Soil Biology’s Impact on Soil Health

Understanding the Importance of a Healthy and Functioning Soil Ecosystem

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Regional Soil Health Specialists, MT, WY, ID
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How does the soil function?

What is the energy source or food for the microbes?

What is the green stuff in the leaves?

What is the process?

What are the products?

What elements are in carbohydrates?

Where does the plant get the carbon from?

Why do plants feed microbes?

What is the most important element in this diagram?
Care for your belowground livestock as you would your aboveground livestock.

Two simple rules:
1. Feed (and provide access to water)
2. Protect their home

In return, the belowground livestock (soil organisms):
- Provide nutrients for plants
- Build organic matter
- Aggregate soil particles together
- Help plants resist ‘stress’
How much biomass belowground supports the life aboveground?

<table>
<thead>
<tr>
<th>Microorganism</th>
<th>Biomass (lbs/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fungi</td>
<td>9760</td>
</tr>
<tr>
<td>Bacteria</td>
<td>5840</td>
</tr>
<tr>
<td>Actinomycetes</td>
<td>5840</td>
</tr>
<tr>
<td>Algae</td>
<td>2720</td>
</tr>
<tr>
<td>Earthworms</td>
<td>1840</td>
</tr>
<tr>
<td>Protozoa</td>
<td>400</td>
</tr>
<tr>
<td>Nematodes</td>
<td>240</td>
</tr>
</tbody>
</table>

~27,000 lbs per acre!

Care for your belowground livestock as you would your aboveground livestock

Equivalent to ~18 cows

Value #1: Microbes are the factories that make organic matter
Value #1: Microbes are the factories that make organic matter

- Increases WHC
- Every 1% SOM holds 16,000+ gallons of H₂O (1.5 qt ft³)
- Increases water infiltration
- Stores nutrients
- Buffers temperature
- Granular/ crumb structure
- Home for soil organisms

Dark colored topsoil showing high levels of SOC due to abundant plant roots and their associated soil fauna and microbes in a cultivated soil in central Iowa.

© 2012 Nature Education Photo courtesy of Todd Ontl.
Value #2: Microbes make the glues that stick particles together

Fungi and Actinomycetes: physically enmesh soil particles
Fungi & Bacteria: release sticky by-products during decomposition
Value #3: Microbes make ‘free’ nitrogen fertilizer!
Value #4: Diverse communities keep the 'bad' guys down

Collembolan (spring tail) protection of roots from infection by *Rhizoctonia solani*

An SCN second-stage juvenile parasitized by the fungus *Hirsutella minnesotensis*

the vampyrellids (protest), eat fungi (this fungus is a root pathogen...take-all disease).
Value #5: Microbes team up with plants to make them healthier

- Mycorrhizae
  - Fungus-root association (carrot root)

- Rhizobium
  - root-bacteria association

Austrian pea  Hairy vetch  Pea-rhizosphere
JOHN DEERE 510 DISK RIPPER CO2 FLUX DATA
SWAN LAKE TILLAGE DEMONSTRATION AUGUST 24, 1994

CO2 FLUX (g/m\(^2\)/h)

TIME AFTER TILLAGE (hours)

NOT TILLED

J.D. 510 DISK RIPPER

MOLDBOARD PLOW

Reicosky et al., 1995
Where do Soil Organisms Live

- **In Humus**
- **On Surface of Soil Aggregates**
- **Spaces between aggregates**
- **Around Roots**
- **In Armor**
Rhizosphere
Where Roots Meet Soil

Zone of Concentrated Biological Activity
- Bacteria
- Fungi
- Protozoa
- Nematodes
### Typical Numbers of Soil Organisms in Healthy Ecosystems

<table>
<thead>
<tr>
<th></th>
<th>Crop Land</th>
<th>Prairie</th>
<th>Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Organisms per gram (teaspoon) of soil</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacteria</td>
<td>100 mil. - 1 bil.</td>
<td>100 mil. - 1 bil.</td>
<td>100 mil. - 1 bil.</td>
</tr>
<tr>
<td>Fungi</td>
<td>Several yards</td>
<td>10s - 100’s of yds</td>
<td>1-40 miles (in conifers)</td>
</tr>
<tr>
<td>Protozoa</td>
<td>1000’s</td>
<td>1000’s</td>
<td>100,000’s</td>
</tr>
<tr>
<td>Nematodes</td>
<td>10-20</td>
<td>10’s - 100’s</td>
<td>100’s</td>
</tr>
<tr>
<td>Arthropods</td>
<td>&lt; 100</td>
<td>500-2000</td>
<td>10,000-25,000</td>
</tr>
<tr>
<td>Earthworms</td>
<td>5-30</td>
<td>10-50</td>
<td>10-50 (few in conifers)</td>
</tr>
<tr>
<td></td>
<td></td>
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</tbody>
</table>
Basic facts about the Soil food web

