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

Last update: 1 August 2017

Birth of an Earthworm

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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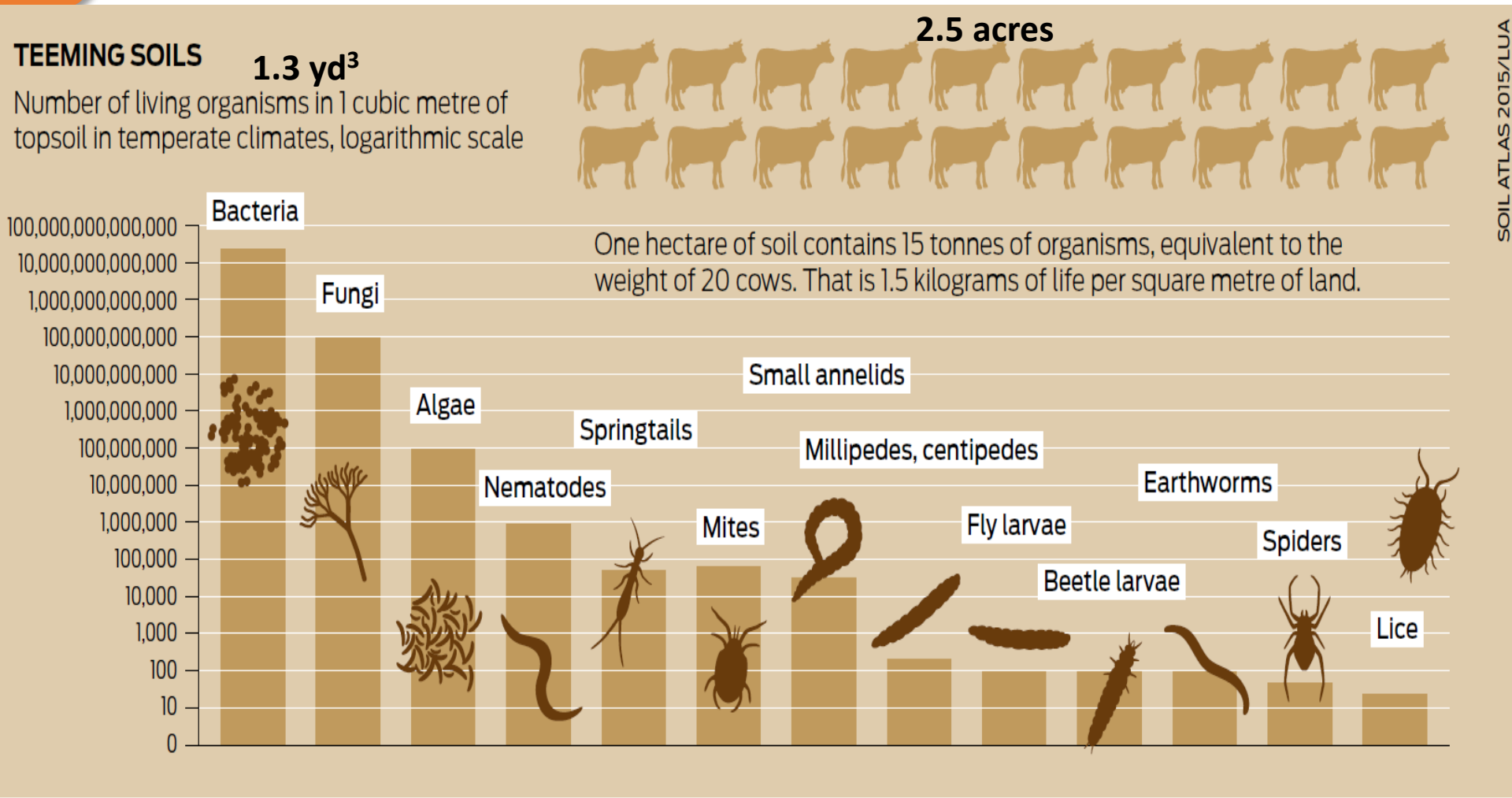
ALL OF THEM!

Soils Host Vast Numbers & Mass of Organisms

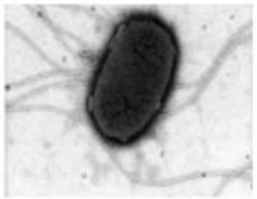


Source: http://globalsoilweek.org/soilatlas-2015

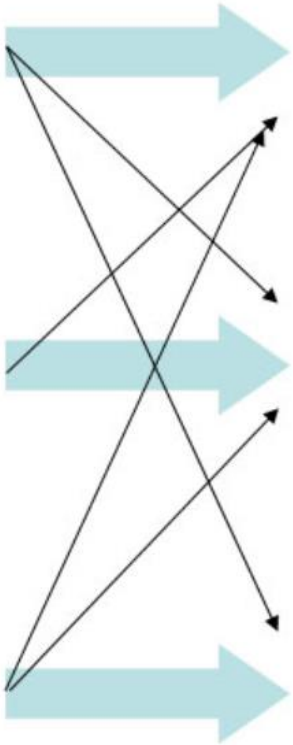
Three Broad Functional Groups

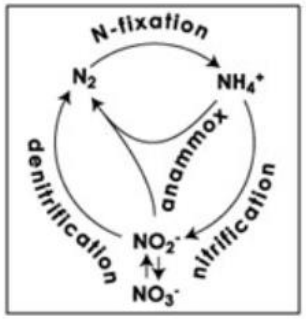
- Soil ecosystem engineers

- Biological regulators



- Chemical engineers/ microbial decomposers



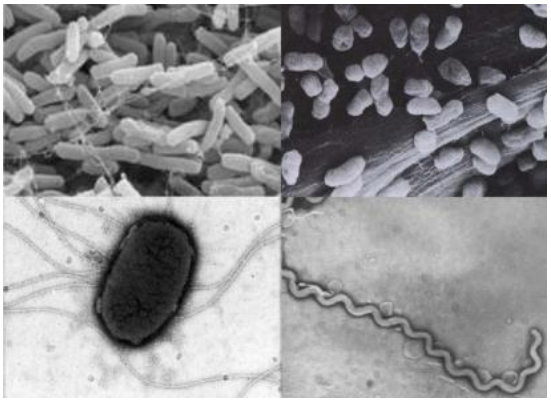


Turbe et al., 2010

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

Conclusions:

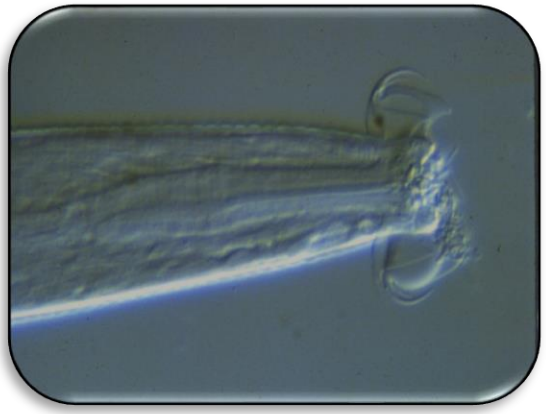
"Soil borne diseases are most damaging when soil conditions are poor as a result of inadequate drainage, poor soil structure, low organic matter, low soil fertility, and high soil compaction".

Impact of soil health management practices on soil borne pathogens, nematodes and root diseases of vegetable crops
G.S. Abawi, T.L. Widmer , 2000. Applied Soil Ecology

Applied Soil Ecology
www.elsevier.com/locate/apsoil

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)

