UCCE
El Dorado County Master Gardeners Present

Turning Dirt in to Gold

Understanding the Soil Food Web

and Making it Work for You

Turning Dirt in to Gold

Agenda:

- Overview and Resources
- Mechanical Aspects of Soil
- The Soil Food Web
- Soil Improvement
- Q & A Class Wrap-Up

It Starts with the Soil

The Role of Soil

- Topsoil formation occurs when living material descends into Mother Earth followed by the movement of waste material from living things into plants. And the cycle continues…

Soil functions

Soils deliver ecosystem services that enable life on Earth

2015 International Year of Soils

fao.org/soils-2015

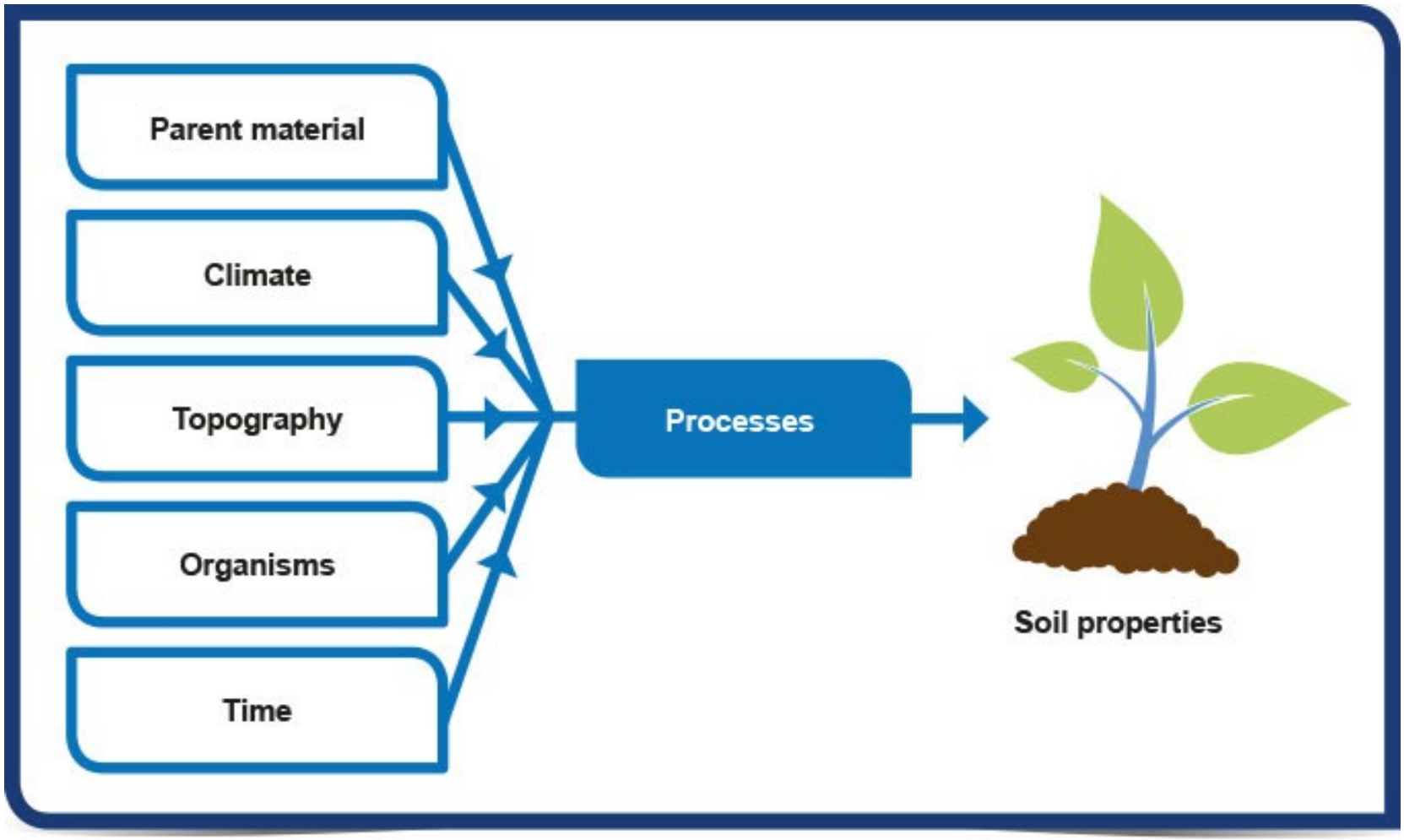
Food and Agriculture Organization of the United Nations

with the support of

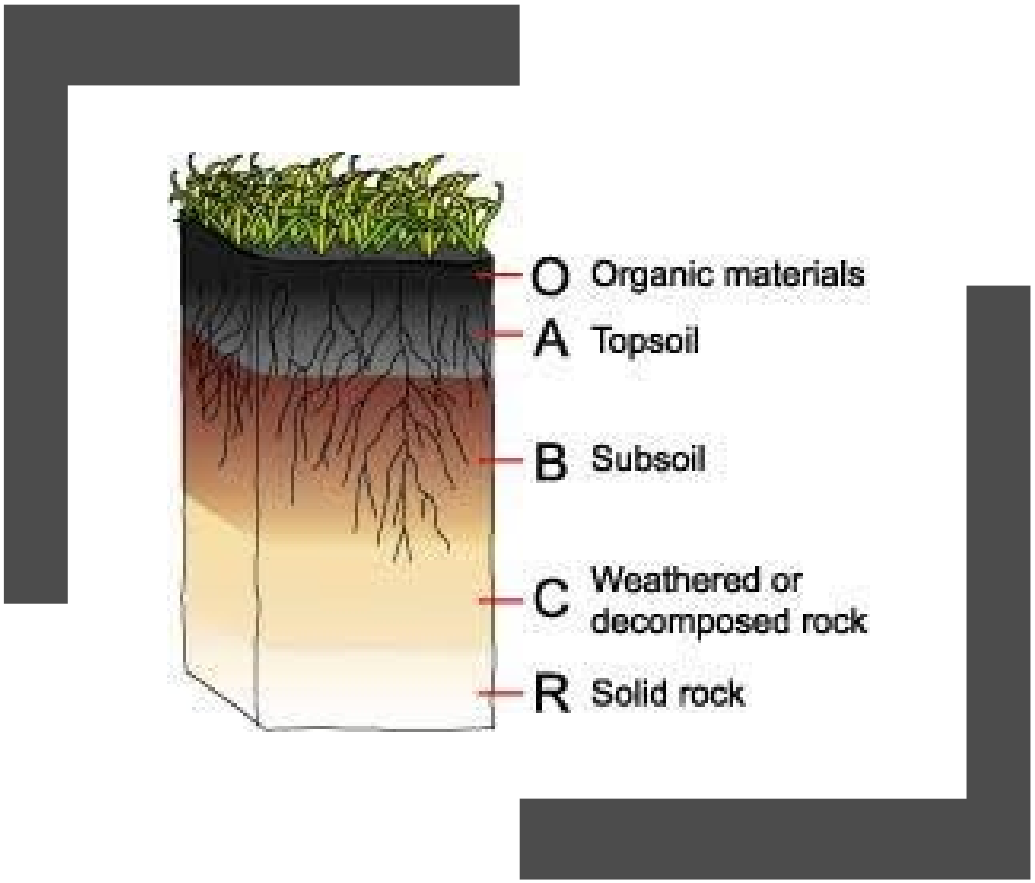
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
Federal Office for Agriculture FOAG

Soil Formation



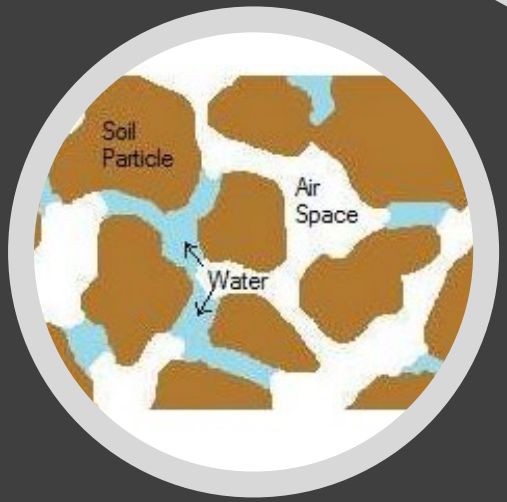
Soil Profiles and Horizons

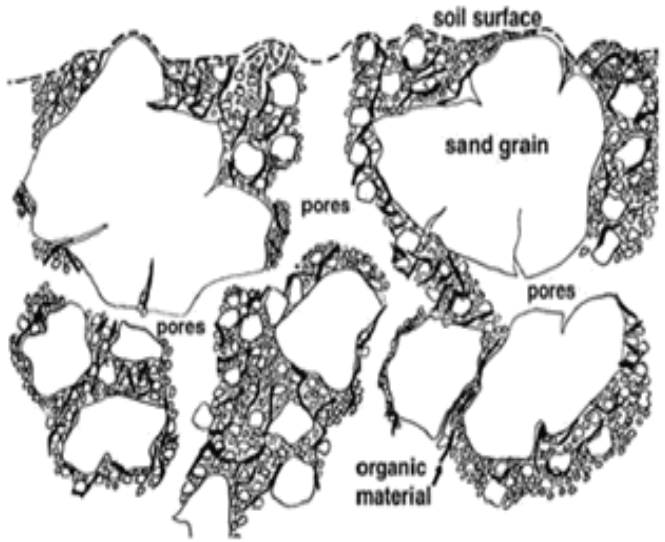


- **Top 3 layers are most important for the gardener**
  - **O – Organic layer**
  - **A – lies under the organic matter**
    - organic material and minerals
    - Level with greatest biological activity
    - Area of root growth
  - **B – Parent material**

What is Soil?

