Soil Biology for the Western Region
Organic Practices to Recruit and Nurture Beneficial Biota in the Soil

Mark Schonbeck, PhD
Organic Farming Research Foundation

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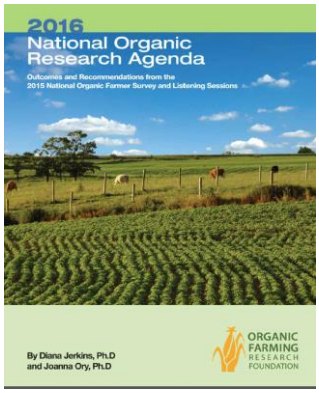
Western Region Organic Farmer Research Priorities



Available at http://ofrf.org/

Soil health and biology – 71%
- Microbes, fertility, and crop health
- Crop diversity and soil biota
- Soil life and nutrients in dry areas
- Effects of tillage on soil life
- Restoring degraded soils

Disease management – 52%
- Soil diseases and nematodes
- Breeding disease resistant crops

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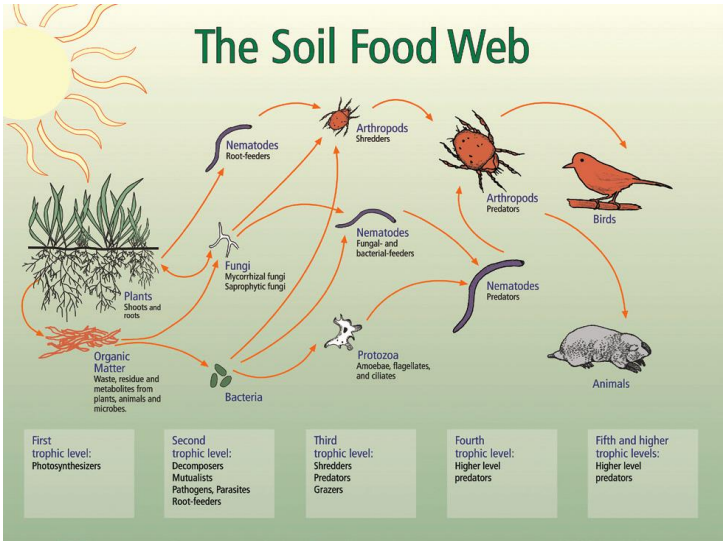
Building Soil Biology in Organic Farming

The Players

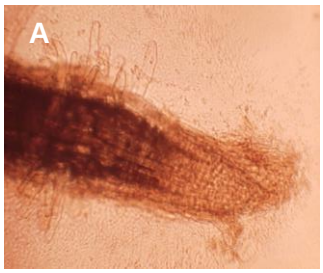
The Processes

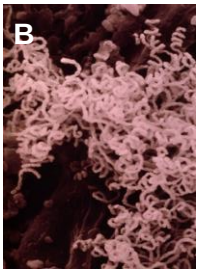
The Practices

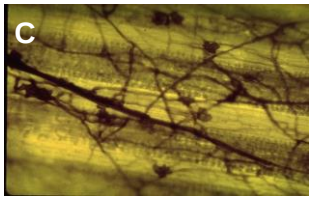


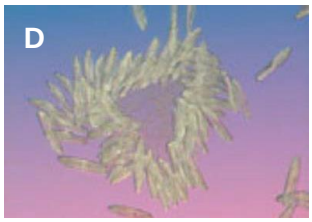
Ingham, E. R., A. R. Moldenke, and C. A. Edwards. 2000. *Soil Biology Primer.* Soil and Water Conservation Society (SWCS). Rev. ed. Ankeny, IA. https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology/

Soil Microbiota









Ingham et al., 2000. *Soil Biology Primer* (A, B, C)

A. Bacteria near root tip
B. Actinobacteria (= actinomycetes)
C. Decomposer fungi on fallen leaf
D. Ciliate protozoa feeding on bacteria

Fotosearch Waukesha, WI.

