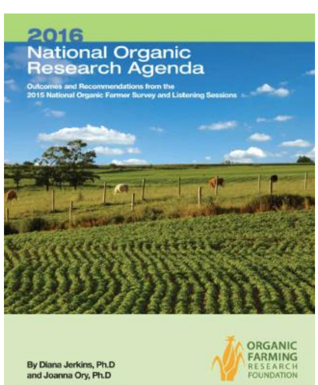
Understanding and Managing Soil Biology for Soil Health and Crop Production

Research-based Practical Guidance for Organic and Transitioning Farmers

Mark Schonbeck
Organic Farming
Research Foundation

Produced with funding from the Clarence E. Heller Charitable Foundation

Soil Biology and Organic Farming



Available at http://ofrf.org/.

Farmer Research Priorities

Soil health – 74%

- Needs of soil microbes
- Role of soil life in crop nutrition and health
- Mycorrhizal fungi and other plant symbionts
- Nematode and insect pests
- Soil-borne diseases

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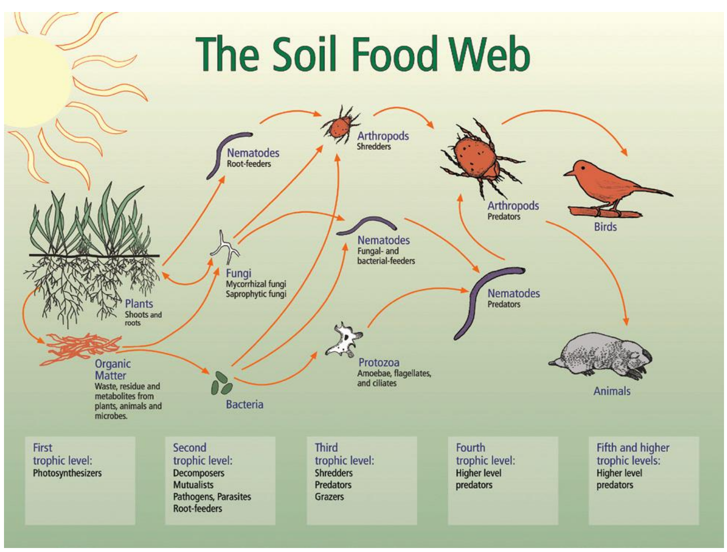
Soil Biology 101

A Brief Tour of the Soil Food Web



Ingham, E. R., A. R. Moldenke, and C. A. Edwards. 2000. *Soil Biology Primer.*
https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology/

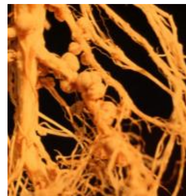
Bacteria and Archaea

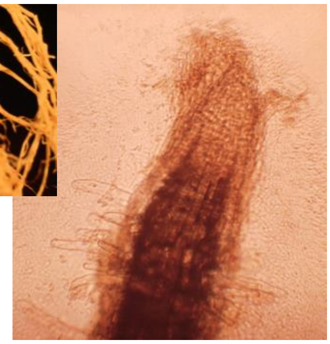
Soil bacteria include:

- Decomposers
- Root zone bacteria
- Nitrogen (N) fixers
- Nitrifying bacteria
- Gut microbiomes
- Plant pathogens

Soil archaea include:

- Nitrifiers, sulfur oxidizers
- Methanogens





Ingham et al., 2000. *Soil Biology Primer*

Legume nodules containing *Rhizobium* bacteria (left); soil bacteria near root tip (right).