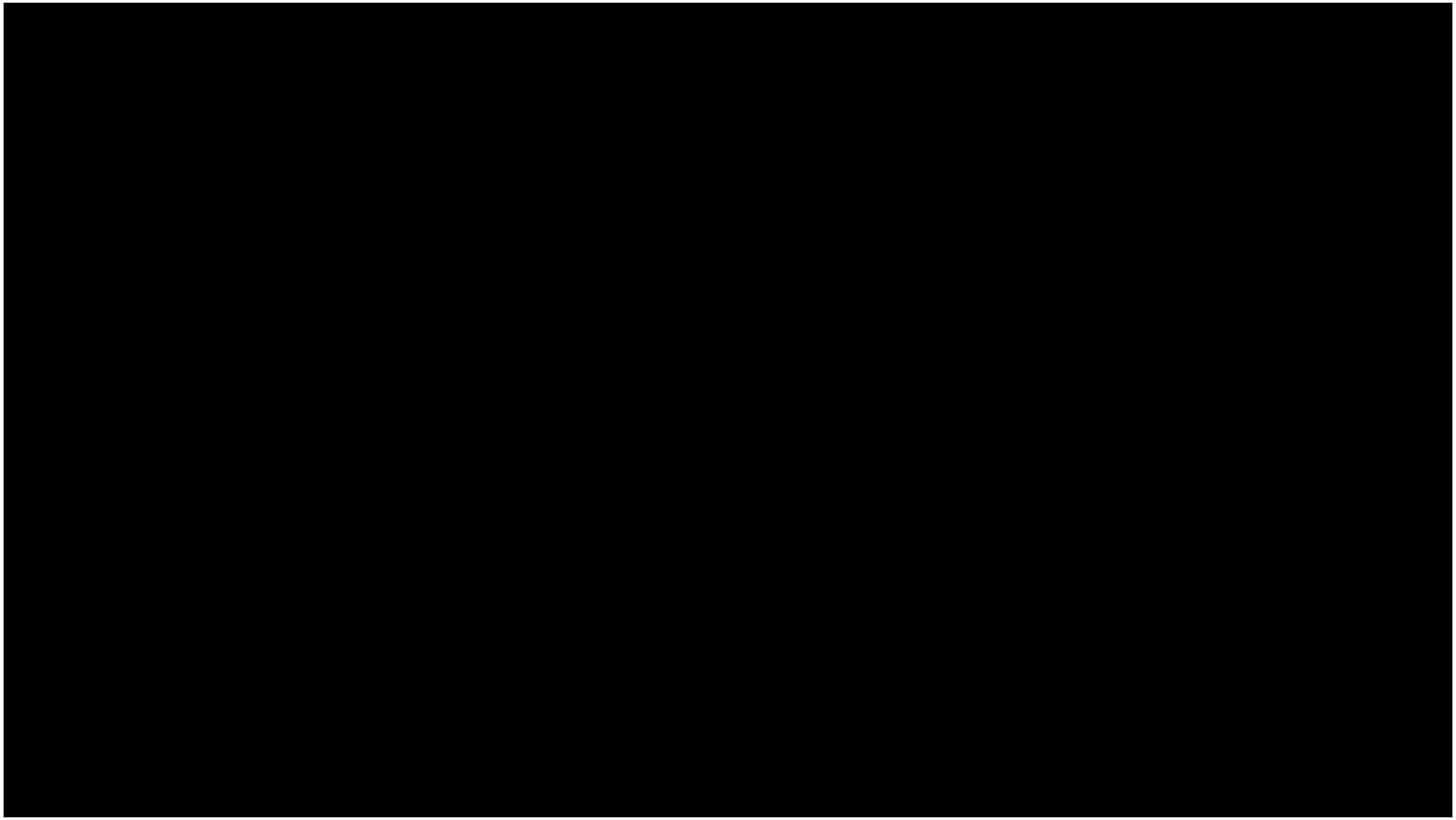


File name: Arthrobotrys.jpg at 265K. (Also: F-4 at 1600KB shows whole Bug Biography)
Photo Credit: George L. Barron, University of Guelph, Ontario.

Turbe et al., 2010

Regulators and nutrient cycling

Protozoa gathering around an air bubble video



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?


Photo: Ray Archuleta


Photo: Marlon Winger

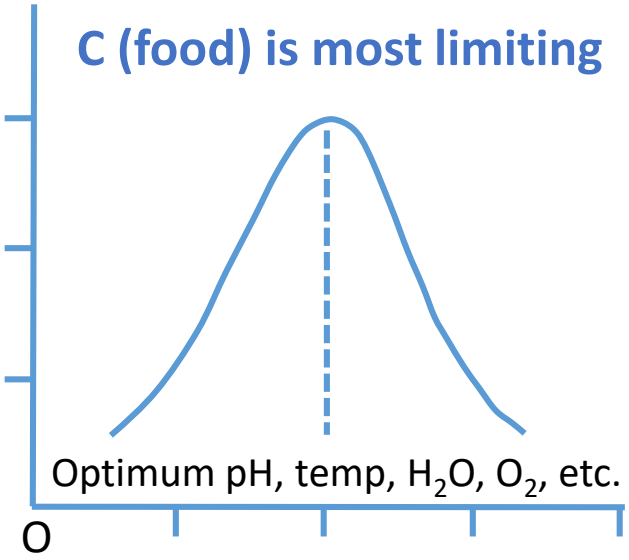

Photo: Marlon Winger


Photo: Marlon Winger

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

Survival Strategies, Sleeping Beauty & Prince Charming

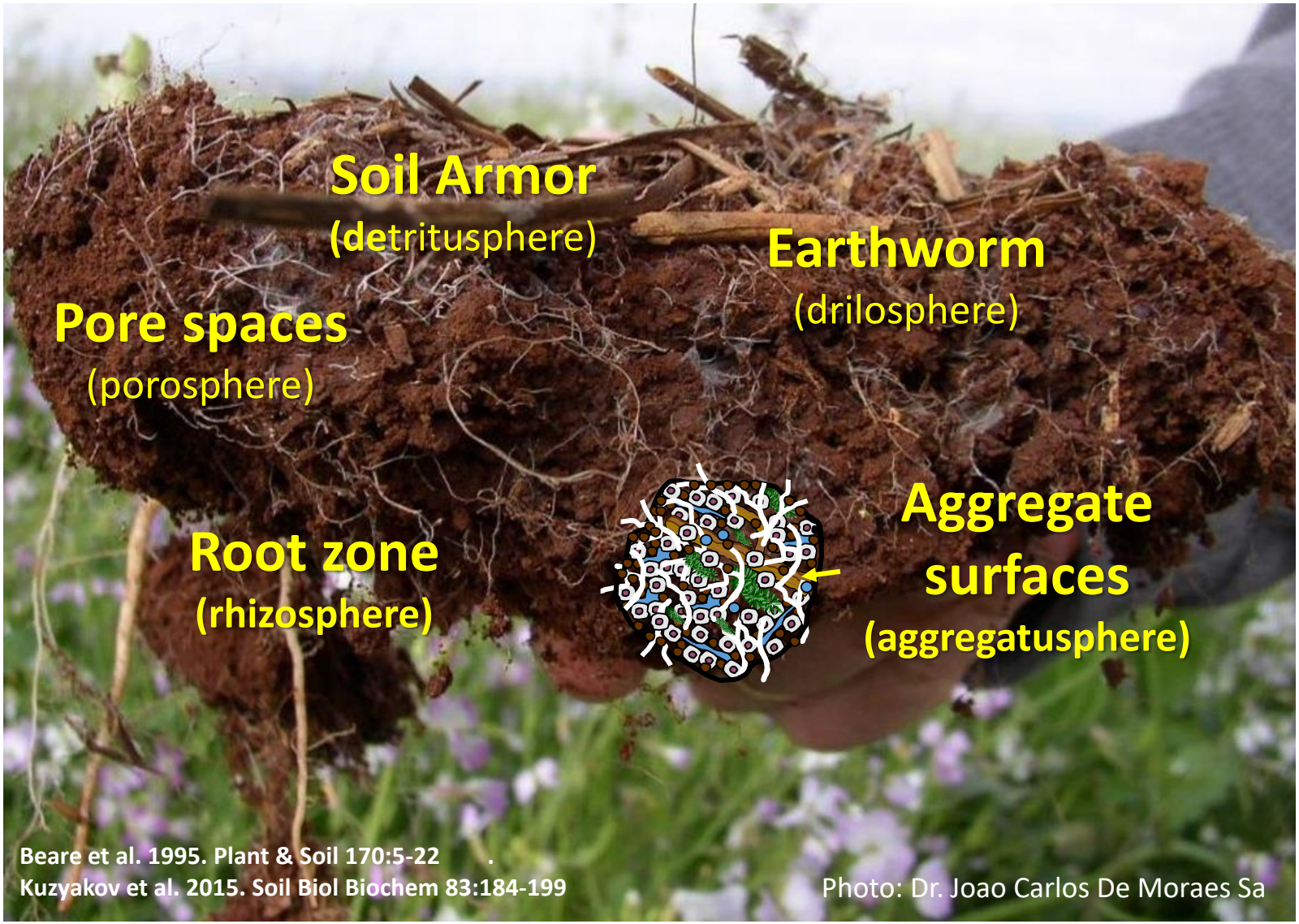

Cysts of nematodes; Turbe et al. 2010

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

https://www.youtube.com/watch?v=AnsYh6511Ic


Bacteria move on fungal hyphal highways

Biological Spheres of Influence of Soil Function

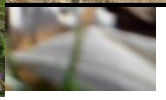


Beare et al. 1995. Plant & Soil 170:5-22 .
Kuzyakov et al. 2015. Soil Biol Biochem 83:184-199

Photo: Dr. Joao Carlos De Moraes Sa



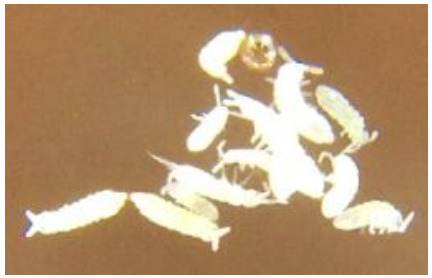




Detritusphere: Key Soil Organisms

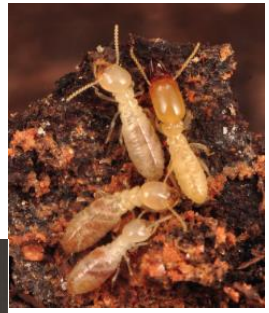
Mesofauna (Biological regulators)