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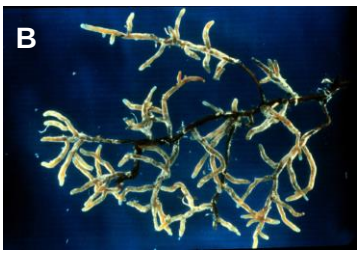
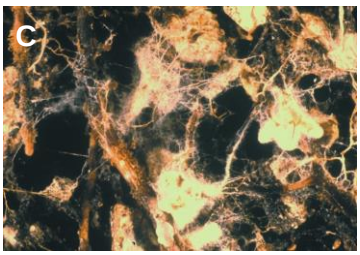
Root Symbionts





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

A. Rhizobium nodules on legume root
B. Ectomycorrhizal fungi
C. Arbuscular mycorrhizal fungi

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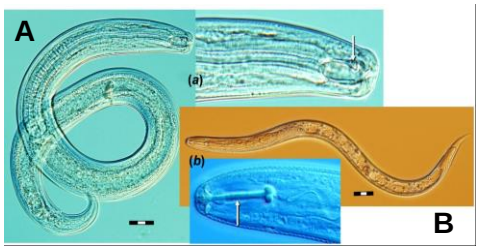
Soil Nematodes

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



James Hoorman, Ohio State University

Predatory nematodes (A) consume pests like soybean cyst nematode (B). Rhizosphere bacteria attract protozoa and bacterial-feeding nematodes (C).

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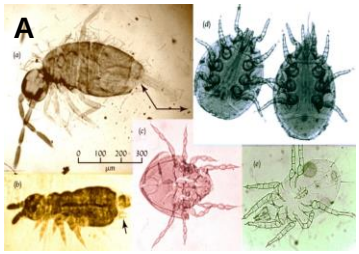
Shredders and Ecosystem Engineers



Photos by Ray R. Weil

A. Micro-arthropods: mites and springtails shred residues.
B. Earthworms turn, aggregate, and enrich soil.
C. Dung beetles incorporate manure.

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Building Soil Biology in Organic Farming

The Players

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The Practices

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)

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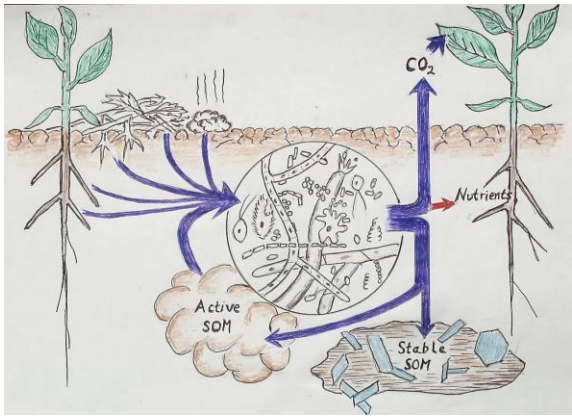
Soil Life Processes All Organic Inputs



Mineralization
- Plant nutrition and growth

Stabilization
- Soil health
- Tilth
- Carbon sequestration

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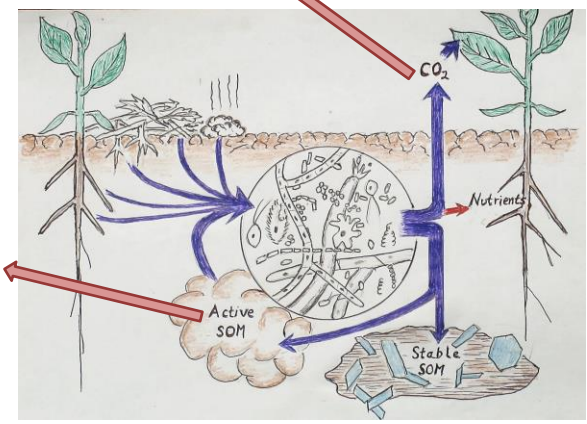
Monitoring Soil Biological Function