- Average garden soil is a complex mixture of
  - 45% minerals (weathered rock)
  - <50% air and water (approximately half and half)
  - 5% organic matter





Air and Water

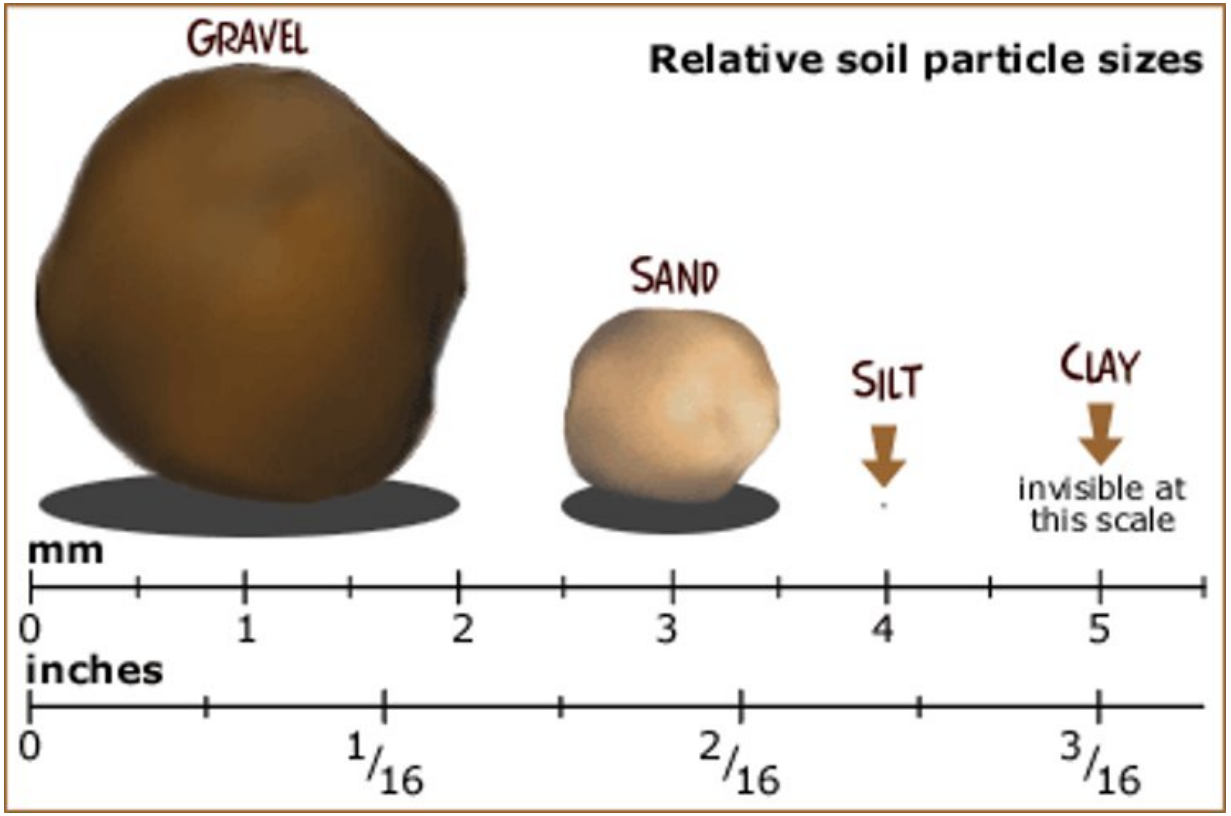
- Fills the voids between the mineral and organic particles
- Water moves through the soil 2 ways
  - Gravitational water moves freely and down
  - Capillary water moves by the molecular attraction of water molecules for each other and can move up and down
- Water movement pushes stale air out and sucks in air from the surface and displaces carbon dioxide

Air and Water (cont.)

- Water movement pushes stale air out and sucks in air from the surface and displaces carbon dioxide
- Soil compaction reduces pore space so that water and air can't move through it and is prone to anaerobic activity
  - In the absence of air, organisms produce alcohols that kill plant roots
- Hydroscopic water
  - A few molecules thick on the surface of particles and hard to break the bond
  - Cannot be used by roots
  - Critical to the ability of microbes to travel and live

Relative Soil Particle Sizes

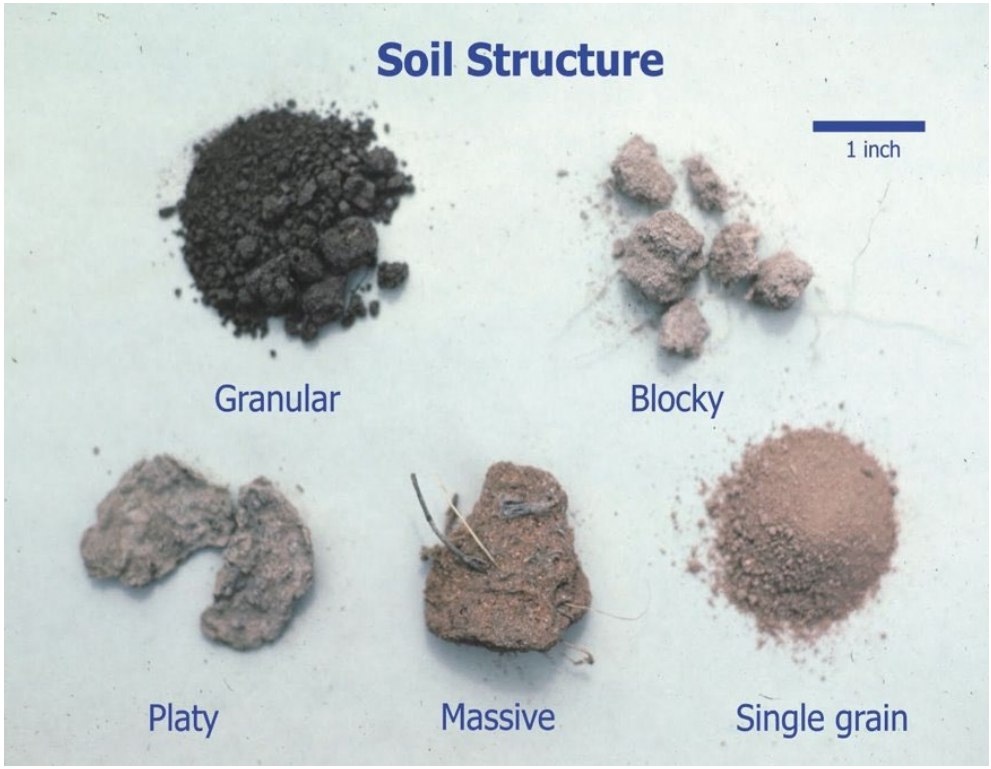
- **Texture**
  - **Sand – 0.0625 to 2 mm**
  - **Silt - 0.004 – 0.0625 mm**
  - **Clay - < 0.004 mm**



Sand magnified
300 times

Soil Structure

- The arrangement of the solid parts of the soil and of the pore space located between them
  - Affects drainage and water movement
  - Affects air circulation
  - Space for soil organisms to live



Soil Structure

- **Good soil structure**
  - Granular, crumbly like cookie crumbs
  - Resists erosion
  - Resists drying
  - Nutrient retention is high
- **Poor Soil Structure**
  - Won’t hold water
  - Little air for roots or organisms
  - Nutrients are locked up because inaccessible to organisms
  - Often leads to over-watering and fertilizing

Soil Structure

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Soil Structure (cont.)