The soil food web:
1) Is complex
2) Individual organisms are small in size
3) Individual organisms are numerous
4) Is greatly impacted by temperature / moisture
5) Is most active near the soil surface
Can you measure the Foodweb

• Counting
  – Direct counts
  – Plate counts

• Measuring activity levels
  – Measure by-products, e.g. CO2
  – Disappearance of substance, e.g. residue
    • Respiration
    • Nitrification rates
    • Decomposition rates

• Measuring cellular constituents
  – Total biomass
  – Biomass carbon, nitrogen or phosphorus
  – Enzymes
  – Phospholipids
  – DNA and RNA
What does it tell us?

- Structure of a food web
- Numbers or biomass of organisms in the soil
- Effectiveness of organisms doing specific activities
- Unique characteristic or “fingerprints” of the soil community
<table>
<thead>
<tr>
<th>Two Years Mob Grazing</th>
<th>No Mob Grazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Side of Shelterbelt</td>
<td>East Side of Shelterbelt</td>
</tr>
<tr>
<td>Total Biology</td>
<td>Total Biology</td>
</tr>
<tr>
<td>6105 ng/g soil</td>
<td>4228 ng/g soil</td>
</tr>
<tr>
<td>Actinomycetes</td>
<td>Actinomycetes</td>
</tr>
<tr>
<td>213 ng/g soil</td>
<td>418 ng/g soil</td>
</tr>
<tr>
<td>Bacteria</td>
<td>Bacteria</td>
</tr>
<tr>
<td>4417 ng/g soil</td>
<td>3349 ng/g soil</td>
</tr>
<tr>
<td>Fungi</td>
<td>Fungi</td>
</tr>
<tr>
<td>786 ng/g soil</td>
<td>386 ng/g soil</td>
</tr>
<tr>
<td>Mycorrhiza</td>
<td>Mycorrhiza</td>
</tr>
<tr>
<td>230 ng/g soil</td>
<td>145 ng/g soil</td>
</tr>
</tbody>
</table>
BACTERIA - Functions

- 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)
Fungi - Service they provide

- Decompose Tough Organic Matter
- Glomalin secretion develops soil structure
- Extract nutrients
- Hold nutrients
The Workers: Mycorrhizal Fungi

- Enhance plant growth via mycorrhizae (fungus-root)
- Nutrients and H\textsubscript{2}O uptake area is 10x greater with mycorrhizae
  Receive C in exchange (5-30% of PS)
- P solubilizers
- Mycorrhizae are the rule, not the exception, for most plant species

Cost to Mycorrhizae – nutrient shuttle to plant
Benefit to Mycorrhizae – get sugars directly from plant

Cost to plant – 5-10% of PS
Benefit to plant - 10X the absorptive surface
Aggregates are formed by the underground livestock

Plant root material enmeshed in soil particles

Netlike fungal mycelia stabilize micro-aggregates

Stabilization of soil structure by actinomycete (bacteria) filaments

http://www.microped.uni-bremen.de/SEM_index.htm
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
Quantum dots attached to amino acids

Mycorrhizae assist with Organic Nitrogen Uptake

Amino Acids inside mycorrhizal hyphae
Amino Acids have entered the root from mycorrhizal hyphae

Dr. Michael Amaranthus, University of California, Irvine
Glomalin is naturally brown. A laboratory procedure reveals glomalin on hyphae and soil aggregates as the bright green material shown here.

Dr. Kris Nichols – Microbiologist - USDA ARS
Fungi - requirements

- Need aerobic conditions - 5 to 6 mg oxygen per liter
- In low oxygen conditions anaerobic bacteria attack and eat fungi
- Disease causing fungi benefit under anaerobic conditions
Mycorrhizae Fungi
Attached to root hair
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.
PROTOZOA-(Predator)
Flagellates-Amoebae-Ciliates

- Single Celled Animals
- Feed on Bacteria and Release Nutrients (N)
- Increase Decomposition Rates
- Food Source for Other Soil Organisms
- Prevent some Pathogens From Establishing on Plants
- Need Soil Moisture to Move
Protozoa – Services they provide

- Nutrient mineralization
- Regulation of bacterial populations
- Food source themselves
ARTHROPODS
Microscopic to Several Inches
From Mites to Grasshoppers...

