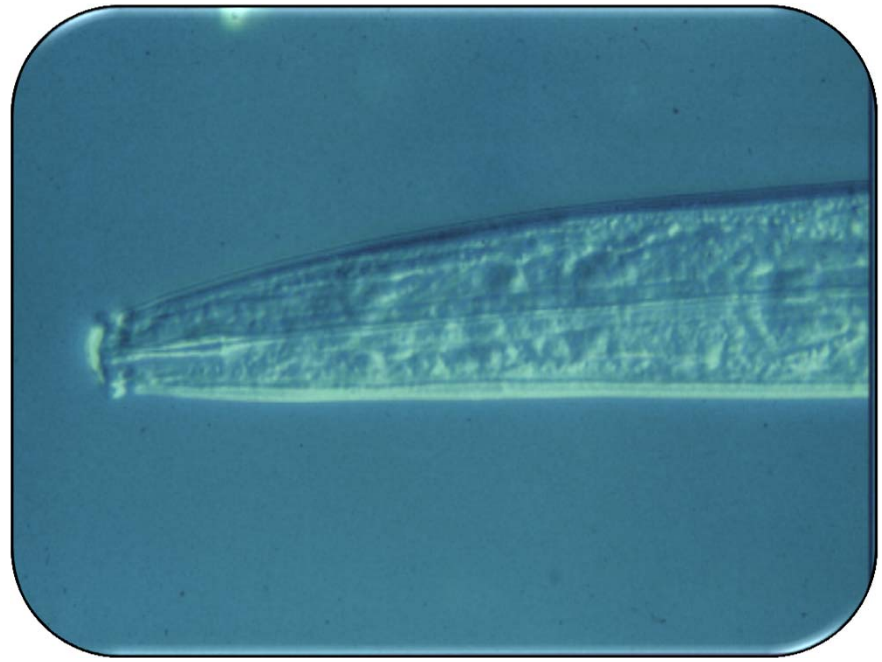
…but similar to the rate for male Pelodera chitwoodi of 3.9×10^5 bacteria per day averaged over an 8-d life span (Mercer and Cairns 1974).

Nematodes – Services they provide

- Control disease
- Cycle nutrients
- Disperse bacteria & fungi



A bacteria-feeding nematode



A fungal-feeding nematode

Biological Hot Spots

- List five biological hot spots in soil
- Identify key soil organisms in each hot spot/zone of influence and describe major functions?
  - Will have time in field to discuss this and try to find these hot spots!
- More than 70% of the microbial community is inactive in soils until conditions improve. List four of the seven conditions that are considered optimal for most soil organisms in agricultural systems.

Key Functions of Soil Organisms

Function	Description
Decomposition	Recycle wastes, create organic matter,
Modifies soil structure	Increase amount and rate of air and water exchange; increase infiltration, drainage, and storage capacity; resist erosion
Nutrient cycling	Decomposition, retains, cycles, and releases nutrients
Soil detoxification	Degrade agrichemicals, pollutants, toxins
Symbiotic/ assoc.	N-fixation (converts atmospheric N_2 ⇔ organic forms), mycorrhizae (increase root adsorptive surface for H_2O, nutrients
Biological population regulation	Suppress and/or feed on soil-borne plant pathogens and plant-parasitic nematodes
Weed suppression	Eat and/or decompose weed seeds
Plant protection	Enhance plant growth by protecting plants from pathogens. Example, can form biofilms around roots and sends chemical signals that influence plant response to pathogens

Microbes make 'free' nitrogen fertilizer!