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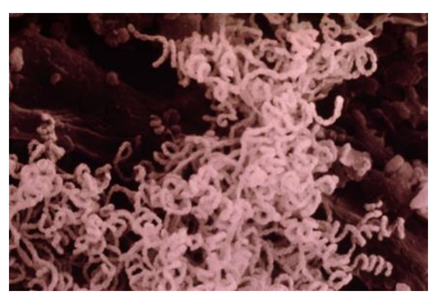
Actinobacteria

Filamentous bacteria, including:

- Decomposers that can digest woody materials
- Plant root symbionts
- N_2 fixers – certain shrubs and trees
- Pathogen antagonists
- A few plant pathogens
- Some tolerant to dry or saline conditions



Soil actinobacteria

Ingham et al., 2000. *Soil Biology Primer*

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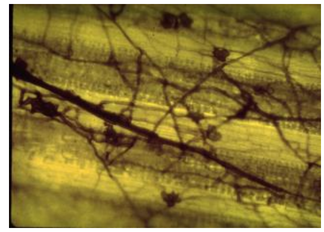
Fungi

Decomposer fungi
- Digest woody materials
- Build SOM

Root-symbiotic fungi
- Ectomycorrhizal – trees and shrubs
- Arbuscular mycorrhizal fungi (AMF) – most crops

Plant pathogens

Parasites of pathogens, pests
- Bio-fungicides



Ingham et al., 2011. *Soil Biology Primer*

Decomposer fungi on leaf (top)
Ectomycorrhizal fungi (bottom)

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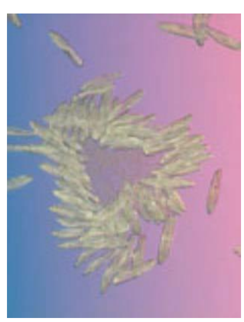
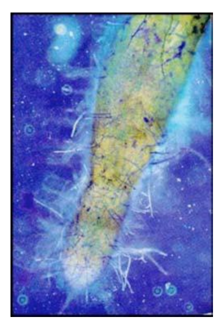
Protozoa

Flagellates, ciliates, and amoebas
- Feed primarily on bacteria
- Important role in releasing N in rhizosphere
- Ciliates in wet soil; flagellates in drier soil



Fotosearch Waukesha, WI.



James Hoorman, Ohio SU

Ciliate protozoa feeding on soil bacteria (left) . Bacteria and protozoa proliferating in rhizosphere (right).

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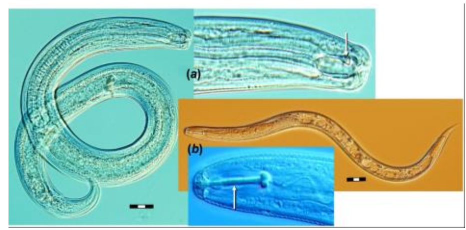
Nematodes

Bacterial feeders
Fungal feeders
- Release crop nutrients

Root feeders
- Potential pests

Predators, Omnivores
- Consume root feeders

Entomopathogenic
- Bacterial symbiont
- Bio-pesticides



Predatory nematode (a) and mouth part (arrow); root-feeding soybean cyst nematode (b) and retractable piercing mouth part (arrow).

Photos by Lisa Stocking Gruver, U Maryland; courtesy of Joel Gruver, Western Illinois U.

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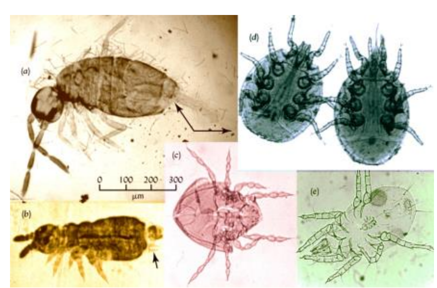
Micro-arthropods

Mites
- Shredders – help microbes digest residues, mineralize nutrients.
- Predators

Collembola (springtails)
- Shredders
- Fungal and bacterial feeders



Ray R. Weil, U. Maryland

Springtails (left) and orbatid mite center) consume residues and fungi; predatory mites (right) eat smaller arthropods and nematodes.

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Earthworms

Ecosystem engineers:

- Build macropores and deep channels.
- Ingest soil and residues, mix with gut microbiome.
- Leave enriched casts.
- Turn over 9 – 450 tons soil/ac-year.
- Mineralize 45 – 80 lb. N/ac-year.