- 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

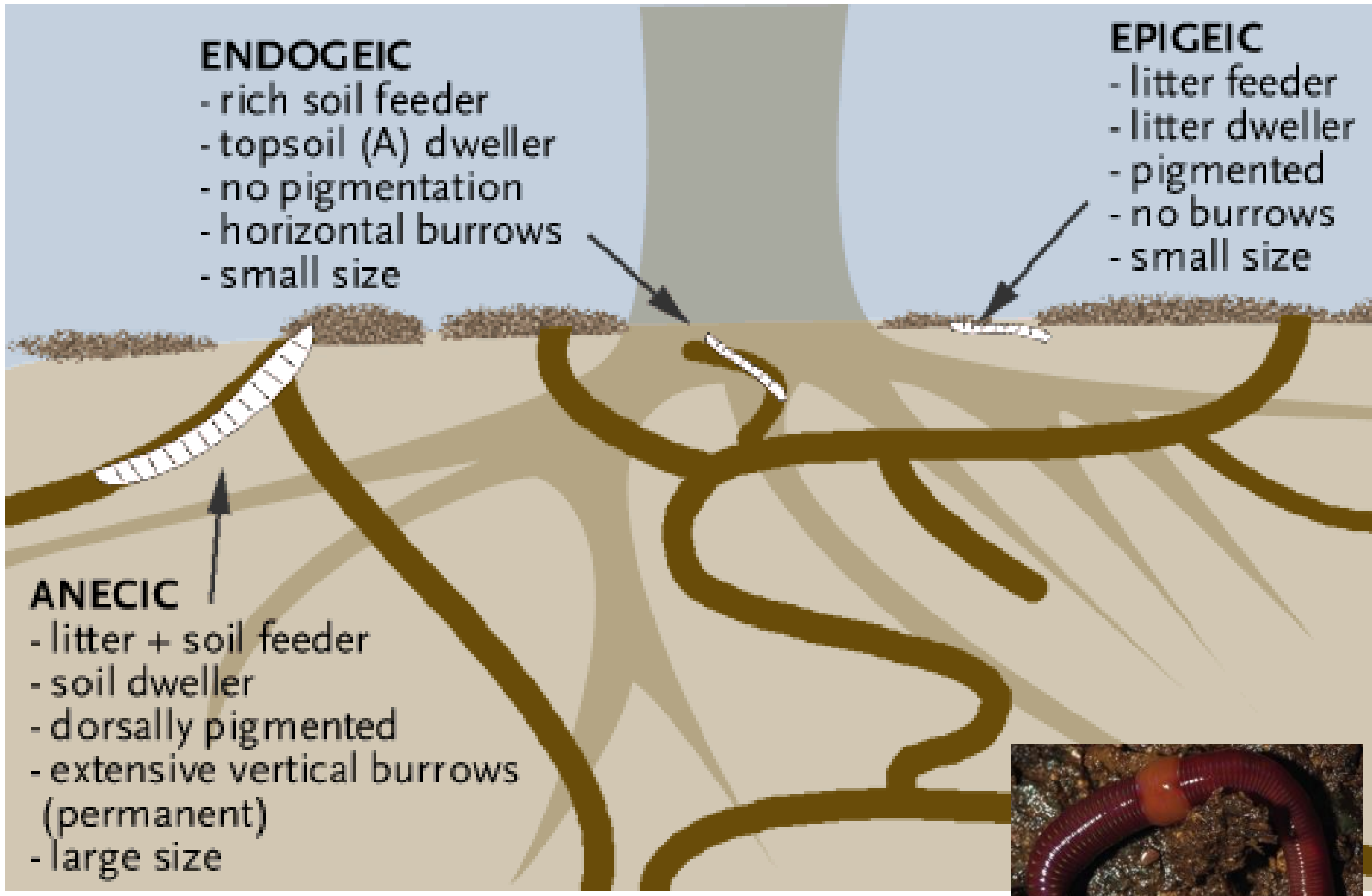
Move microbial community

Stable aggregates

Consume seeds

Large pores

Transport microbes



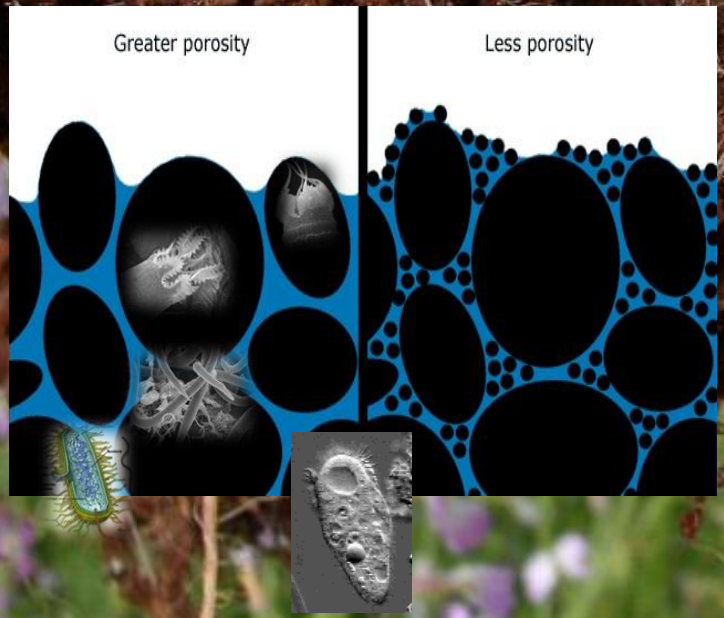
Turbe et al 2010; Orgiazzi, Bardgett,

Barrios et al. 2016. Global Soil Biodiversity Atlas.


TOTAL VIDEO CONVERTER
HTTP://EFFECTMATRIX.COM

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

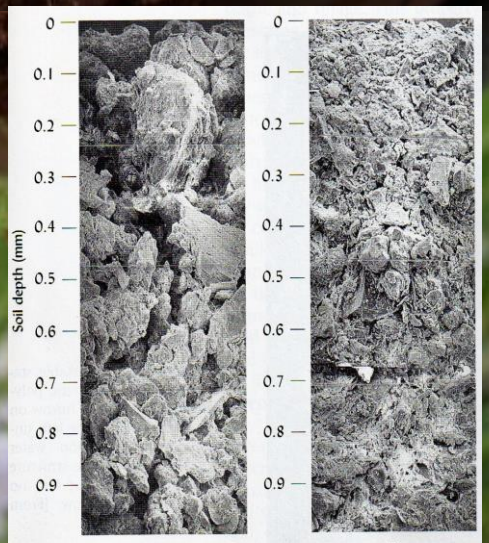
Porosphere: Arrangement of Solids & Voids



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

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



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

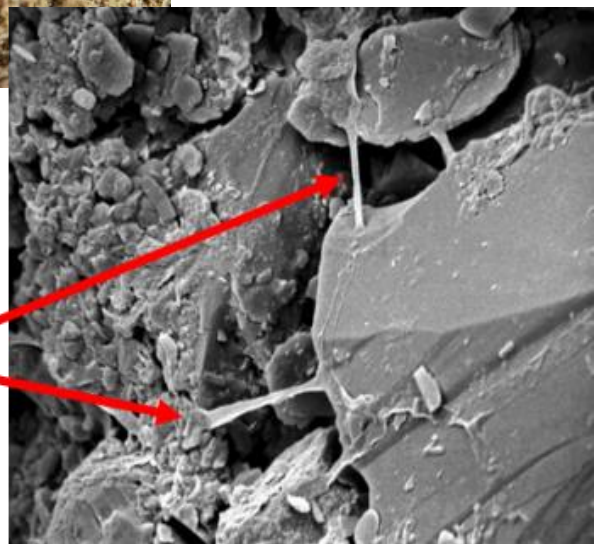
They are linked mainly by fungi hyphae, roots fibers, polysaccharides, Glomalin, rhizo-deposition, and aromatic humic materials

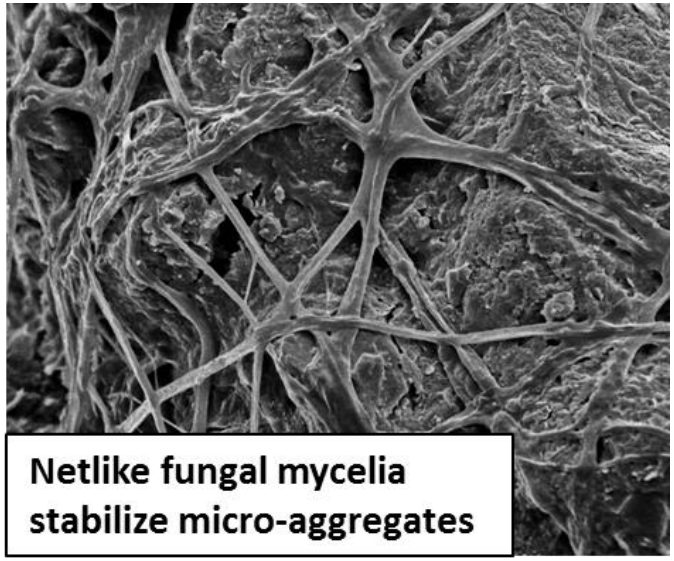
Beare, D.C. Coleman, D.A. Crossley Jr., P.F. Hendrix and E.P. Odum (1995)