Continuous Flow of C Drives System

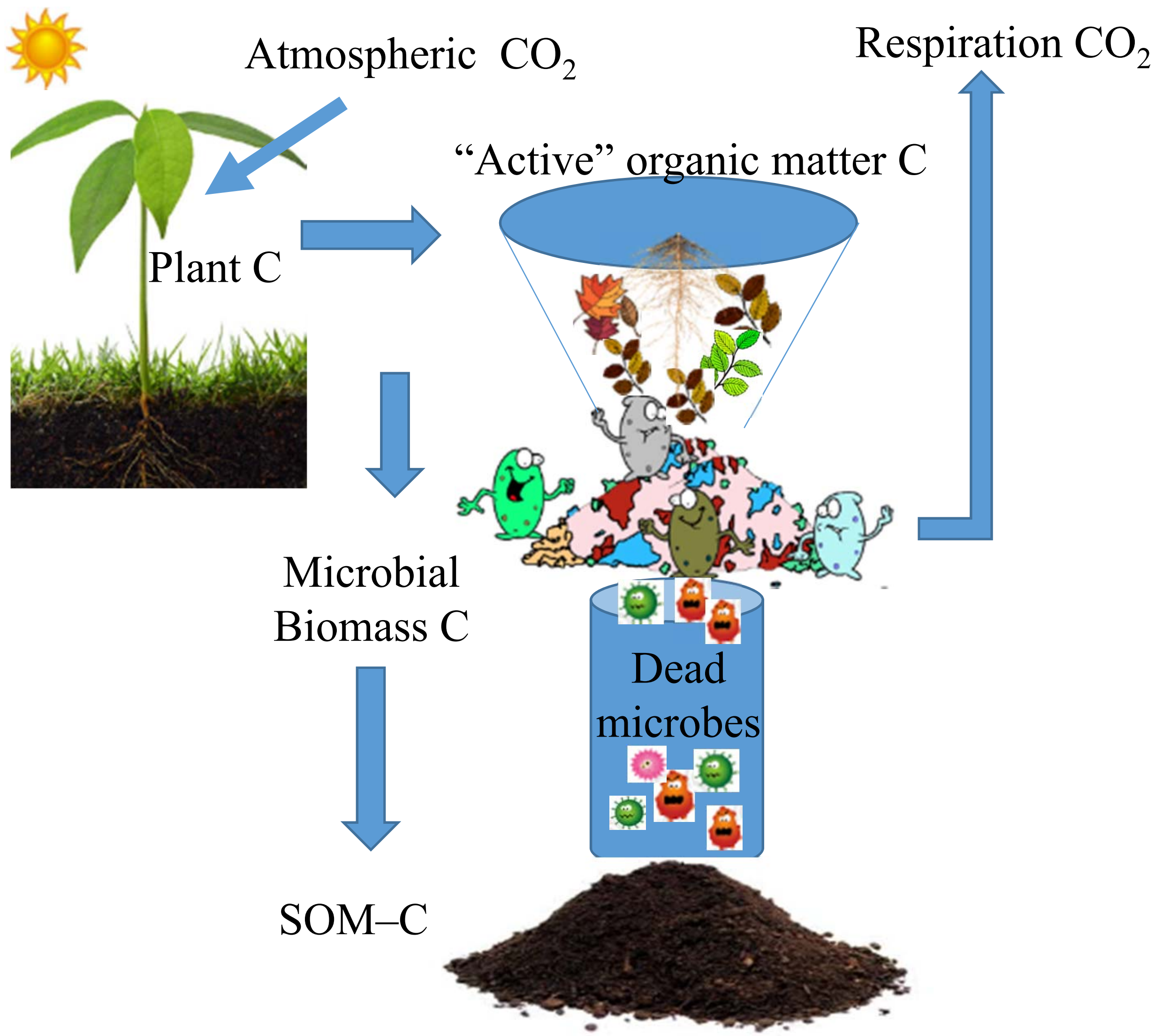
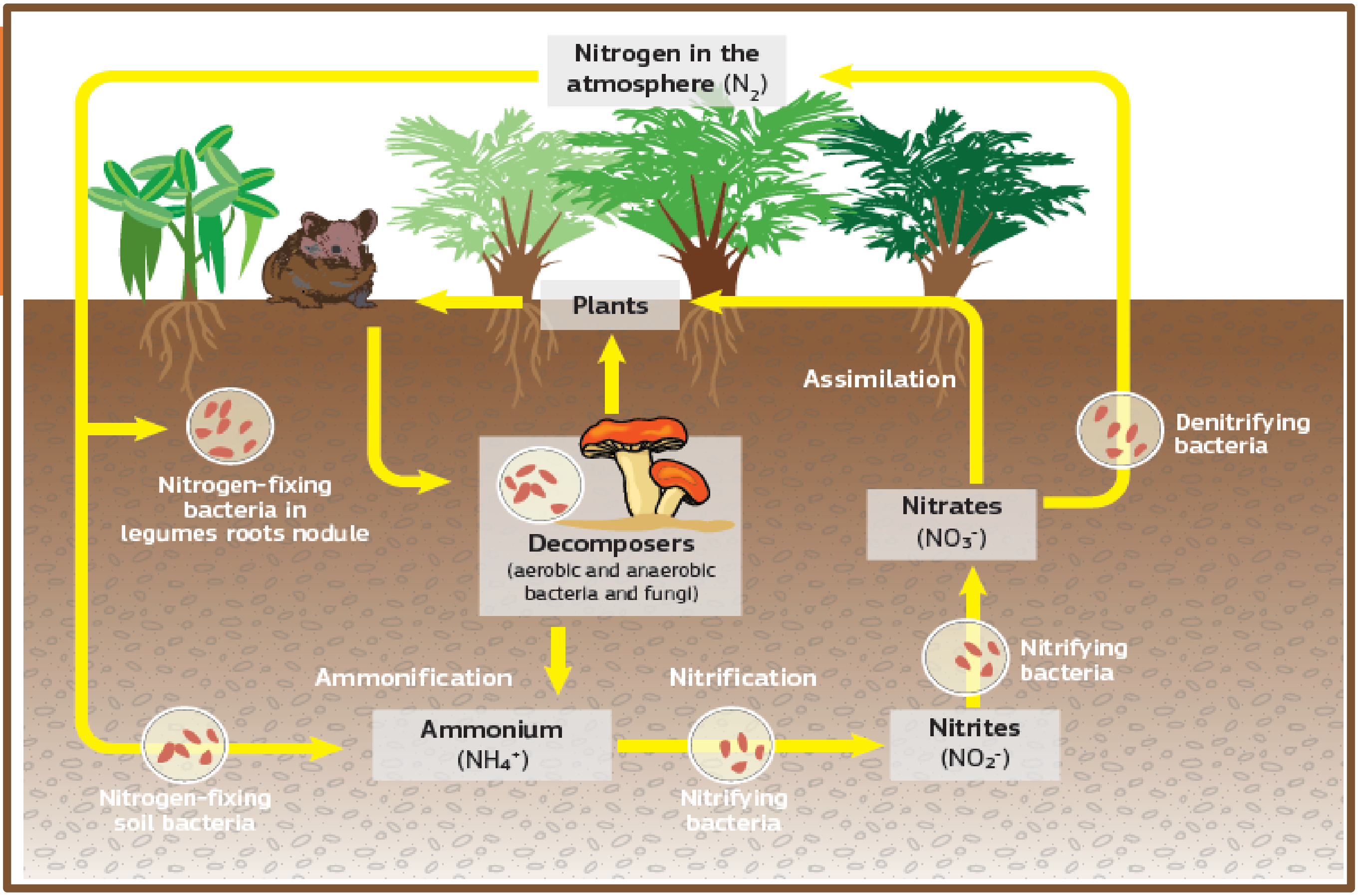


Image courtesy of Dr. Chenhui Li

Soil Biology and Nutrient Cycling

- Majority of fertilizer, **no matter what initial form**, goes through microbes before plant gets it
- Soil microbial biomass accounts for:
  - 1-5% of total organic C
  - 2-6% of total organic N
  - ~3% of total organic P in arable soils
  - 5-24% of total organic P in grassland soils

Paul, 1984, Plant and Soil 76:275-285;
Brookes et al., 1984. Soil Biol Biochem, 16:169-175