Ray R. Weil

European nightcrawler and casts (above)
Red wiggler in organic residue (left).

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Other Soil Macro-fauna

- Termites are ecosystem engineers in tropics.
- Ants incorporate residues and cycle nutrients in many forests and grasslands.
- Dung beetles process manure, reduce pathogens, and remove livestock pests and parasites from pasture.

Ray R. Weil

In burying manure in the soil, dung beetles facilitate nutrient cycling, disrupt parasite life cycles, and reduce food safety risks.

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Soil Life and Soil Functions

Soil Biology, Plant Nutrition, Crop Protection, and the Impacts of Production Practices

"Feed the Soil …"

… and the soil will feed the plant.

Sir Albert Howard's Law of Return

- Manure
- Crop residues
- Compost

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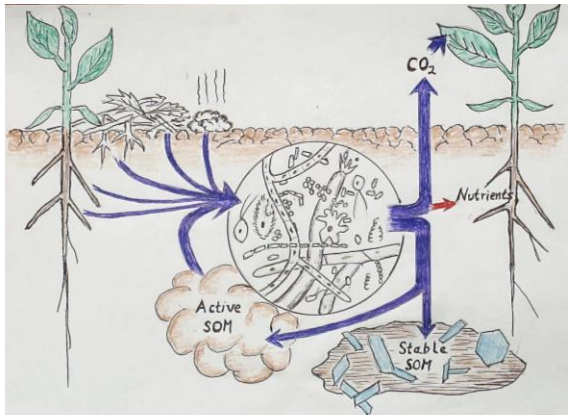
Soil Life Processes All Organic Inputs



Mineralization
- Plant nutrition and growth

Stabilization
- Soil health
- Tilth
- Carbon sequestration

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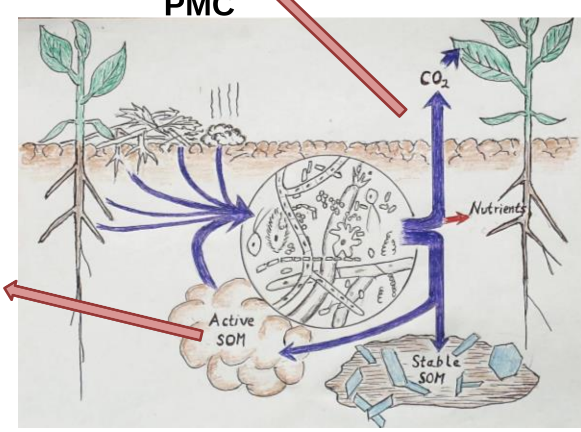
Monitoring Soil Biological Function

Mineralization:
4-day respiration
PMC



Stabilization:
Oxidation in dilute $KMnO_4$
POX-C

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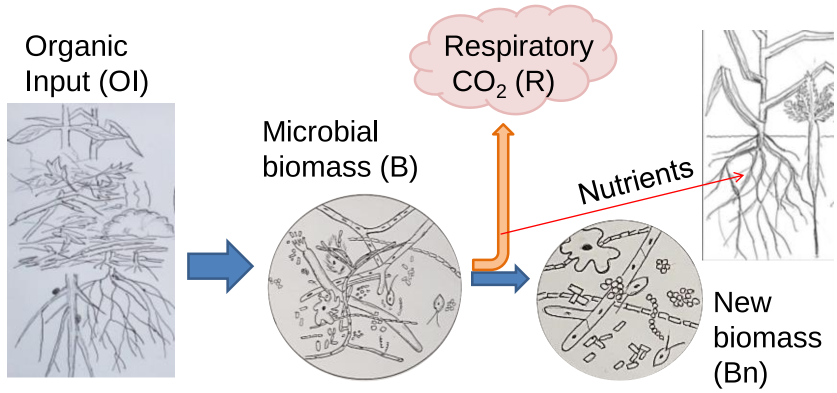
A Matter of Balance