- **Poor Soil Structure**
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Mechanical Analysis of Soils "The Jar Test"

- **Materials**:
  - Various soil samples (remove pebbles, rocks and OM)
  - Mesh sieve or old colander
  - 1 one-quart canning jar (with lid and ring) for each sample
  - Calgon water softener, Dawn detergent or powder dishwasher soap
  - Ruler (metric)
  - ½ cup measuring cup
  - Tablespoon
  - Masking tape and pen (or similar materials for labeling jars)

Mechanical Analysis of Soils

"The Jar Test"

Procedure:

1. Place approximately ½ cup of loose (clod- and rock-free) soil in a quart jar. Add 1 heaping tablespoon of Calgon and 3 ½ cups of water. Cap and shake for five minutes (alternately inverting the jar will suffice). Allow the jar to sit, undisturbed, for at least 24 hours.
2. At the end of 24 hours, measure the depth of settled soil. This represents the total depth of soil. Shake thoroughly for five minutes (again, alternately inverting the jar). Let the jar sit, undisturbed, for 40 seconds. Now measure the depth of the settled soil with a ruler. This is the sand layer.
3. At the end of 30 minutes, measure the depth of the settled soil again. From this depth, subtract the thickness of the sand layer to obtain the depth of the silt layer above it.
4. The remaining unsettled particles in suspension represent the clay fraction and can be obtained by subtracting the depths of the sand and silt layers from the total depth determined in step 2.

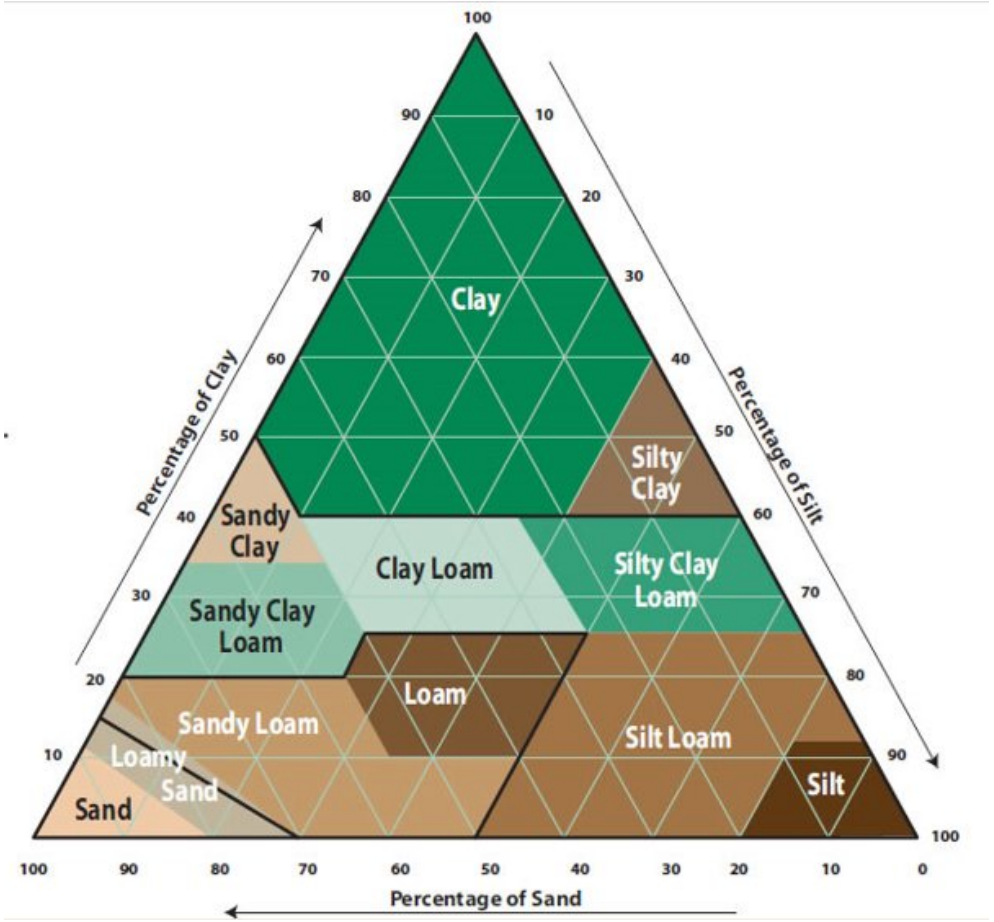
Mechanical Analysis of Soils "The Jar Test"

- Refer to the soil triangle and determine the textural class of your soil.

  % sand = 9mm/23mm x 100% = 39%

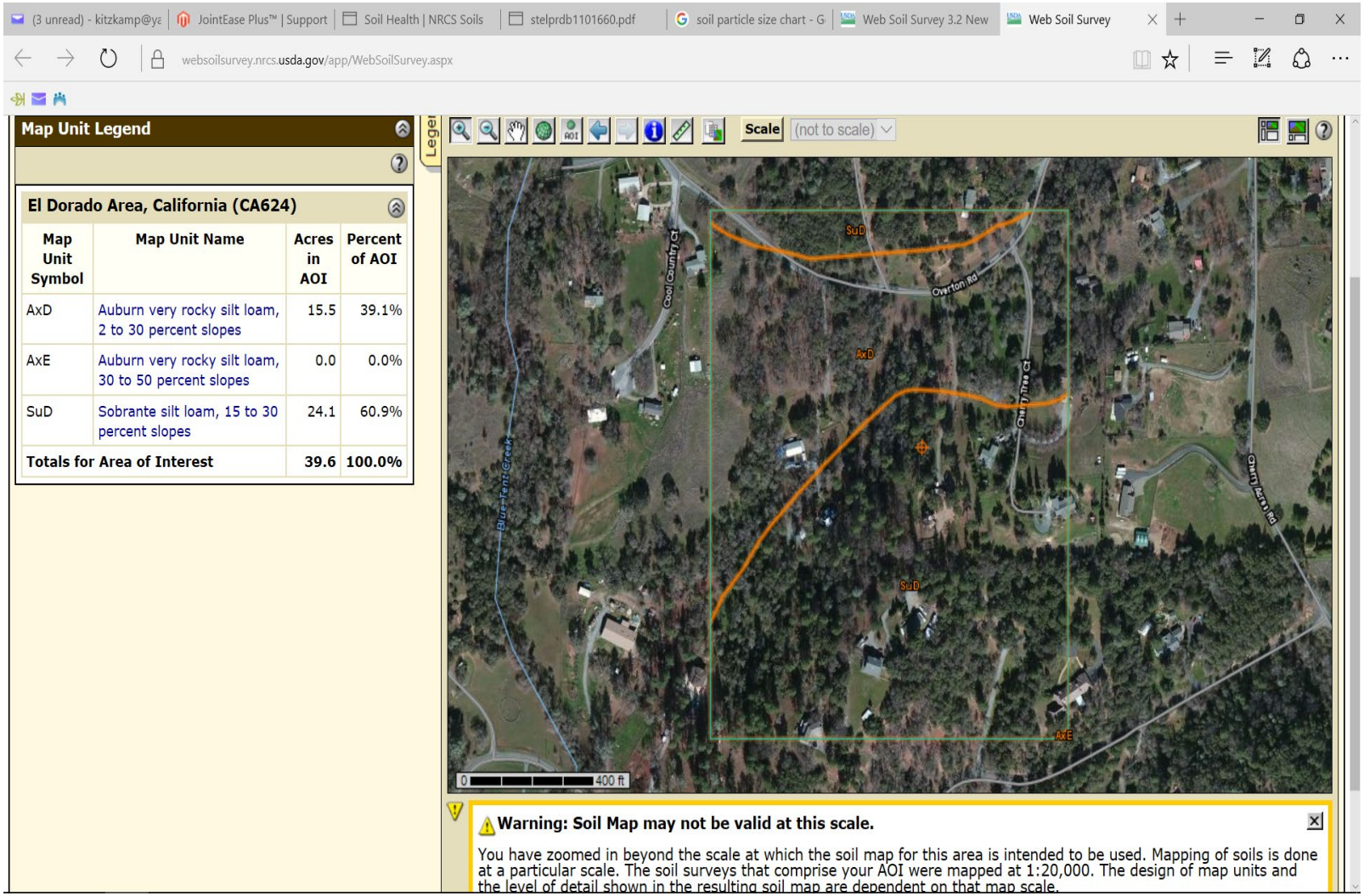
  % silt = 10mm/23mm x 100% = 43.5%

  % clay = 100% - 39% - 43.5% = 17.5%



NRCS Web Soil Survey

https://websoilsurvey.nrcs.usda.gov/app/HomePage.htm



Tilth

- **Composite of**
  - **Texture**
  - **Structure**
    - Aggregation
  - **Density (level of compaction)**
  - **Drainage**
  - **Water-holding capacity**

Drainage Test

- Dig a hole 12” deep by 6” wide
- Fill with water and allow to drain completely
- Fill again and see how long it takes to drain
- If more than 8 hours, address drainage problems