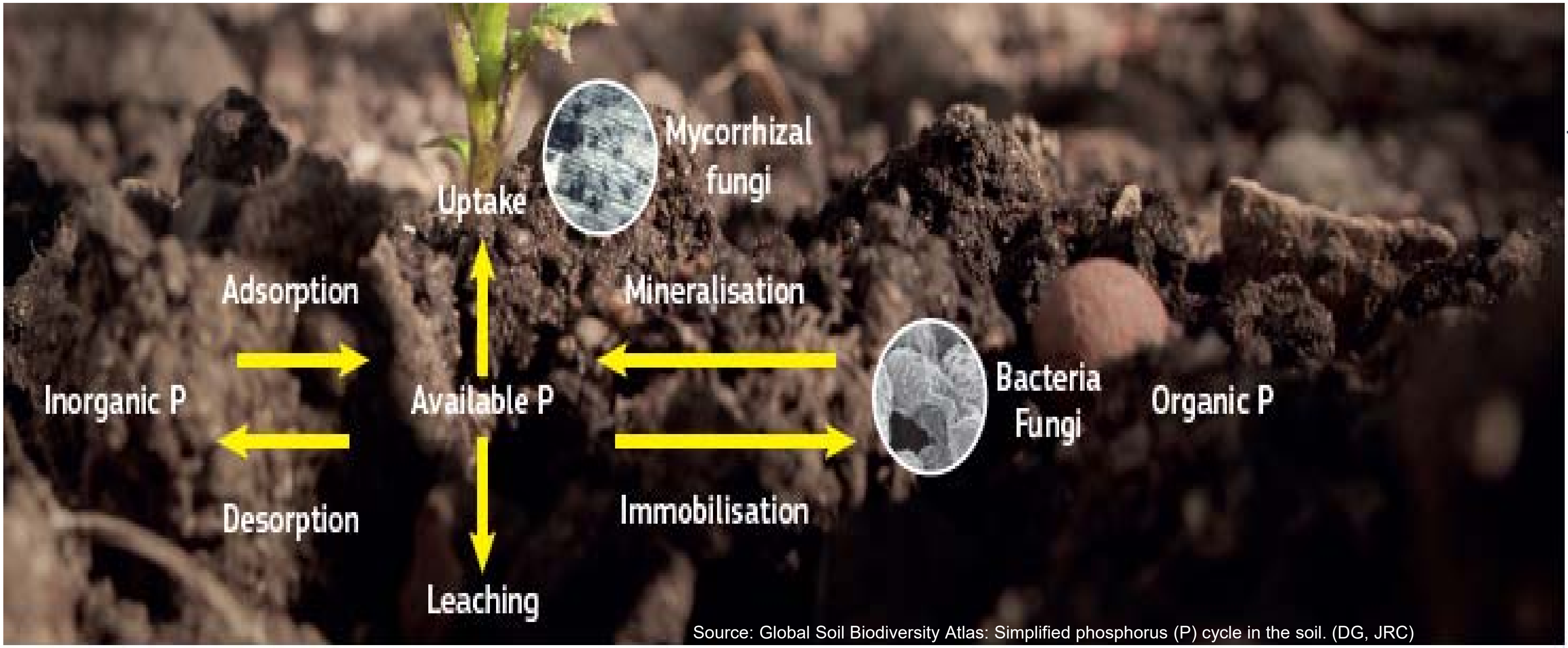


Microbes are Involved in All Steps of Soil N Cycle

- N-fixation: N_2 → Organic N
- Ammonification: Organic N → NH_4^+
- Nitrification: NH_4^+ → NO_2^- → NO_3^-
- Denitrification: NO_3^- → → N_2O → N_2

Schematic representation of the main flows of nitrogen (N) through the terrestrial environment. The importance of soil bacteria and fungi in the cycle is immediately recognized as being a key element, providing different forms of N compounds assimilable by higher organisms, such as plants. (JJB, FVI, NLA, NRCS)

Microbes help release P from organics and minerals



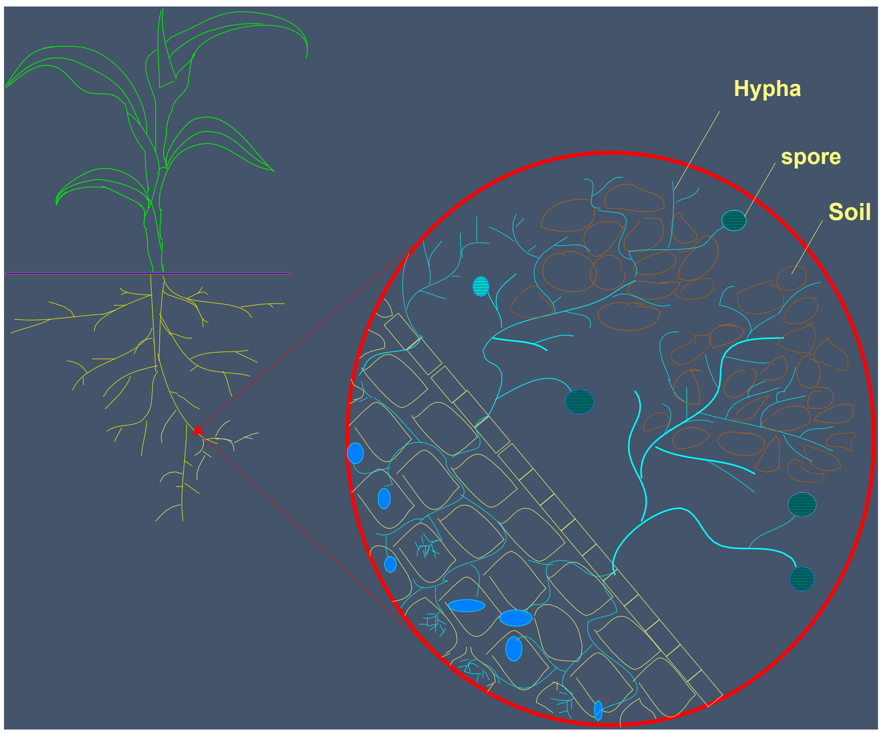
Source: Global Soil Biodiversity Atlas: Simplified phosphorus (P) cycle in the soil. (DG, JRC)

- **P fertilizer use efficiency 5-40%**
- **P sources mainly from ancient rocks and deposits**
- **P binds to Al, Fe at low pH**
- **P binds to Ca, Mg at high pH**
- **P most available pH 6-7**