• Shred large plant residue and mix with soil
• Improve soil structure by burrowing and creating fecal pellets
• Stimulate additional microbial activity
• Help control disease causing organisms
• Regulate populations of other members of the soil food web
Types of Arthropods

- Shredders
- Predators
- Herbivores
- Fungal-feeders
Herbivorous Arthropods

- Cicadas
- Mole-Crickets
- Root Maggots
- Centipedes
- Eat Plant Roots
Nematodes – Services they provide

- Control disease
- Cycle nutrients
- Disperse bacteria & fungi
Earthworm video
Video by Barry Fisher (Soil Health Division) 2 and 4 times speed.
Managing for Soil Biology
Less Disturbance – More Diversity

• Reduce Physical Disturbance (Tillage)
  – Ratio of fungi to bacteria increases – availability of nutrients and water to roots increases
  – Earthworms and arthropods increase

• Crop Rotation / Plant Diversity
  – Grow as many crop types and species possible
  – Living Roots as long as possible

• Pesticide Management – Integrated Pest Mgmt
Take Home Message

- Less Disturbance
- Keep the Soil Covered
- More Diversity
- Living Roots as Much as Possible
- Incorporate livestock into cropping system
- Treat the “Soil like a Habitat”!
I ain't no wise man
But I'm no fool I believe that Mother Nature
Has taken us to school Maybe we just took too much
Or put too little back It isn't knowledge
It's humility we lack I'm prayin' for rain

Praying for rain
Extra slides below
Two Years Mob Grazing
West Side of Shelterbelt

Total Biology – 6105 ng/g soil
Actinomycetes – 213 ng/g soil
Bacteria – 4417 ng/g soil
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No Mob Grazing
East Side of Shelterbelt

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Actinomycetes – 418 ng/g soil
Bacteria – 3349 ng/g soil
Fungi – 386 ng/g soil
Mycorrhiza – 145 ng/g soil

Gabe Brown, ND
What kind of functions do you want from soil on your farm?

- Support productive plants and livestock
- Be stable and resist erosion
- Efficient at cycling nutrients internally
- Allow $\text{H}_2\text{O}$ to enter quickly
- Drain well to avoid drowning plant roots
- Store $\text{H}_2\text{O}$ for future plant use
- Resist pests, pathogens, and disease
- Help plants grow during ‘stressful’ events

What do you from your soil?
But soils can’t perform for us if we don’t take care of them.....
The Soil Food Web is complex. Every trophic level must function for the soil food web to function!

First trophic level:
- Photosynthesizers

Second trophic level:
- Decomposers
- Mutualists
- Pathogens, parasites
- Root-feeders

Third trophic level:
- Shredders
- Predators
- Grazers

Dr. Nardi
A healthy foodweb occurs when:

1. All the organisms the plant requires are present and functioning.

2. Nutrients in the soil are in the proper forms for the plant to take-up.
   
   ▪ Healthy foodweb hold soil nutrients in non-leachable forms until the plant requires the nutrients
   
   ▪ The plant "**turns-on**" the right biology to convert the nutrients into forms the plant can take-up (but which are typically very leachable).

Dr. Elaine Ingham
A healthy foodweb occurs when:

3. Correct ratio are present
   - Fungi to bacteria
   - Predator to prey

Results
   - Soil pH, soil structure, and nutrient cycling occur at the rates and produce the right forms of nutrients for the plant.

Dr. Elaine Ingham
The functions of a healthy foodweb are:

1. Retention of nutrients so they do not leach or volatilize from the soil. Reduction or complete deletion of inorganic fertilizer applications is possible.

2. Cycling nutrients into the right forms at the right rates for the plant desired. The right ratio of fungi to bacteria is needed for this to happen, as well as the right numbers and activity of the predators.

Dr. Elaine Ingham
The functions of a healthy foodweb are:

3. Building soil structure, so oxygen, water and other nutrients can easily move into the soil and into deep, well-structured root systems. Roots should go down into the soil for at least several to 10’s and perhaps 100’s of feet, but the compaction that humans

Dr. Elaine Ingham
The functions of a healthy foodweb are:

4. Suppression of disease-causing organisms through competition with beneficials, by setting up the soil and foliar conditions to help the beneficials instead of the diseases.

Dr. Elaine Ingham
The functions of a healthy foodweb are:

5. Protection of plant surfaces, above or below ground by making certain the foods the plant surfaces release into the soil are used by beneficial, not disease organisms
   a) making certain that infection sites on plant surfaces are occupied by beneficial, and not disease-causing organisms.
   b) making certain predators that prefer disease-causing organisms are present to consume disease-causing organisms.

Dr. Elaine Ingham
The function of a healthy foodweb are:

6. Production of plant-growth-promoting hormones and chemicals can result in larger root systems, although whether forcing larger root systems on plants is a positive results needs to be understood.

7. Decomposition of toxic compounds

Dr. Elaine Ingham
Foodweb Structure

- Fungi to bacteria ratio related to system.
- Organism reflect food source.
- Management practices change food web.