

Soil Life in Organic Farming

*The Role of Soil Organisms in
Soil Health and Resource Conservation*



Mark Schonbeck
Research Associate

[NRCS Logo]

November XX, 2022

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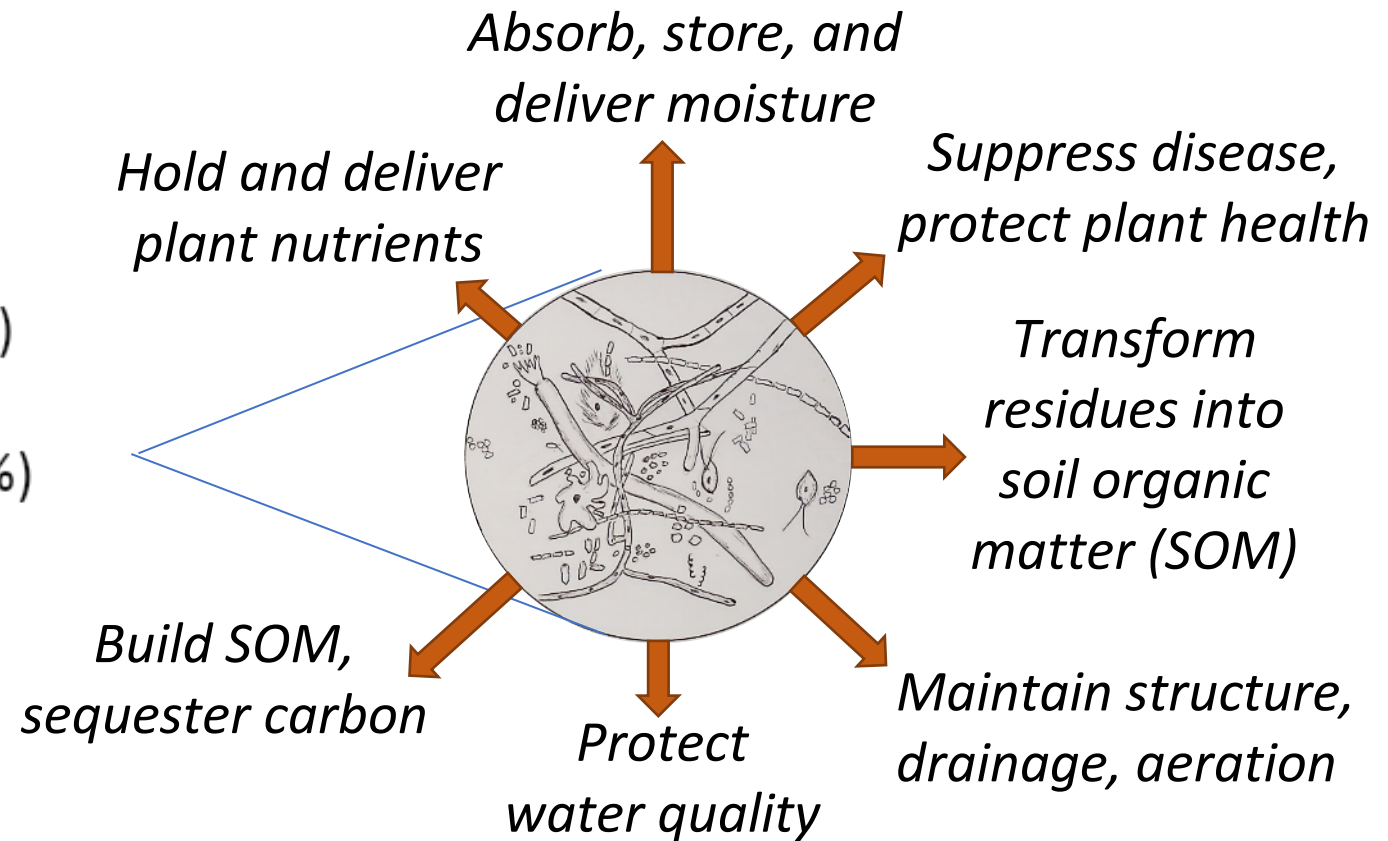
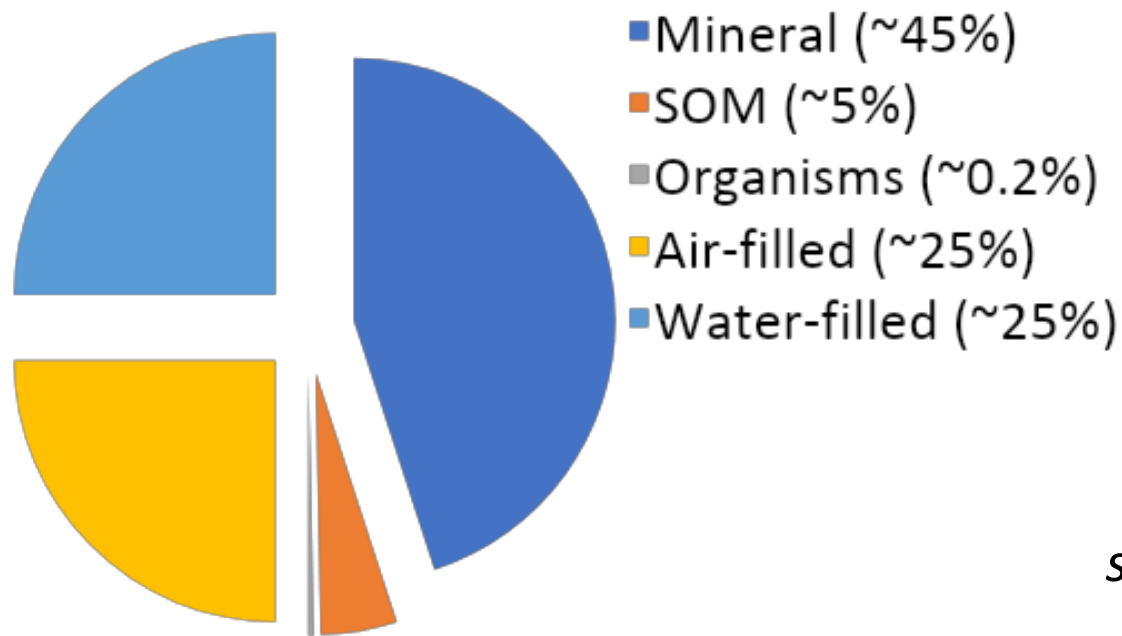
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Tiny yet Mighty: Soil Organisms Perform All Key Functions of a Healthy Soil

Soil Components by Volume



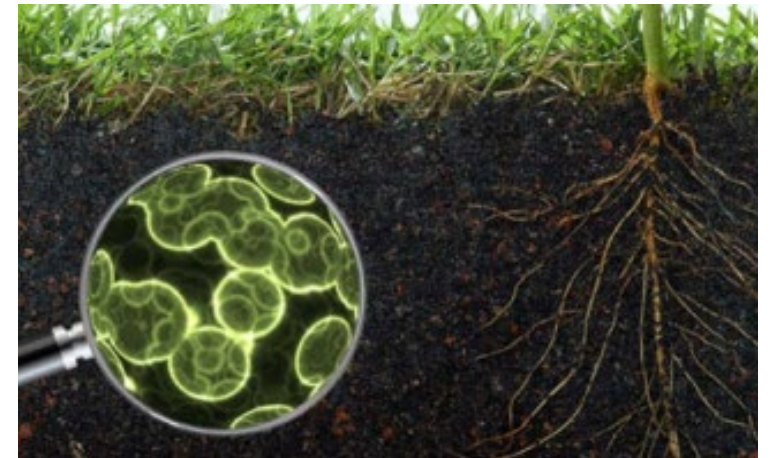
Organic Farmers Rely on Soil Life for Crop Nutrition

“Feed the soil, and the soil will feed the crop”.

- Manure, compost
- Crop residues, cover crops, green manures
- Organic mulch – straw, leaves, etc.

Protect the soil life:

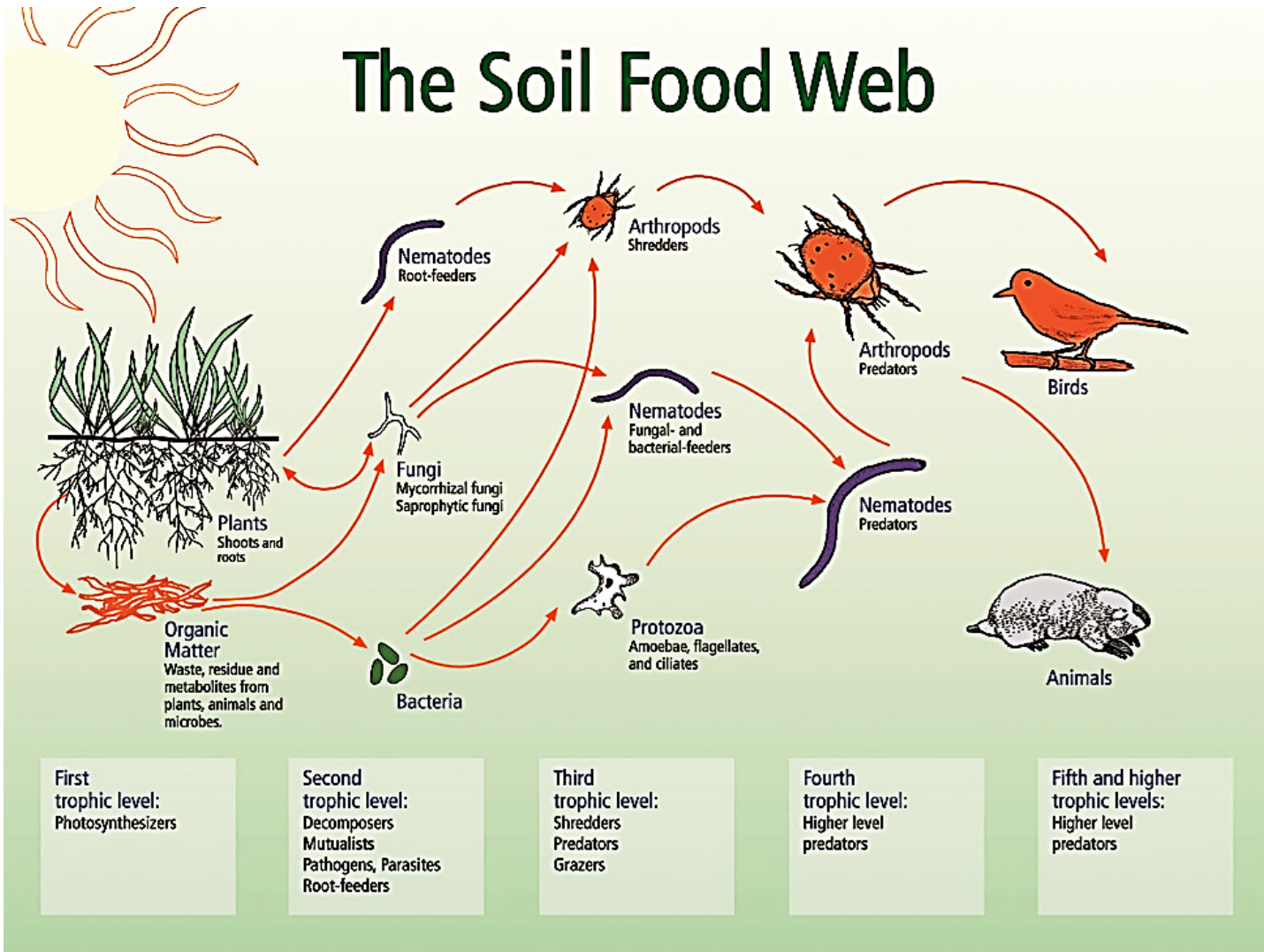
- No synthetic pesticides
- NOP-allowed pesticides only if needed
- Keep soil covered
- Till with care



Soil Biology 101

A brief tour of the Soil Food Web

The Soil Food Web



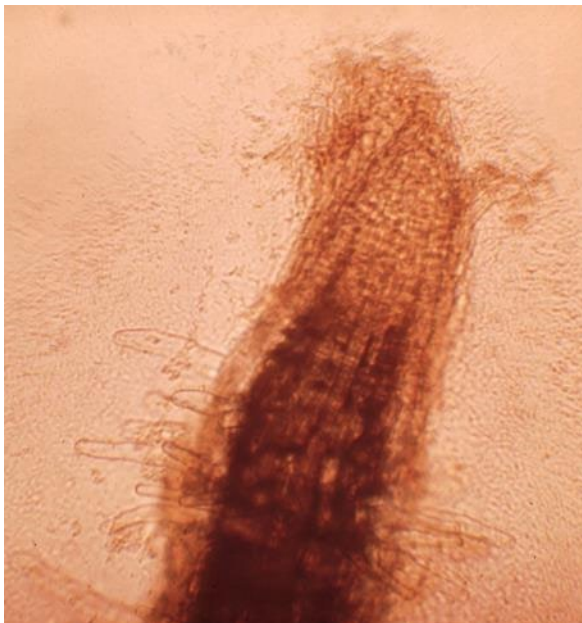
The soil ecosystem consists of:

- Micro-organisms (*the soil microbiome*)
- Larger organisms
- Their habitat – food, water, air
- Plant roots
- Trophic relationships (*food web – who eats whom*)

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

>1 billion per gram (1/4 tsp) of topsoil



Legume nodules containing *Rhizobium* bacteria (left); soil bacteria near root tip (right). *Photo credit: Ingham et al., 2000. Soil Biology Primer*

Soil bacteria include:

- Decomposers
- Nitrogen (N) fixers
- Nitrifying and denitrifying bacteria
- Rhizosphere (root zone) bacteria
- Beneficial endophytes
- Plant pathogens

Soil archaea include:

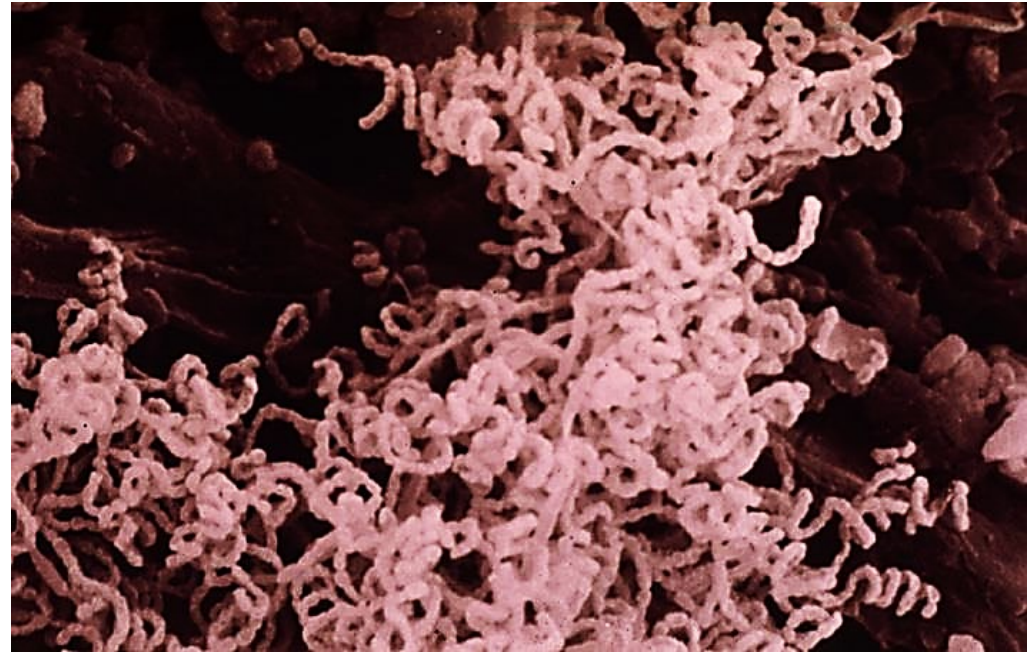
- Nitrifiers, sulfur oxidizers
- Methanogens

Actinobacteria, sometimes called Actinomycetes are filamentous bacteria. *They include:*

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

Actinobacteria

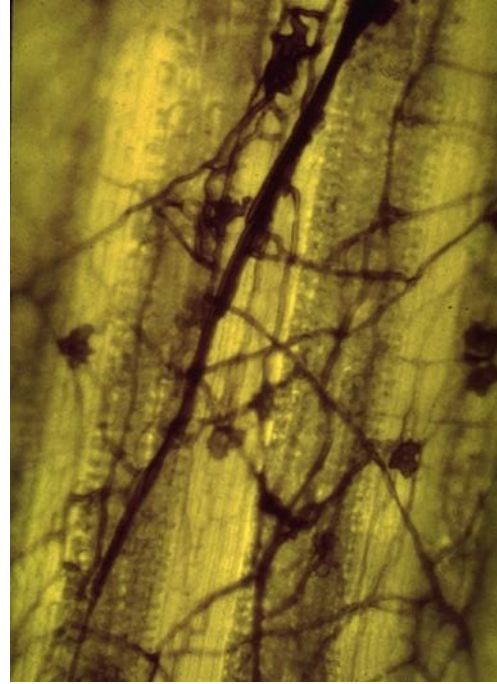
>10 million per gram of soil



Soil actinobacteria. *Photo credit: Ingham et al, 2000. Soil Biology Primer*

Fungi

>30 ft hyphae per gram of soil



Ectomycorrhizal fungi (left). Decomposer fungi on plant residue (right). *Photo credit: Ingham et al., 2000 Soil Biology Primer*

Decomposer fungi:

- Digest woody materials
- Build stable SOM

Root-symbiotic fungi:

- Ectomycorrhizal – trees and shrubs
- Arbuscular mycorrhizal fungi (AMF) – most crops
- Build stable SOM
- Aid nutrient and water uptake

Plant pathogens

Parasites of pathogens and pests

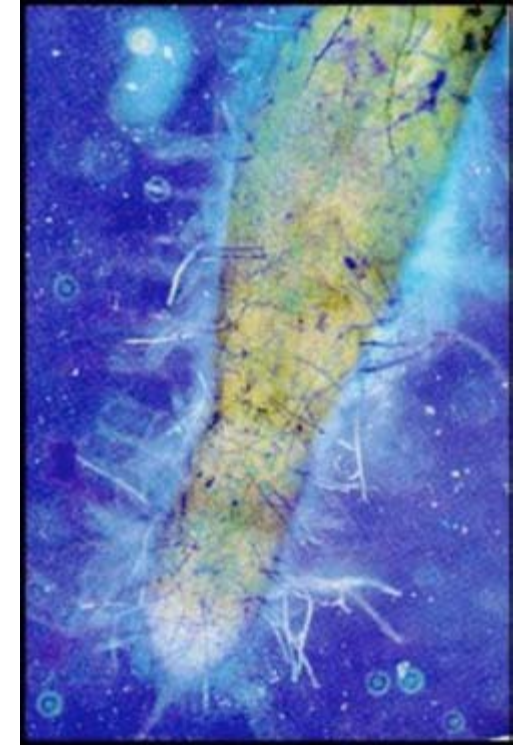
- Bio-fungicides, biopesticides

Protozoa

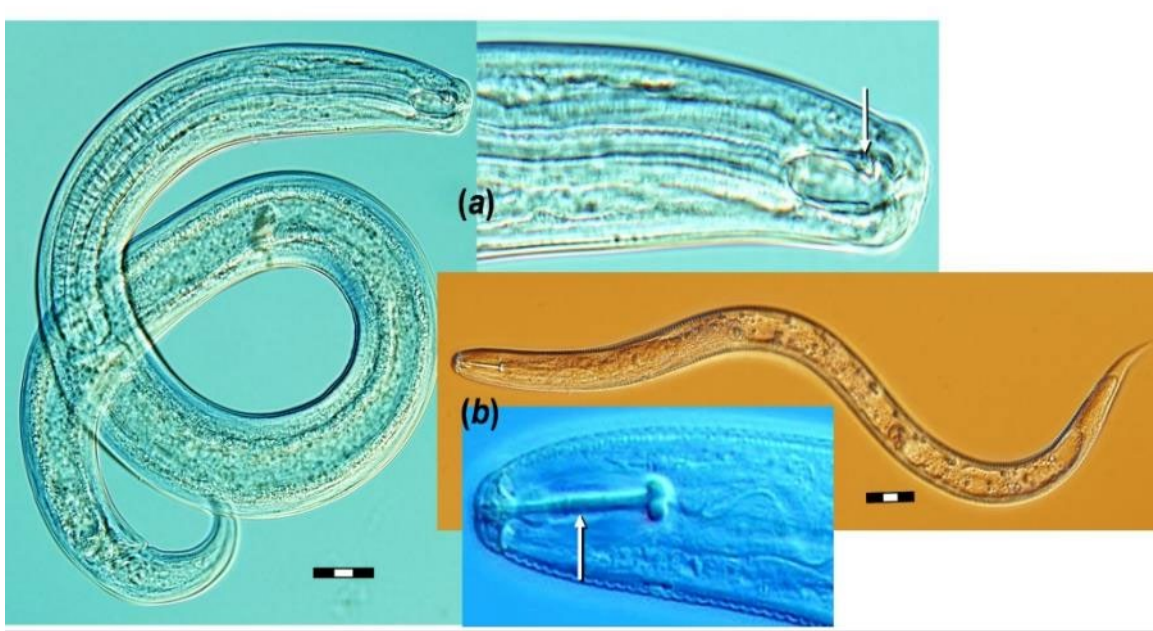
>100 per gram of soil

Flagellates, ciliates, and amoebas:

- Feed primarily on bacteria
- Important role in releasing N and other nutrients in the rhizosphere
- Ciliates in wet soil; flagellates in drier soil



Ciliate protozoa feeding on soil bacteria (left) . Bacteria and protozoa proliferating in rhizosphere (right). *Photo credits Fotosearch, Waukesha, WI (left); James Hoorman, Ohio State University (right)*



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

*Photo credit: Lisa Stocking Gruver, U Maryland;
courtesy of Joel Gruver, Western Illinois U..*

Nematodes

1 – 100 per gram of soil

Bacterial feeders and fungal feeders

- Release crop nutrients

Root feeders

- Potential pests

Predators, Omnivores

- Consume root feeders

Entomopathogenic

- Bacterial symbiont
- Bio-pesticides

Micro-arthropods

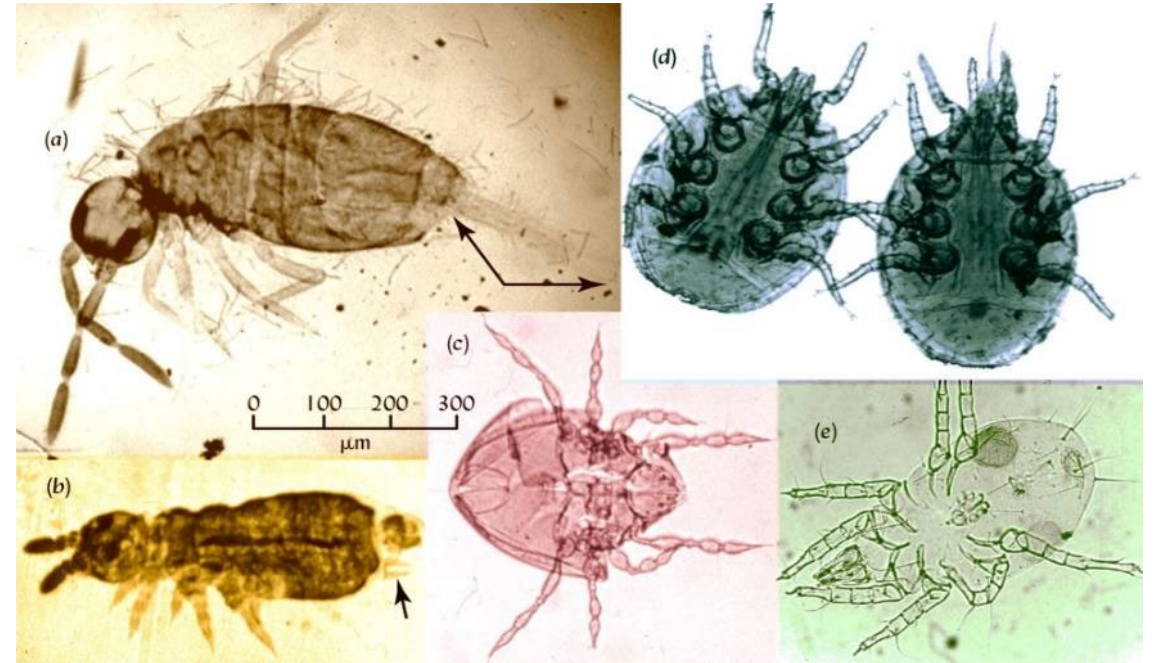
1 – 20 per gram of soil

Mites

- Shredders – help microbes digest residues and mineralize nutrients.
- Predators

Collembola (springtails)

- Shredders
- Fungal and bacterial feeders



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

Photo credit: Ray R. Weil, U. Maryland

Earthworms

1 – 100 per square foot

Earth movers (“ecosystem engineers”):

- Build macro-pores 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.



European nightcrawler and casts (above; *photo credit Ray R. Weil*)
Red wiggler in compost (left).

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.



As they bury manure in the soil, dung beetles facilitate nutrient cycling, disrupt parasite life cycles, and reduce food safety risks. *Photo credit: Ray R. Weil, U. Maryland.*

Soil Life and Soil Functions

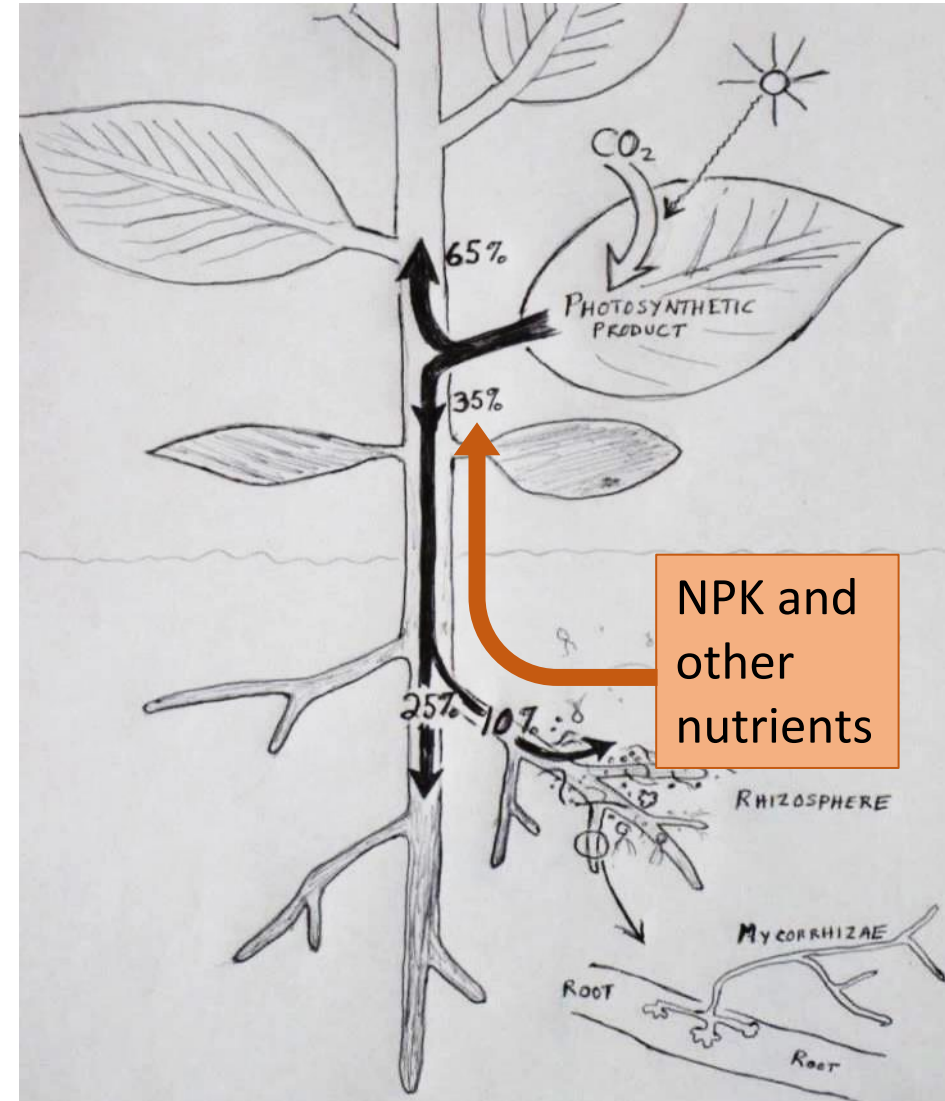
*Nutrients, water, crops, carbon,
soil self-maintenance*

Crop Production

| Crop Needs | Soil Functions | Key Organisms |
|--|--|---|
| Crop nutrition | Retain and recycle nutrients from organic residues | Decomposer bacteria and fungi, earthworms, arthropods |
| | Deliver nutrients to plants | Microbial grazers (protozoa, and nematodes), N-fixing bacteria, mycorrhizal fungi |
| Plant-available water, drainage, and aeration | Maintain SOM, aggregation, network of small and large pores, and deep channels | Bacteria (glues) fungi (mycelia), earthworms, arthropods, plant roots (pores, channels, exudates) |
| Crop protection | Deter pests and pathogens | Disease-suppressive microbes, pest predators and parasites |
| | Enhance plant resilience | Microbial root symbionts that induce systemic resistance (ISR) |

An Ancient Partnership

- Plants donate 10 – 30% of their photosynthetic product to the soil life, mainly via root exudates.
- In return, soil microbes help plants obtain nutrients and ward off pathogens.
- The Earth's first land plants co-evolved with their mycorrhizal fungal symbionts 450 million years ago.



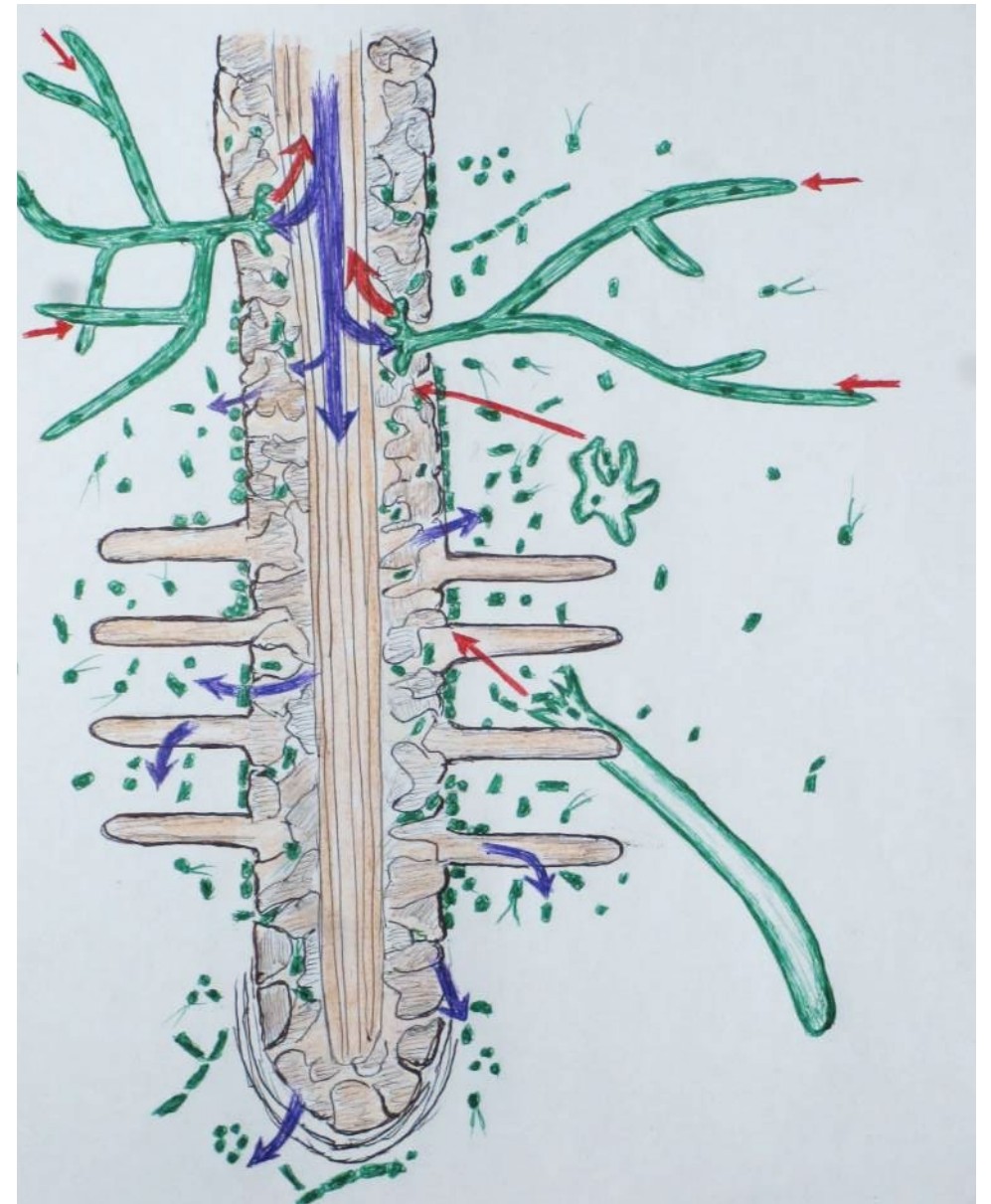
Rhizosphere (root zone)

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

- AMF exchange
- Root exudates
- Root cell sloughing

Plants receive nutrients (red) via:

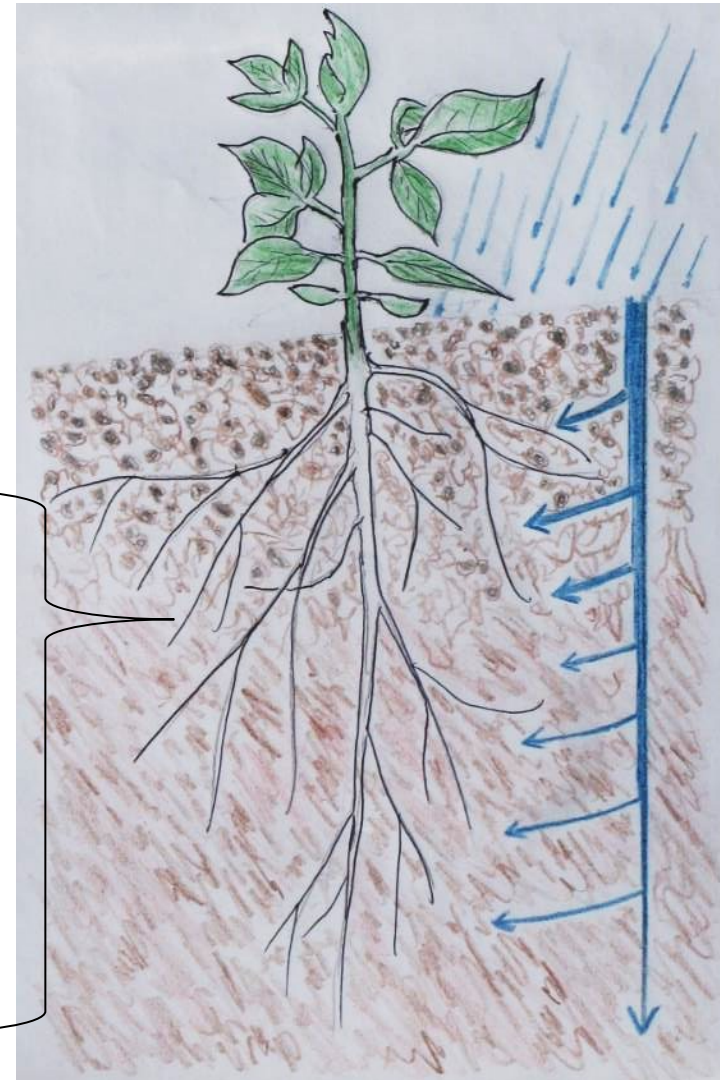
- AMF exchange
- Microbial N₂ fixation
- Nutrient mineralization by microbial grazers



Based on diagram by Ray R. Weil

How a Biologically Active Soil Absorbs and Retains a Downpour

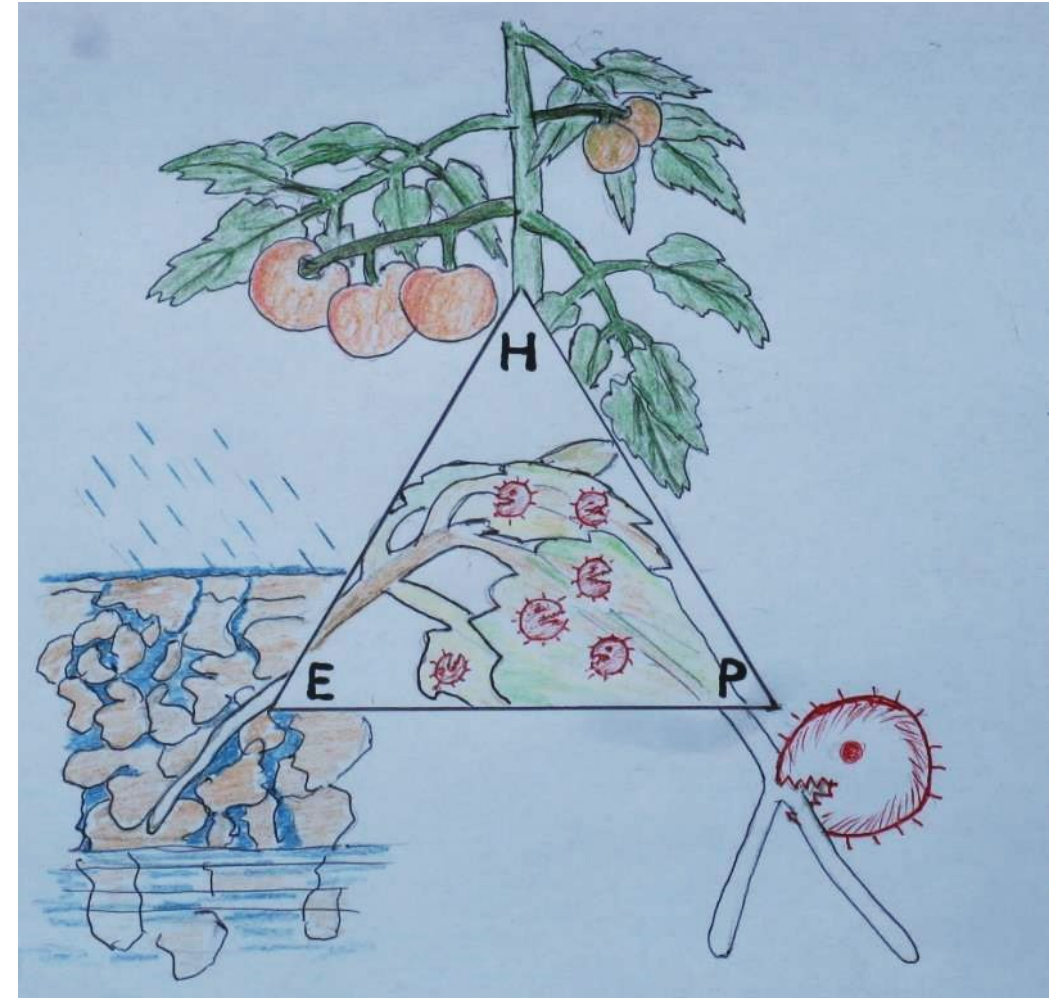
Plant roots and soil biota aggregate soil and maintain a network of large and small pores.