Soil Organisms Physically Stabilize Soil Aggregates

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

Stabilization of soil structure by actinomycete (bacterial) filaments



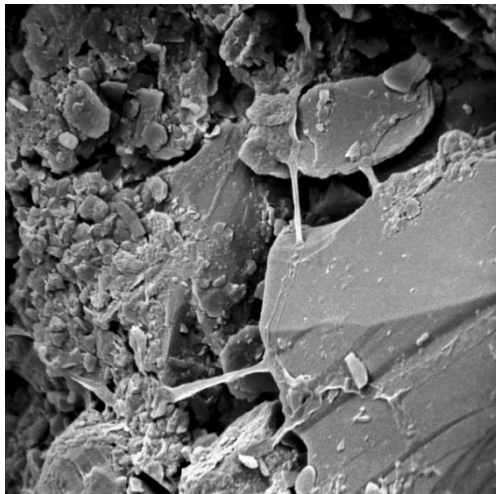


Netlike fungal mycelia stabilize micro-aggregates

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

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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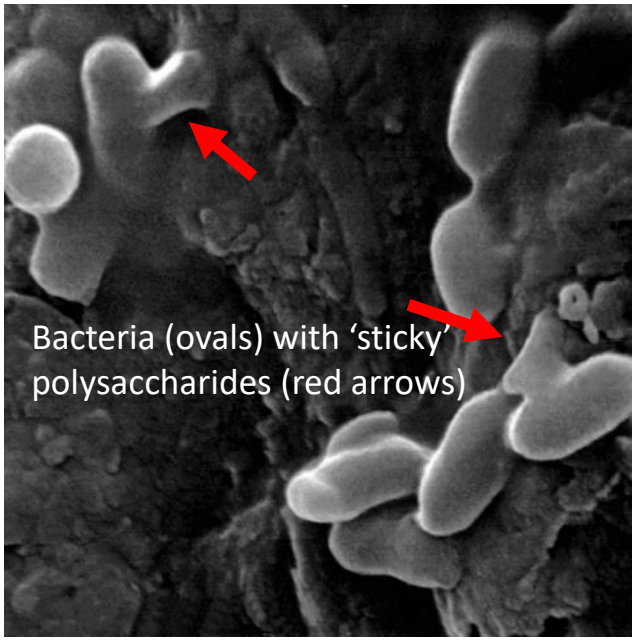
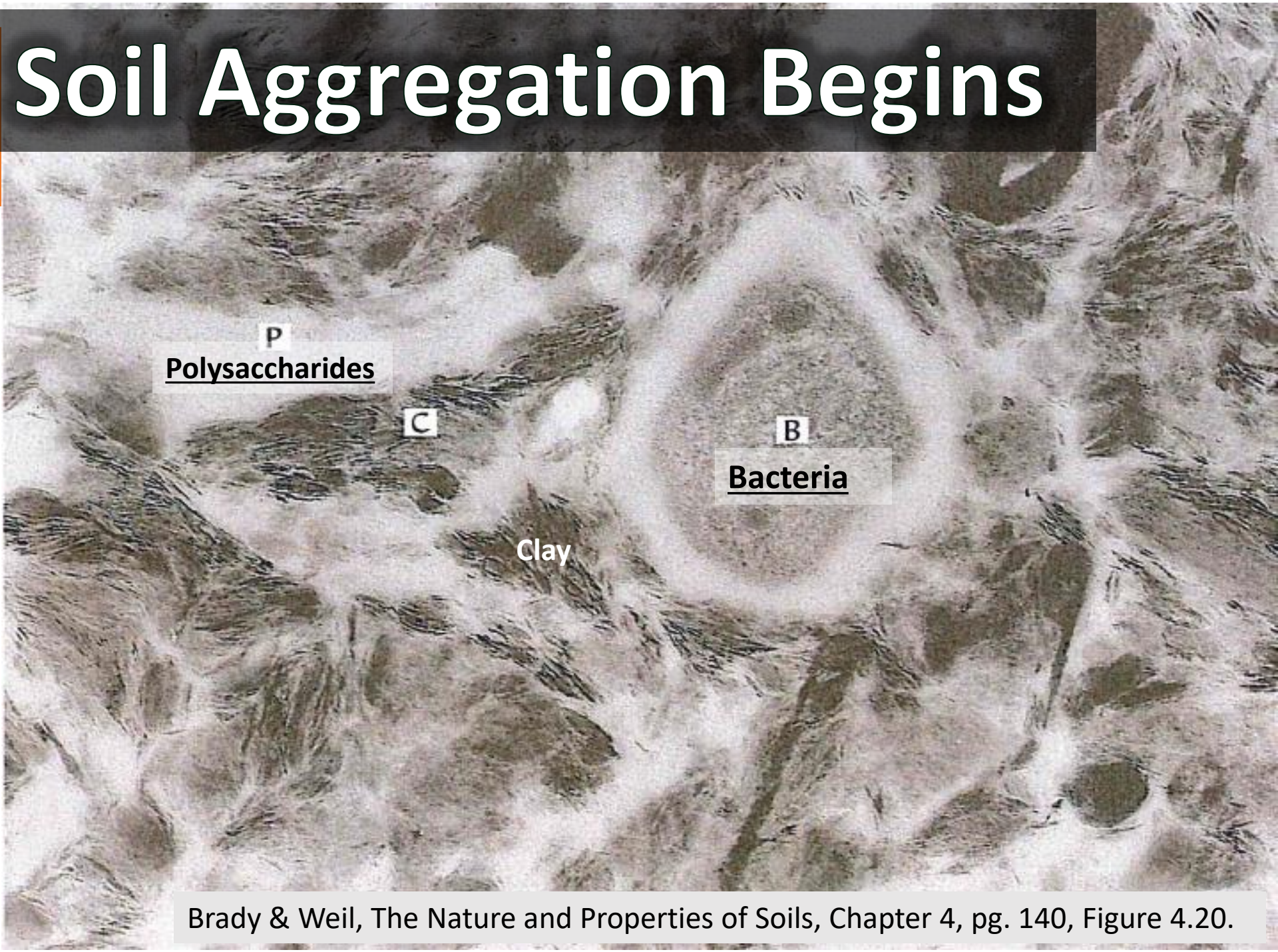


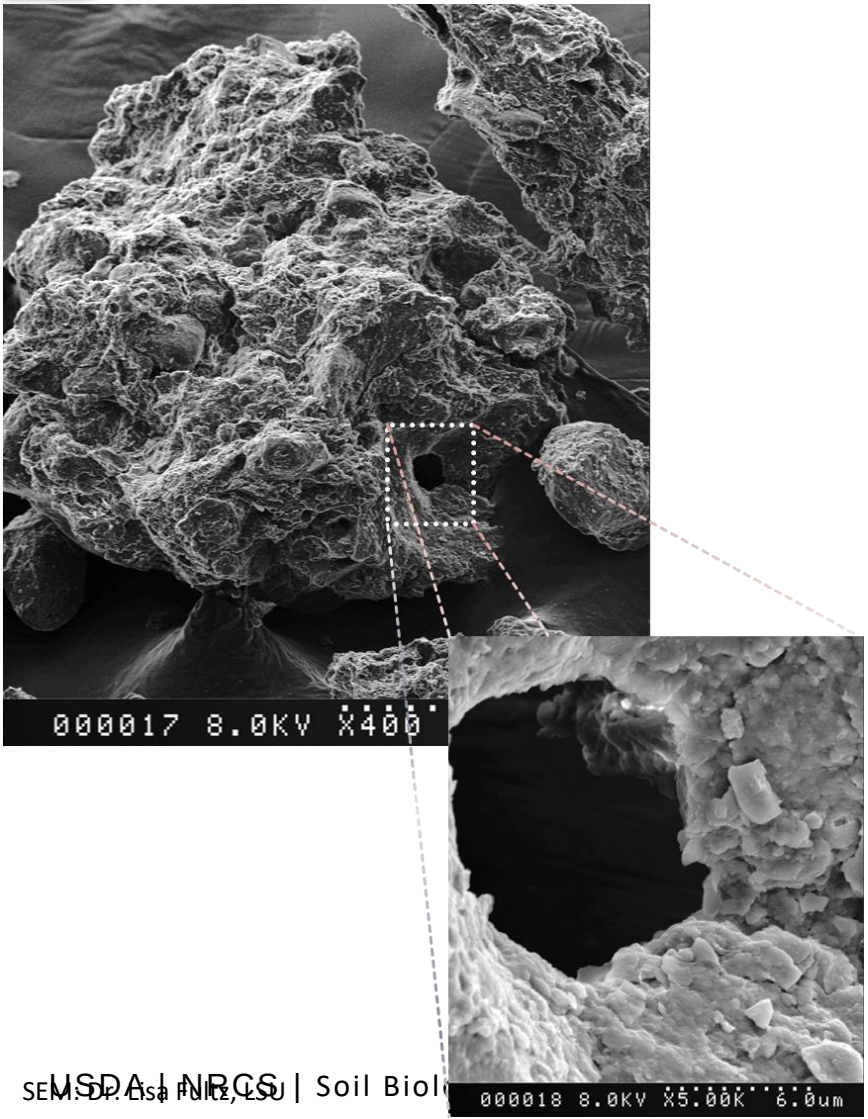
SEM photo source: Eickhorst, Thilo & Tippkoetter, Rolf. Micropedology – The hidden world of soils. University of Bremen, Germany. http://www.microped.uni-bremen.de