Mineralization:
4-day respiration

PMC



Stabilization:
Oxidation in dilute $KMnO_4$

POX-C

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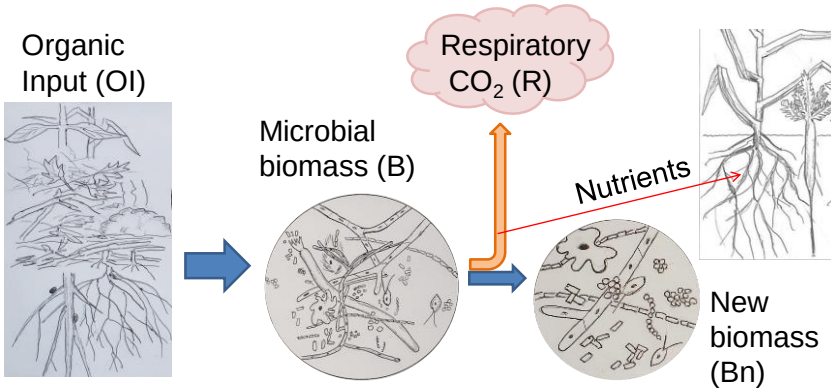
A Matter of Balance



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

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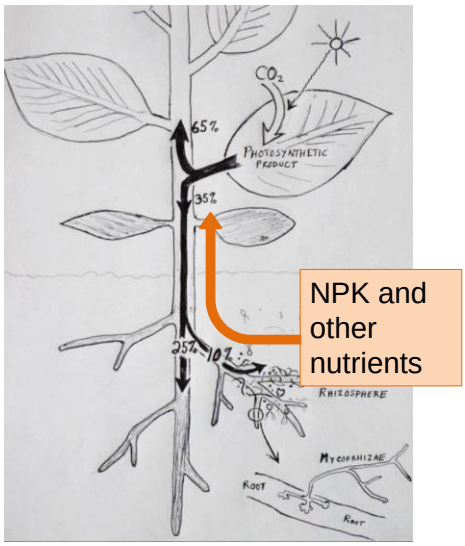
Two-way Exchange

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



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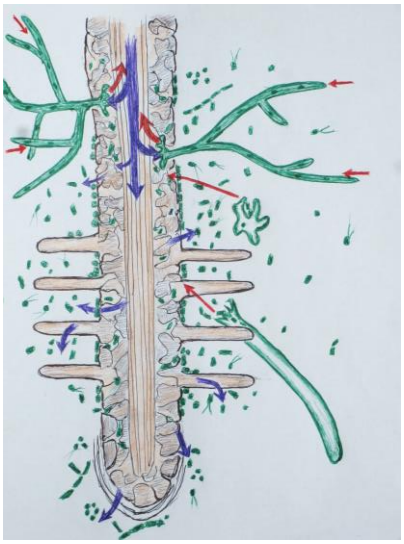
Rhizosphere

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

- AMF exchange
- Root exudates
- Root cell sloughing

Plants receive nutrients (red) via:

- AMF exchange
- N_2 fixation
- Mineralization by microbial grazers



Based on diagram by Ray R. Weil

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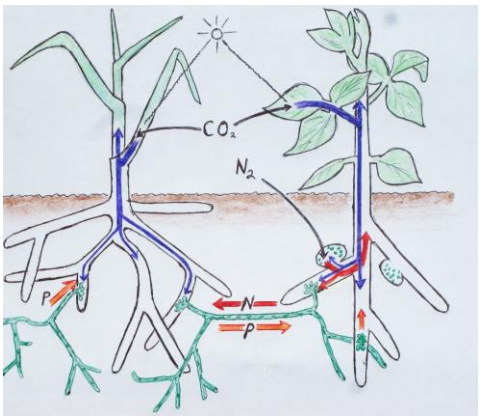
Four-way Symbiosis

- 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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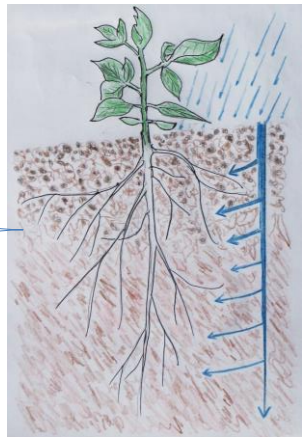
Soil Life and Plant-available Moisture

Plant roots and soil biota maintain tilth and a 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 outcompete, consume, parasitize, or chemically deter plant pathogens
Suppress plant pests	Predatory nematodes Fungal parasites Entomopathogenic nematodes
Enhance crop disease resistance	Microbes that induce systemic resistance (ISR)
Reduce animal and human pathogens	Dung beetles Decomposer micro-organisms