Microbial growth efficiency (MBE) = Bn / OI
Metabolic quotient (qCO_2) = R / B

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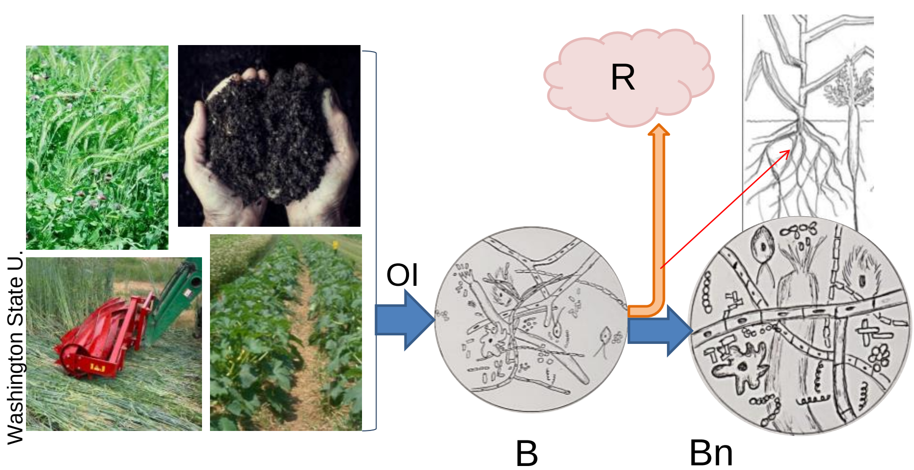
Building Biomass and Stable SOM



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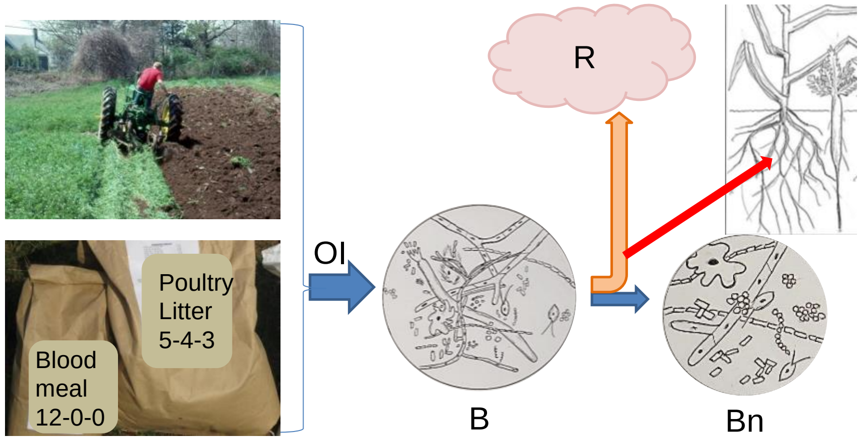
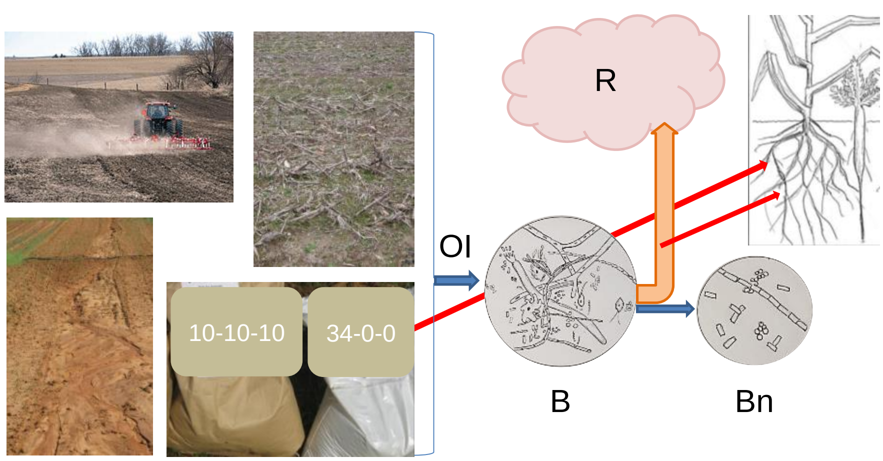
Promoting Mineralization