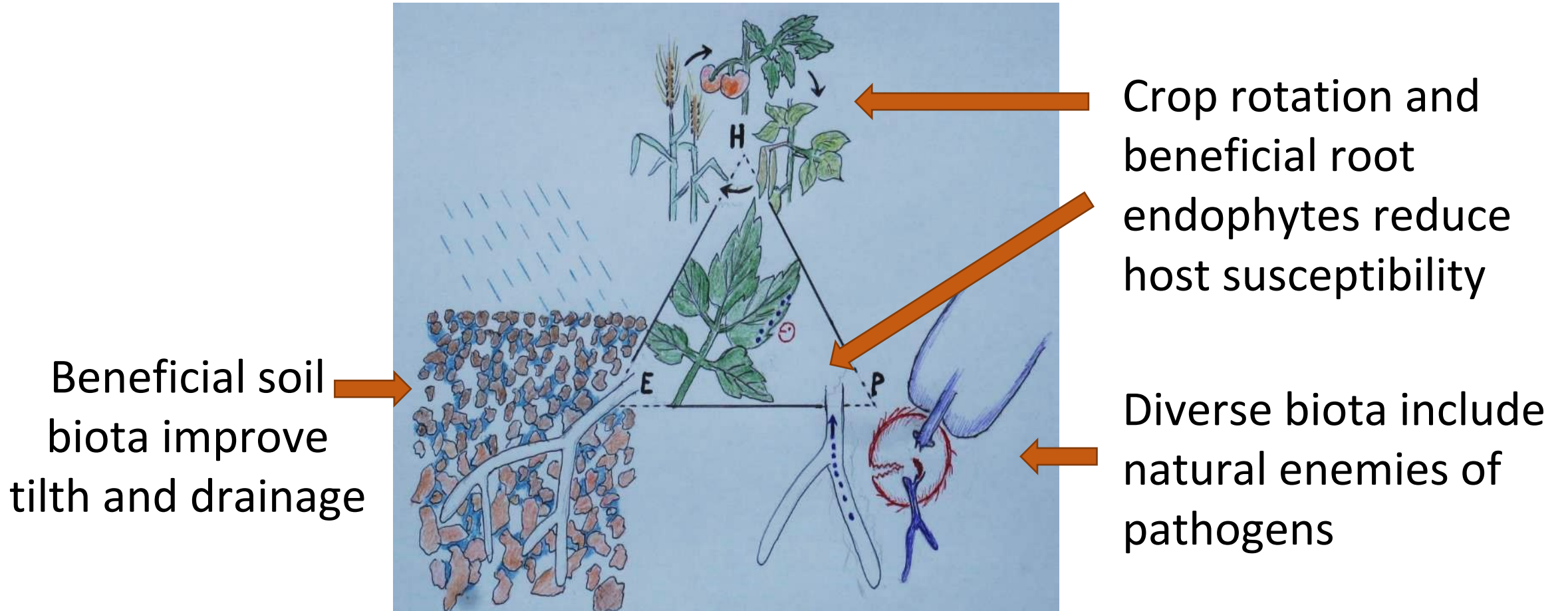
Rapid infiltration
Moisture retained
Unrestricted root growth
Excess drains out

The Plant Disease Triangle

Virulent pathogen (P)
+
Susceptible host (H)
+
Conducive environment
(E)
=
Plant disease outbreak



How Soil Life Can Help Break the Disease Triangle



Beneficial soil biota improve tilth and drainage

Crop rotation and beneficial root endophytes reduce host susceptibility

Diverse biota include natural enemies of pathogens

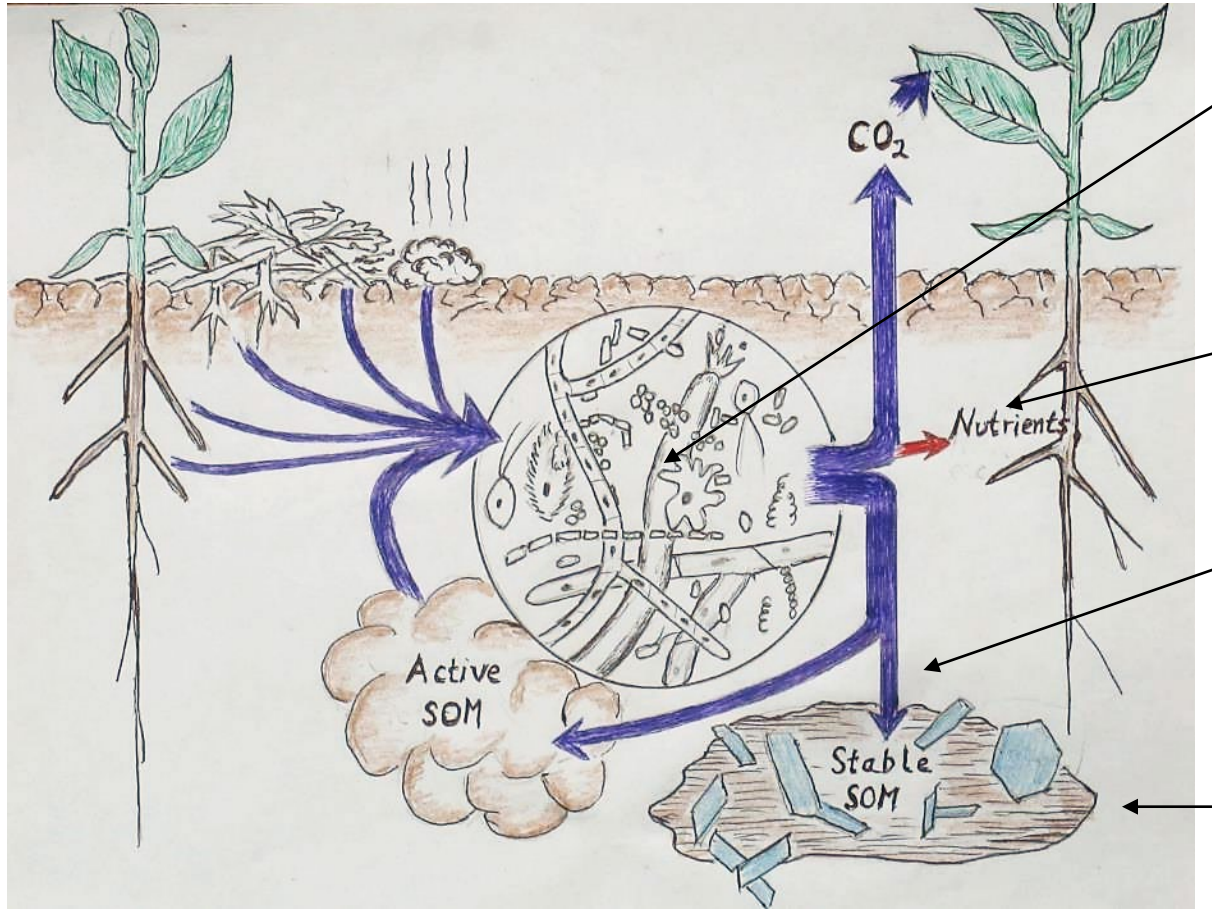
Ecosystem Services

| Service | Soil Functions | Key Organisms |
|-----------------------------|---|--|
| Water quality | Minimize leaching and runoff; retain nutrients | Plant roots and cover, microbes that immobilize nutrients |
| Detoxification | Attenuate pathogens. Bind or decompose toxins | Dung beetles, decomposer fungi and bacteria, microbes that degrade pesticides and bind heavy metals |
| Carbon sequestration | Build stable soil organic matter (SOM) | Plants (root exudates and residues), fungi, bacteria |

Soil Self-maintenance

| Soil Need | Soil Function | Key Organisms |
|--------------------------------|---|--|
| Stability against erosion | Protect and hold soil | Plant cover and roots |
| | Maintain aggregation | Fungi (mycelia), bacteria (glues) |
| Resilience and tilth | Restore structure after tillage, traffic, or heavy rain | Plant roots, earthworms, arthropods, fungi, bacteria |
| Active and stable SOM | Digest plant and animal residues into SOM | Decomposer bacteria and fungi, earthworms, arthropods |
| Food and habitat for soil life | Provide fresh residues and active SOM | Plants (root exudates, residues), entire soil food web |
| | Maintain pore space | Roots, bacteria (glues), fungi (mycelia) |

Soil Microbes Maintain Soil Structure and Sequester Carbon



Soil microbes continually **regenerate soil structure and habitat** (pore space) as they process organic residues into SOM

SOM mineralization (respiration) releases nutrients and supports plant growth

SOM stabilization (C sequestration) occurs when microbial remains form *mineral-associated organic matter* (MAOM).

Deep roots and leaching soluble SOM become **subsoil MAOM**.

Organic Farming for Soil Biology

Challenges, opportunities, and recent research findings

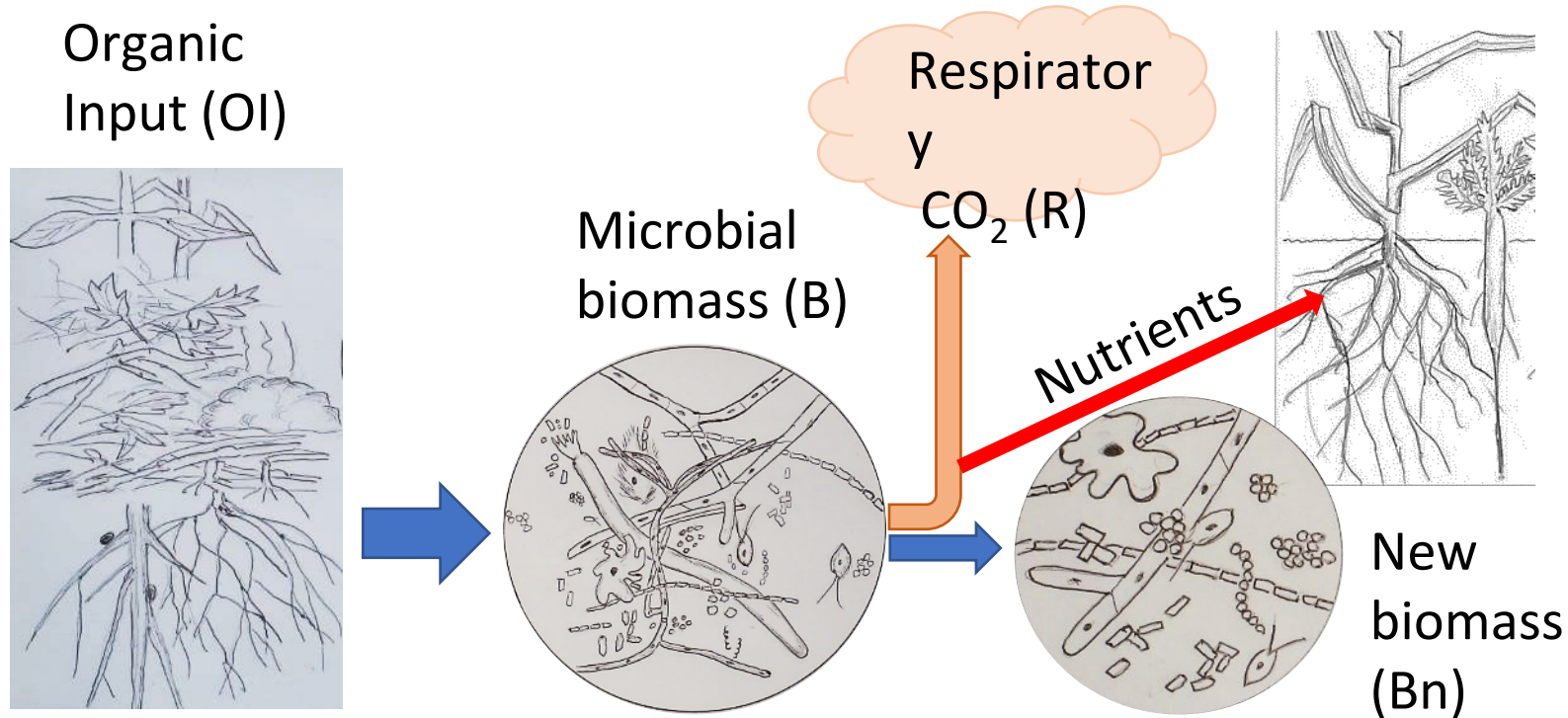
Challenges in Managing Soil Life in Organic Systems

- Farmers may face tradeoffs between SOM mineralization (crop nutrition) and SOM stabilization (soil health and C sequestration).
- Organic nutrient sources can overload P and inhibit mycorrhizal fungi.
- Tillage and cultivation for weed control can damage soil organisms.
- Modern crop cultivars may not partner effectively with soil microbes.
- Organic input vendors carry myriad microbial inoculant products.
- Climate change alters soil microbiome and speeds SOM breakdown.

Organic farmers rely on the soil microbiome to provide nutrients for the current year's crop and to maintain long-term soil health and productivity

Is this an unavoidable tradeoff between consuming SOM to feed the current crop and building SOM for the long term?

Soil organisms can mineralize nutrients *and* build SOM



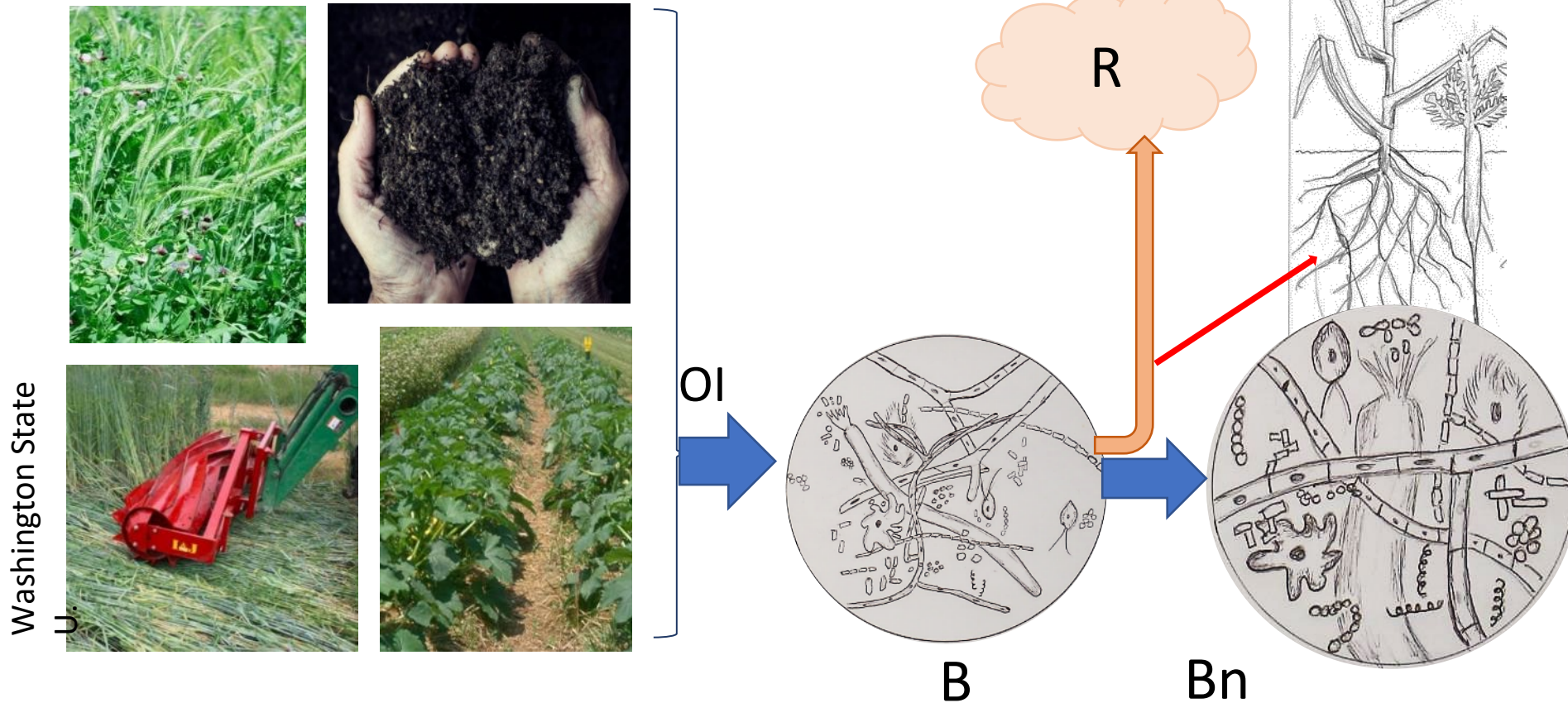
Microbial growth efficiency (MBE) = B_n/OI
Metabolic quotient (qCO_2) = R/B

High respiratory rate (CO_2) emissions does not mean the soil is losing SOM.

Soil test biological activity (STBA), a 3-day lab test measuring soil respiration, is positively related to:

- Total SOM
- Active SOM
- N mineralization
- Soil microbial biomass

Building Microbial Biomass and Stable SOM



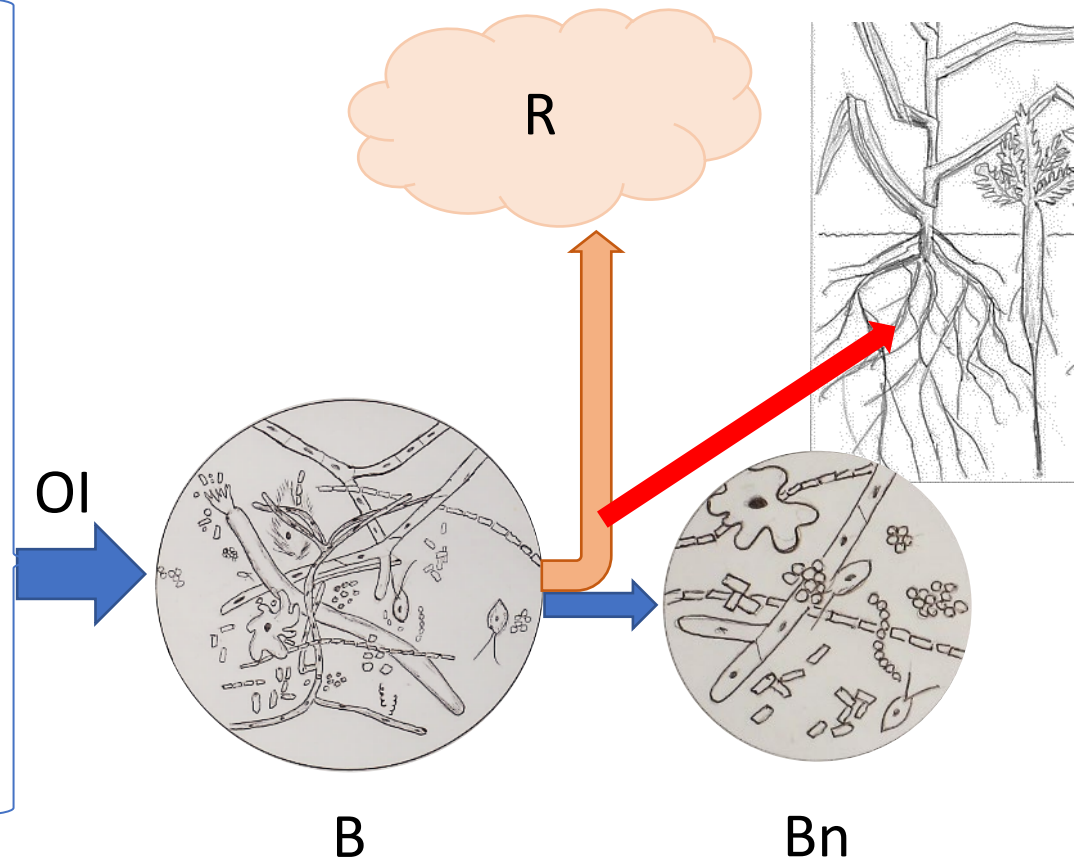
Practices:

- Moderate C:N inputs
- Grass + legume cover crop
- Minimum till

Outcomes:

- Builds SOM
- Crops may be N-limited

Promoting Mineralization



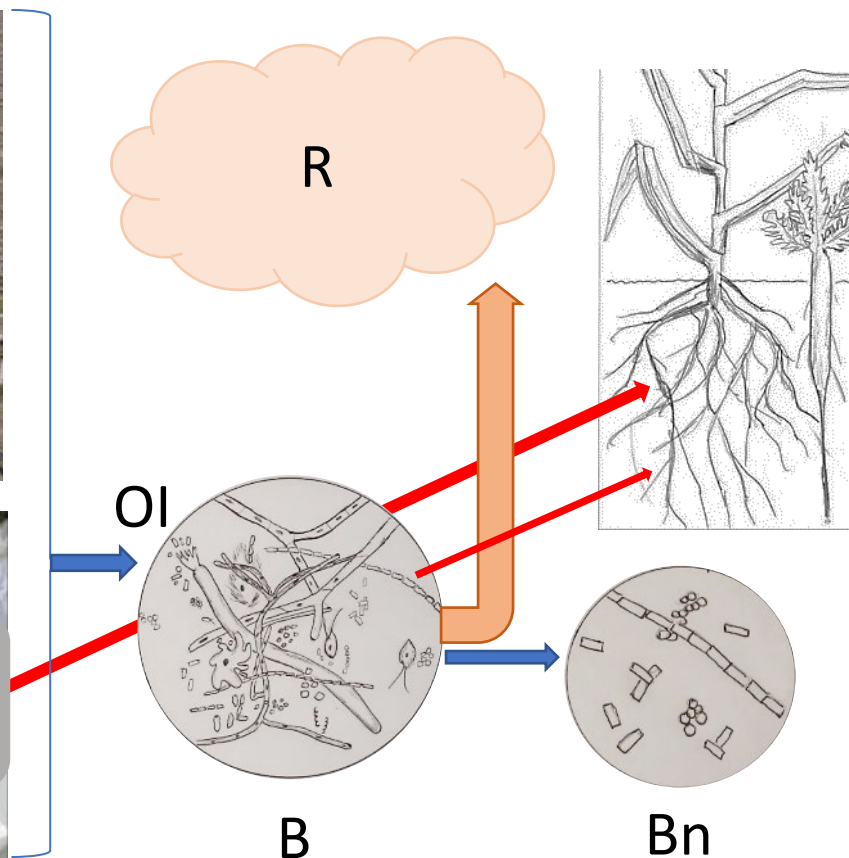
Practices:

- Concentrated, low C:N inputs
- All-legume green manure
- Full tillage

Outcomes:

- Sufficient N for crops
- May oxidize SOM
- May release N₂O

Stressed Soil Microbiome



Stresses:

- Intensive tillage
- Bare soil
- High input of soluble NPK
- Chemical no-till without living cover

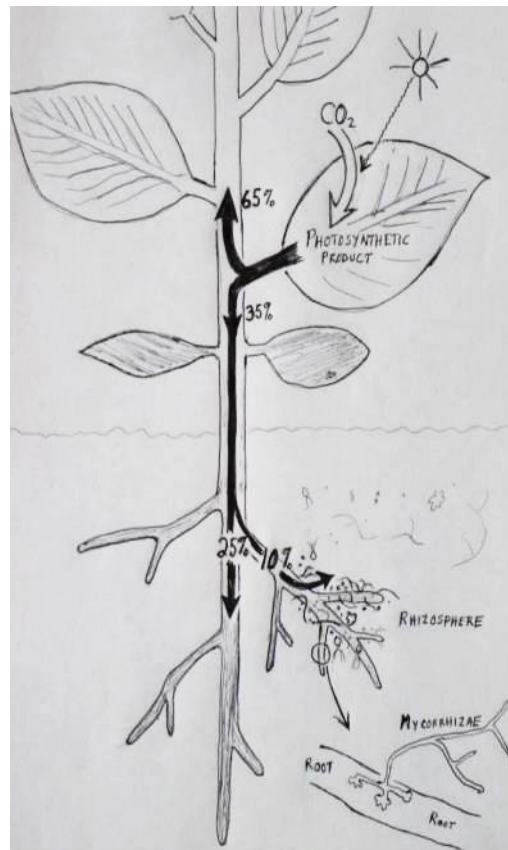
Outcomes:

- SOM losses
- Low microbial biomass
- High $q\text{CO}_2$
- Nutrient leaching

Enhancing Root Exudation for a Vibrant Soil Biota

Practices that provide nourishing root exudates for soil microbes:

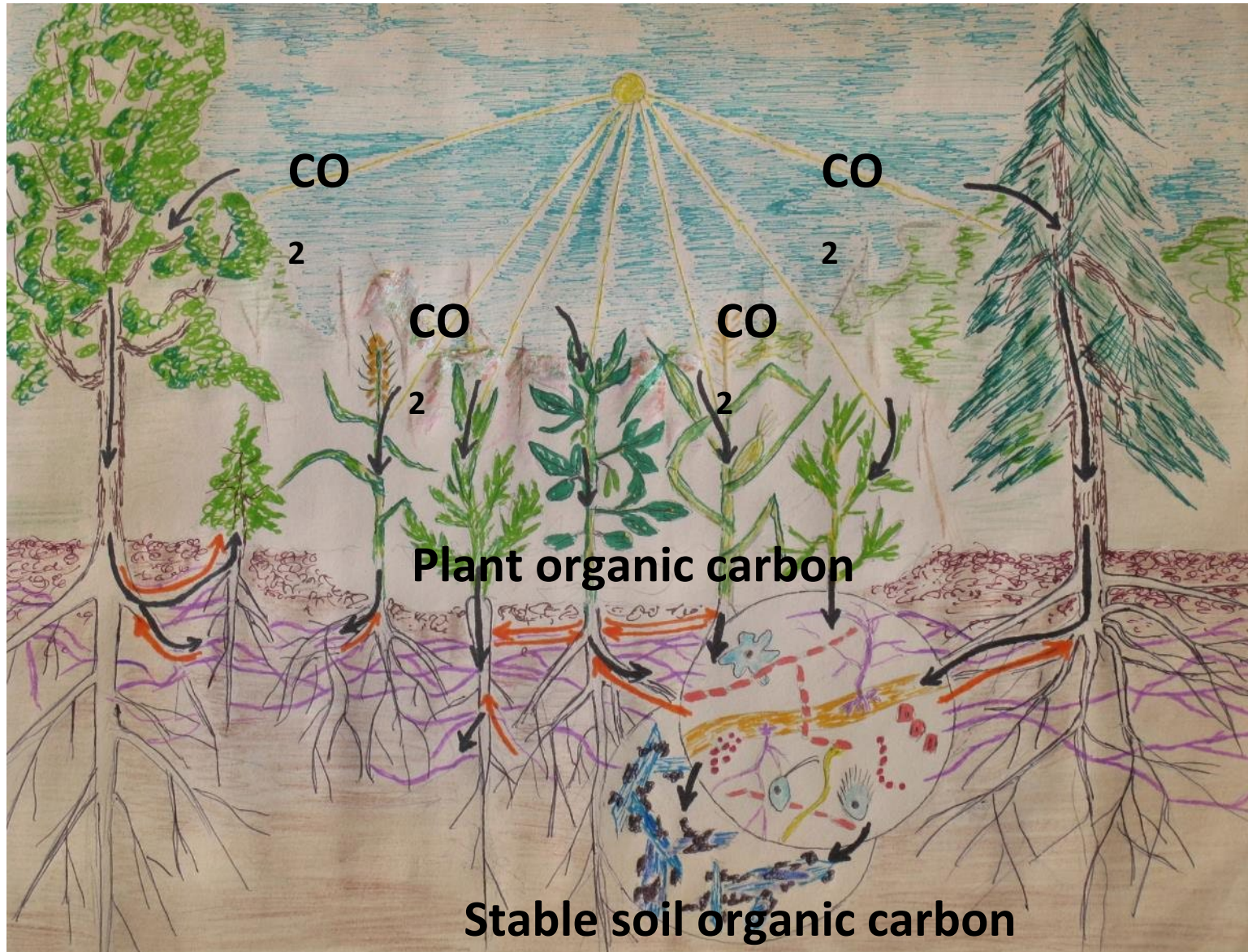
- N, P, and water provided at rates slightly below optimum for top growth
- Legumes in the crop rotation or pasture
- Rotational grazing late in the rapid growth phase



Practices that limit root exudation and leave soil microbes hungry:

- Ample N, P, and water to maximize top growth
- Overuse of synthetic or organic fertilizer
- Unmanaged grazing, *or* grazing too early or too late in forage life cycle

Mycorrhizal Networks Build Soil and Plant Health in Forestland

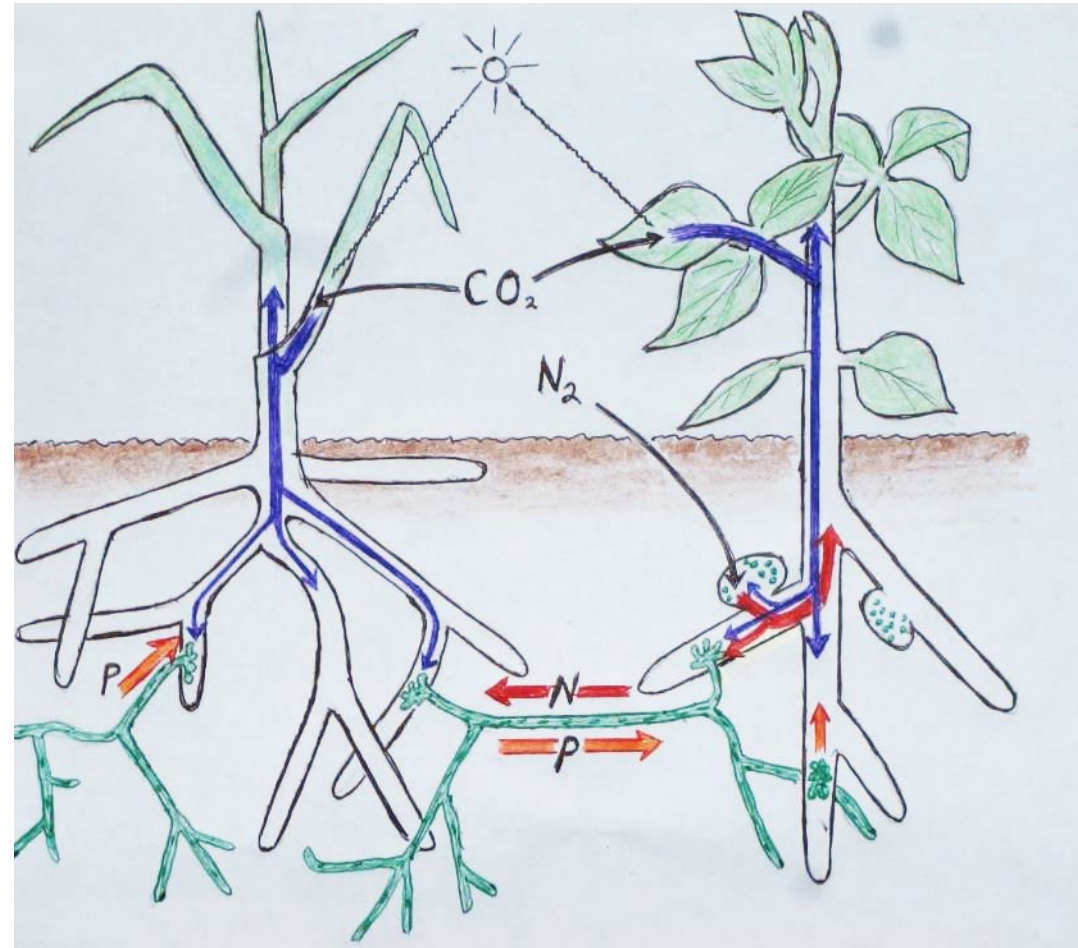


Research has shown that the mycorrhizal “internet” (**purple threads**):

- Link plants of the same or different species for sharing of resources.
- Receive plant sugars (**black arrows**) and deliver NPK and other plant nutrients (**orange arrows**).
- Enhance plant vigor and resilience to drought and pests.
- Play a major role in soil health and carbon sequestration.

Four-way Symbiosis in Grass-Legume Pasture

- 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

Meeting Organic Farmers' Phosphorus Challenge

The Problem:

- Using manure, poultry litter, and compost to meet crop N needs will build excess soil P and inhibit mycorrhizal activity.

The Solution:

- Reduce P inputs to match P removal in harvest.
- Provide N through legumes and credit N from SOM mineralization.
- Use diverse organic inputs with moderate overall C:N (15 – 20:1) to optimize soil biology.
- Reduce N applications: in biologically active soils, actual N need is far lower than standard “4Rs” recommendations and can be zero.

Balancing C and N in Organic Inputs

Puyallup, WA (maritime)
organic vegetable rotations
receiving:



Compost,
Mod. C:N

or



Fertilizer
,

Same total N
low C:N

After 11 years, soil receiving compost had:

- Better soil structure and water infiltration.
- 35% higher microbial activity.
- 43% higher total SOC.
- Changes in soil biota that can limit N₂O.

Other research findings:

- Compared to soluble NPK, organic nutrient sources double the biomass of soil bacteria, fungi, and microbe-feeding nematodes.
- Using organic sources at equivalent *total* N rates maintains yields and reduces N losses.
- Heavy use of low C:N organic inputs causes N₂O emissions similar to synthetic N.

Meeting Organic Farmers' Tillage Challenge

The Concern:

- A single tillage pass is thought to destroy soil life and SOM

The Research:

- Shallow non-inversion tillage doubles soil microbial biomass over either moldboard plowing or strict no-till.
- Tillage affects soil fungal, bacterial, and nematode communities to a much lesser degree than pesticides.

The solution:

- Organic weed IPM to reduce cultivation passes.
- Use shallow non-inversion tillage – only when needed.



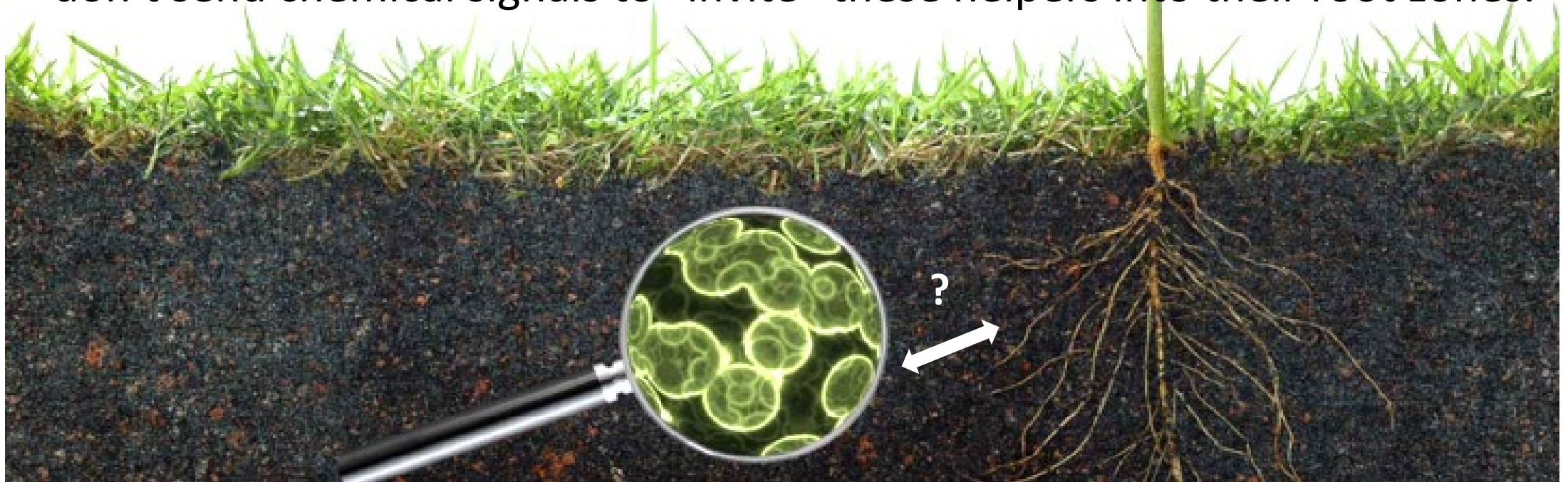
The high-speed disk provides shallow (~3 in) non-inversion tillage to terminate cover crops and prepare fields for planting.
Photo credit: Justin Rich

Does organic agriculture entail more soil disturbance?

- Organic eliminates synthetic pesticides, allows judicious tillage.
- Conservation agriculture eliminates tillage, allows judicious pesticide use.
- Intensive tillage hurts soil life; infrequent, shallow tillage may not.
- Recent research has shown that pesticides, herbicides, and fungicides:
 - Alter soil microbiomes, reduce microbial diversity.
 - Reduce mycorrhizal symbioses and soil microbial N fixation.
 - Reduce nematode biomass.
 - Harm earthworms and other soil invertebrates.
 - Copper fungicide and vinegar herbicide can also harm soil life.

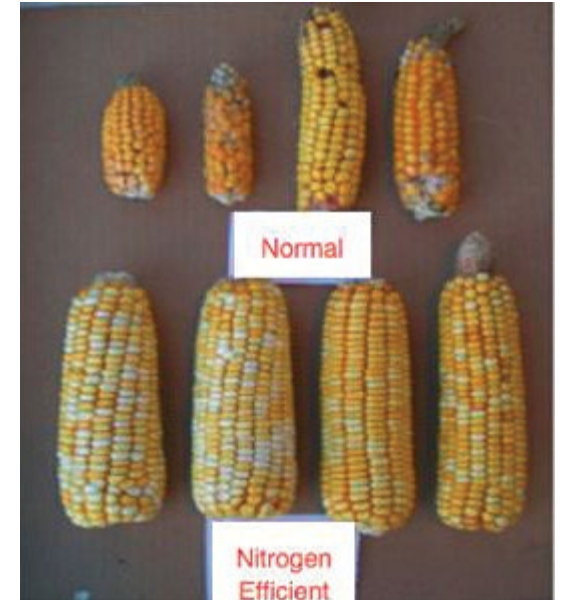
Meeting Organic Farmers' Seed Challenge: *have Modern Cultivars Forgotten How to "Talk" with Soil Life?*

- Growing crops in NPK-saturated fields can make mycorrhizal fungi, N fixers, and other valuable microbes go dormant or die out altogether.
- Breeding and selecting crops in such systems has created cultivars that don't send chemical signals to "invite" these helpers into their root zones.



Research Findings on Plant Genetics and Soil Microbes

- Using Mexican land races, Mandaamin Institute is developing N-efficient field corn that hosts N-fixing and N-cycling bacteria, a capacity lost in most modern hybrids (right).
- Substantial cultivar differences in AMF colonization have been found in carrot, pepper, tomato, sorghum, and other crops.
- Tomato breeders are developing new cultivars with enhanced disease resistance response to root-associated *Trichoderma*.
- Carrot breeding lines differ in their capacity to host root endophytes that improve nutrient uptake and disease resistance.



Ears from standard and N-efficient corn grown on tropical soil low in N.

Mandaamin Institute, Elkhorn, WI

Another Organic Challenge: Smart Shopping for Microbes

Do they Work?

Do they Pay?

Will your indigenous soil microbes outcompete them?

Will they upset soil microbiomes?

- *Rhizobium* legume seed inoculants
- Mycorrhizal fungi –seed / root
- Compost, on-farm.
- Compost tea, worm casting tea

- Effective micro-organisms, bokashi, on-farm sourced.

- Proprietary mycorrhizal and other microbe blends for soil application

- Natural enemies of plant pathogens and pests – bio-fungicides and biopesticides

- Microbial foods – seaweed extract, fulvic acids (fungi), amino acids, molasses (bacterial).

Do We Need to Introduce Microbes to Restore Soil?

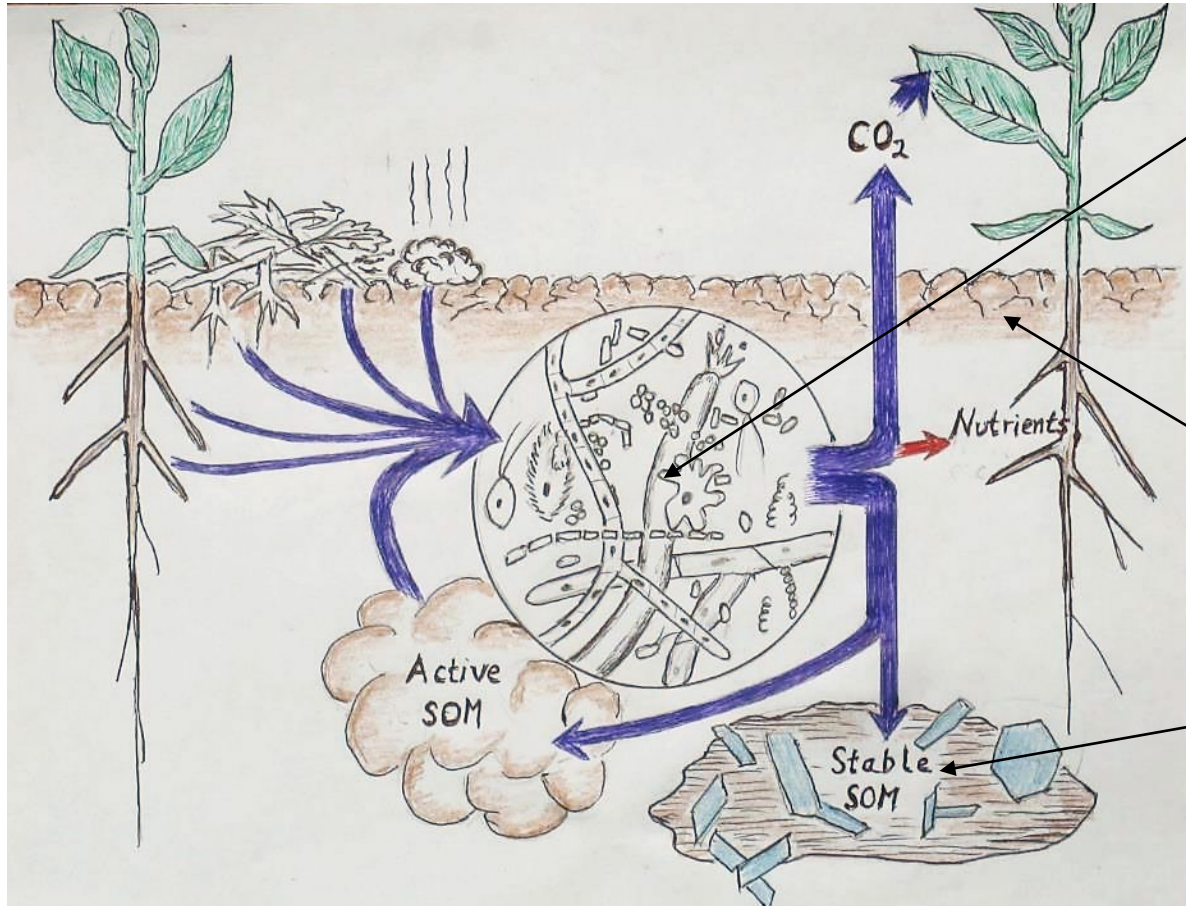
“There will still be some small bit of life in [the soil] even in the most chemically dependent or heavily tilled operations. If you give that life a chance to grow, it will respond. If you build it, or if you stop destroying it, they will come.”

