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 flow
- Water storage
- Water filtration
- Decompose residues
- Influence atmospheric composition
- Detoxify pollutants
- Nutrient cycling
- N fixation
- Plant protection
- Pathogen suppression
Energy

Critical to microbial survival and function in the soil environment

Early chemists describe the first dirt molecule.

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

\[ \text{Sun} + \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{O}_2 + \text{Sugars} \]

Photo: J. Moore Kucera, NRCS-SHD

Jennifer Moore Kucera, NRCS
Capture Energy & Exude C

Soil organisms

Nutrient cycling
Soil aggregation
Plant protection & productivity
Detoxification
Organic matter formation

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 \(\rightarrow\) Rhizosphere

\[
\begin{align*}
\text{sugars} & \quad \text{CO}_2 \quad \text{H}_2\text{O} \\
\text{sugars} & \quad \text{O}_2 \\
\text{sugars} & \quad \text{bacteria}
\end{align*}
\]

Jennifer Moore Kucera, NRCS
The Rhizosphere = a Carbon pump

Exudates
Secretions
Lysates

Root exudates & chemical signals stimulate microbes & predators
The Symbiotic Cycle

The plant feeds the soil organisms

Cyanobacteria, Bacteria, Fungi, Actinomycetes, Algae, Protozoa

Soil organisms feed the plant

Hormones, Growth regulators, Antibiotics, Enzymes, Minerals

Microbiome
Bacteria

Decompose OM
Release nutrients
Retain nutrients
Control pathogens
Are pathogens!
Solubilize P
Aggregate soil
Form soil organo-mineral association
The Nitrogen Cycle

Atmospheric fixation and deposition

Animal manures and biosolids

Biological fixation by legume plants

Atmospheric nitrogen

Crop harvest

Industrial fixation (commercial fertilizers)

Volatilization

Runoff and erosion

Denitrification

Leaching

Plant residues

Plant uptake

Organic nitrogen

Ammonium (NH₄⁺)

Nitrate (NO₃⁻)

Immobilization

Mineralization
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

Feed me!
Give me roots!
Give me surfaces
‘talk’ to me
Don’t poison me!
Fungi

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

Agar culture

Mycelium in soil
vesicular-arbuscular mycorrhizae (VAM)

vesicules

Arbuscules

hyphae
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
Appraoches

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
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
Fungal and litter grazers

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www.naturfoto.cz
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 source: NRCS

Photo: J Moore Kucera NRCS
Detritusphere: Key Soil Organisms

**Mesofauna (Biological regulators):**
- Springtails (Collembola)
- Mites

**Macrofauna (ecosystem engineers):**
- Earthworms, beetles, centipedes, ants, isopods
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.).

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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
Soil Organisms Chemically Stabilize Soil Aggregates

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

- **chemical factors**
  - pH, moisture, O₂, CO₂, inorganic nutrients

- **physical factors**
  - texture, porosity, compaction, bulk density, temperature

- **biological factors**
  - competition, predation, allelopathy
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
\textit{Rhizoctonia}
\textit{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.