Stressed Soil Microbiome

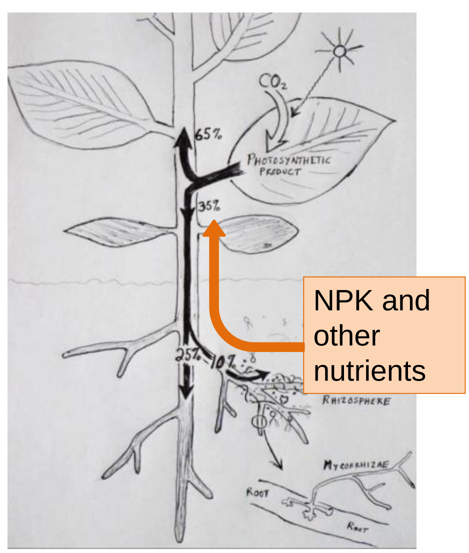


Soil Life, Plant Nutrients, and Moisture

Functions	Organisms
Digest residues into SOM. Recycle nutrients.	*Decomposers:* bacteria and fungi *Mixers:* mites, springtails, earthworms, dung beetles
Provide nutrients to crops.	*Grazers:* protozoa, nematodes *Root symbionts:* N-fixing bacteria, mycorrhizal fungi
Maintain aggregation (tilth) and drainage. Hold and deliver moisture.	Bacteria (glues), fungi (hyphae), plant roots, earthworms (pores, channels)
Protect water quality.	Bacteria, fungi (tie-up nutrients) Plant roots (utilize nutrients)

Two-way Exchange

- Plants donate 10 – 30% of their photosynthetic product to the soil life.
- In return, soil microbes help plants obtain nutrients.



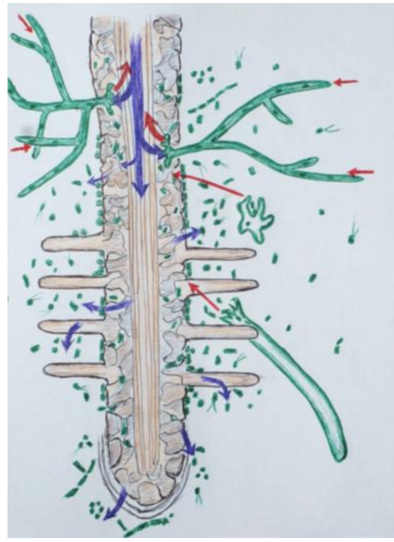
Rhizosphere

Plants provide organic carbon (blue) to their microbiome (green) via:

- AMF exchange
- Root exudates
- Root cell sloughing

Plants receive nutrients (red) via:

- AMF exchange
- Microbial N_2 fixation
- Nutrient mineralization by microbial grazers



Based on diagram by Ray R. Weil

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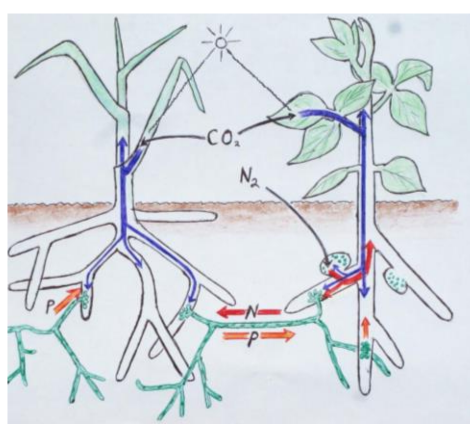
Four-way Symbiosis

- Legume rhizobia fix N (red).
- AMF help plants absorb P (orange).
- Plants provide sugars to their symbionts (blue)
- Grass and legume trade N and P via AMF connection.