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

- Started with 5,000 ac of depleted rangeland.
- Crops + livestock with rotational grazing.
- Implemented 4 NRCS principles – cover soil, living roots, diversify, minimize disturbance
- SOM 2% → 7% in 20 years, drought resilient system.
- No purchased inoculants used.



How will Climate Change Affect Soil Life and SOM?



Microbial communities are likely to change as mean temperatures climb. **Research and adaptation, including developing new crops and cultivars for the new normal, will be vital.**

SOM physically sequestered in **near-surface aggregates is highly sensitive to rising temperatures and to tillage.**

Stable **MAOM** is less sensitive to rising temperatures and tillage, especially subsoil MAOM.

Organic Farming for Soil Biology

Guidelines for optimizing practices and outcomes

Four NRCS Principles of Soil Health



Keep the soil covered



Diversify the farming system



Maintain living roots



Minimize soil disturbance

Tips for Enhancing Soil Biology in Organic Systems

- Maintain continuous living plant cover and living roots.
- Diversify the cropping system to support microbial diversity.
- Reduce disturbance
 - Till with care and only when necessary
 - Use NOP-allowed pest control substances only when all else fails.
- Use a diversity of organic inputs with moderate overall C:N.
- Use concentrated nutrient sources sparingly.
- Find out how much N your crop really needs – do side-by side trials and/or assessments of soil N mineralization potential.



Questions?

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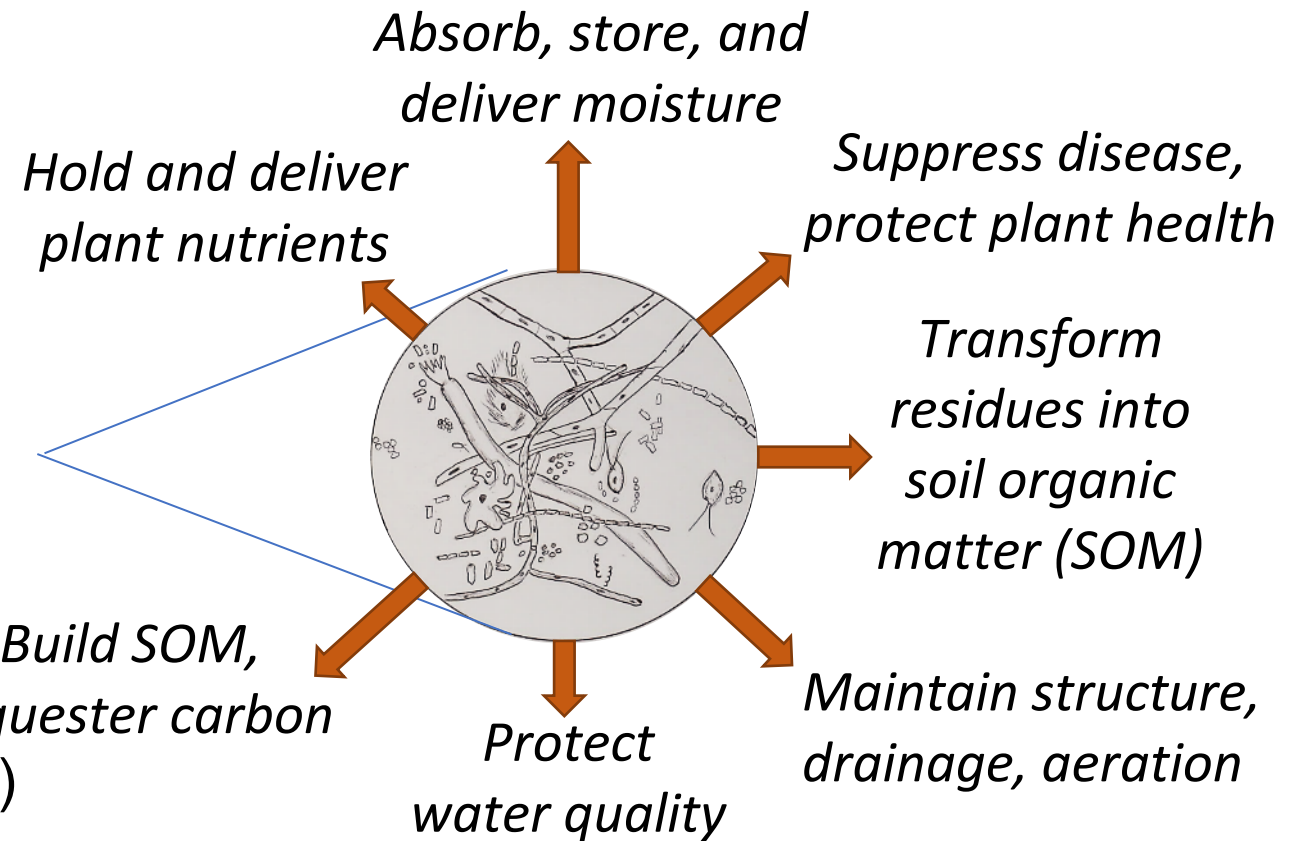
■ Mineral (~45%)

■ SOM (~5%)

■ Organisms (~0.2%)

■ Air-filled (~25%)

■ Water-filled (~25%)



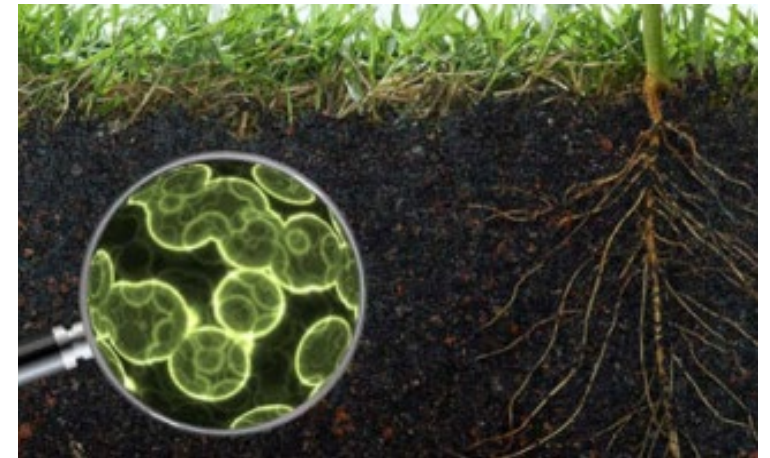
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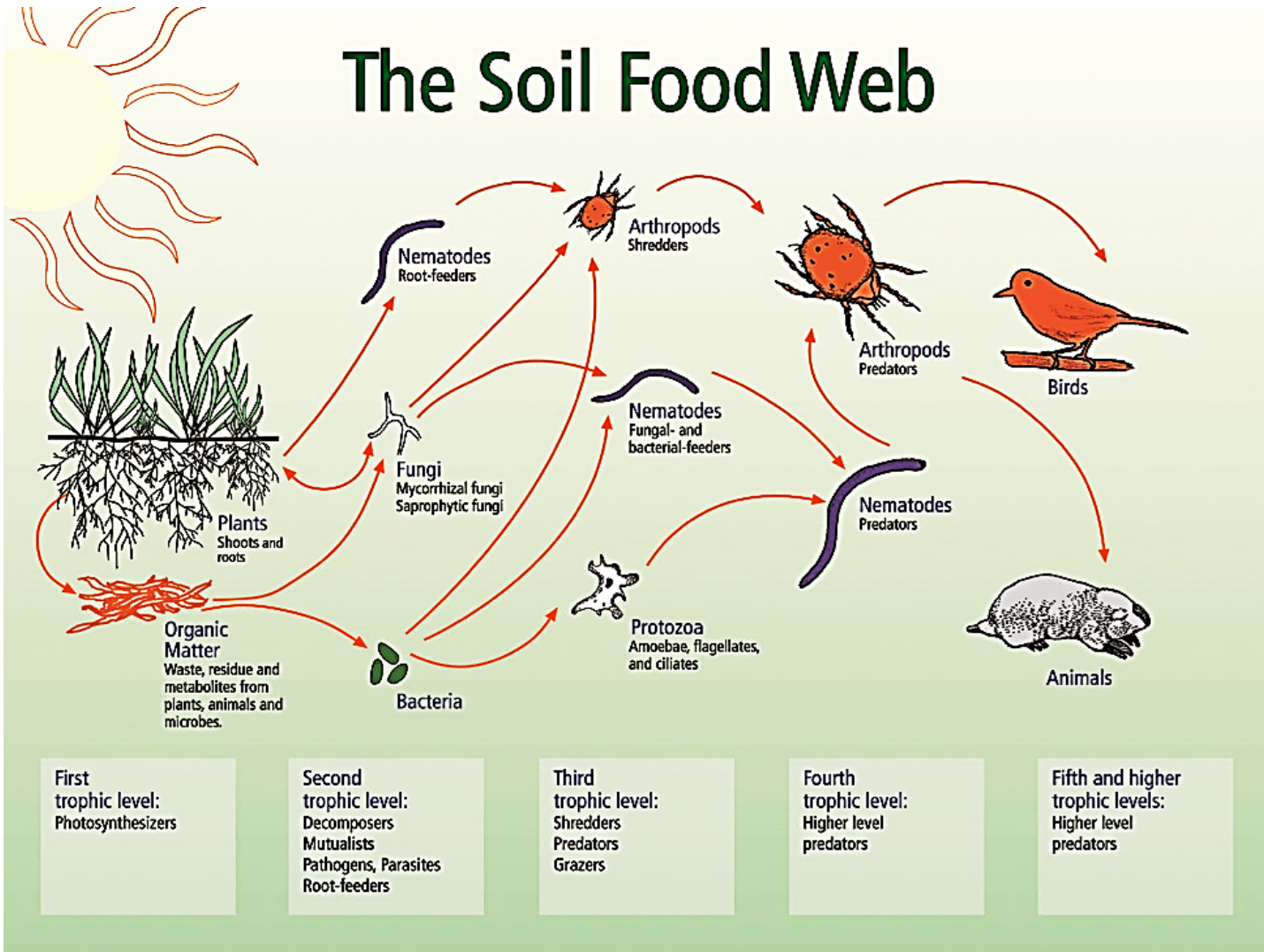
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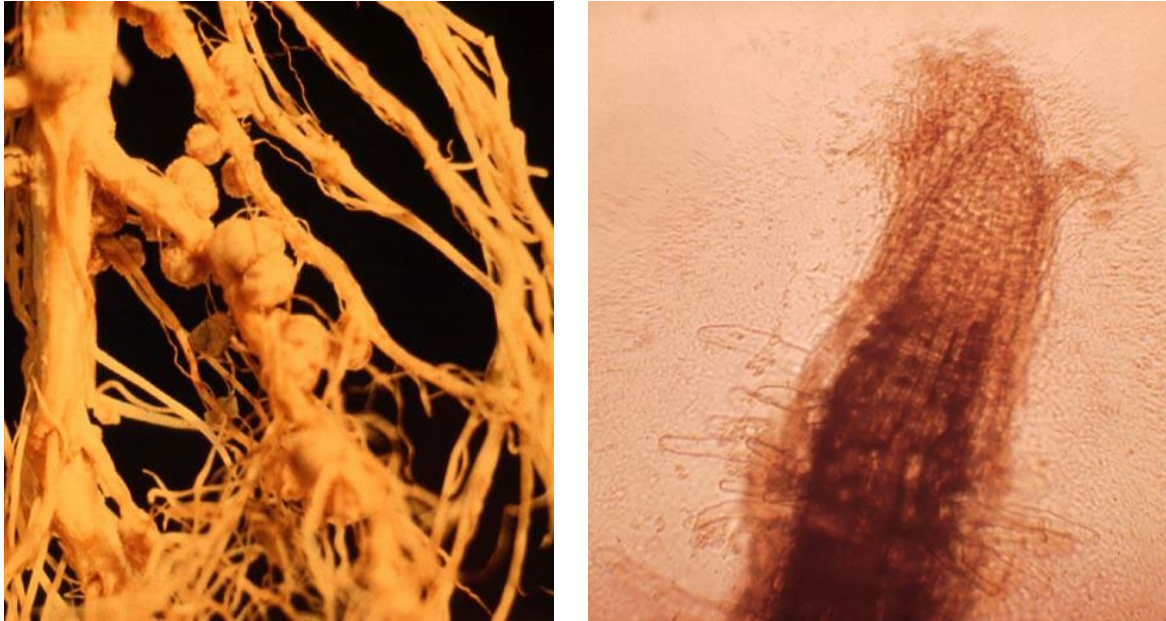
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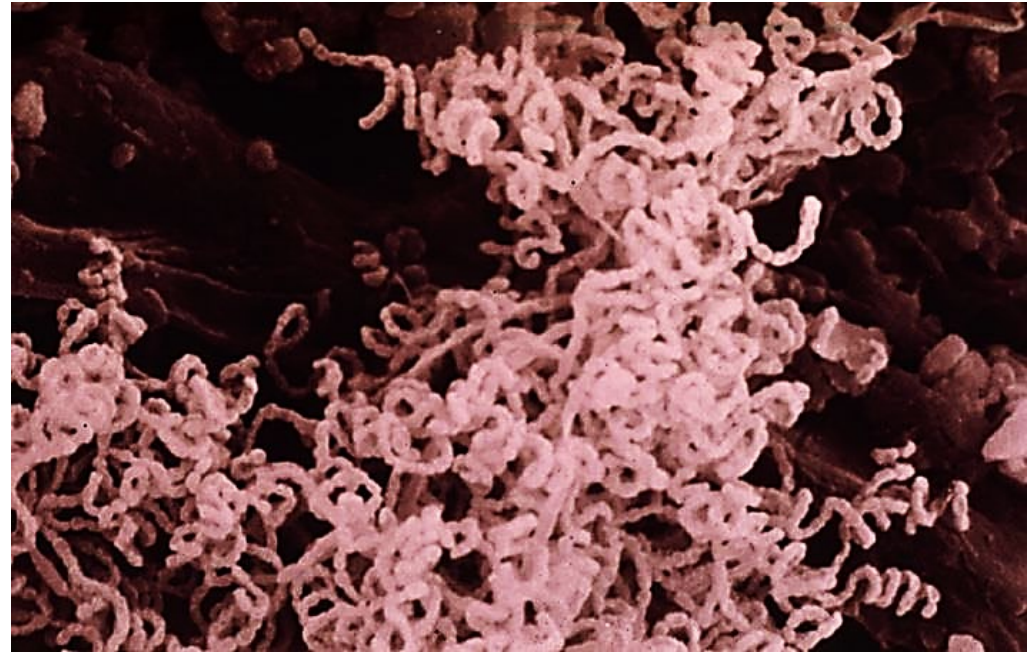
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Actinobacteria

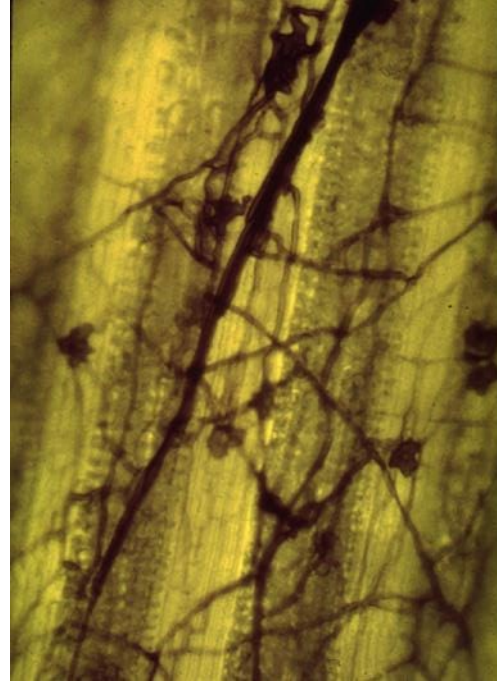
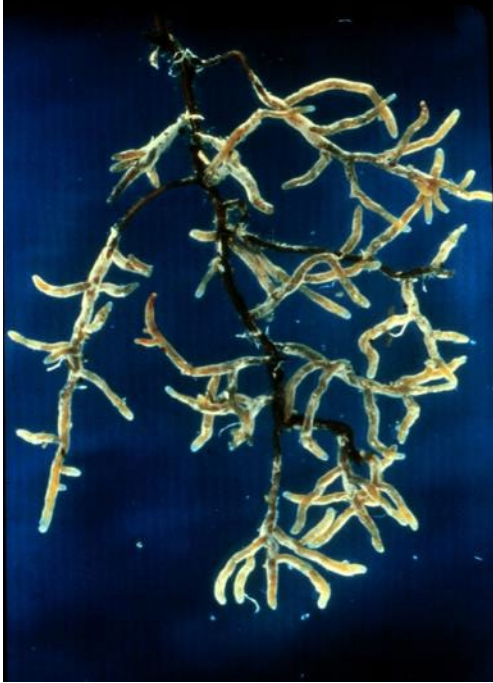
>10 million per gram of soil



Soil actinobacteria. *Photo credit: Ingham et al, 2000. Soil Biology Primer*

Fungi

>30 ft hyphae per gram of soil



Ectomycorrhizal fungi (left). Decomposer fungi on plant residue (right). *Photo credit: Ingham et al., 2000 Soil Biology Primer*

Decomposer fungi:

- Digest woody materials
- Build stable SOM

Root-symbiotic fungi:

- Ectomycorrhizal – trees and shrubs
- Arbuscular mycorrhizal fungi (AMF) – most crops
- Build stable SOM
- Aid nutrient and water uptake

Plant pathogens

Parasites of pathogens and pests

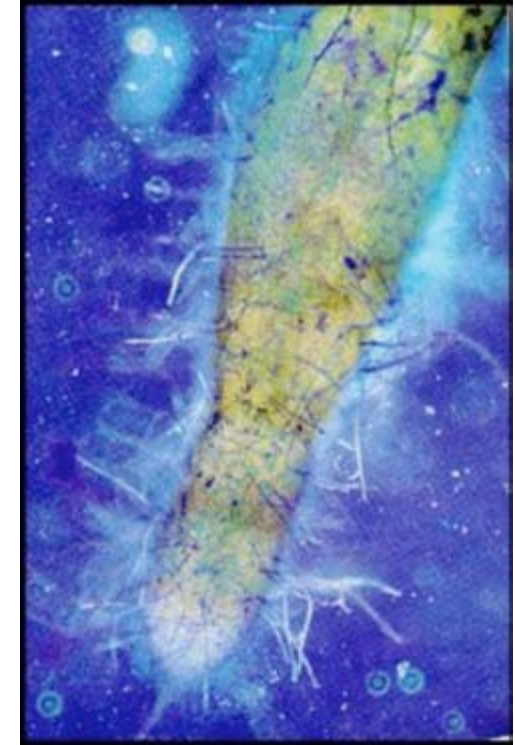
- Bio-fungicides, biopesticides

Protozoa

>100 per gram of soil

Flagellates, ciliates, and amoebas:

- Feed primarily on bacteria
- Important role in releasing N and other nutrients in the rhizosphere
- Ciliates in wet soil; flagellates in drier soil



Ciliate protozoa feeding on soil bacteria (left) . Bacteria and protozoa proliferating in rhizosphere (right). *Photo credits Fotosearch, Waukesha, WI (left); James Hoorman, Ohio State University (right)*

Nematodes

1 – 100 per gram of soil

Bacterial feeders and fungal feeders

- Release crop nutrients

Root feeders

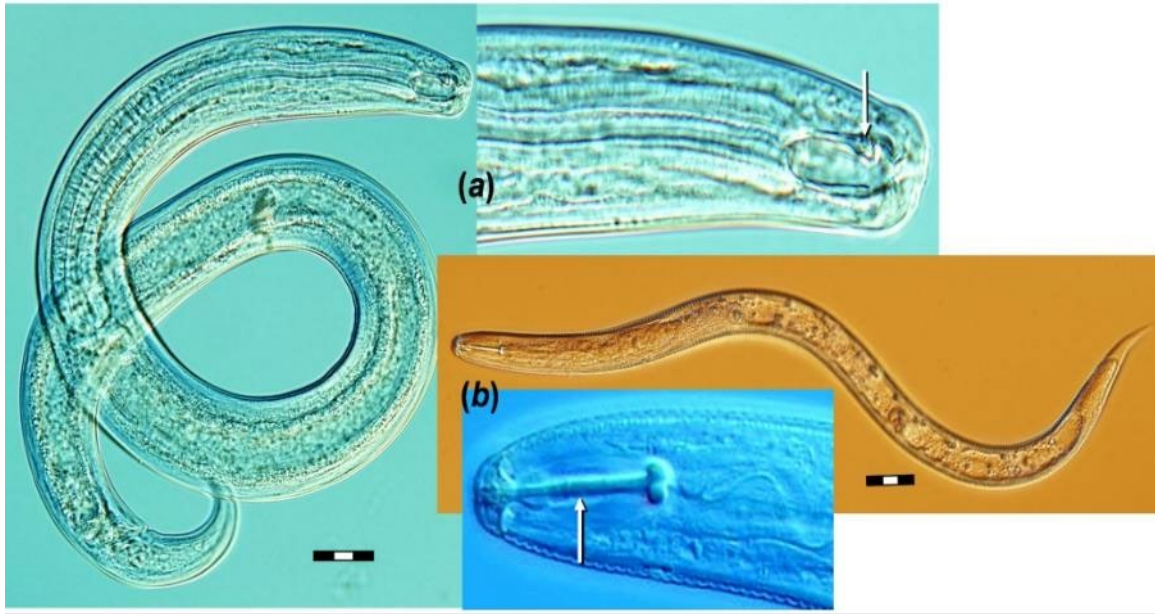
- Potential pests

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).