Soil Color

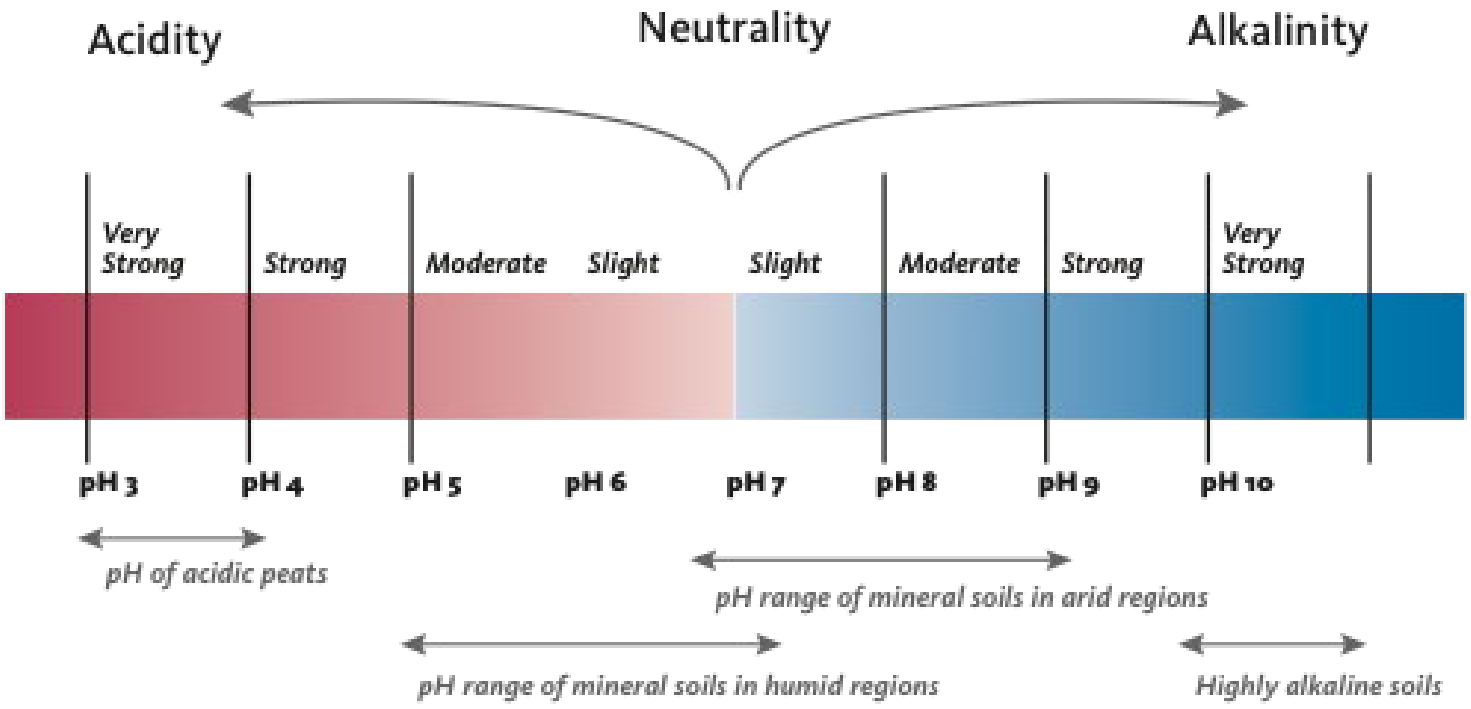
Soil Color

- Dependent on a soil's specific mineral and organic components
- Organics result in darker color; darker soil warms up more quickly in spring
- 70% chocolate or dark coffee is the goal
- Gray indicates a lack of organic matter and/or aerobic conditions
- Orange to red indicates the presence of oxidized iron

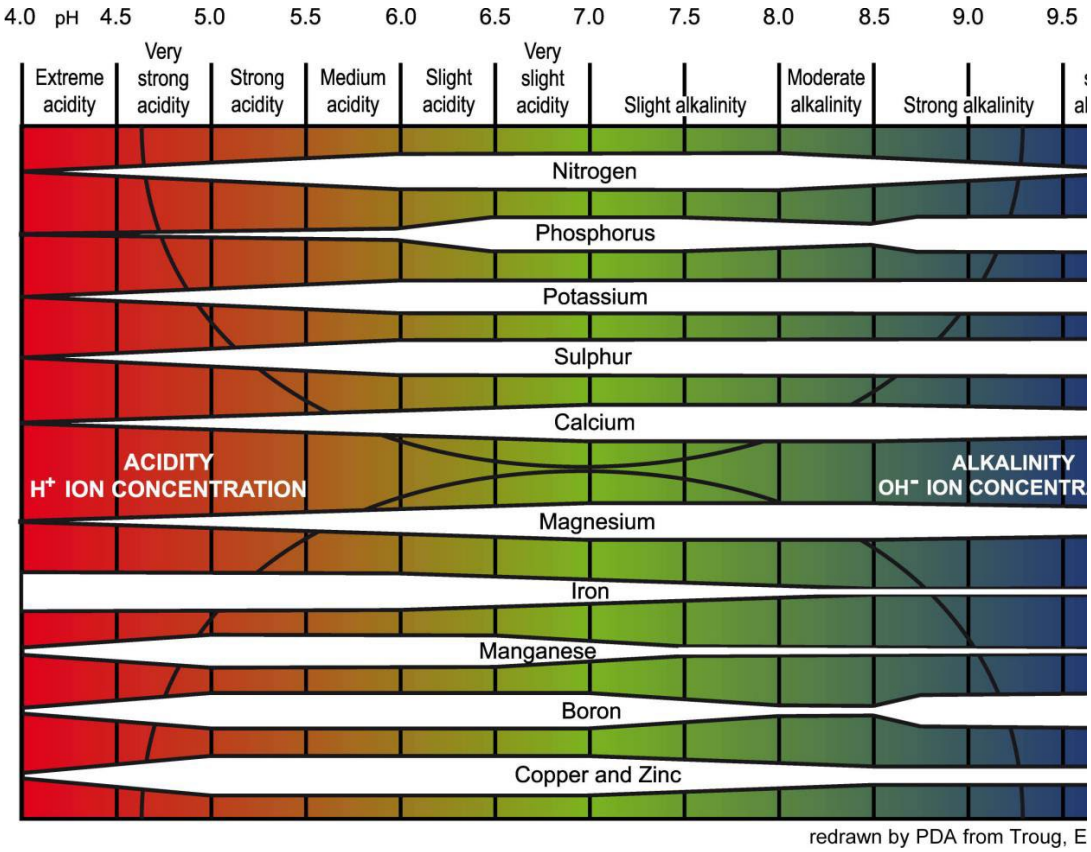
Soil Nutrient Testing

- **Traditional soil tests (NPK Test) only determine elemental deficiencies, pH, and CEC** (must be done by a lab)
  - Do not measure plant-available nutrients
  - Chemical reagents used in the lab don't interact with the soil like plants do
  - Soil chemistry changes throughout the year
  - Procedures vary greatly from lab to lab

Soil pH


Acidity
Neutrality
Alkalinity
Very Strong
Strong
Moderate
Slight
Slight
Moderate
Strong
Very Strong
pH 3
pH 4
pH 5
pH 6
pH 7
pH 8
pH 9
pH 10
pH of acidic peats
pH range of mineral soils in arid regions
pH range of mineral soils in humid regions
Highly alkaline soils

Soil pH



redrawn by PDA from Troug, E

Typical Gardening Approach

- Rototill
- Fertilize
- Water like crazy
- Rake away, burn or toss the leaves
- Spray weeds with herbicides
- Killing pests with insecticides

- Most gardeners rely on
  - a blend of old wives' tales
  - anecdotal "science"
  - slick sales pitches designed to sell products

Typical Gardening Approach

The ‘Old’ Approach

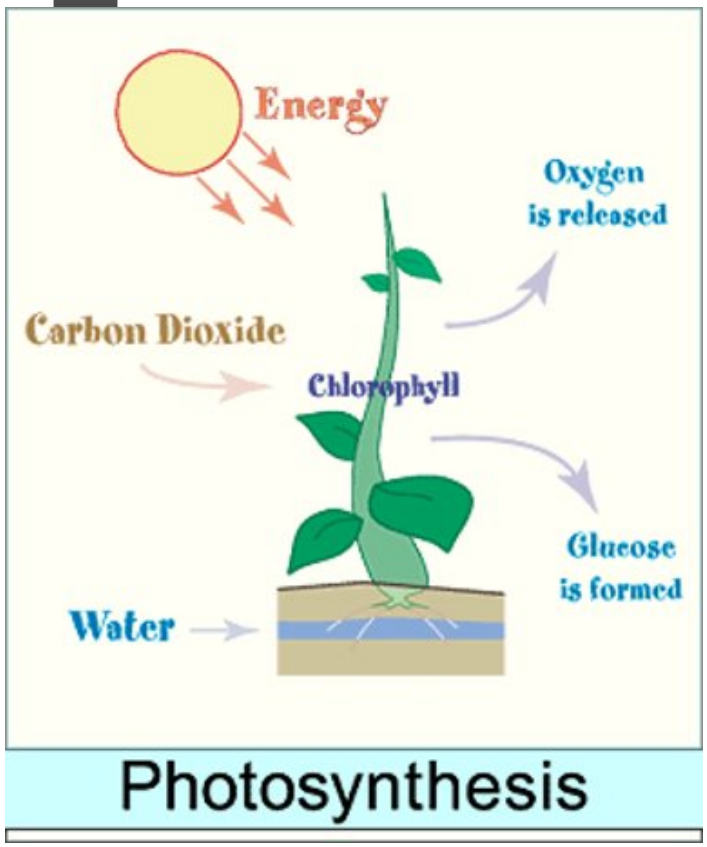
- **The science limited to traditional soil science**
  - **physical structure**
  - **NPK-chemistry of the soil**