Based on diagram by Ray R. Weil

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Soil Life and Plant-available Moisture

Plant roots and soil biota maintain tilth and network of large and small pores.

Rapid infiltration

Moisture retained

Unrestricted root growth

Excess drains out

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Soil Life, Pathogens, and Pests

Functions	Organisms
Suppress plant disease	Microbes that crowd-out, consume, or parasitize plant pathogens, or release antibiotics.
Suppress plant pests	Predatory nematodes Fungal parasites Entomopathogenic nematodes
Enhance crop disease resistance	Rhizosphere microbes that induce systemic resistance (ISR)
Reduce animal and human pathogens	Dung beetles Decomposer micro-organisms

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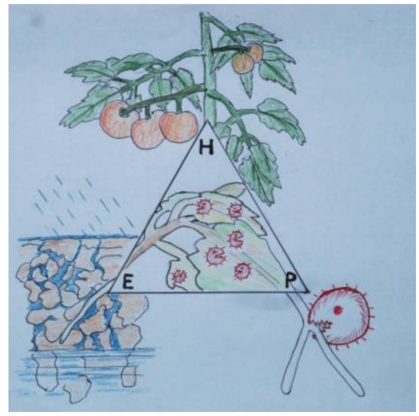
The Plant Disease Triangle

Virulent pathogen (P)
+
Susceptible host (H)
+
Conducive environment (E)
=
High risk of disease



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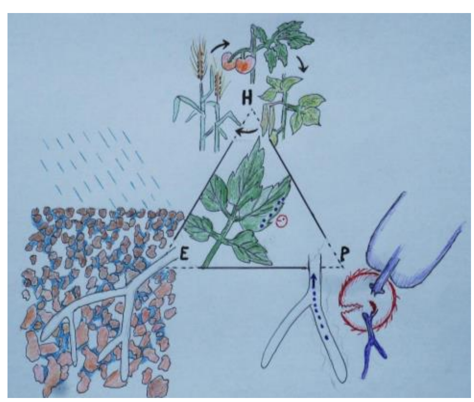
How a Healthy Soil Biota can Break the Disease Triangle

Beneficial soil biota improve tilth and drainage (E).

Diverse biota include natural enemies of pathogens (P).

Crop rotation and beneficial root endophytes reduce host susceptibility (H).



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Organic Practices for Soil Life

Practical Tips for Recruiting the Microbiome your Crops Need

NRCS Principles of Soil Health

Keep soil covered.

Diversify the cropping system.

Maintain living roots.

Minimize disturbance:

- Tillage
- Chemicals
- Invasives

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Two More Principles for Building Soil Food Webs

Integrate livestock and crops.

Law of Return: return all organic "wastes" to the land

Rotational grazing (left) feeds soil life and builds SOM.
Tree leaf mulch promotes beneficial soil fungi (center).
Yard and food "wastes" make valuable compost (right).

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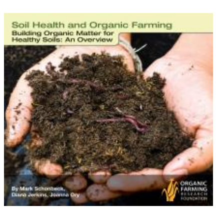

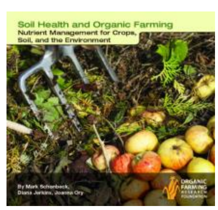

Soil Health and Organic Farming. http://ofrf.org.

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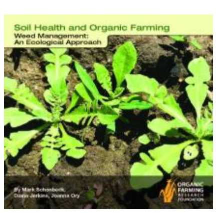
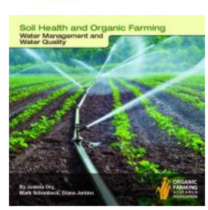
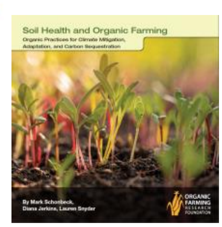






Webinars at https://articles.extension.org/organic_production.