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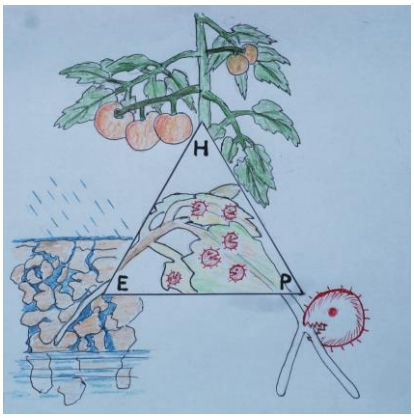
The Plant Disease Triangle

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



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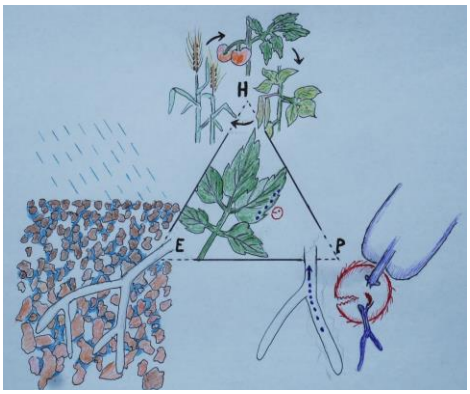
How a Healthy Soil Biota can Break the Disease Triangle

Beneficial soil biota improve tilth and drainage (E).

Diverse biota include natural enemies of pathogens (P).

Crop rotation and microbially induced ISR (blue dots) reduce host susceptibility (H).



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Building Soil Biology in Organic Farming

The Players

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NRCS Principles of Soil Health

Keep soil covered

Diversify the cropping system

Maintain living roots

Minimize disturbance:

- Tillage
- Chemicals
- Invasive species

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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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Building Biomass and Stable SOM

Washington State U.

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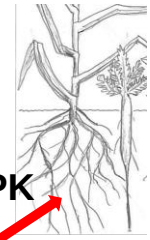
Promoting Mineralization

OI

B

R

↑ NPK



Bn

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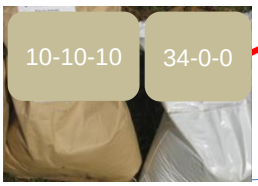
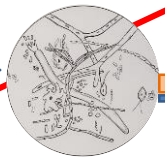
Stressed Soil Microbiome



OI

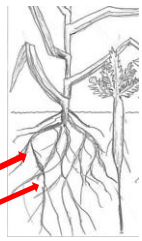
R

↑ qCO_2



B

Bn



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Integrate Complementary Practices

	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	

XXX = major source XX = secondary source X = minor source

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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 microbial inoculants:

- *Are they needed?*
- *Will they help?*

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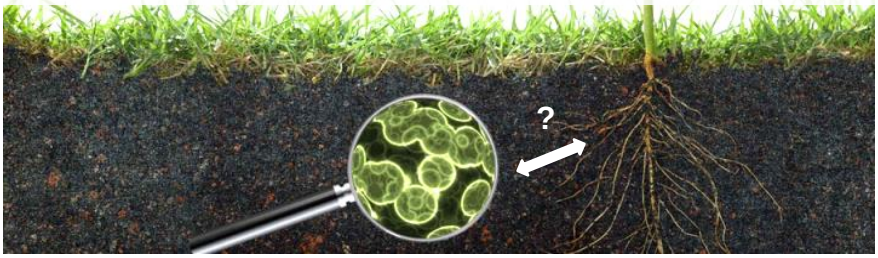
Have Modern Cultivars Forgotten How to "Talk" with Soil Life?

- 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.