The ‘New’ Approach

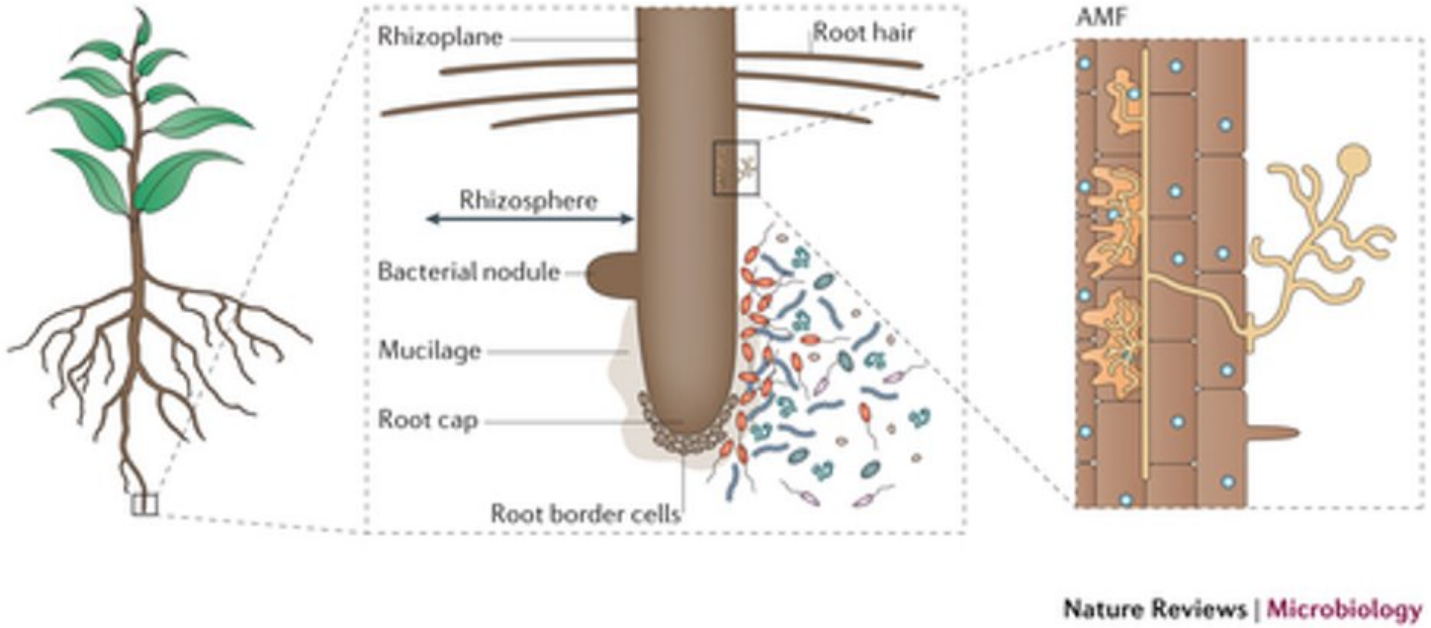
- Understand what is going on in the soil
- Manage the soil in an ecological way
- Let the soil organisms do the work for you
- Become a better gardener and steward

The Soil Food Web

- **Cultivating soil and encouraging plants to grow is nearly as old a practice as man himself**
  - ❖ **Modern life disconnects us from nature**
- **Gardening with the Soil Food Web reconnects us with natural processes**
  - **You can reap the benefits with less work**

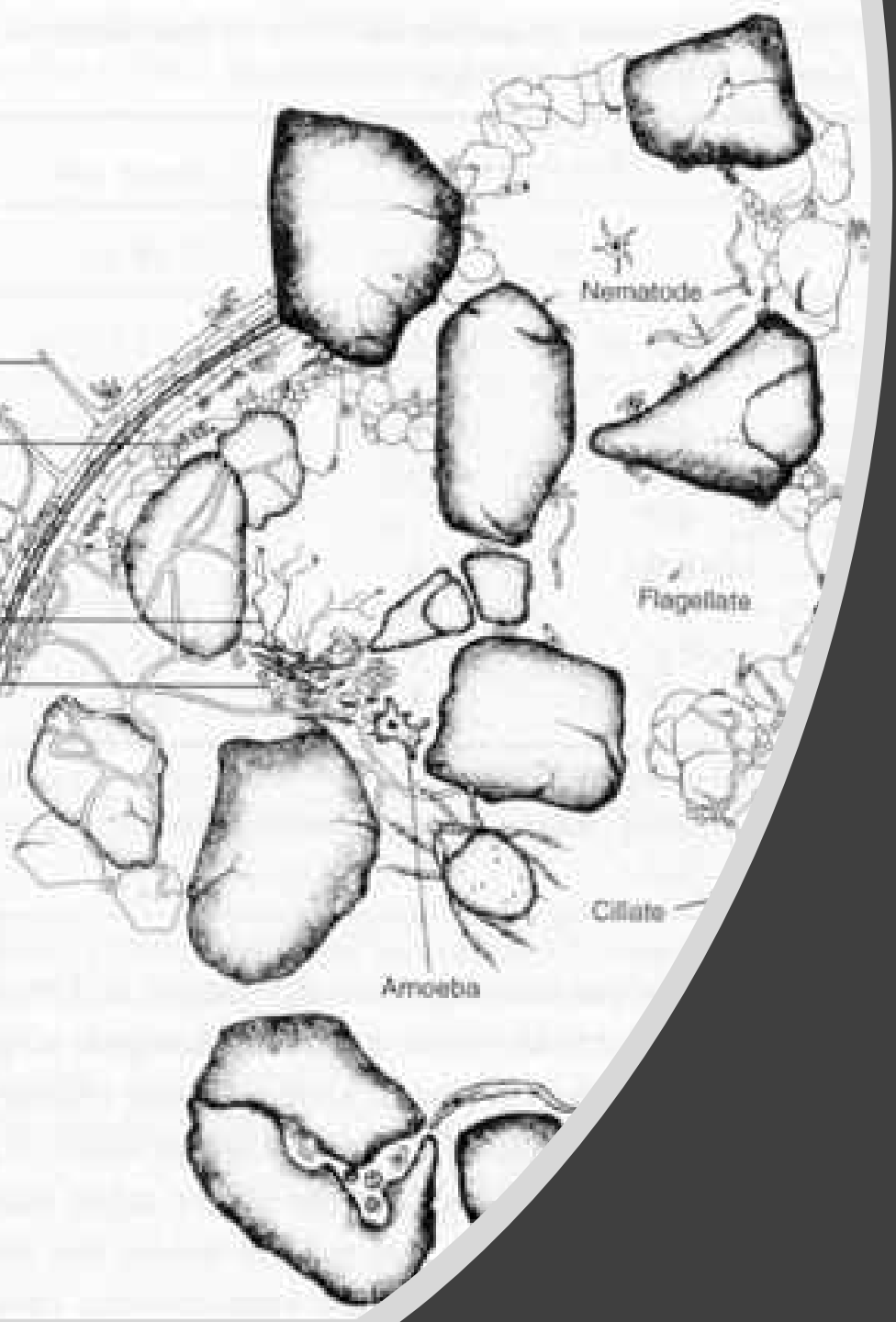


- **Plants are in control**
  - Photosynthesis: process used by plants to convert light energy into chemical energy, stored in the form carbohydrates (liquid carbon)