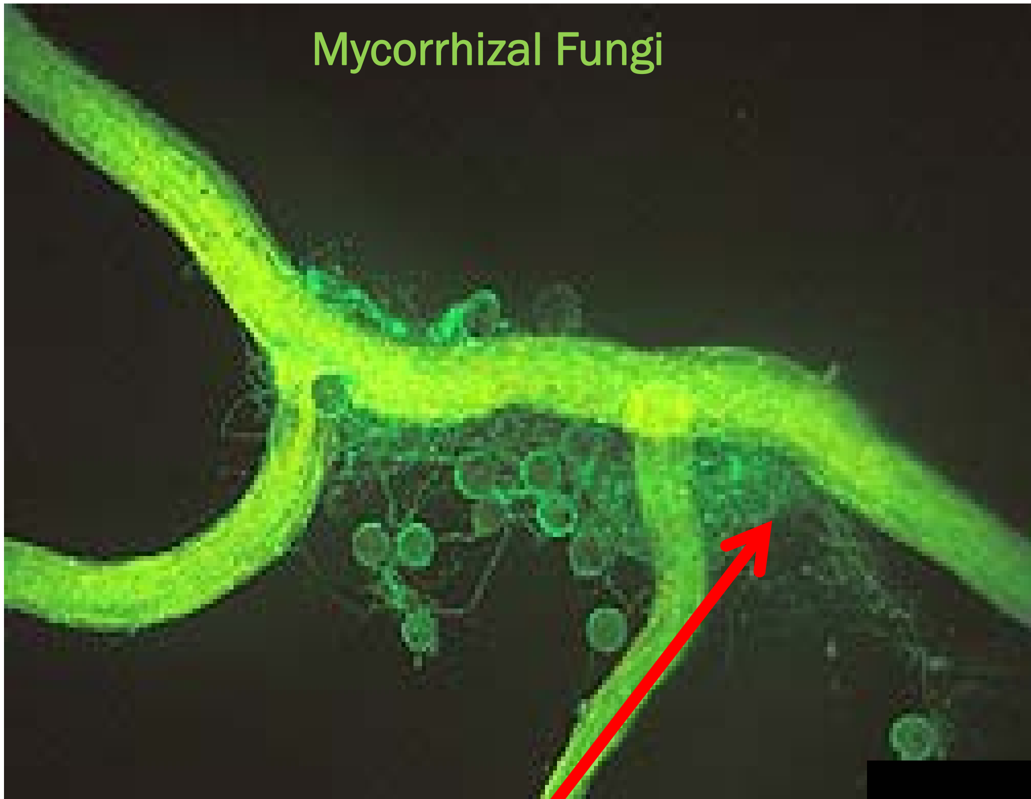
- P-solubilizing bacteria and specialized fungi release enzymes and acids that release stored org-P and mineral-P

Symbiosis Example: Mycorrhizae

Mykós (fungus)- riza (root)

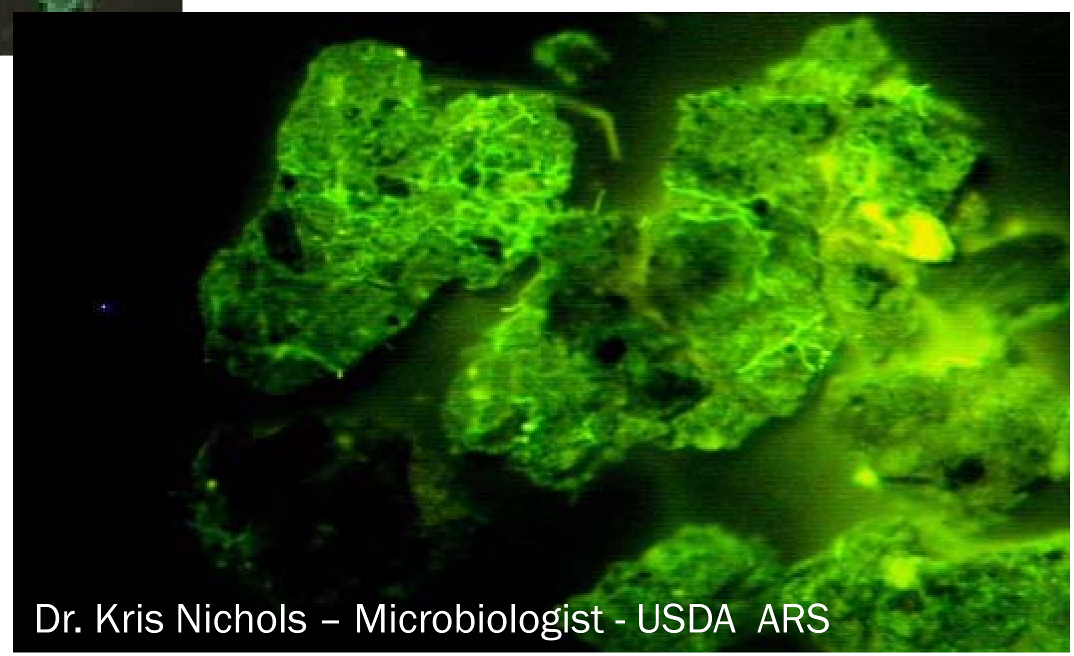


- Plants use 5-20% of C from photosynthesis to ‘feed’ fungi
- Fungi increase adsorptive root surface area at least 10x
- Fungi increase nutrient uptake especially P and Zn
- Fungi suppress pests and diseases
- Fungal networks build soil aggregates