*Photo credit: Lisa Stocking Gruver, U Maryland;
courtesy of Joel Gruver, Western Illinois U..*

Micro-arthropods

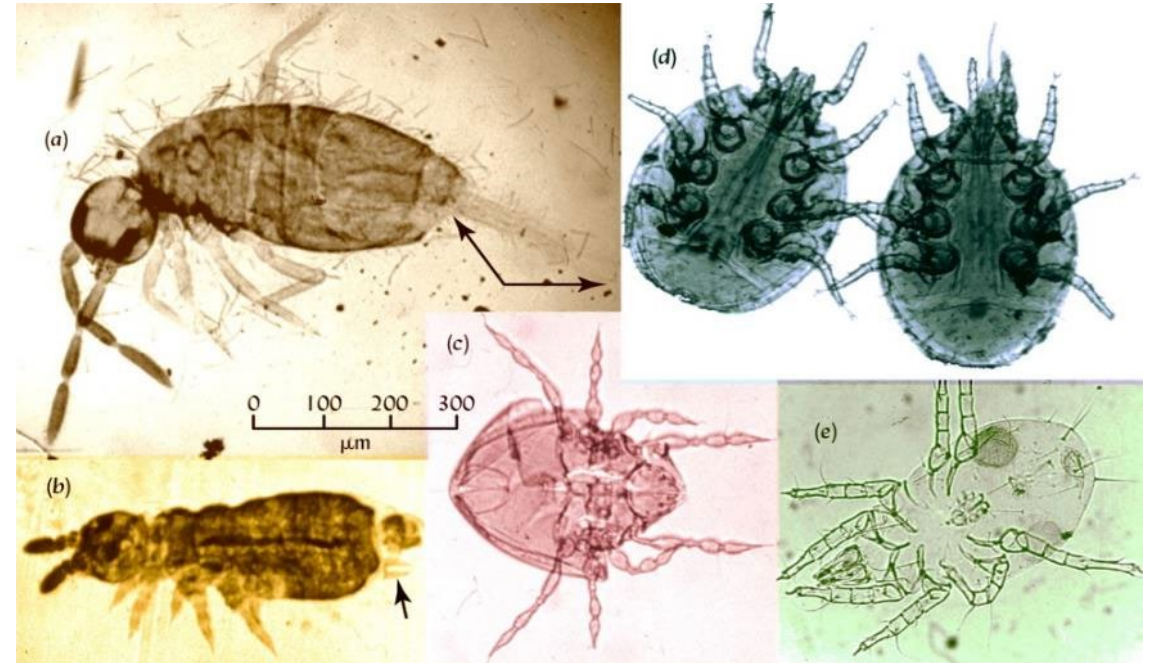
1 – 20 per gram of soil

Mites

- Shredders – help microbes digest residues and mineralize nutrients.
- Predators

Collembola (springtails)

- Shredders
- Fungal and bacterial feeders



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

Photo credit: Ray R. Weil, U. Maryland

Earthworms

1 – 100 per square foot

Earth movers (“ecosystem engineers”):

- Build macro-pores 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.



European nightcrawler and casts (above; *photo credit Ray R. Weil*)
Red wiggler in compost (left).

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.



As they bury manure in the soil, dung beetles facilitate nutrient cycling, disrupt parasite life cycles, and reduce food safety risks. *Photo credit: Ray R. Weil, U. Maryland.*

Soil Life and Soil Functions

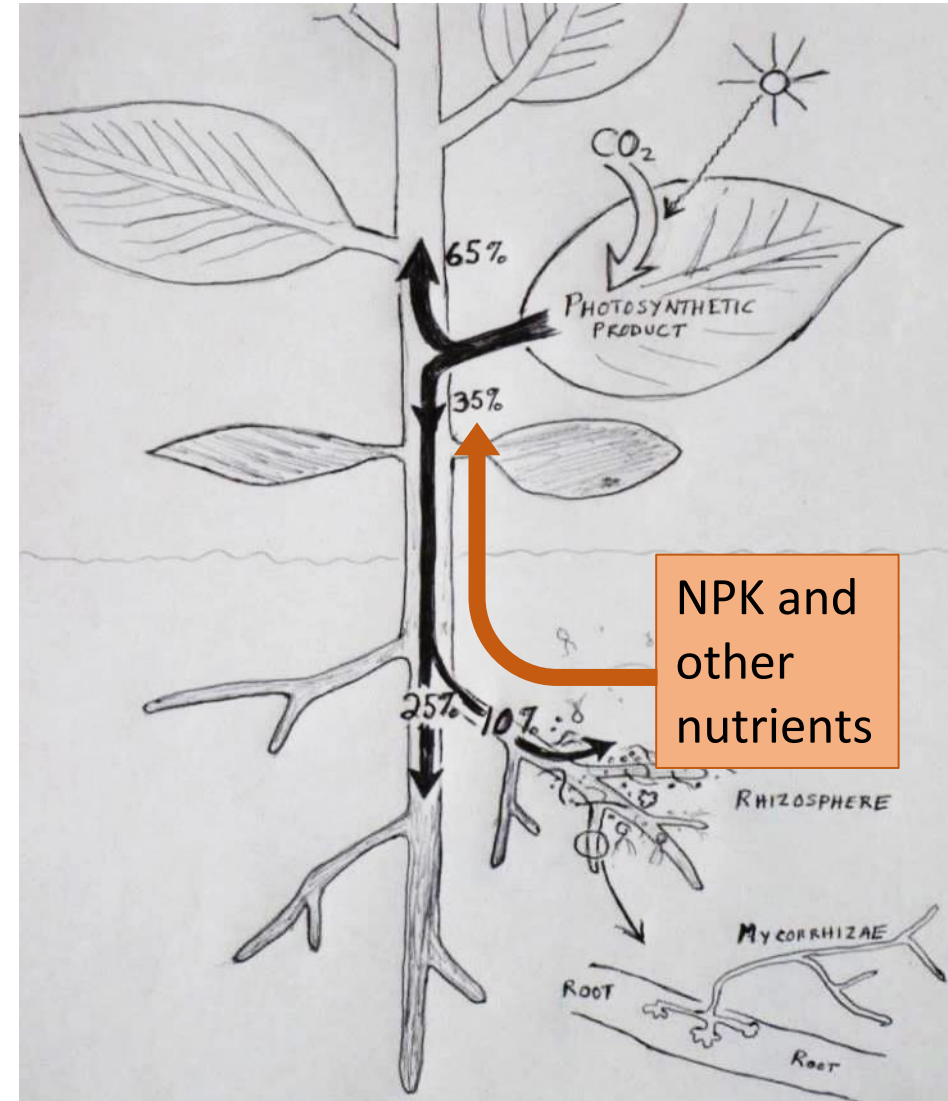
*Nutrients, water, crops, carbon,
soil self-maintenance*

Crop Production

| Crop Needs | Soil Functions | Key Organisms |
|--|--|---|
| Crop nutrition | Retain and recycle nutrients from organic residues | Decomposer bacteria and fungi, earthworms, arthropods |
| | Deliver nutrients to plants | Microbial grazers (protozoa, and nematodes), N-fixing bacteria, mycorrhizal fungi |
| Plant-available water, drainage, and aeration | Maintain SOM, aggregation, network of small and large pores, and deep channels | Bacteria (glues) fungi (mycelia), earthworms, arthropods, plant roots (pores, channels, exudates) |
| Crop protection | Deter pests and pathogens | Disease-suppressive microbes, pest predators and parasites |
| | Enhance plant resilience | Microbial root symbionts that induce systemic resistance (ISR) |

An Ancient Partnership

- Plants donate 10 – 30% of their photosynthetic product to the soil life, mainly via root exudates.
- In return, soil microbes help plants obtain nutrients and ward off pathogens.
- The Earth's first land plants co-evolved with their mycorrhizal fungal symbionts 450 million years ago.



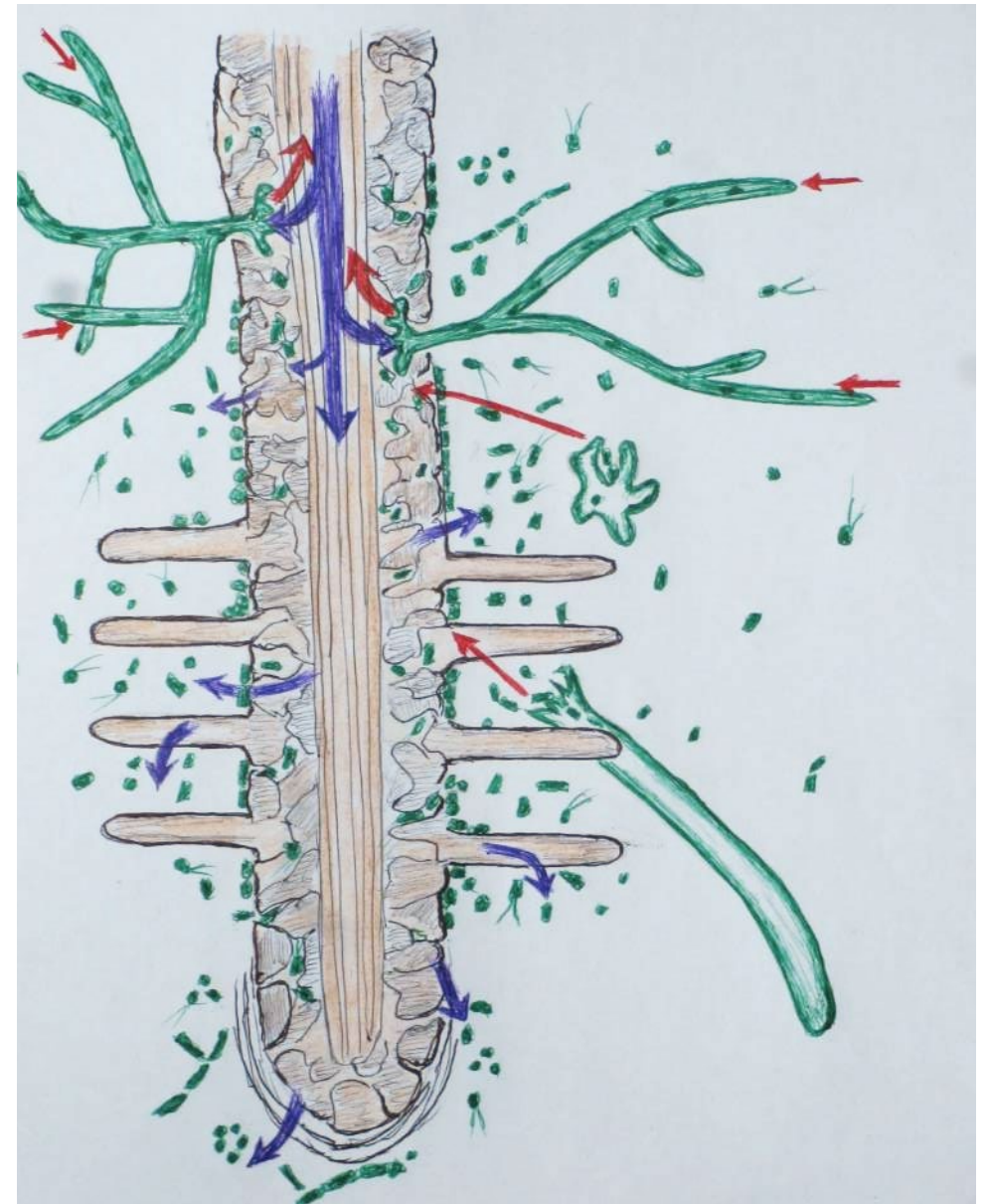
Rhizosphere (root zone)

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

- AMF exchange
- Root exudates
- Root cell sloughing

Plants receive nutrients (red) via:

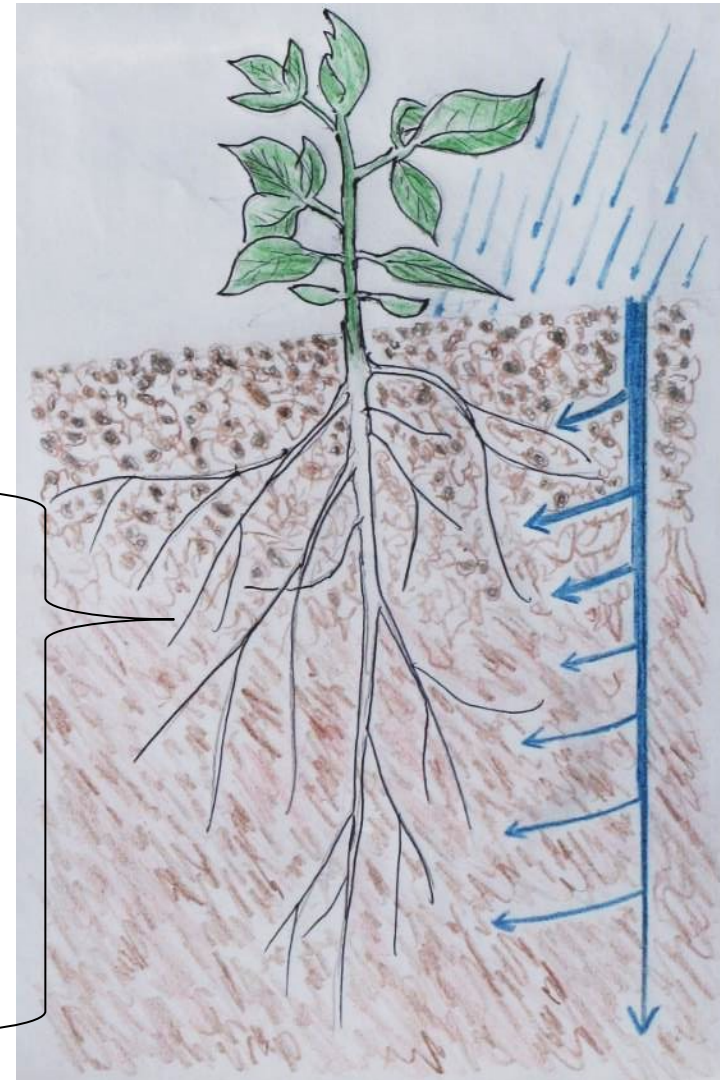
- AMF exchange
- Microbial N₂ fixation
- Nutrient mineralization by microbial grazers



Based on diagram by Ray R. Weil

How a Biologically Active Soil Absorbs and Retains a Downpour

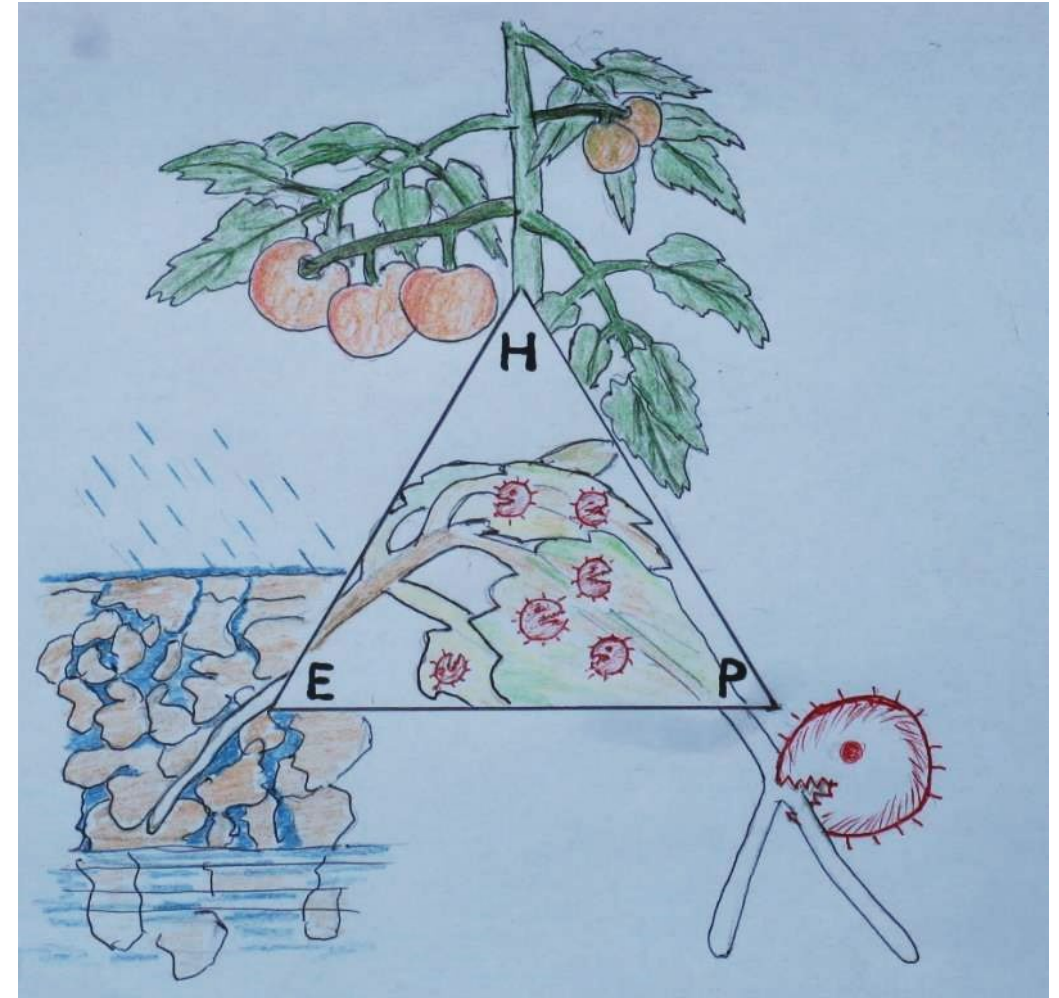
Plant roots and soil biota aggregate soil and maintain a network of large and small pores.