Challenges in Fine-tuning Soil Biology

Monitoring soil life

- *Who is present and what is their condition?*

Complexity of the soil food web

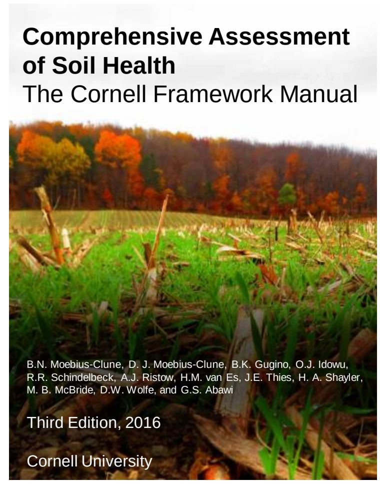
- *How can I predict the impact of a given practice*?

"Beneficial" is context-specific

- *What does* this *field need?*

Climate change

- *How will it affect soil life?*



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Soil Life Challenges for Organic Farmers

Tillage

- *It is not "all or none."*

Phosphorus excesses

- *Use compost in moderation.*

Modern crop cultivars

- *Lost connection with soil?*

Commercial soil inoculants, biostimulants, and biofertilizers

- *Will they make a difference?*

Drew Lyon, U Nebraska

The blade plow works just below the surface, leaving residue cover and most of soil profile undisturbed.

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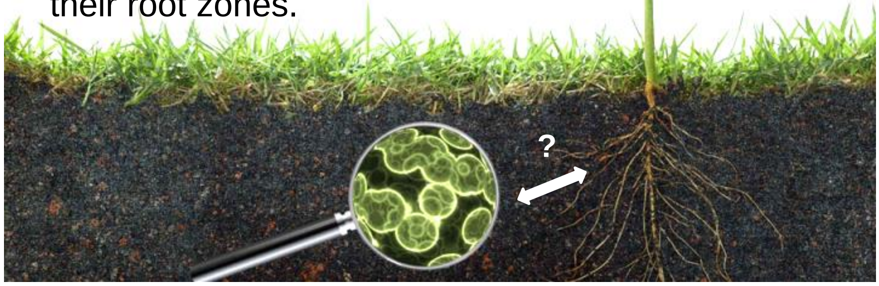
Have Modern Cultivars Forgotten How to "Talk" with Soil Life?

- Growing crops in NPK-saturated, conventional fields can put mycorrhizal fungi, N fixers, and other valuable microbes out of work.
- Breeding and selecting crops in such systems has created cultivars that don't "invite" these helpers into their root zones.



Smorgasbord of Microbial Products

- *Rhizobium* legume seed inoculants
- Mycorrhizal fungi
- Biodynamic preparations
- Compost teas, worm casting teas
- Effective micro-organisms, bokashi
- Proprietary microbe blends
- Natural enemies of plant pathogens and pests
- Fungal foods – seaweed extract, fulvic acids, etc.
- Bacterial foods – amino acids, molasses, etc

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Building the Soil Biotic Community

	Organisms	Food	Habitat
Plant roots		XXX	XXX
Plant residues, green		XXX bac.	
Plant residues, dry		XX fungi	XX
Manure	XX	XXX	
Finished compost	XXX	X	XXX
Organic fertilizers		X	
Biochar, humates			XXX
Compost tea	XXX	X	

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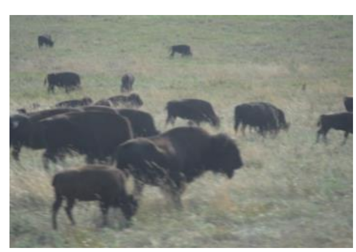
Do We Need to Introduce Microbes?