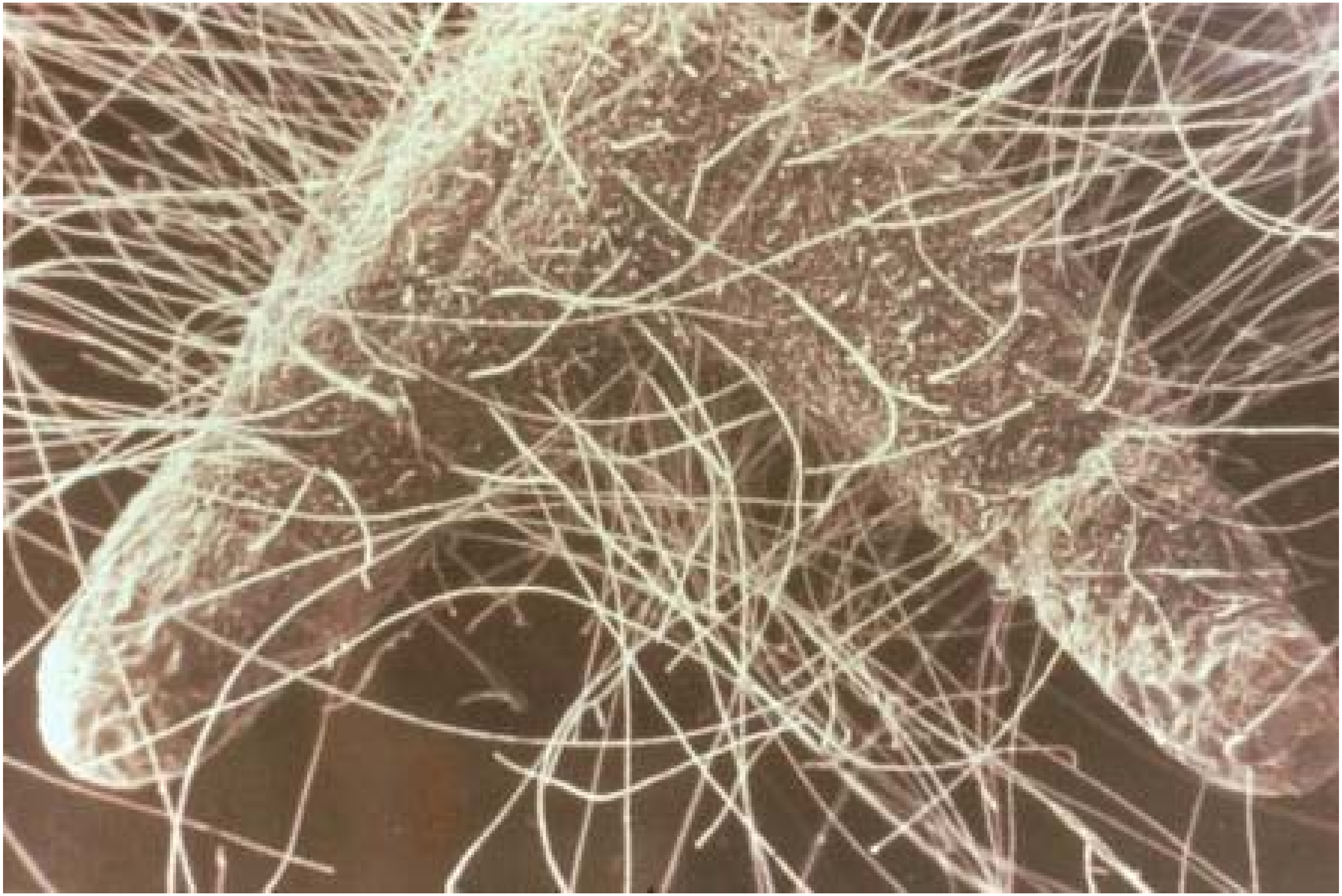


Glomalin is naturally brown. A laboratory procedure reveals glomalin on hypae and soil aggregates as the bright green material shown here.