Exudates

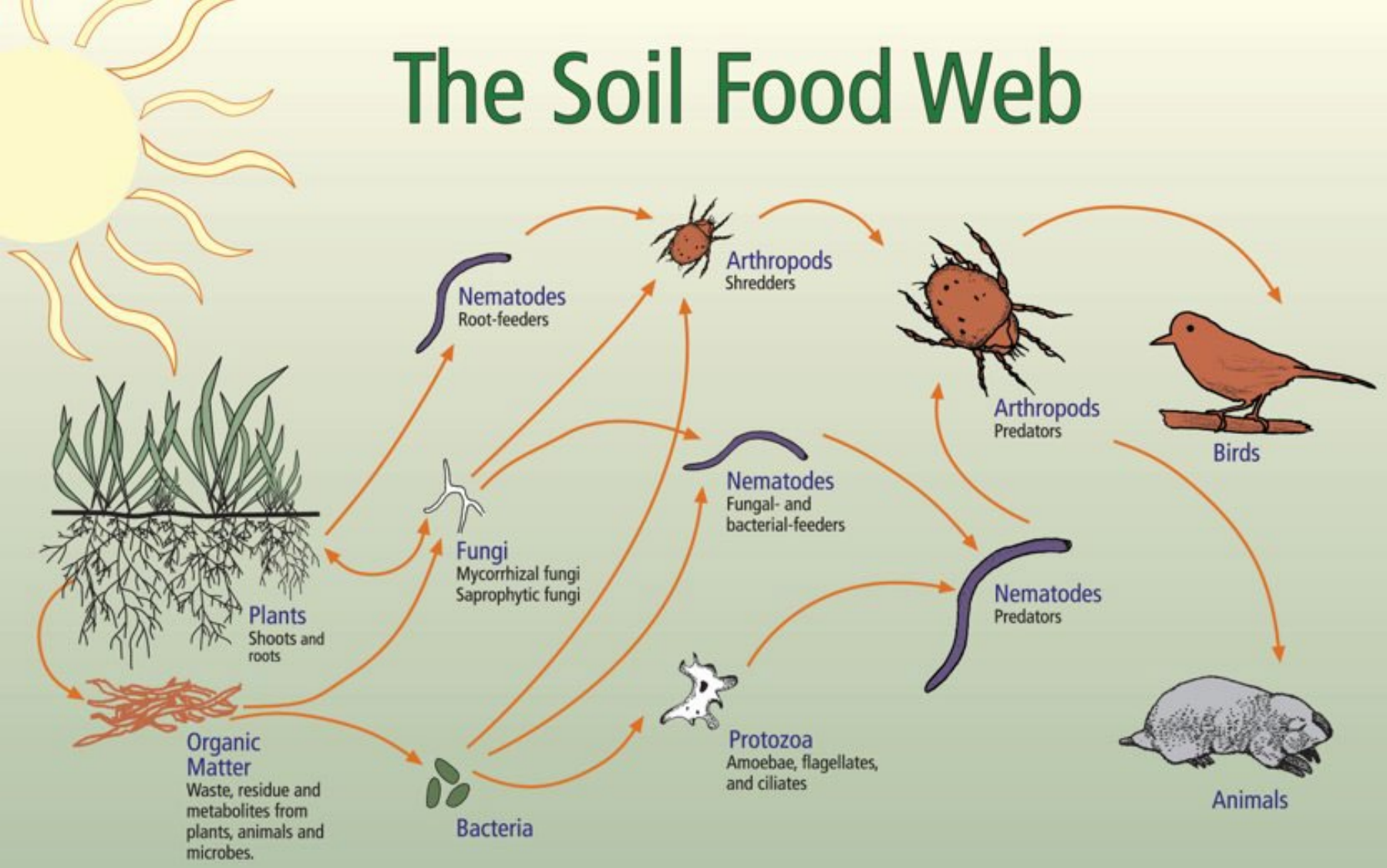
- Exudates: carbohydrate secretions (like humans perspire) in the rhizosphere are traded for nutrients the plant needs for growth
- In healthy soil, plants get 85-90% of nutrients they need through this carbon exchange