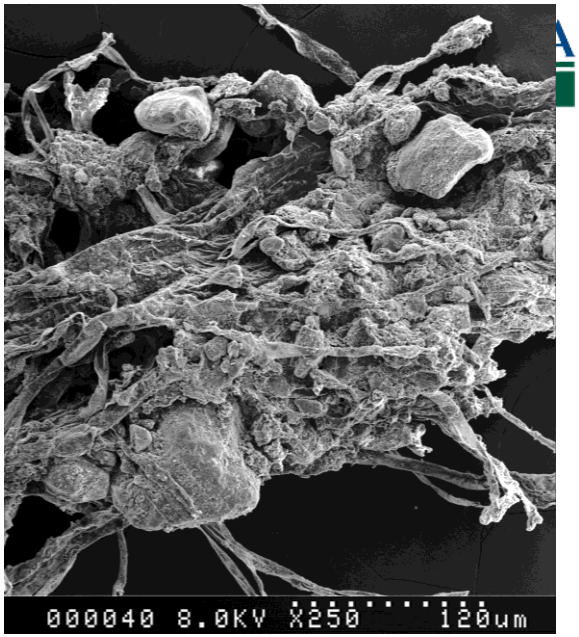
Soil Aggregation Begins



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

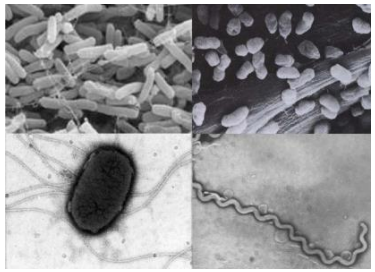
Pea -rhizosphere

Photo: Marlon Winger

Rhizosphere: Key Organisms

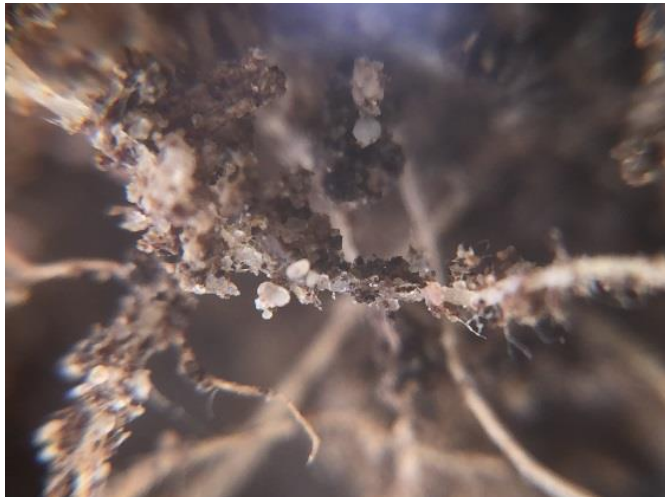
Bacteria

- 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

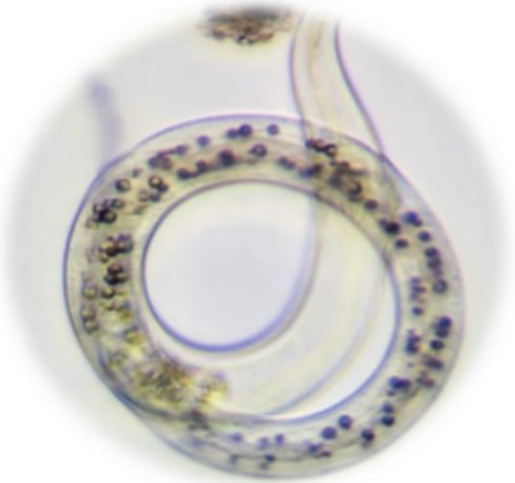


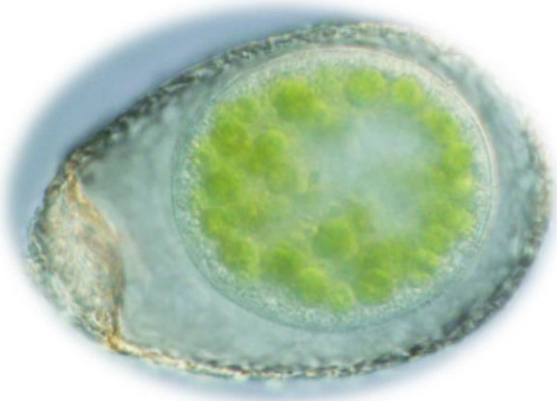
Turbe et al 2010; Coleman & Crossley 1996; Nannipieri & Badalucco 2003; Global Soil Biodiversity Atlas. 2016. Orgiazzi, Bardgett, Barrios et al.

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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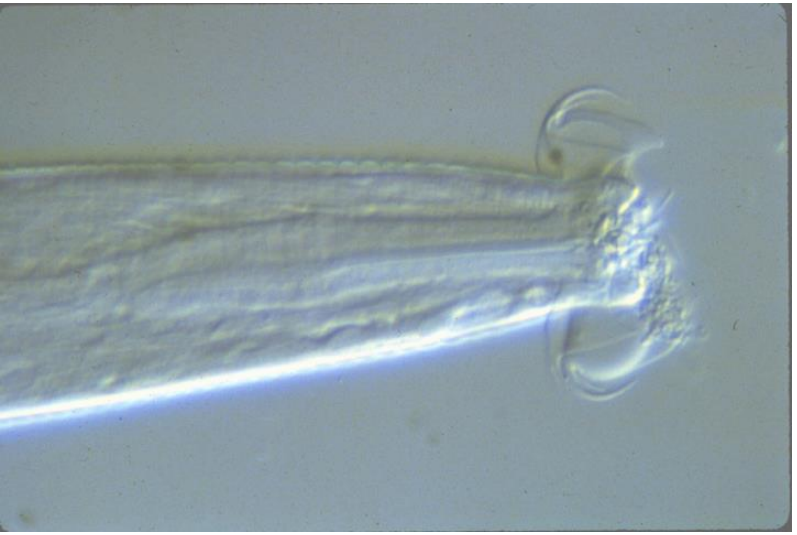
Bacteria Feeding Nematode

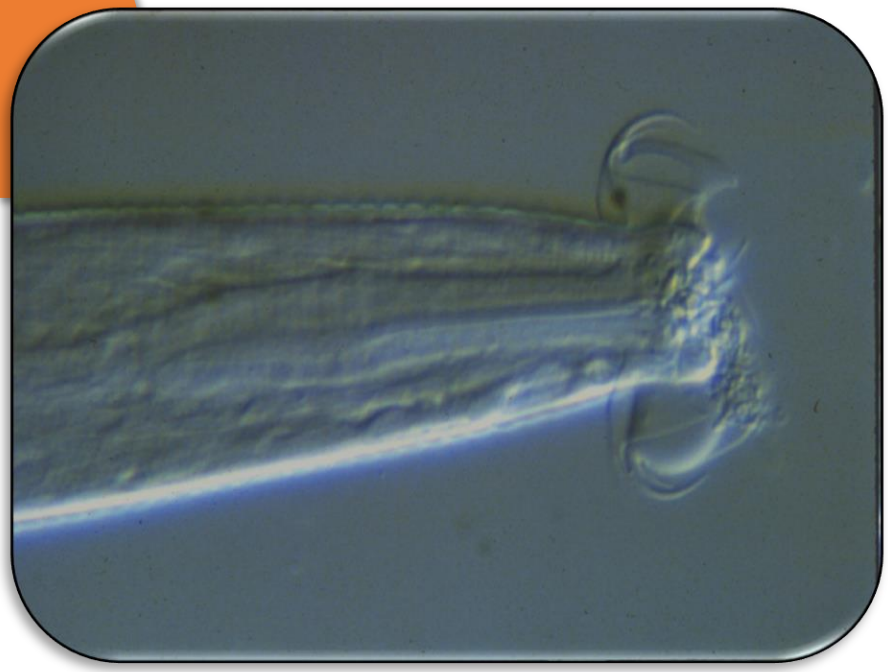


•Bacteria are high in protein that in turn is high in nitrogen.

• 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.

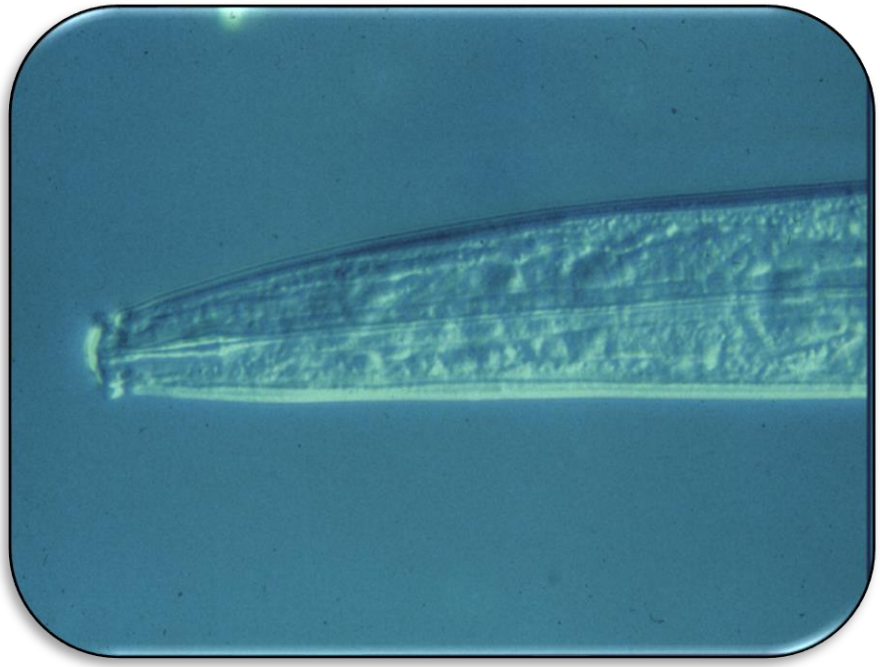
…but similar to the rate for male Pelodera chitwoodi of 3.9 x 10^5 bacteria per day averaged over an 8-d life span (Mercer and Cairns 1974).