Fungal Hyphae

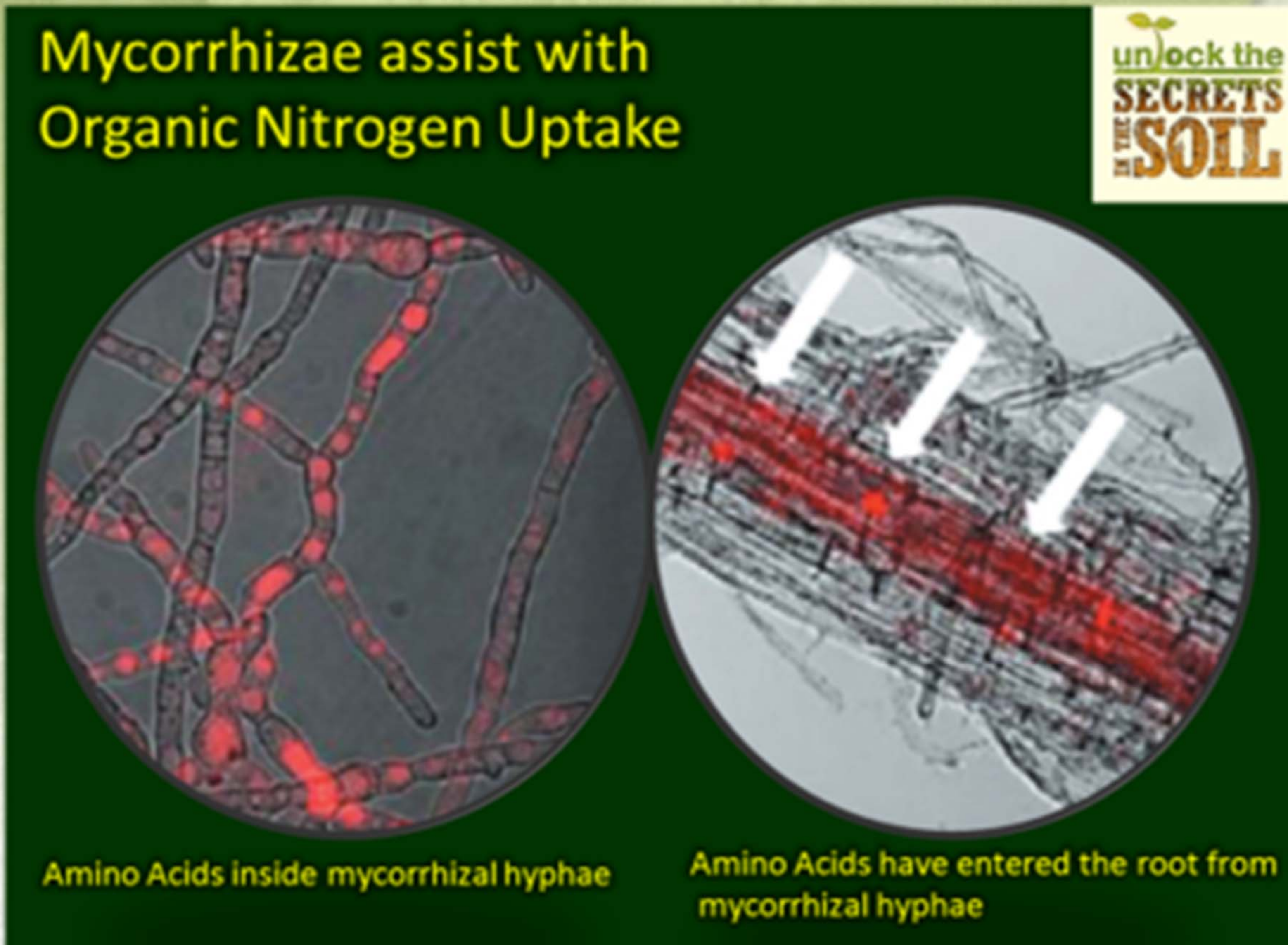


Mycorrhizae Fungi
Attached to root hair

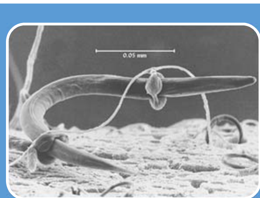


USDA

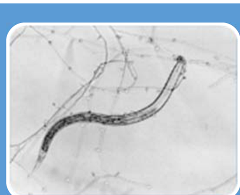
Quantum dots attached to amino acids



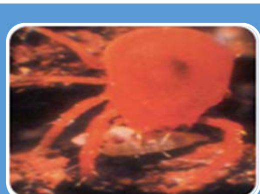
Examples of Biological Regulators



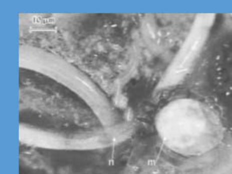
Fungi: regulating nematode populations

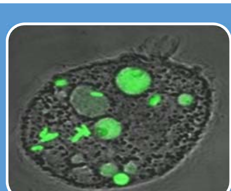


Fungi: parasitizing a soybean cyst nematode



Mites: regulating springtail (L) and nematode (R) populations

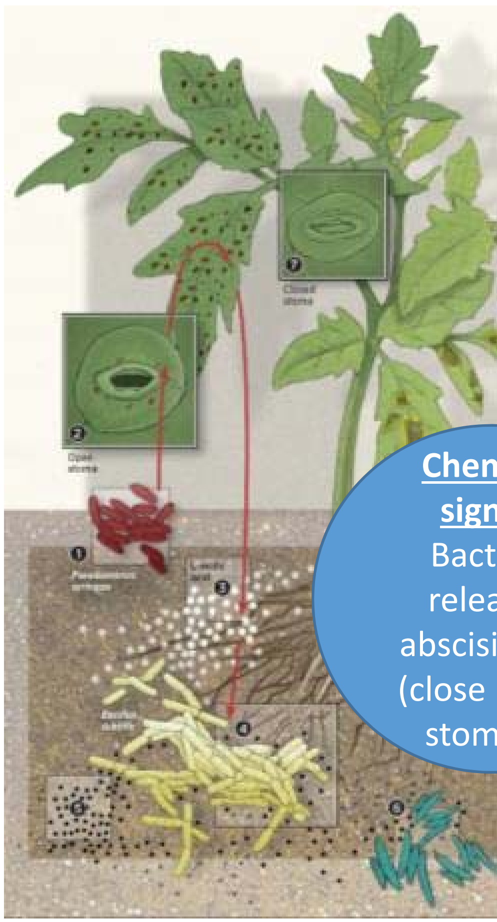




Protozoa prey on bacteria
(can consume 10^6 to 10^9 bacteria day^{-1})!

http://www.extension.umn.edu/agriculture/soybean/soybean-cyst-nematode/chemical-biological-potential.html

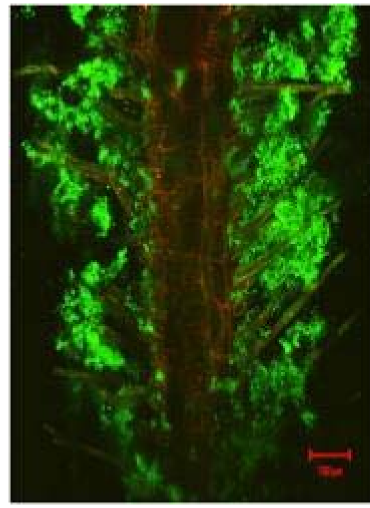
Soil Food Web Benefits: Plant Protection Examples



http://www.the-scientist.com/?articles.view/articleNo/34209/title/The-Soil-Microbiome/

Antibiotic Production
Fungi
Bacteria

Chemical signals
Bacteria released abscisic acid (close plants stomata)

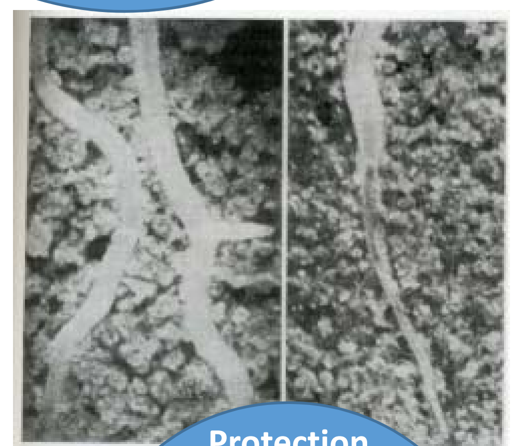


http://www.udel.edu/udaily/2009/oct/bais101708.html

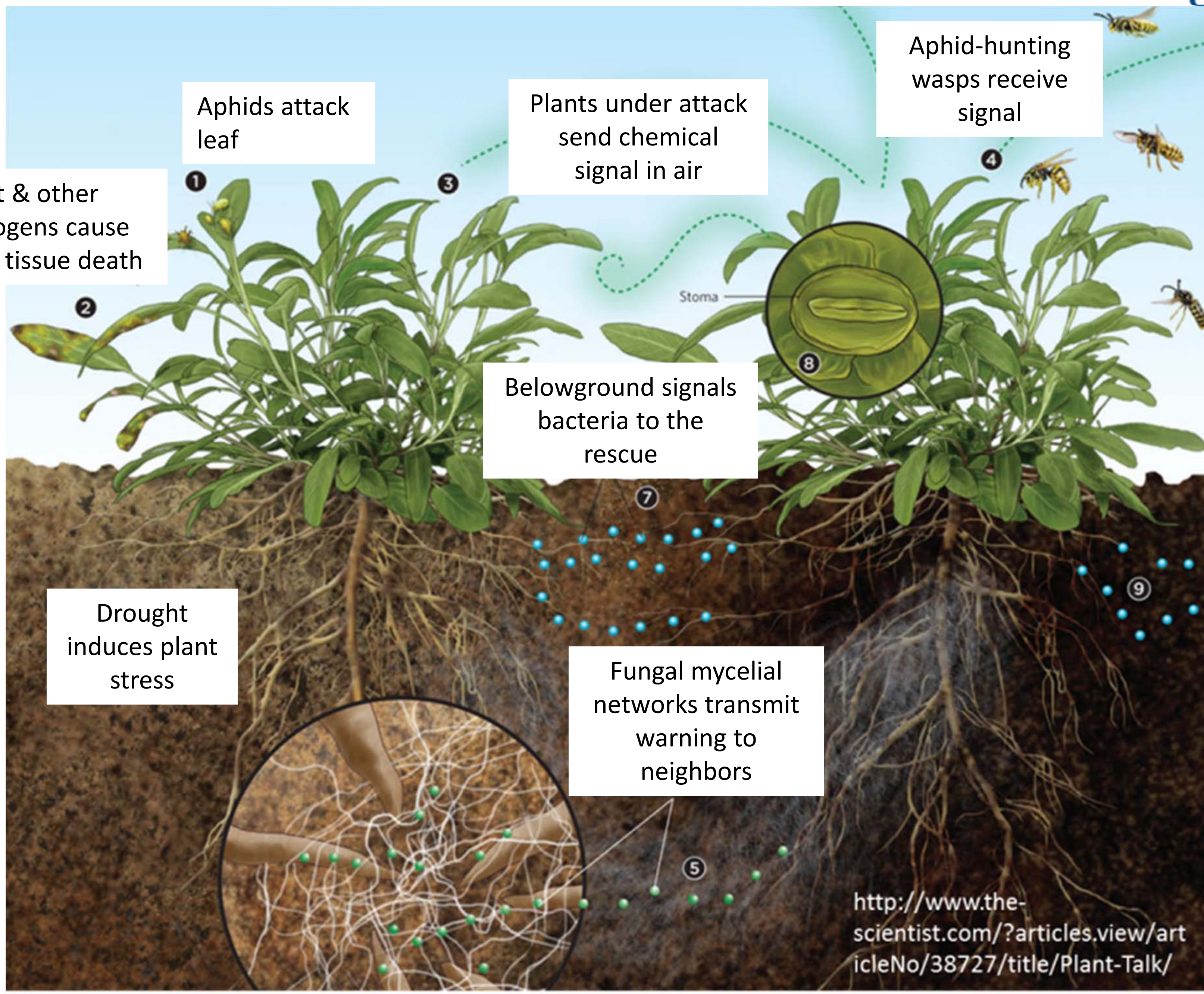
Protection
Biofilm of beneficial bacteria protecting against *P. syringae*