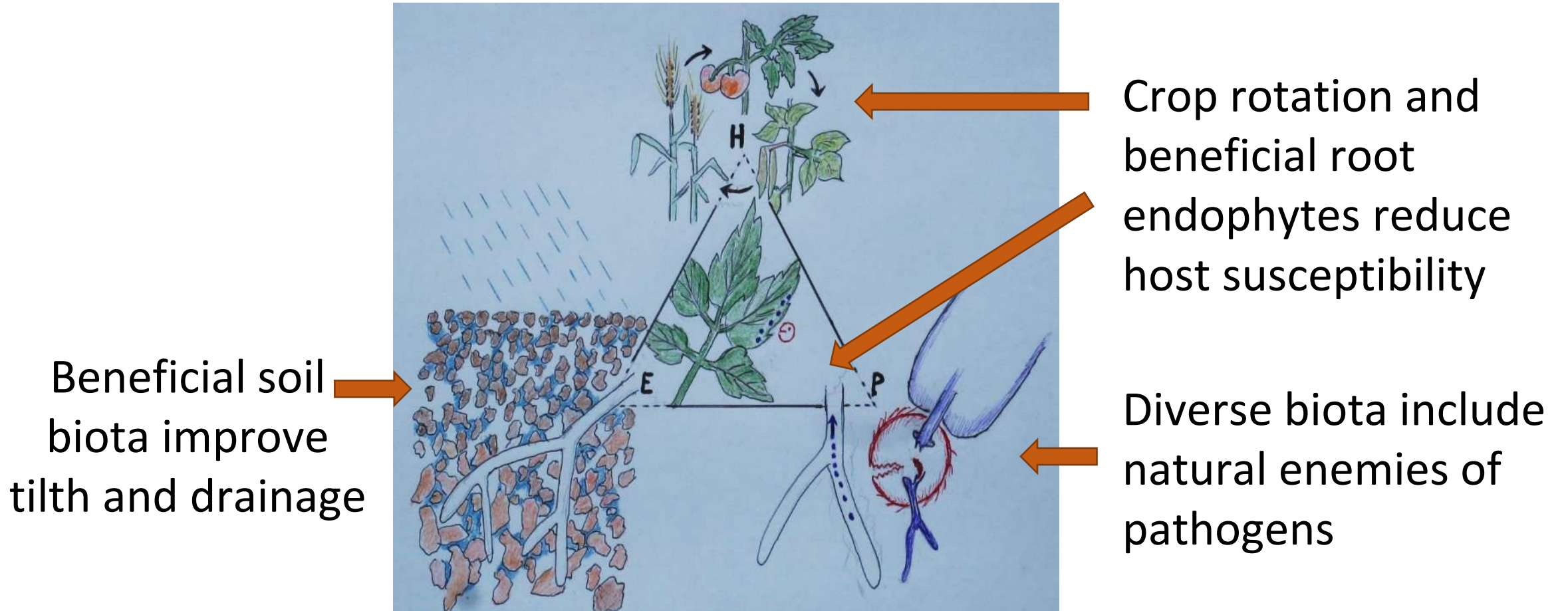
Rapid infiltration
Moisture retained
Unrestricted root growth
Excess drains out

The Plant Disease Triangle

Virulent pathogen (P)
+
Susceptible host (H)
+
Conducive environment
(E)
=
Plant disease outbreak



How Soil Life Can Help Break the Disease Triangle



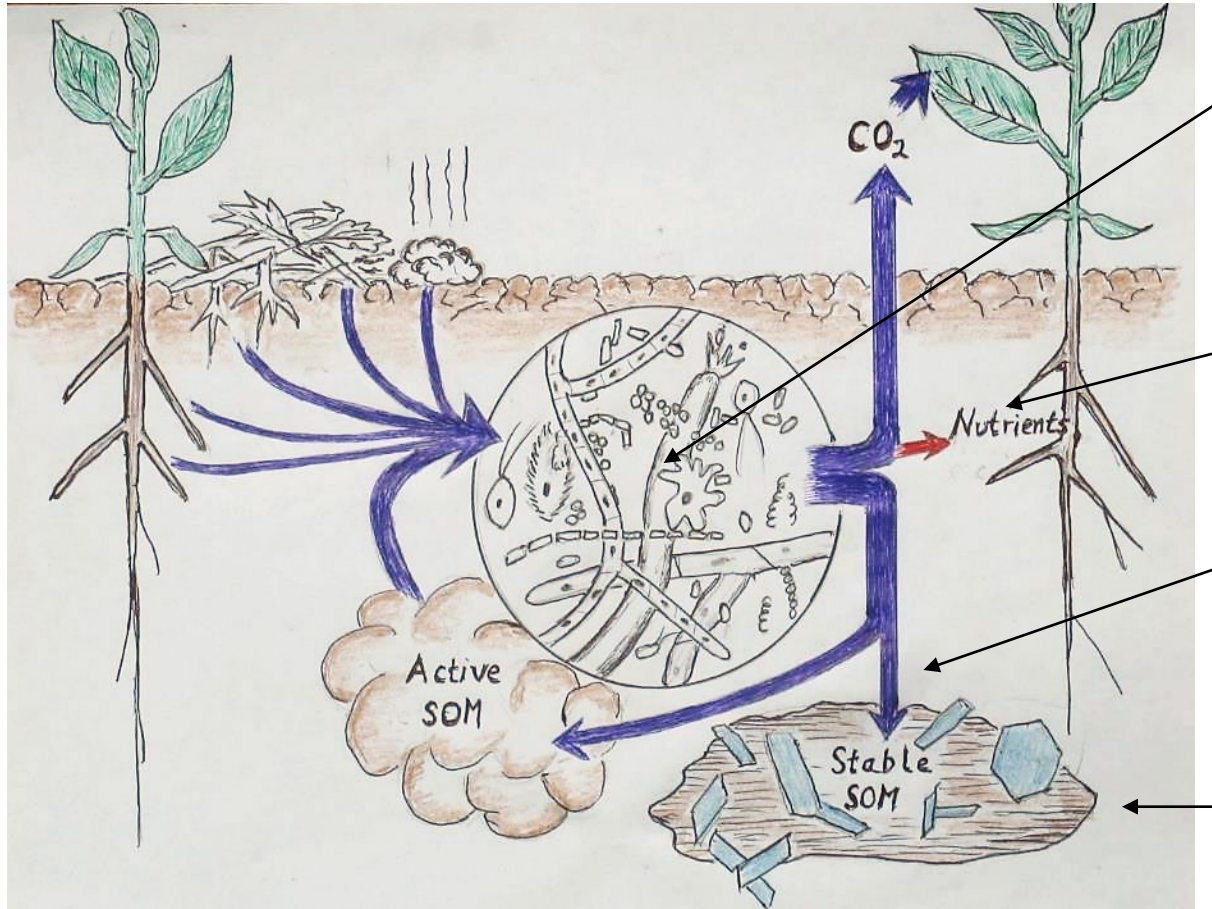
Ecosystem Services

| Service | Soil Functions | Key Organisms |
|-----------------------------|---|--|
| Water quality | Minimize leaching and runoff; retain nutrients | Plant roots and cover, microbes that immobilize nutrients |
| Detoxification | Attenuate pathogens. Bind or decompose toxins | Dung beetles, decomposer fungi and bacteria, microbes that degrade pesticides and bind heavy metals |
| Carbon sequestration | Build stable soil organic matter (SOM) | Plants (root exudates and residues), fungi, bacteria |

Soil Self-maintenance

| Soil Need | Soil Function | Key Organisms |
|--------------------------------|---|--|
| Stability against erosion | Protect and hold soil | Plant cover and roots |
| | Maintain aggregation | Fungi (mycelia), bacteria (glues) |
| Resilience and tilth | Restore structure after tillage, traffic, or heavy rain | Plant roots, earthworms, arthropods, fungi, bacteria |
| Active and stable SOM | Digest plant and animal residues into SOM | Decomposer bacteria and fungi, earthworms, arthropods |
| Food and habitat for soil life | Provide fresh residues and active SOM | Plants (root exudates, residues), entire soil food web |
| | Maintain pore space | Roots, bacteria (glues), fungi (mycelia) |

Soil Microbes Maintain Soil Structure and Sequester Carbon



Soil microbes continually **regenerate soil structure and habitat** (pore space) as they process organic residues into SOM

SOM mineralization (respiration) releases nutrients and supports plant growth

SOM stabilization (C sequestration) occurs when microbial remains form *mineral-associated organic matter* (MAOM).

Deep roots and leaching soluble SOM become **subsoil MAOM**.

Organic Farming for Soil Biology

Challenges, opportunities, and recent research findings

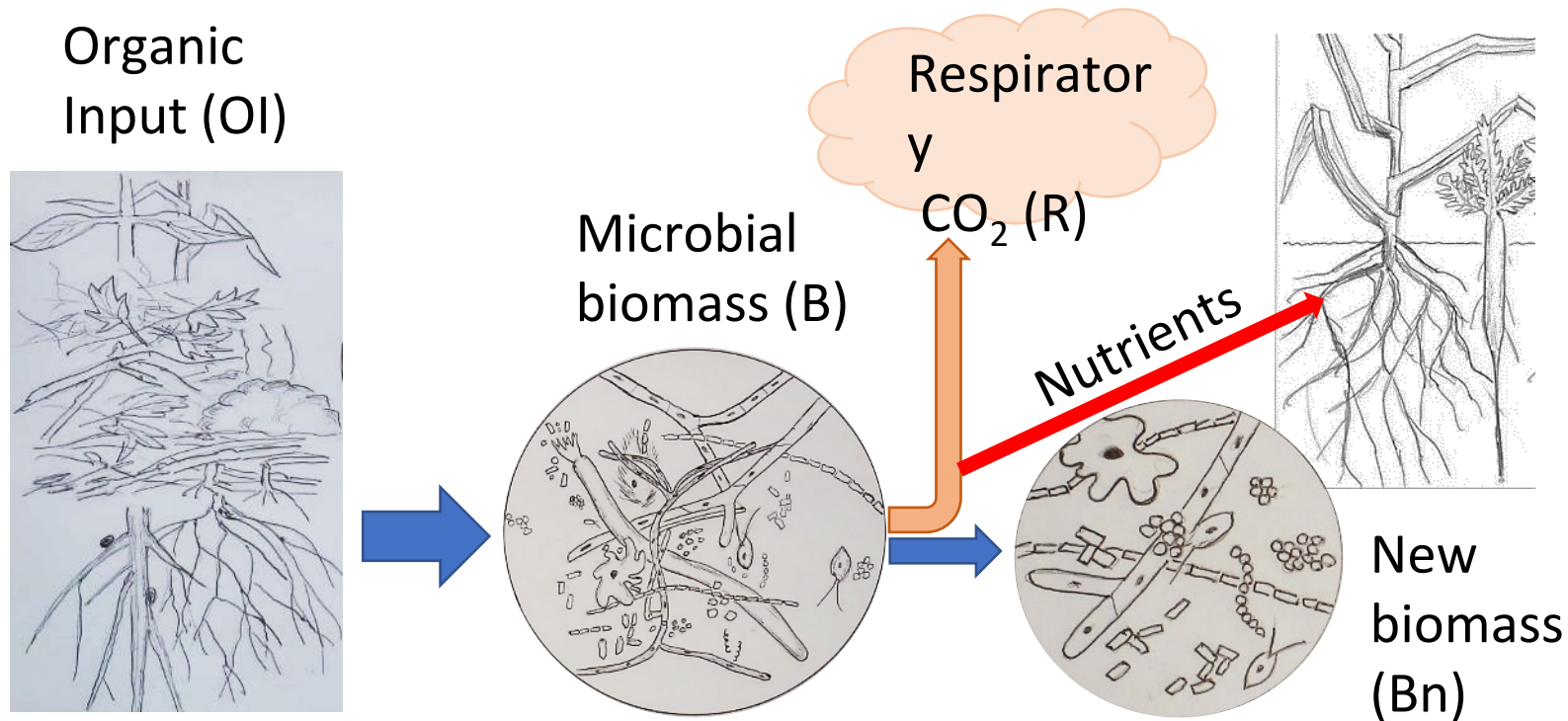
Challenges in Managing Soil Life in Organic Systems

- Farmers may face tradeoffs between SOM mineralization (crop nutrition) and SOM stabilization (soil health and C sequestration).
- Organic nutrient sources can overload P and inhibit mycorrhizal fungi.
- Tillage and cultivation for weed control can damage soil organisms.
- Modern crop cultivars may not partner effectively with soil microbes.
- Organic input vendors carry myriad microbial inoculant products.
- Climate change alters soil microbiome and speeds SOM breakdown.

Organic farmers rely on the soil microbiome to provide nutrients for the current year's crop and to maintain long-term soil health and productivity

Is this an unavoidable tradeoff between consuming SOM to feed the current crop and building SOM for the long term?

Soil organisms can mineralize nutrients *and* build SOM



High respiratory rate (CO₂) emissions does not mean the soil is losing SOM.

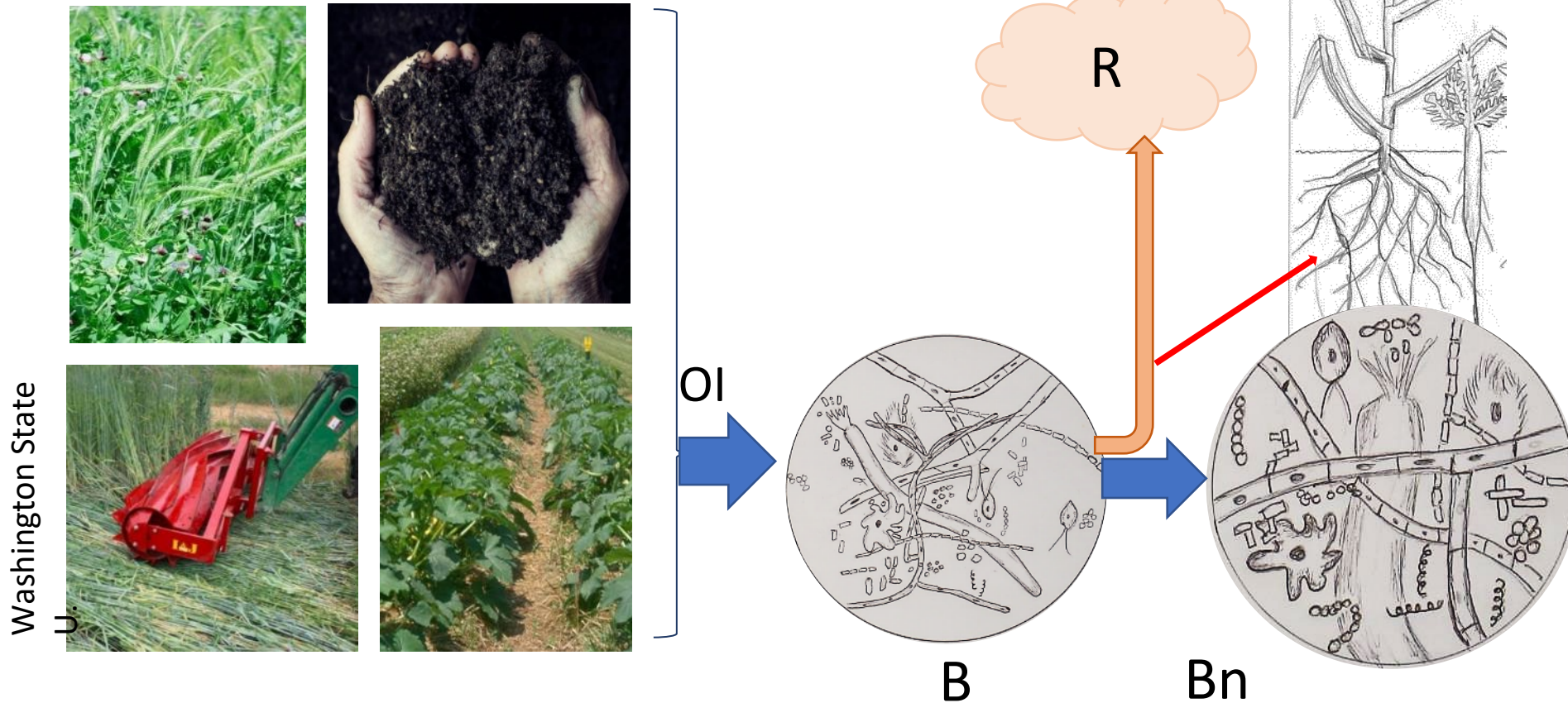
Soil test biological activity (STBA), a 3-day lab test measuring soil respiration, is positively related to:

- Total SOM
- Active SOM
- N mineralization
- Soil microbial biomass

Microbial growth efficiency (MBE) = B_n/OI

Metabolic quotient (qCO_2) = R/B

Building Microbial Biomass and Stable SOM



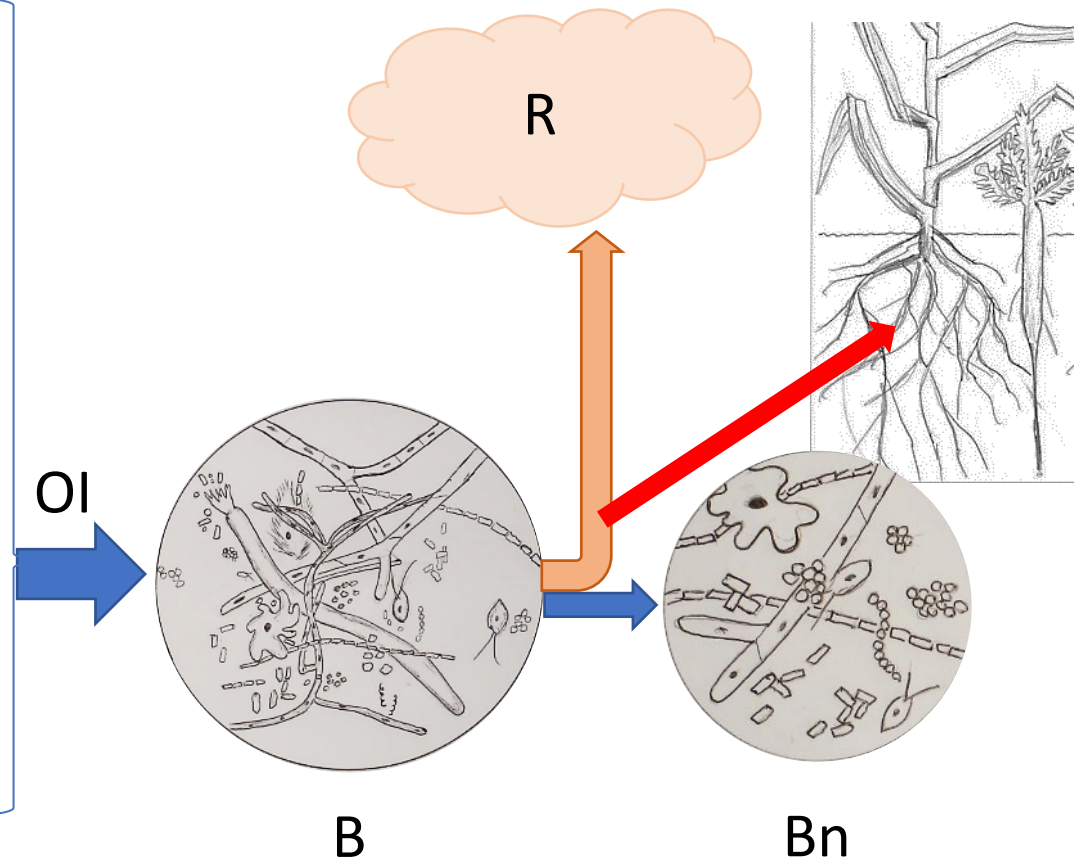
Practices:

- Moderate C:N inputs
- Grass + legume cover crop
- Minimum till

Outcomes:

- Builds SOM
- Crops may be N-limited

Promoting Mineralization



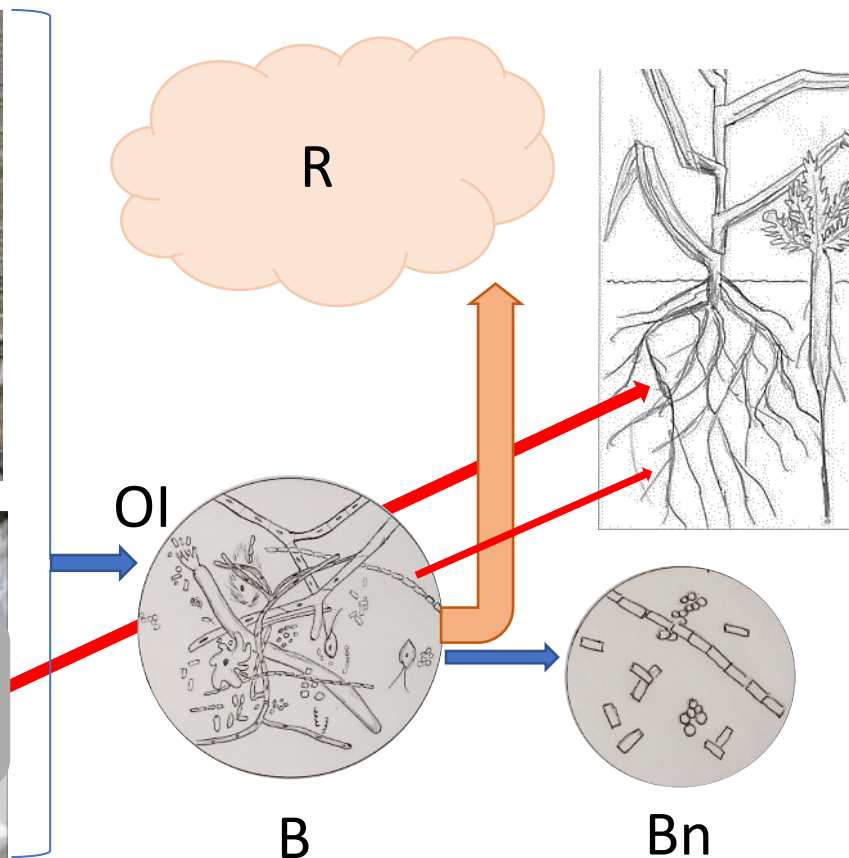
Practices:

- Concentrated, low C:N inputs
- All-legume green manure
- Full tillage

Outcomes:

- Sufficient N for crops
- May oxidize SOM
- May release N₂O

Stressed Soil Microbiome



Stresses:

- Intensive tillage
- Bare soil
- High input of soluble NPK
- Chemical no-till without living cover

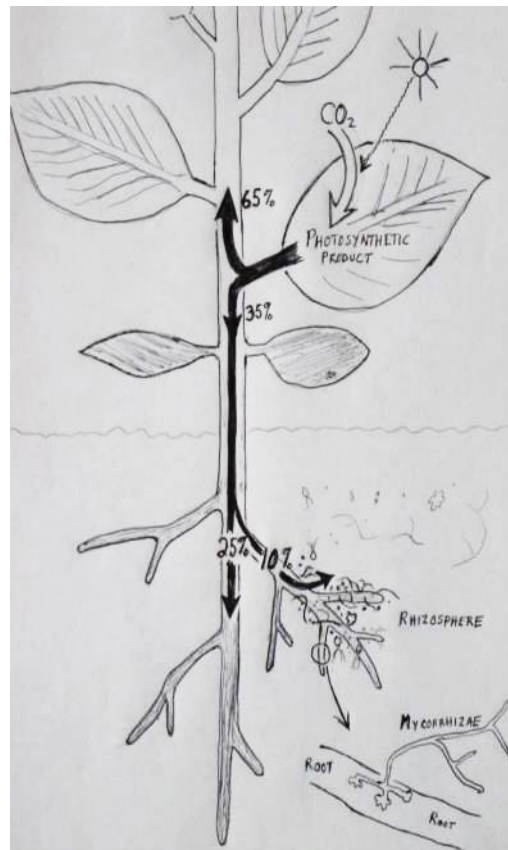
Outcomes:

- SOM losses
- Low microbial biomass
- High $q\text{CO}_2$
- Nutrient leaching

Enhancing Root Exudation for a Vibrant Soil Biota

Practices that provide nourishing root exudates for soil microbes:

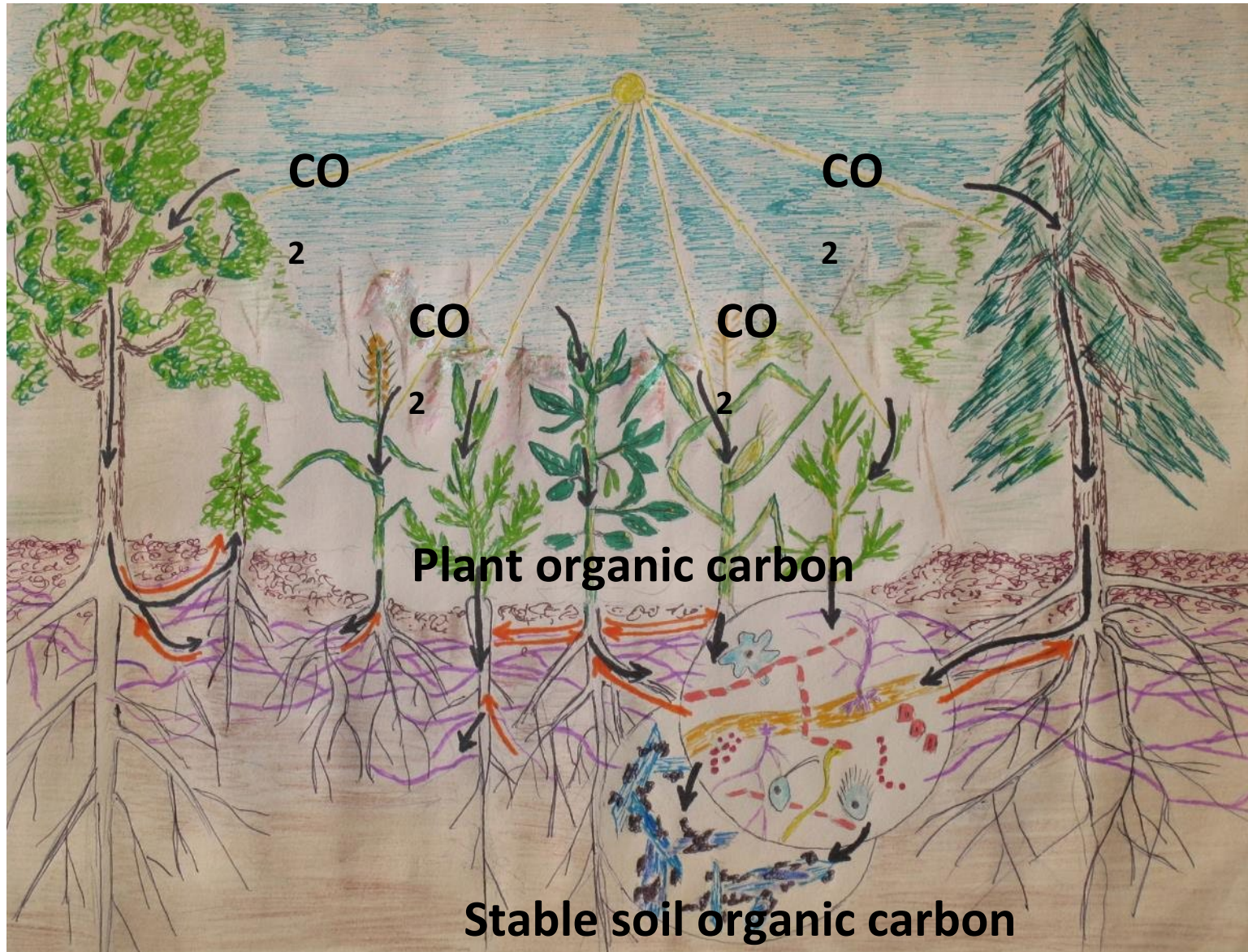
- N, P, and water provided at rates slightly below optimum for top growth
- Legumes in the crop rotation or pasture
- Rotational grazing late in the rapid growth phase



Practices that limit root exudation and leave soil microbes hungry:

- Ample N, P, and water to maximize top growth
- Overuse of synthetic or organic fertilizer
- Unmanaged grazing, *or* grazing too early or too late in forage life cycle

Mycorrhizal Networks Build Soil and Plant Health in Forestland

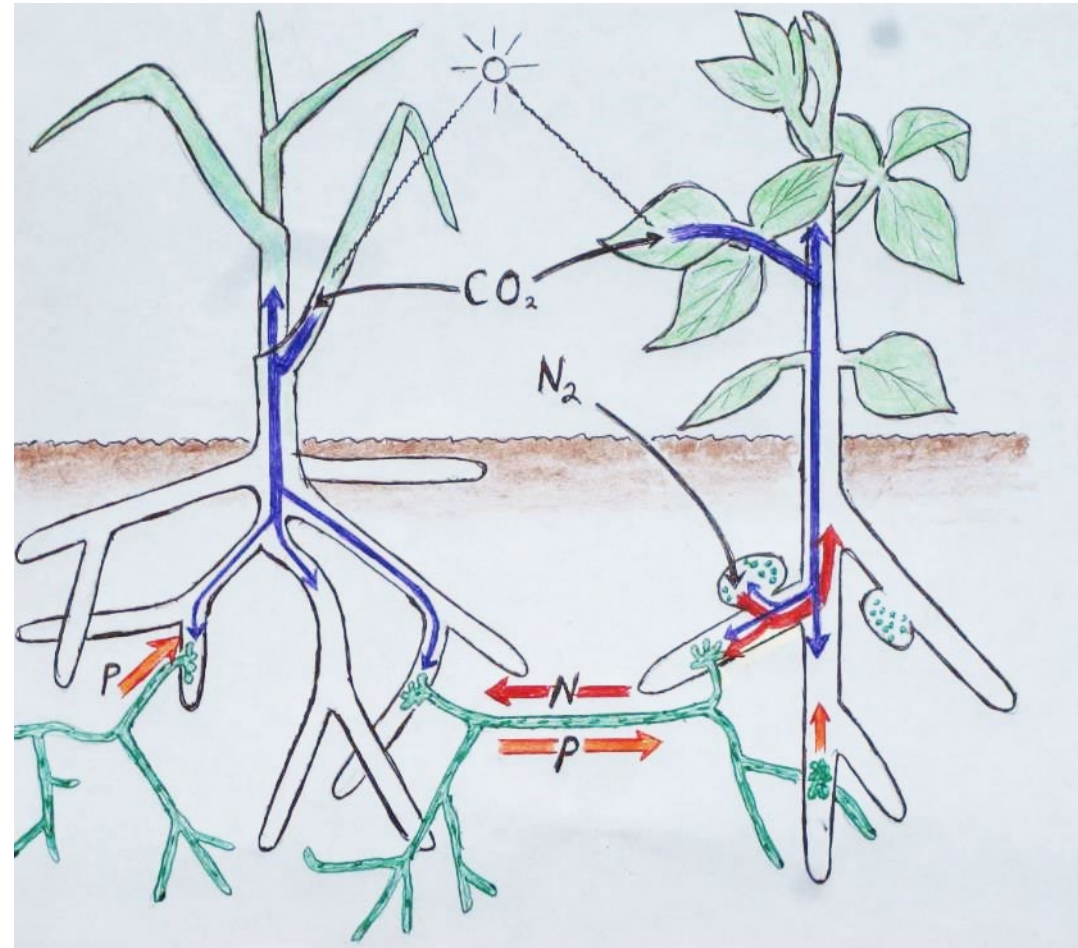


Research has shown that the mycorrhizal “internet” (**purple threads**):

- Link plants of the same or different species for sharing of resources.
- Receive plant sugars (**black arrows**) and deliver NPK and other plant nutrients (**orange arrows**).
- Enhance plant vigor and resilience to drought and pests.
- Play a major role in soil health and carbon sequestration.

Four-way Symbiosis in Grass-Legume Pasture

- 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

Meeting Organic Farmers' Phosphorus Challenge

The Problem:

- Using manure, poultry litter, and compost to meet crop N needs will build excess soil P and inhibit mycorrhizal activity.

The Solution:

- Reduce P inputs to match P removal in harvest.
- Provide N through legumes and credit N from SOM mineralization.
- Use diverse organic inputs with moderate overall C:N (15 – 20:1) to optimize soil biology.
- Reduce N applications: in biologically active soils, actual N need is far lower than standard “4Rs” recommendations and can be zero.

Balancing C and N in Organic Inputs

Puyallup, WA (maritime)
organic vegetable rotations
receiving:



Compost,
Mod. C:N

or



Fertilizer
,

Same total N
low C:N

After 11 years, soil receiving compost had:

- Better soil structure and water infiltration.
- 35% higher microbial activity.
- 43% higher total SOC.
- Changes in soil biota that can limit N₂O.

Other research findings:

- Compared to soluble NPK, organic nutrient sources double the biomass of soil bacteria, fungi, and microbe-feeding nematodes.
- Using organic sources at equivalent *total* N rates maintains yields and reduces N losses.
- Heavy use of low C:N organic inputs causes N₂O emissions similar to synthetic N.

Meeting Organic Farmers' Tillage Challenge

The Concern:

- A single tillage pass is thought to destroy soil life and SOM

The Research:

- Shallow non-inversion tillage doubles soil microbial biomass over either moldboard plowing or strict no-till.
- Tillage affects soil fungal, bacterial, and nematode communities to a much lesser degree than pesticides.

The solution:

- Organic weed IPM to reduce cultivation passes.
- Use shallow non-inversion tillage – only when needed.



The high-speed disk provides shallow (~3 in) non-inversion tillage to terminate cover crops and prepare fields for planting.
Photo credit: Justin Rich

Does organic agriculture entail more soil disturbance?

- Organic eliminates synthetic pesticides, allows judicious tillage.
- Conservation agriculture eliminates tillage, allows judicious pesticide use.
- Intensive tillage hurts soil life; infrequent, shallow tillage may not.
- Recent research has shown that pesticides, herbicides, and fungicides:
 - Alter soil microbiomes, reduce microbial diversity.
 - Reduce mycorrhizal symbioses and soil microbial N fixation.
 - Reduce nematode biomass.
 - Harm earthworms and other soil invertebrates.
 - Copper fungicide and vinegar herbicide can also harm soil life.

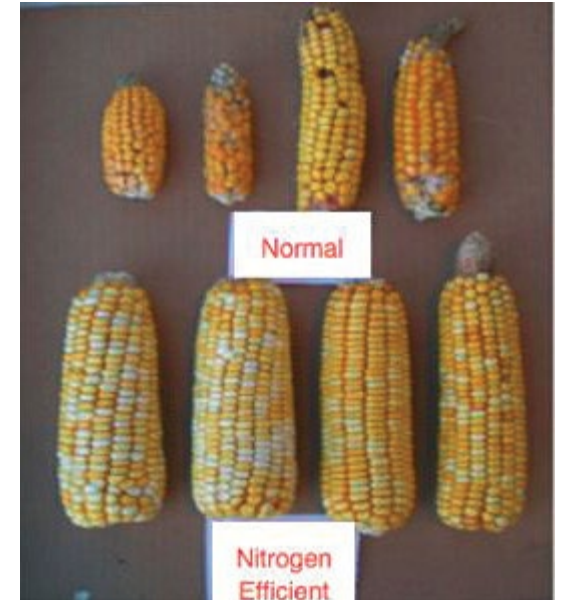
Meeting Organic Farmers' Seed Challenge: *have Modern Cultivars Forgotten How to "Talk" with Soil Life?*

- Growing crops in NPK-saturated fields can make mycorrhizal fungi, N fixers, and other valuable microbes go dormant or die out altogether.
- Breeding and selecting crops in such systems has created cultivars that don't send chemical signals to "invite" these helpers into their root zones.



Research Findings on Plant Genetics and Soil Microbes

- Using Mexican land races, Mandaamin Institute is developing N-efficient field corn that hosts N-fixing and N-cycling bacteria, a capacity lost in most modern hybrids (right).
- Substantial cultivar differences in AMF colonization have been found in carrot, pepper, tomato, sorghum, and other crops.
- Tomato breeders are developing new cultivars with enhanced disease resistance response to root-associated *Trichoderma*.
- Carrot breeding lines differ in their capacity to host root endophytes that improve nutrient uptake and disease resistance.



Ears from standard and N-efficient corn grown on tropical soil low in N.

Mandaamin Institute, Elkhorn, WI

Another Organic Challenge: Smart Shopping for Microbes

Do they Work?

Do they Pay?

Will your indigenous soil microbes outcompete them?

Will they upset soil microbiomes?

- *Rhizobium* legume seed inoculants
- Mycorrhizal fungi –seed / root
- Compost, on-farm.
- Compost tea, worm casting tea

- Effective micro-organisms, bokashi, on-farm sourced.

- Proprietary mycorrhizal and other microbe blends for soil application

- Natural enemies of plant pathogens and pests – bio-fungicides and biopesticides

- Microbial foods – seaweed extract, fulvic acids (fungi), amino acids, molasses (bacterial).

Do We Need to Introduce Microbes to Restore Soil?

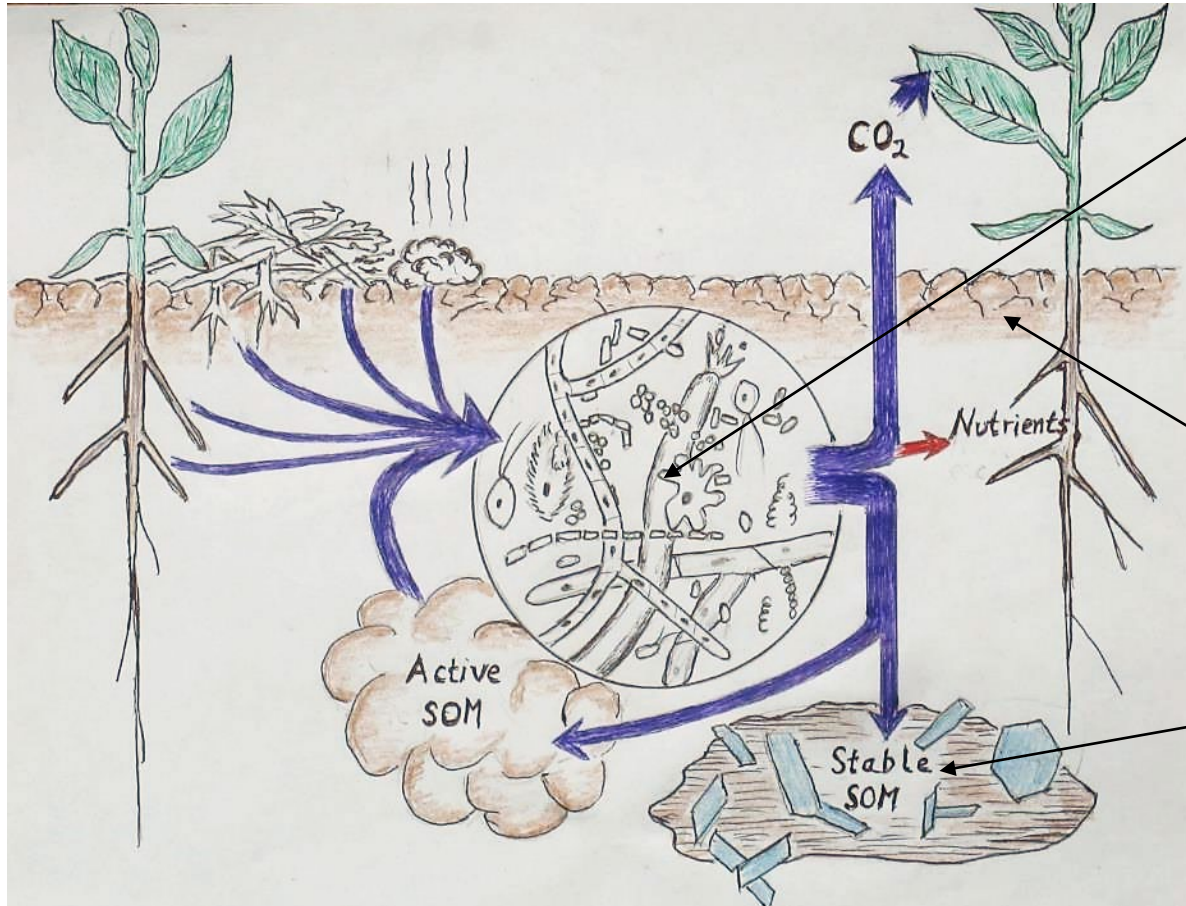
“There will still be some small bit of life in [the soil] even in the most chemically dependent or heavily tilled operations. If you give that life a chance to grow, it will respond. If you build it, or if you stop destroying it, they will come.”

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

- Started with 5,000 ac of depleted rangeland.
- Crops + livestock with rotational grazing.
- Implemented 4 NRCS principles – cover soil, living roots, diversify, minimize disturbance
- SOM 2% → 7% in 20 years, drought resilient system.
- No purchased inoculants used.



How will Climate Change Affect Soil Life and SOM?



Microbial communities are likely to change as mean temperatures climb. **Research and adaptation, including developing new crops and cultivars for the new normal, will be vital.**

SOM physically sequestered in **near-surface aggregates is highly sensitive to rising temperatures and to tillage.**

Stable **MAOM** is less sensitive to rising temperatures and tillage, especially subsoil MAOM.

Organic Farming for Soil Biology

Guidelines for optimizing practices and outcomes

Four NRCS Principles of Soil Health



Keep the soil covered



Diversify the farming system



Maintain living roots



Minimize soil disturbance

Tips for Enhancing Soil Biology in Organic Systems

- Maintain continuous living plant cover and living roots.
- Diversify the cropping system to support microbial diversity.
- Reduce disturbance
 - Till with care and only when necessary
 - Use NOP-allowed pest control substances only when all else fails.
- Use a diversity of organic inputs with moderate overall C:N.
- Use concentrated nutrient sources sparingly.
- Find out how much N your crop really needs – do side-by side trials and/or assessments of soil N mineralization potential.



Questions?