Nematodes – Services they provide



A bacteria-feeding nematode

- Control disease
- Cycle nutrients
- Disperse bacteria & fungi



A fungal-feeding nematode

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

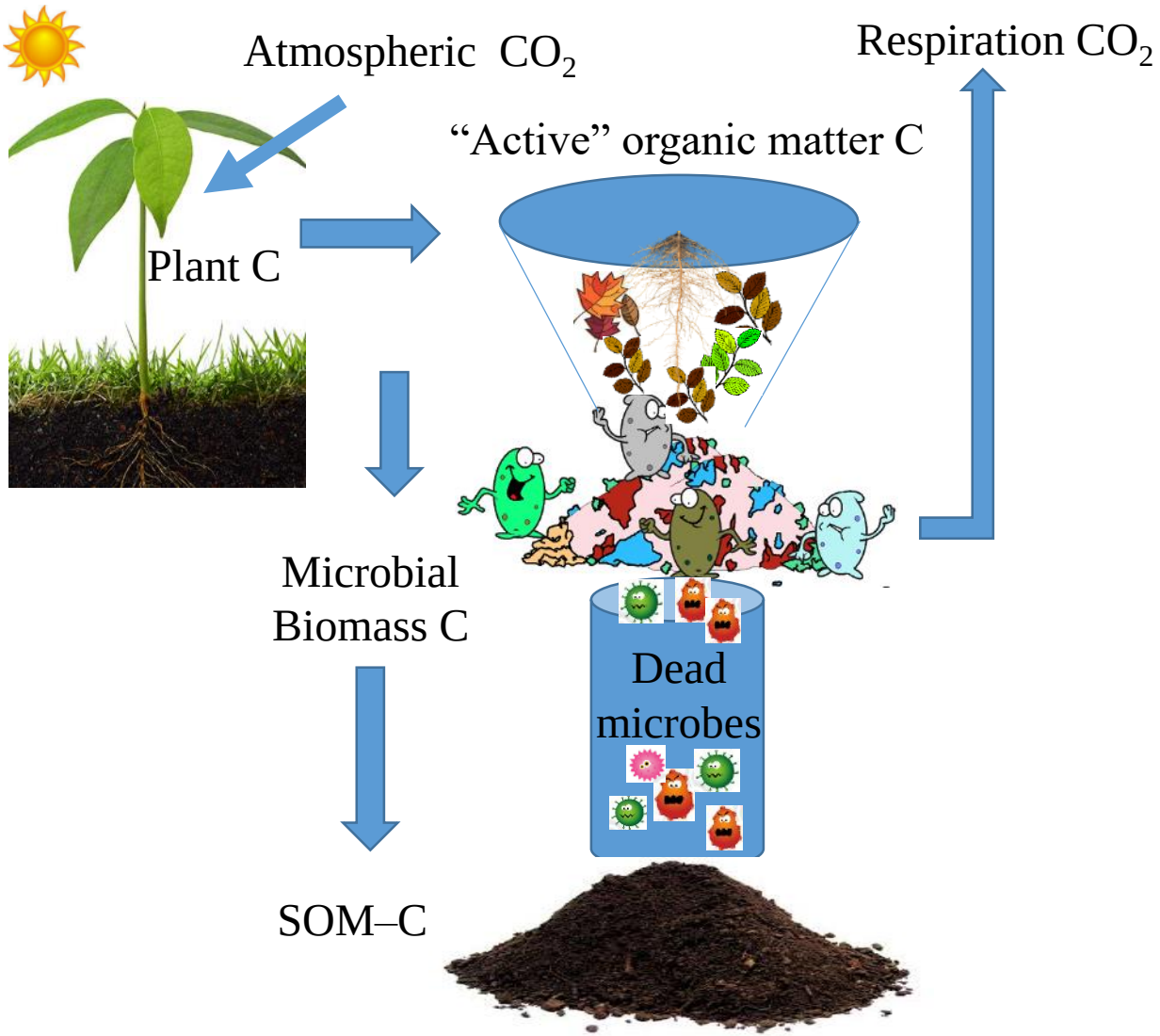
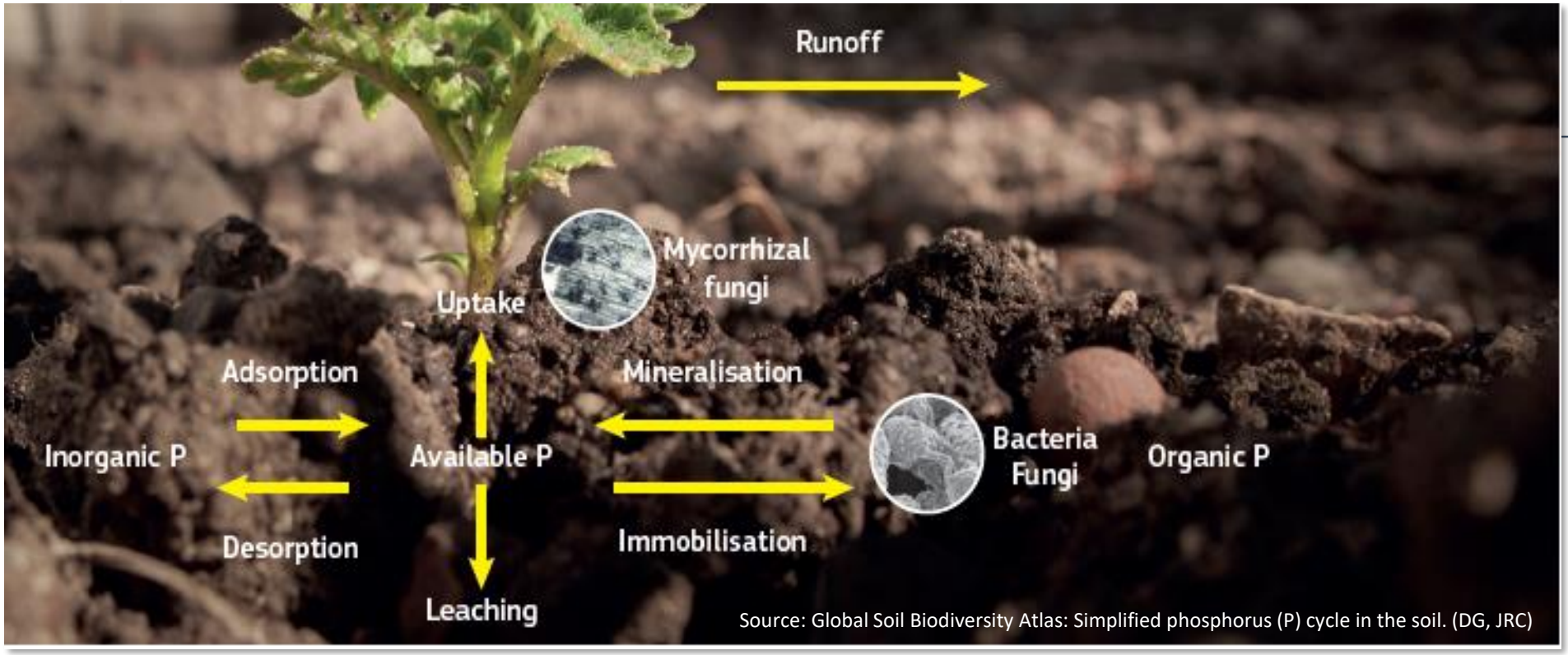


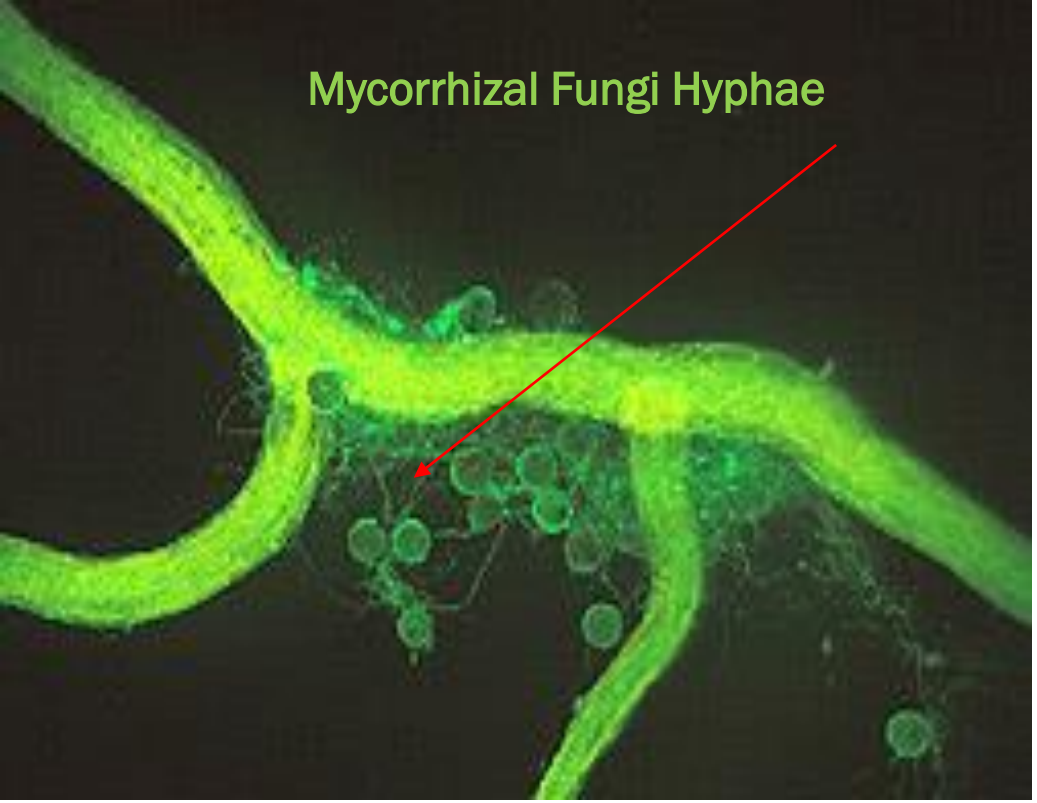
Image courtesy of Dr. Chenhui Li

Microbes help release P from organics and minerals



- **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**

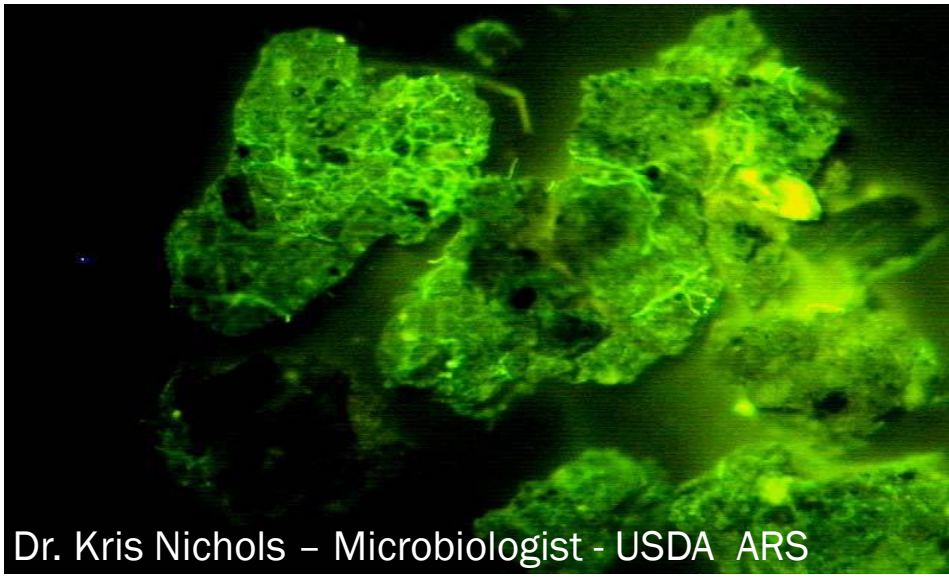
- P-solubilizing bacteria and specialized fungi release enzymes and acids that release stored org-P and mineral-P