Predation
Soybean cyst nematode parasitized by a fungus

http://www.extension.umn.edu/agriculture/soybean/soybean-cyst-nematode/chemical-biological-potential.html



Protection
Roots protected from *Rhizoctonia solania* by springtails (left) and without (right)


Aphids attack leaf
Plants under attack send chemical signal in air
Aphid-hunting wasps receive signal
Blight & other pathogens cause plant tissue death
Stoma
Belowground signals bacteria to the rescue
Drought induces plant stress
Fungal mycelial networks transmit warning to neighbors
http://www.the-scientist.com/?articles.view/articleNo/38727/title/Plant-Talk/

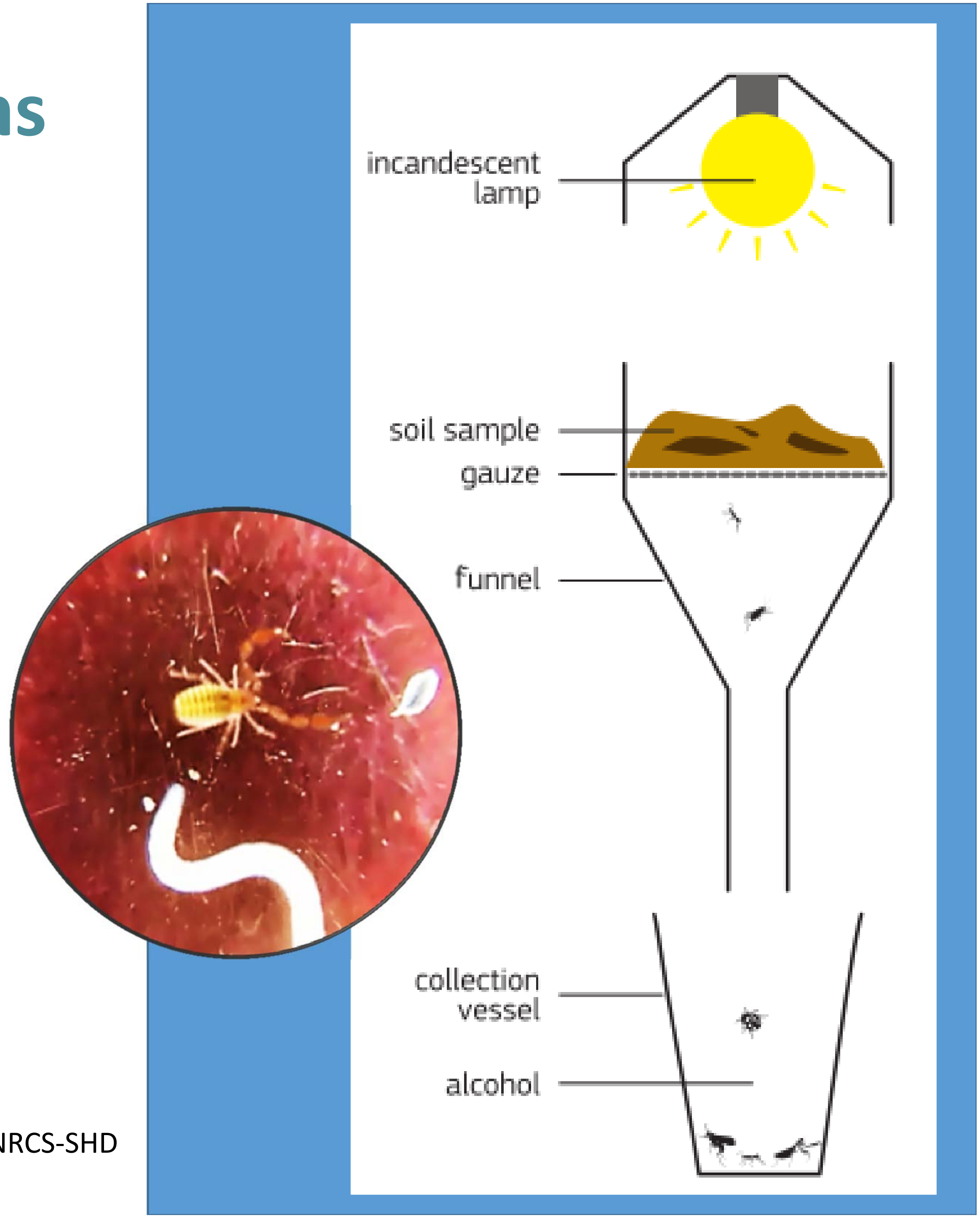
Review Questions

- True or False? Soil bacteria are involved in almost every step of the nitrogen cycle.
- True or False? Soil bacteria can extract phosphorus that is chemically bound to minerals such as calcium (e.g., calcium phosphate).
- True or False? Bacteria are the only soil organisms that are capable of fixing atmospheric nitrogen and converting it to NH3.
- List two important services that mycorrhizal fungi provide to plants.
- True or False? Soil aggregates are formed by physical processes only.
- True or False? Plants and microbes can communicate through release of biochemical compounds that can help plants fight pathogens and stress.