Encouraging Mycorrhizal Fungi

- Maintain living roots.
  - Grass-legume cover crops
  - Other AMF host crop
- Diversify the rotation.
- Reduce tillage intensity.
- Avoid excess N and P.
- Avoid soil-applied fungicides.
- Inoculants may be helpful.
  - On-farm propagated AMF
  - Specific ectomycorrhizae for woody perennial crops

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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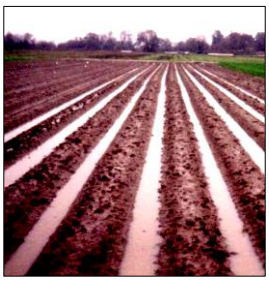
Building Soil Biological Function in the Western Region

Research and Practice

Maritime CA and Pacific NW



Z. Kabir, NRCS,, Davis, CA

Spring lettuce → Fall broccoli → Winter fallow

Leaching, denitrification, slaking, compaction

No food,
No air,
No microbes

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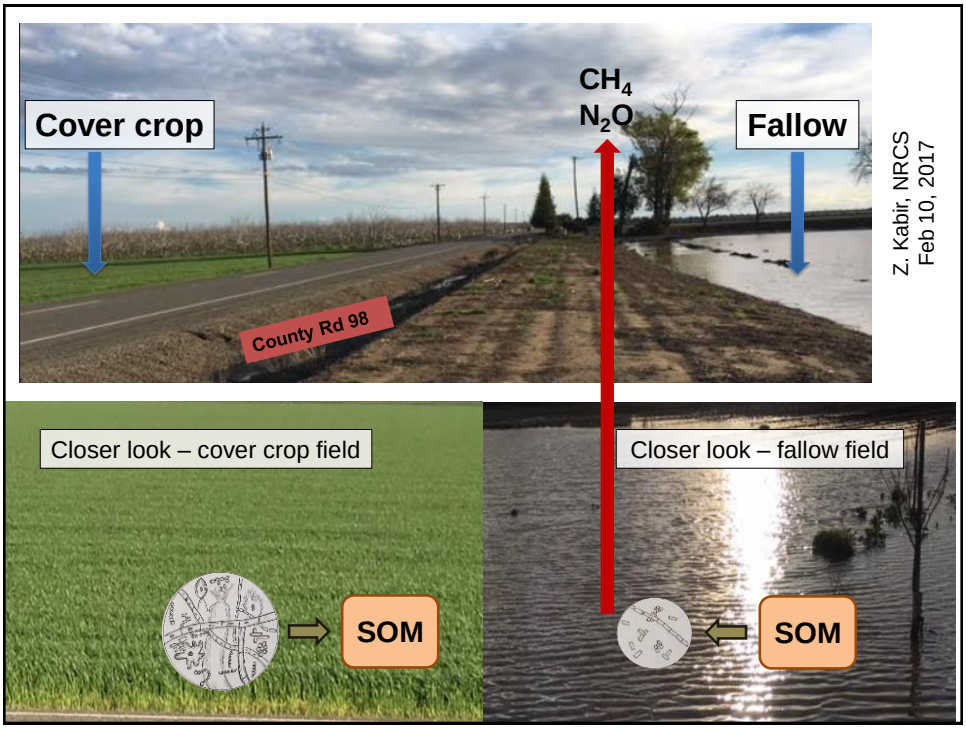
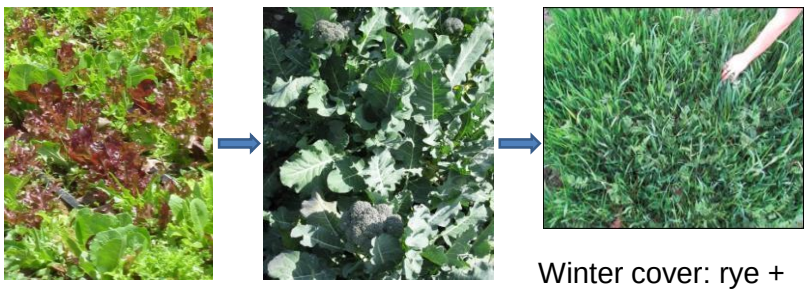


Organic Vegetables + Cover Crop



Spring lettuce

Fall broccoli

Winter cover: rye + legume mix

Sarah Brown, Oregon Tilth

N recovery, SOM, higher lettuce yield

Eric Brennan, USDA ARS, https://www.youtube.com/watch?v=JurC4pJ7Lb4

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Salinas Organic Cropping Systems

- Compost + cover crop → 2 – 3X microbial biomass
- Compost alone →1.5X
- SOM increased with compost and cover crop.
- Cover crops affected microbial community.
- All systems shift from fungi toward bacteria due to tillage and inputs.