"There will still be some small bit of life in [the soil] even in the most chemically dependent or heavily tilled operations. If you give that life a chance to grow, it will respond. If you build it, or if you stop destroying it, they will come."

Gabe Brown, 2018, *Dirt to Soil,* p. 25.

- 5,000 ac of depleted land
- Crops + livestock, NRCS principles, rotational grazing
- SOM 2% → 7% in 20 years
- No purchased inoculants used



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Do Commercial Inoculants Work?

- Mixed results:
  - Little effect on already-fertile soils
  - Beneficial on low-fertility soils
- Reasons inoculants fail:
  - They are outcompeted by indigenous soil biota.
  - Their intended functions are already provided by existing biota.
  - They are attacked by existing biota.
  - The product has lost viability.

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Do Commercial Inoculants Work? Some Research Findings

- 13 products, 21 trial sites in 7 states, 7 crops → *no benefits* (Ohio State U).
- Meta-analysis - mycorrhizal inoculants improve yield when:
  - Crops are P-limited.
  - Diverse soil biota are present.
- Humic substances + N_2-fixing endophyte boosted corn yield 65% in Brazil.
- Trichoderma improved corn yield in saline soil.

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Tips for Using Microbial Products

- Clarify your goals.
- Research products carefully.
- Conduct side-by-side trials.
- Store and handle product carefully – protect from sun, heat, freezing, etc.
- Apply plant symbionts to seeds or roots.
- Apply whole-field treatments in evening or cloudy weather, or just before rain.

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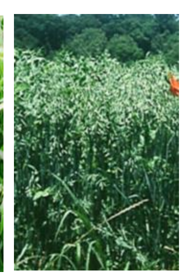
Encouraging Mycorrhizal Fungi

- Maintain living roots.
- Avoid prolonged fallow.
- Diversify rotation.
- Follow non-host crops with grass-legume cover crop.
- Reduce tillage intensity.
- Avoid excess N and P.
- Avoid soil-applied fungicides.
- Propagate indigenous (on farm) AMF from healthy soil.

Grass cover crops like pearl millet (left) and oats (right), and legumes can sustain AMF populations for the next cash crop.

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Managing Disease with Soil Biology

- Optimize soil health to break "disease triangle".
- Apply pathogen antagonists or ISR triggers:
  - *Trichoderma, Streptomyces, Gliocladium, Conionthyrium, Bacillus, Pseudomonas,* etc.
- Modify soil biota to suppress disease:
  - Mustard seed meals, green manures.
  - Bio-solarization, anaerobic soil disinfestation.
- Many excellent articles and webinars available at: https://articles.extension.org/pages/59458/disease-management-in-organic-farming-systems.

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Anaerobic Soil Disinfestation (ASD)

- Add organic amendment, water to saturation, plastic mulch 3 – 6 wks.
- Anaerobic microbial activity kills some pathogens.
- Disease suppressive microbes proliferate.
- Reduces strawberry pathogen, *Verticillium dahliae*, by 80%.
- Yields and net returns improve.
- ASD widely adopted by farmers.

Dr. Carol Shennan and colleagues tested ASD as an alternative to fumigation for organic strawberry.

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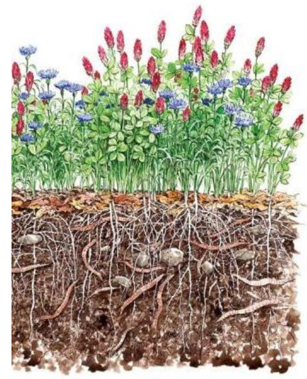
Summary: How to Build a High-functioning Soil Food Web

- Feed the soil life via plant roots.
- Diversify the farming system.
- Supplement with a little compost.
- Balance input C:N.
- Limit use of concentrated NPK.
- Reduce tillage when practical.
- Avoid prolonged fallow.
- Purchased inoculants may help on low-fertility soil.



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