Soil Food Web

Microorganisms comprise the major part of the Soil Food Web

The Soil Food Web



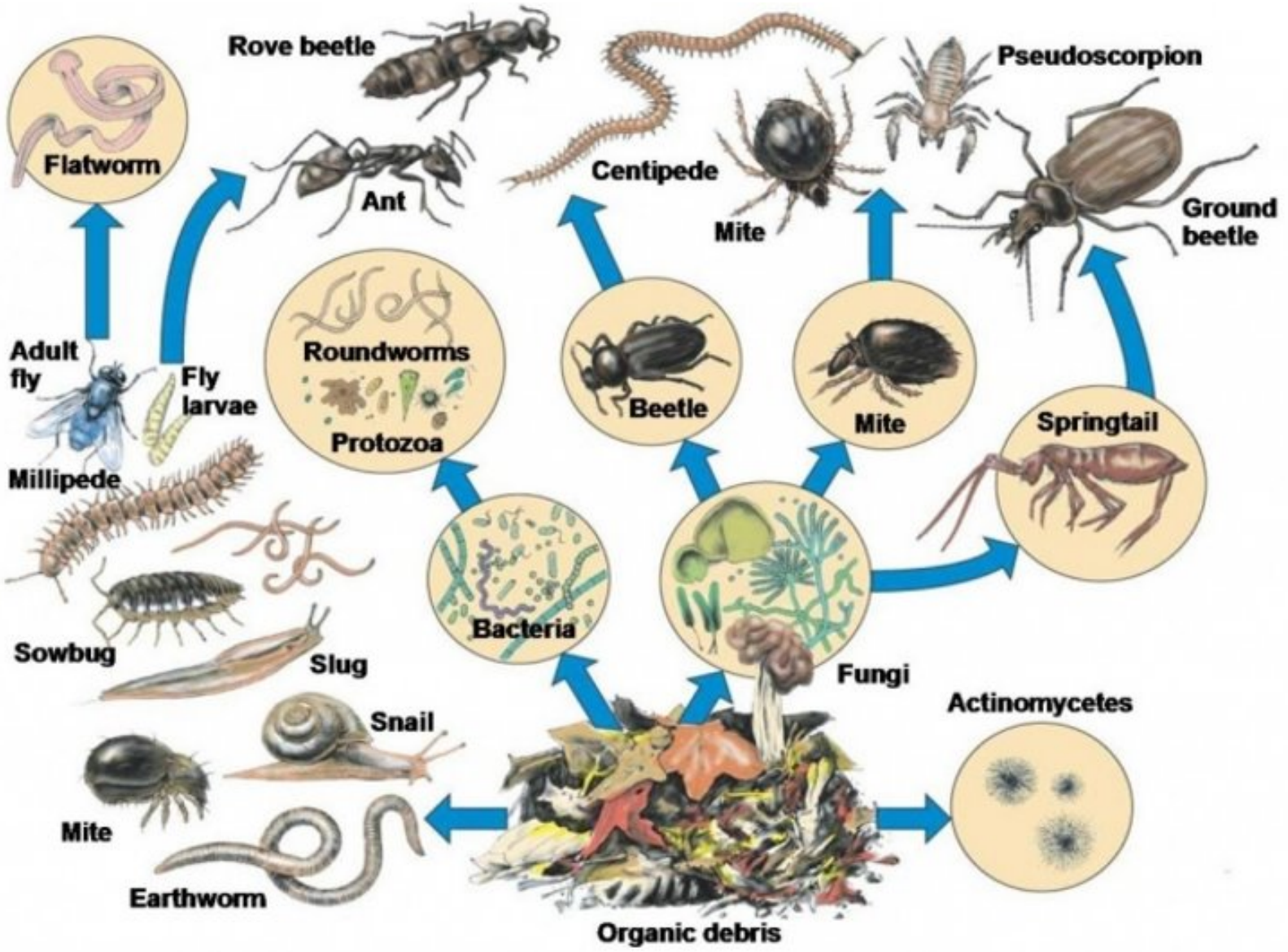
First trophic level:
Photosynthesizers

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

Third trophic level:
Shredders
Predators
Grazers

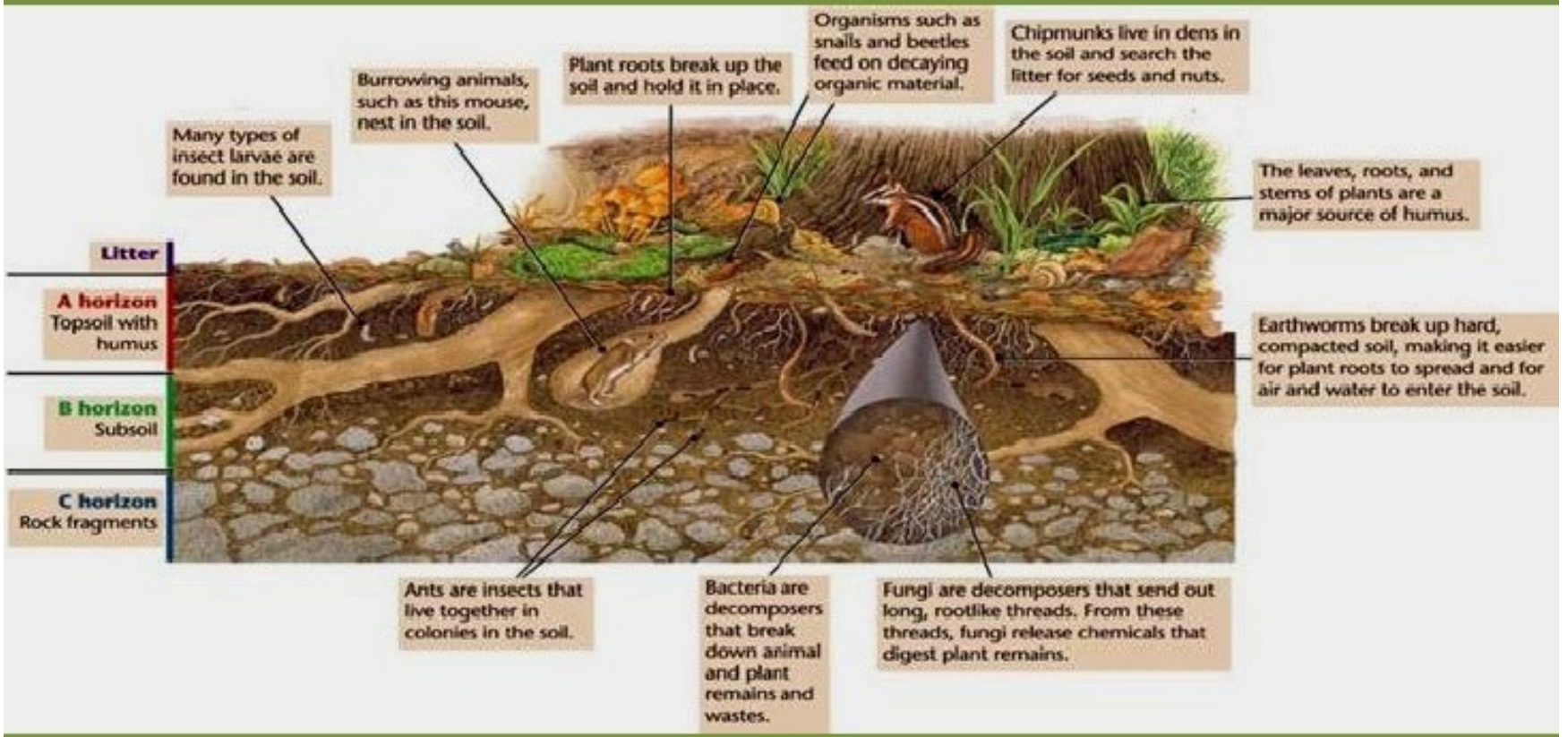
Fourth trophic level:
Higher level predators

Fifth and higher trophic levels:
Higher level predators


Rove beetle
Flatworm
Ant
Centipede
Mite
Pseudoscorpion
Ground beetle
Adult fly
Fly larvae
Roundworms
Protozoa
Beetle
Mite
Springtail
Millipede
Bacteria
Fungi
Sowbug
Slug
Snail
Actinomycetes
Mite
Earthworm
Organic debris

Activities of organisms affect soil.

- There is a whole world alive below your feet!



Soil Food Web

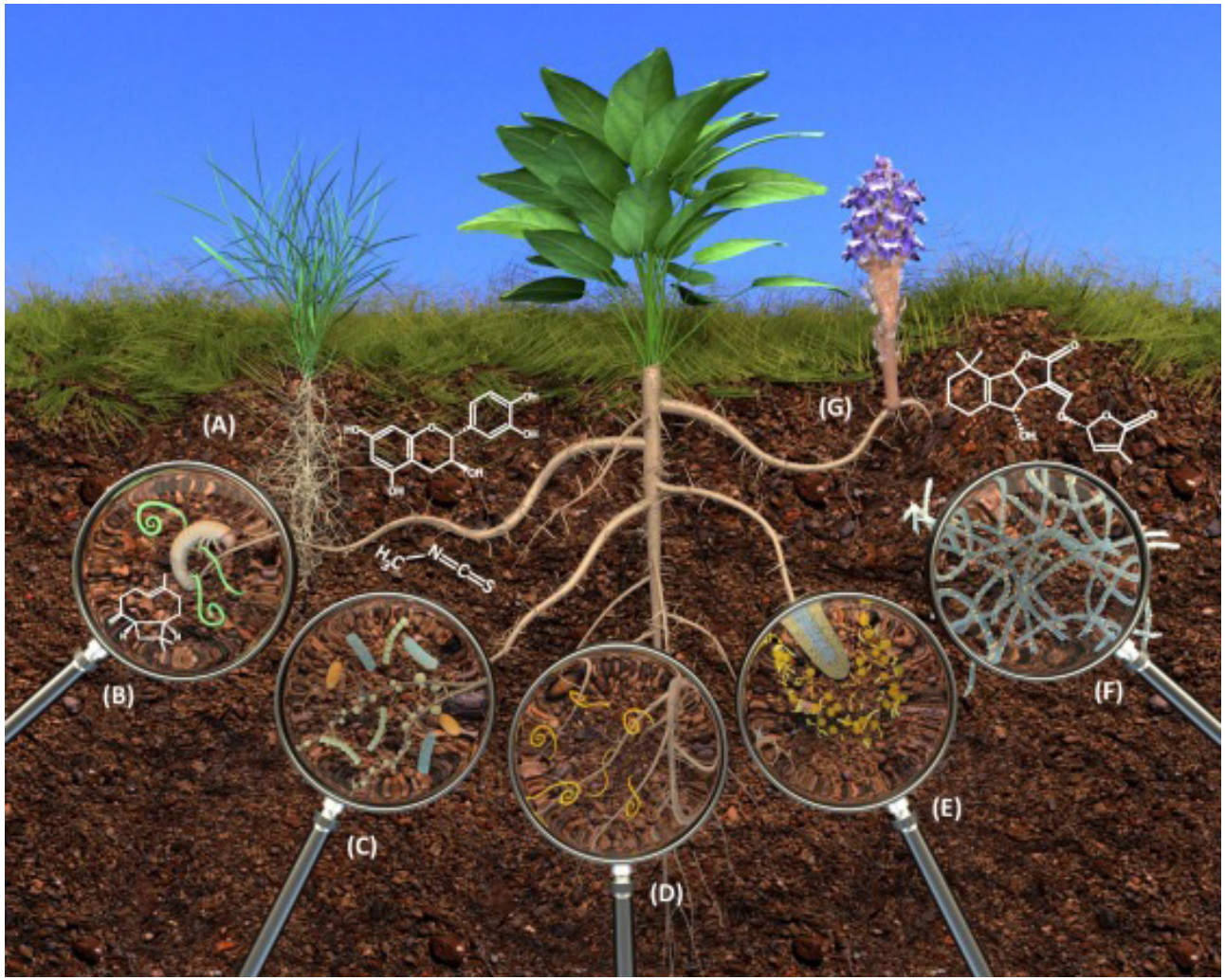
- **Per teaspoon of healthy soil:**
  - 1M to 1B bacteria
  - Miles of fungal hyphae
  - 10,000 to 100,000 protozoa
  - 15 to 500 beneficial nematodes
  - Thousands of microarthropods
  - More organisms than people who have ever lived

The Soil Food Web

- **Benefits of a Healthy Soil Food Web**
  - **Eliminate or reduce the need for:**
    - Fertilizers
    - Pesticides
    - Herbicides
    - Fungicides
  - **Improved water- and air-holding capacity**
  - **Healthier, more productive plants**

The Soil Food Web (cont.)

- **Bacteria, Fungi, Protozoa, nematodes**



Plant roots by Christophe Jacquet

A Soil Food Web Glossary

Arthropods Invertebrate animals with jointed legs. They include insects, crustaceans, sowbugs, arachnids (spiders), and others.

Bacteria Microscopic, single-celled organisms that are mostly non-photosynthetic. They include the photosynthetic cyanobacteria (formerly called blue-green algae) and actinomycetes (filamentous bacteria that give healthy soil its characteristic smell).

Fungi Multi-celled, non-photosynthetic organisms that are neither plants nor animals. Fungal cells form long chains called hyphae and may form fruiting bodies such as mold or mushrooms to disperse spores. Some fungi, such as yeast, are single-celled.

Saprophytic fungi: Fungi that decompose dead organic matter.

Mycorrhizal fungi: Fungi that form associations with plant roots. These fungi get energy from the plant and help supply nutrients to the plant.

Grazers Organisms, such as protozoa, nematodes, and microarthropods, that feed on bacteria and fungi.

Microbes An imprecise term referring to any microscopic organism. Generally, "microbes" includes bacteria, fungi, and sometimes protozoa.

Mutualists Two organisms living in an association that is beneficial to both, such as the association of roots with mycorrhizal fungi or with nitrogen-fixing bacteria.

Nematodes Tiny, usually microscopic, unsegmented worms. Most live free in the soil. Some are parasites of animals or plants.

Protozoa Tiny, single-celled animals, including amoebas, ciliates, and flagellates.

Trophic levels Levels of the food chain. The first trophic level includes photosynthesizers that get energy from the sun. Organisms that eat photosynthesizers make up the second trophic level. Third trophic level organisms eat those in the second level, and so on. It is a simplified way of thinking about the food web. In reality, some organisms eat members of several trophic levels.