Eric Brennan, USDA ARS, Salinas, CA

Winter management of organic vegetable rotation: rye, rye + legume, mustard, or fallow 3 years out of 4

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Balancing C and N in Organic Inputs

Puyallup, WA: 11 years organic vegetable crops receiving:

Compost, Mod. C:N

or

Fertilizer, Low C:N

← Same total N →

Plots receiving compost had:

- Improved soil structure.
- 43% higher total SOM.
- 35% higher PMC.
- 60% more POX-C.
- Improved N cycling:
  - Enzyme activity
  - Nitrification potential
  - Capacity to immobilize excess soluble N

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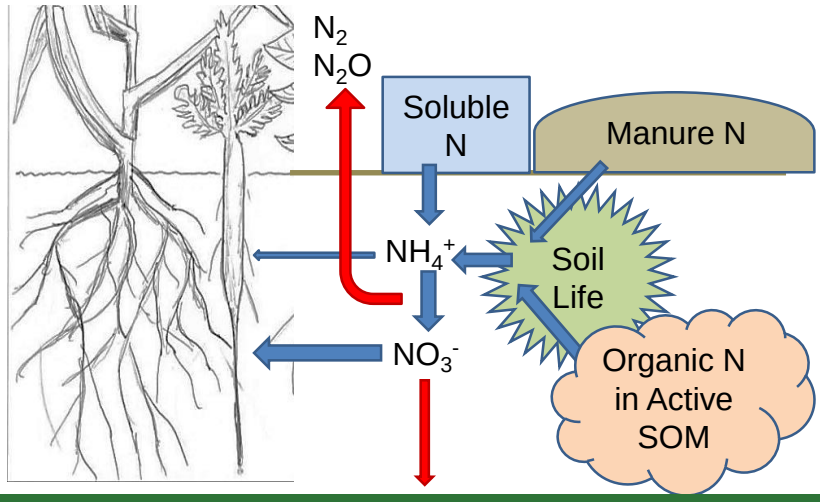
The Universal Nitrogen Challenge



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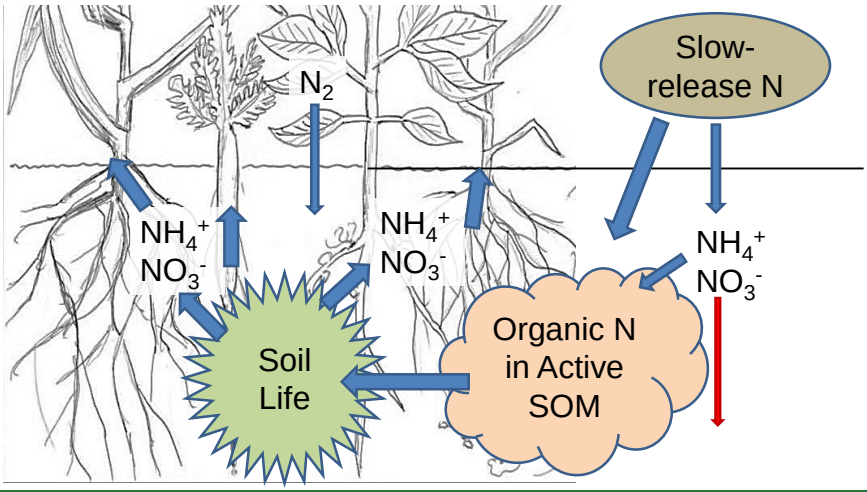
Delivering N where it is Needed



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Tightly Coupled N Cycling

Three types of organic tomato fields:

N deficient:

- Low SOM, low microbial biomass
- Low NO_3-N, low yield

N saturated:

- Mod. SOM, high microbial biomass
- High NO_3-N, high yield

Tight N cycling:

- High SOM, high microbial biomass
- Low NO_3-N, yet high yield

Vigorous tomatoes grown on moderate C:N compost and no concentrated N.

Bowles et al. 2015. PLOS ONE.