Extract organisms using a Tullgren (aka Berlese) Funnel

Video

- **NEXT SLIDE - Video - Fauna Captured from Berlese Funnel Trial**



Video & photo courtesy of Jen Moore Kucera, NRCS-SHD

Video - Fauna Captured from Berlese Funnel

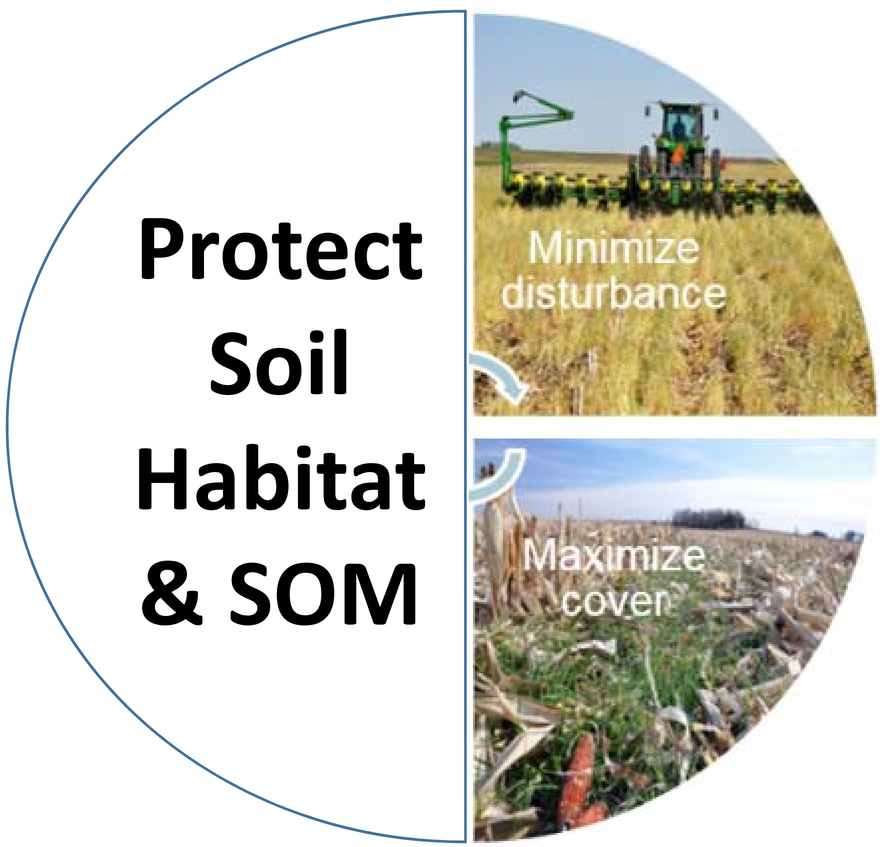
How do We Support Biodiversity to Support Healthy Soils?

Soil Health Principles To Support High Functioning Soils

- **Feed** diverse, continuous inputs (C sources, energy)

- **Protect** habitat (aggregates and organic matter)

Soil Health Principles & Soil Function



Minimize Disturbance & Maximize Soil Cover

- Maintain stable aggregates
- Reduce erosion and runoff risk
- Buffer temperature
- Reduce evaporation
- Maintain soil organic matter

Image courtesy of Barry Fisher, NRCS-SHD

Soil Health Principles & Soil Function

Feed Biota

Maximize Biodiversity & Maximize Living Roots

- Break disease/pest cycles
- Stimulate/change belowground diversity
- Increase soil organic matter
- Increase nutrient cycling
- Enhance plant growth
- Increase predator & pollinator populations

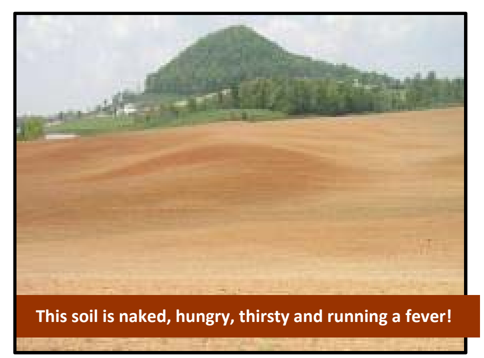
Image courtesy of Barry Fisher, NRCS-SHD

What are Some Practices that Would Support Healthy Soil?

Practice	Soil Health Principle
•	•
•	•
•	•
•	•
•	•
•	•
•	•
•	•

Fungi Management

- Mycorrhizal Fungi decline
  - In fallowed fields
  - In fields with crops that do not form mycorrhizae (mustards, broccoli, beets, lambs quarter, spinach)
  - Fields with frequent tillage
  - Fields with high levels of nitrogen and phosphorus
  - Where broad spectrum fungicides are used.



Agricultural Management Practices and Soil Health

Tend to Reduce Soil Health	Tend to Promote Soil Health
Aggressive tillage	No-till or conservation tillage
Annual/seasonal fallow	Cover crops; Relay crops
Mono-cropping	Diverse crop rotations
Annual crops	Perennial crops
Excessive inorganic fertilizer use	Organic fertilizer use (manures)
Excessive crop residue removal	Crop residue retention
Broad spectrum fumigants/pesticides	Integrated pest management
Broad spectrum herbicides	Weed control by mulching, cultivation

Choose practices that feed soil organisms and protect their habitat (soil aggregate)

Lehman, R. M., et al. (2015). J. Soil Water Conserv. 70(1): 12a-18a.


ALLIED SEED, LLC
Pratex Black Oat


Nematode Resistant Cover crops
Radish varieties

Jeff Parkinson: Ground Preparation Comparison

Method	No Till	Till
Fall Mulch Till of Stubble	X	X
Fall Cover Crop (Radishes)	X	X
Spring Disking		X
Spring Chisel Plow		X
Rolling Cultivator/no hilling	X	X
Ripping During Top Dress Fertilizer Application(Liquid)		X
Harrow Rows After Planting/Prior to Emergence	X	X
Spring Row Mark Out		X

Managing for 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 spheres of influence
- ➢ 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

What do living organisms need?

- How can we feed belowground life force?
  - Choose practices that provide diverse, near continuous inputs and build reserves (soil organic matter)
- How can we provide and protect habitat?
  - Choose practices that minimize disturbance of habitat (aggregates) and food sources (soil organic matter including residues)
  - Choose practices that support a stable habitat from major swings in temperature, water, and chemistry
- The next module will go into greater detail about these principles and identify specific practices to support, maintain, and enhance soil biology and the critical functions they perform.

YouTube: Selected microbes of the soil food web