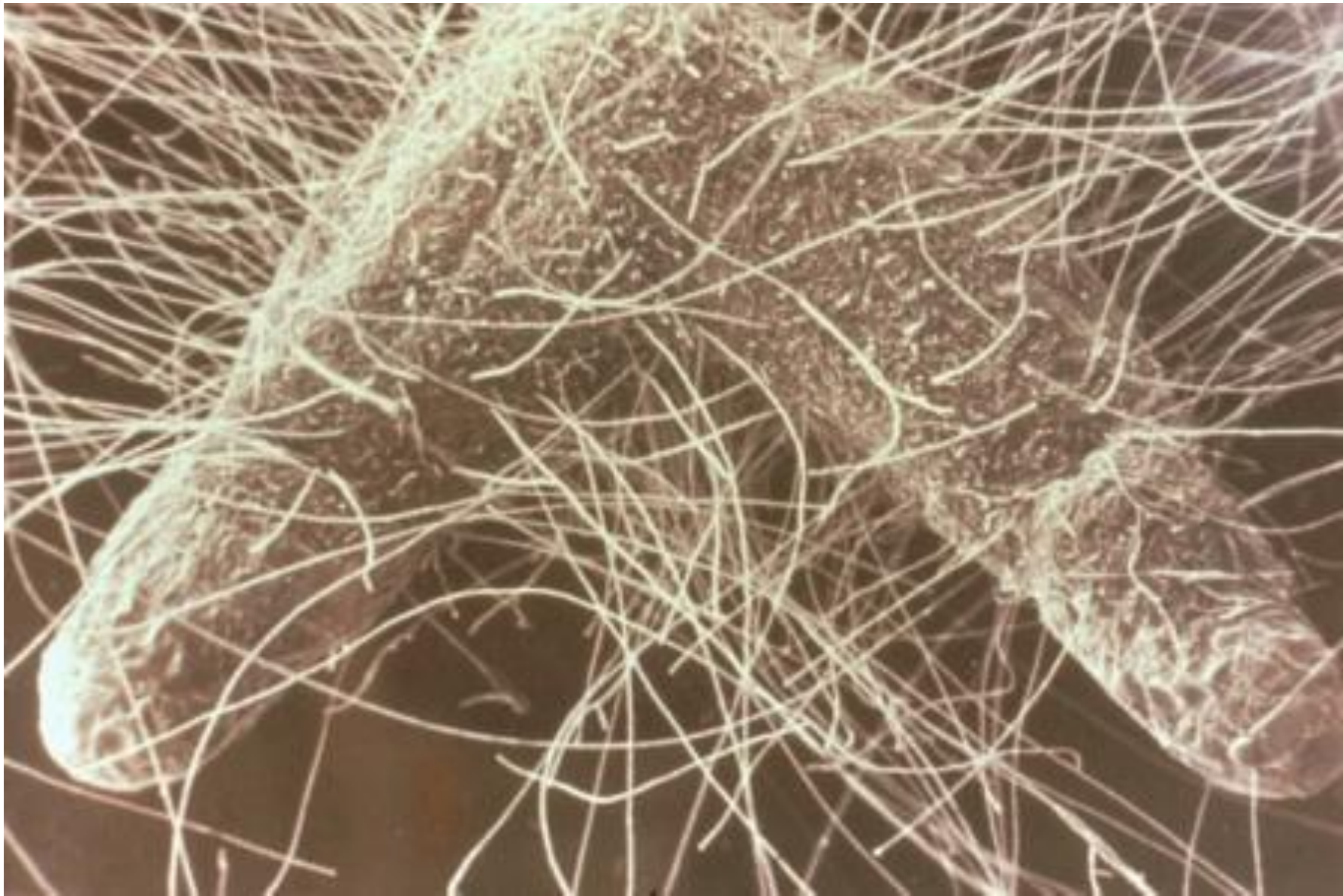
- Transports amino acids into root
- 128 fungal tips (Friese & Allen 1991)

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

- 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



Mycorrhizae Fungi
Attached to root hair



Mycorrhizal Fungi: Highways for Water and Nutrients in Arid Soils

Michael F. Allen* Vadose Sone Journal 6:291-297

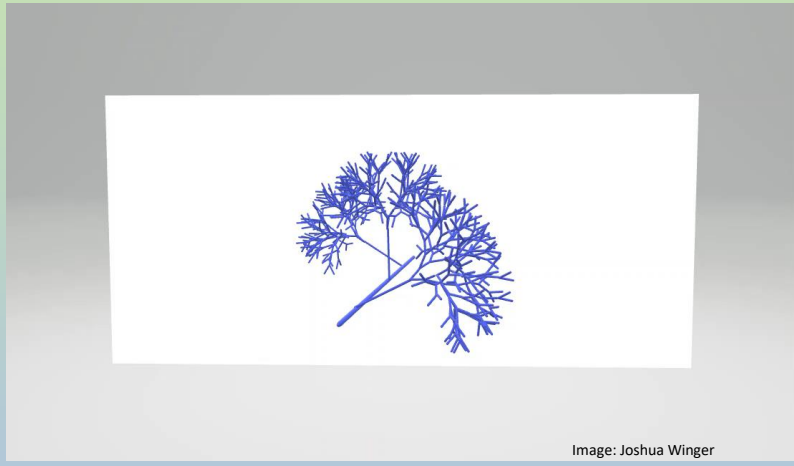


Image: Joshua Winger

Fungal hyphal length in soil up to 1 km/cm^3 soil
AM fungal hyphae can exceed 10^8 m/m^3 (e.g., Miller et al., 1995).

In AM systems, two types of mycelial networks
1st is the "runner" or "arterial" hyphae that extend from an infection point into the soil matrix looking for nutrient resources or new root tips available for infection. These hyphae tend to be large (often 10 µm in diameter or larger), with relatively infrequent branching.

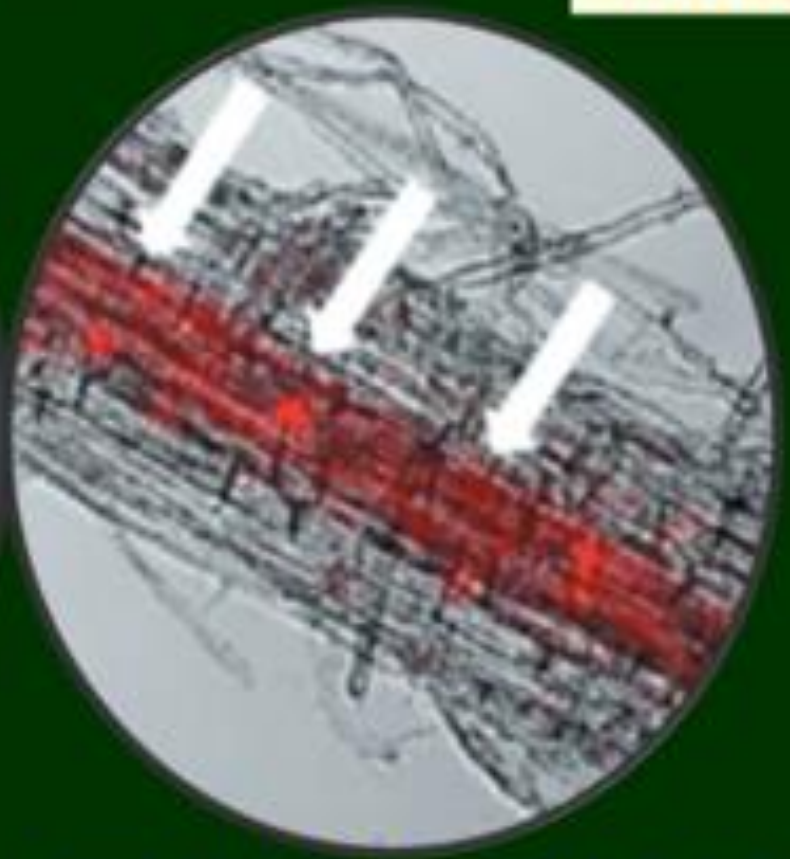
2nd Absorbing networks thus have a distinct fan-shaped architecture starting with a single large hypha, branching into two smaller hyphae, branching into four smaller hyphae, and so forth, to an eight-order branching unit, with 128 tips, each about 2 µm in diameter (Friese and Allen, 1991; Allen et al., 2003). The absorbing unit extends about 6 cm into the soil from a root.

Quantum dots attached to amino acids

(Dr. Michael Amaranthus, University of California, Irvine)

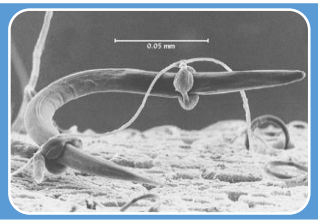
Mycorrhizae assist with Organic Nitrogen Uptake

Amino Acids inside mycorrhizal hyphae



Amino Acids have entered the root from mycorrhizal hyphae

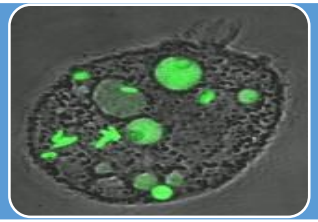
Examples of Biological Regulators



Fungi: regulating nematode populations

Fungi: parasitizing a soybean cyst nematode

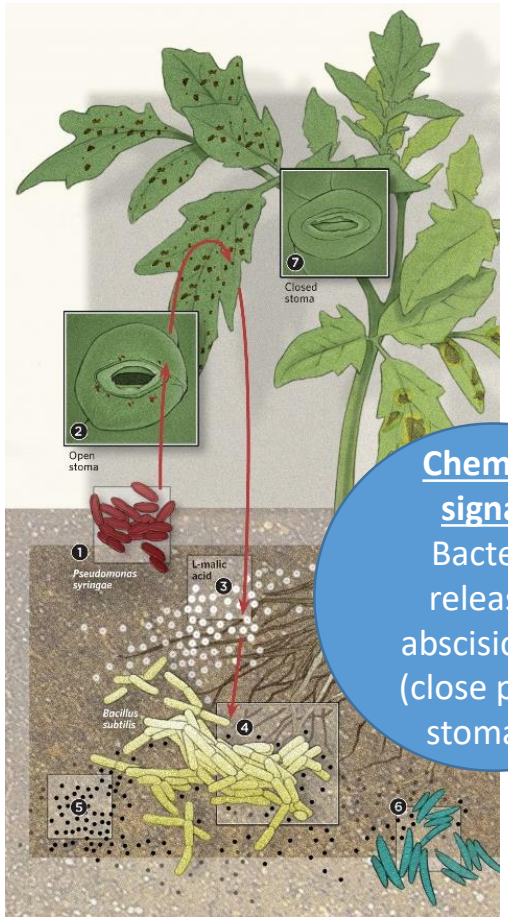
Mites: regulating springtail (L) and nematode (R) populations