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Managing for Tightly Coupled N Cycling

Drip fertigation delivers small doses of soluble N to crops without over-loading soil with N.

- Feed the soil with a diversity of organic materials with moderate C:N (e.g., legume-grass cover crops and finished compost).
- During peak N demand, provide crops with a small amount (~20-30 lb/ac) of more concentrated N via in-row drip or side dressing.
- Encourage mycorrhizal fungi.
- Avoid over applying N and P.

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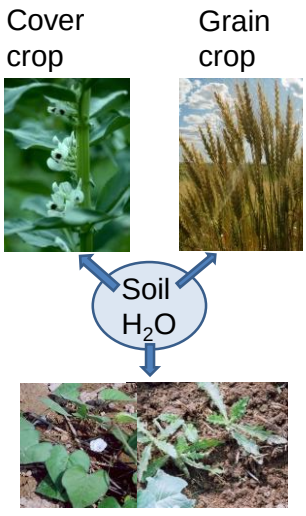
Dryland Challenges

Cover crops feed soil life, build SOM and water-holding capacity, but may also:

- Produce less biomass.
- Suffer from weed pressure.
- Take moisture from next crop.

During fallow year in wheat-fallow rotation:

- Soil life goes hungry.
- Soil loses SOM and fertility.
- Wind erosion increases.



Doug Crabtree

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Diverse Rotation without Fallow at Vilicus Farms, Havre, MT

- 15 cash crops, 10 cover crops, no fallow
- Conservation buffers
- Blade plow
- SOM 2.1 → 2.9% in 9 years

Doug and Anna Crabtree, Vilicus Farms

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Restoring Indigenous Organisms in Dryland Soil

"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 four principles, rotational grazing
- SOM 2% → 7% in 20 years
- No purchased inoculants used

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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 conditions – e.g., pH ~ 7 against clubroot.
- 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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Walnut Orchard in CA After Rain: Cover Crop Breaks Disease Triangle

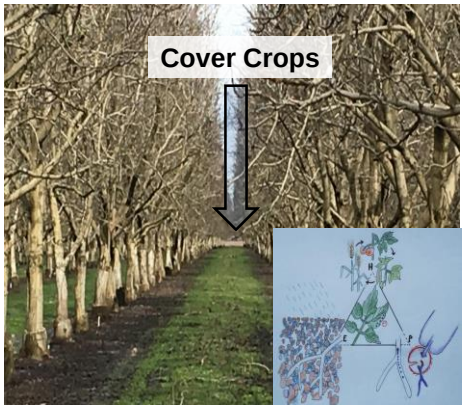

Photo: Kabir, Feb 07, 2017

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Organic Practices Reduce Lettuce Corky Root in Central CA

Protective factors in organic:

- Higher microbial activity
- Pathogen antagonists
- Slow-release N sources
- No synthetic herbicides

Plant disease survey on two long-term organic farms:

- Most diseases absent or minimal
- Serious *Fusarium* and *Verticillium* – more research needed

Compost and cover crops support soil microbes that protect organic lettuce from pathogens.

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Mustard Seed Meal vs. Orchard Replant Disease

- 3 tons/ac mustard seed meal:
  - Isothiocyanates for 2 days
  - Disease suppressed 2+ years
  - Increased *Trichoderma*, nematode-trapping fungi
- Telone C17:
  - Effective ~ 1 yr
  - No change in soil biota
- Tree growth at 3 years: mustard > Telone C17 > untreated

Howard F. Schwartz, Colorado State U

Replacing aging apple trees is often thwarted by pathogenic fungi, oomycetes, and lesion nematodes.

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Anaerobic Soil Disinfestation (ASD)

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

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

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Biosolarization

- Fresh organic matter is tilled in, soil is moistened
- Clear plastic for 4 – 6 weeks during hot weather
- Impacts on pathogens:
  - Heat kill
  - Pathogen-suppressive organisms multiply
  - Induced systemic resistance (ISR)

OFRF-funded study explores allelopathic sudangrass as the organic component of bio-solarization to control weeds, diseases, and pest nematodes.

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Download the Soil Health and Organic Farming Guides at www.ofrf.org

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

Questions?

This webinar was made possible by a grant from USDA Western SARE.