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

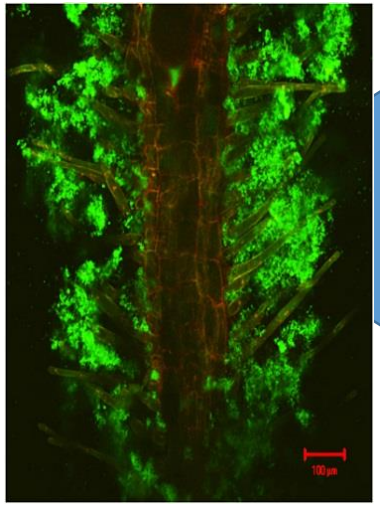
Soil Food Web Benefits: Plant Protection Examples



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)

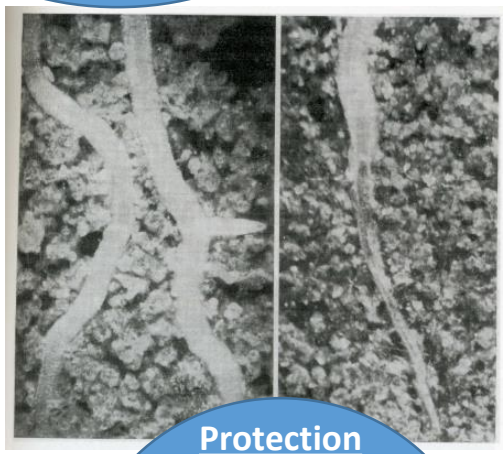


http://www.udel.edu/udaily/2009/oct/bais101708.html

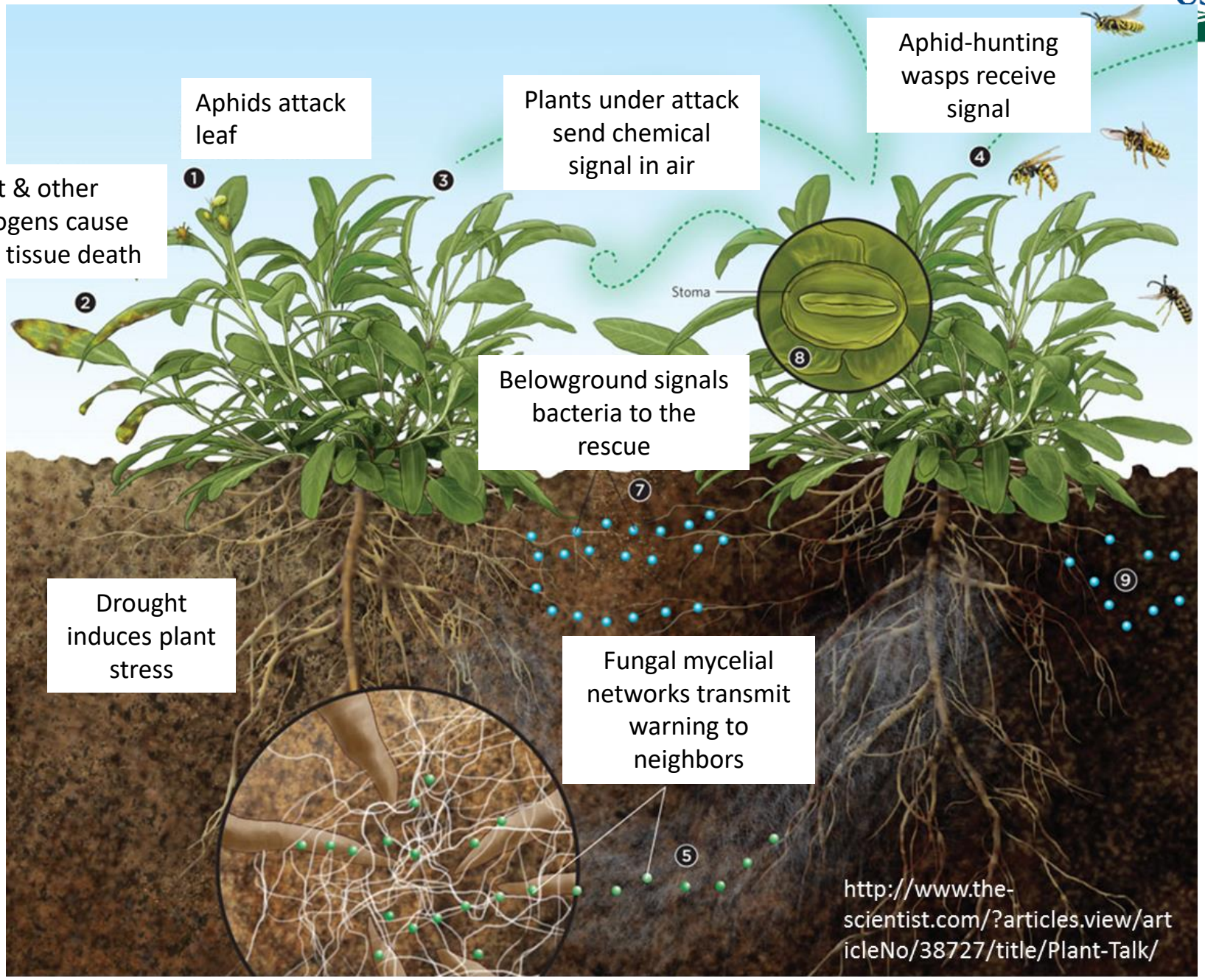
Protection
Biofilm of beneficial bacteria protecting against *P. syringae*

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/

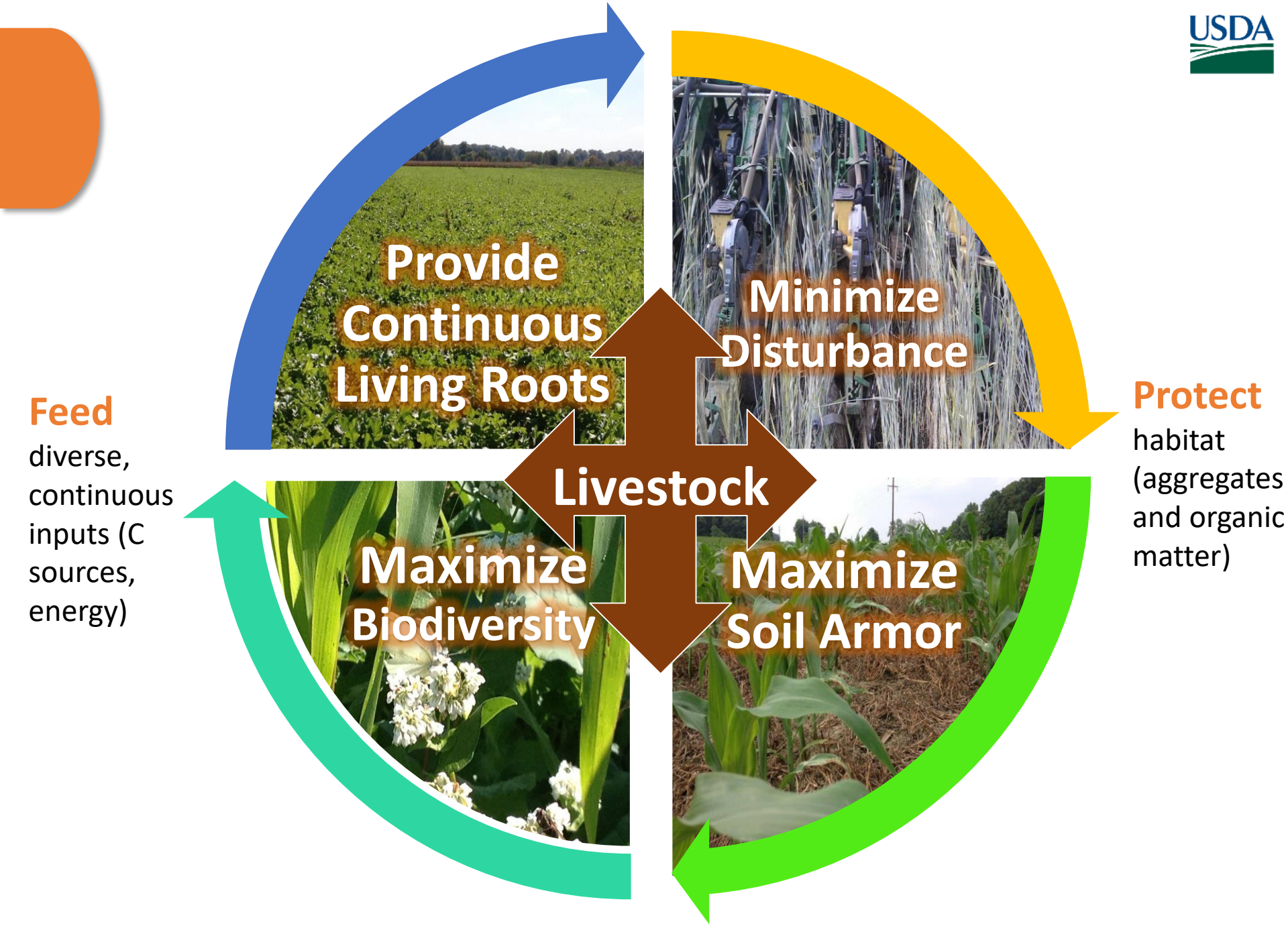
How do We Support Biodiversity to Support Healthy Soils?

Soil Health Principles To Support High Functioning Soils

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

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

Soil Health Principles To Support High Functioning Soils



Feed
diverse, continuous inputs (C sources, energy)

Protect
habitat (aggregates and organic matter)

YouTube: Selected microbes of the soil food web