Soil Organisms

Decompose organic compounds

- manure, plant residues

Sequester nitrogen and other nutrients

Fix nitrogen from the atmosphere, making it available to plants

Enhance soil aggregation and porosity

- increase infiltration and reduce runoff

Prey on pests

Food for each other and above-ground animals

Benefits of the Soil Food Web

Soil fertility is the capacity to nurture healthy plants

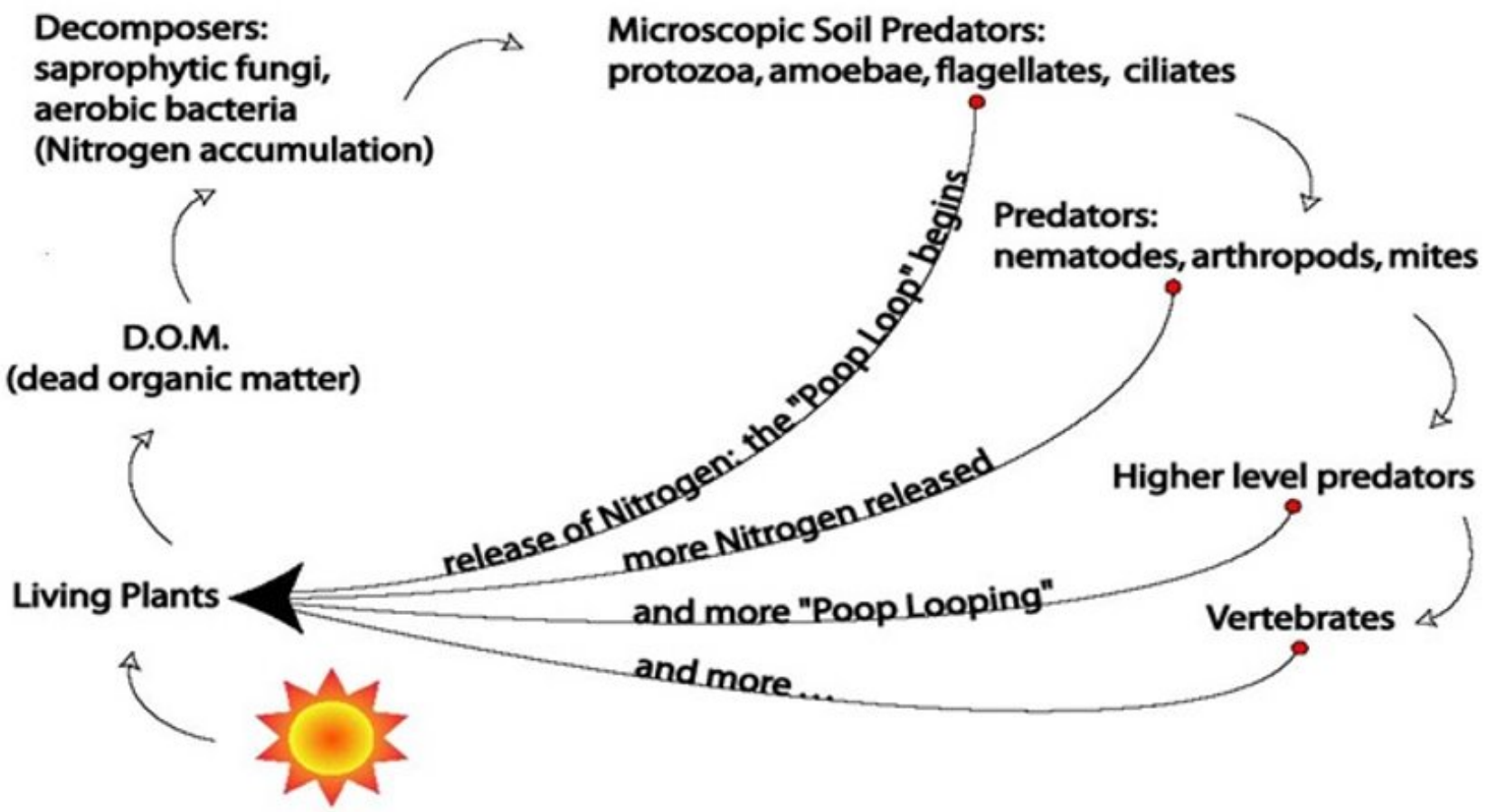
"*Through the activities of soil microbes…the basic raw materials needed by plants are made available at the right time, and in the right form and amount*." – The Soul of the Soil

Microorganisms serve as "nutrient facilitators"

Microorganisms are responsible for the formation of humus.

The Poop Loop

Based on information from Dr. Elaine Ingham and Soil Foodweb, Inc.
by Alane O'Rielly Weber, Botanical Art
(c) 2004



Carbon Cycling

- **Two main pools of carbon:**
  - **Organic carbon:** includes both the living bodies and the dead, decomposing bodies of bacteria, fungi, insects and worms, along with plant debris and manure.
  - **Inorganic carbon:** carbonate ions, typically found as salts like calcium carbonate, and dolomite minerals, mostly in the form of rocks and sand.
    - does not provide microbes with energy for feeding the soil building reactions

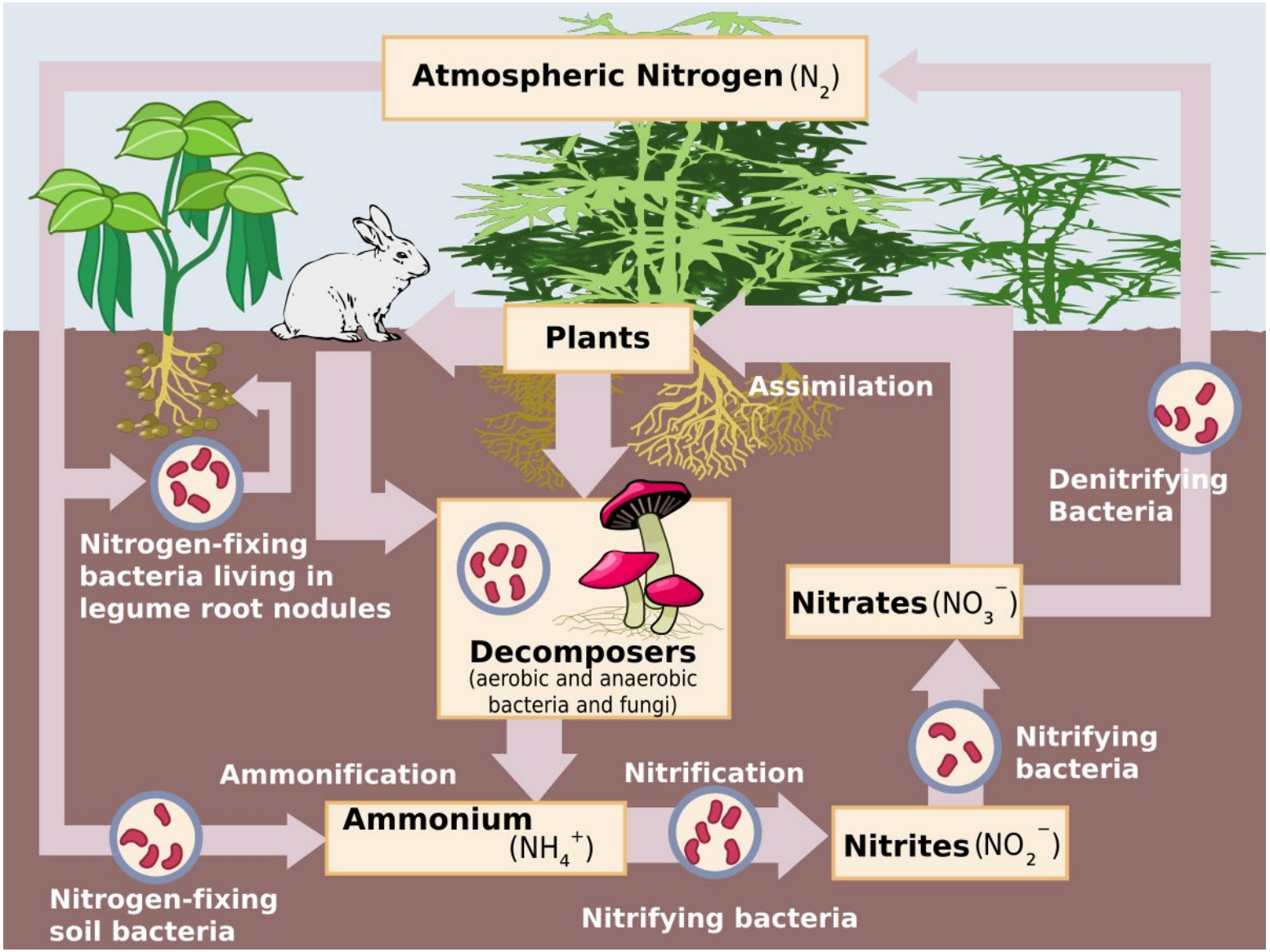
Anaerobic Bacteria

- Anaerobic – lack of oxygen
  - Generally pathogenic
  - Often smelly
  - Examples: Clostridium and E. coli

The Soil Food Web

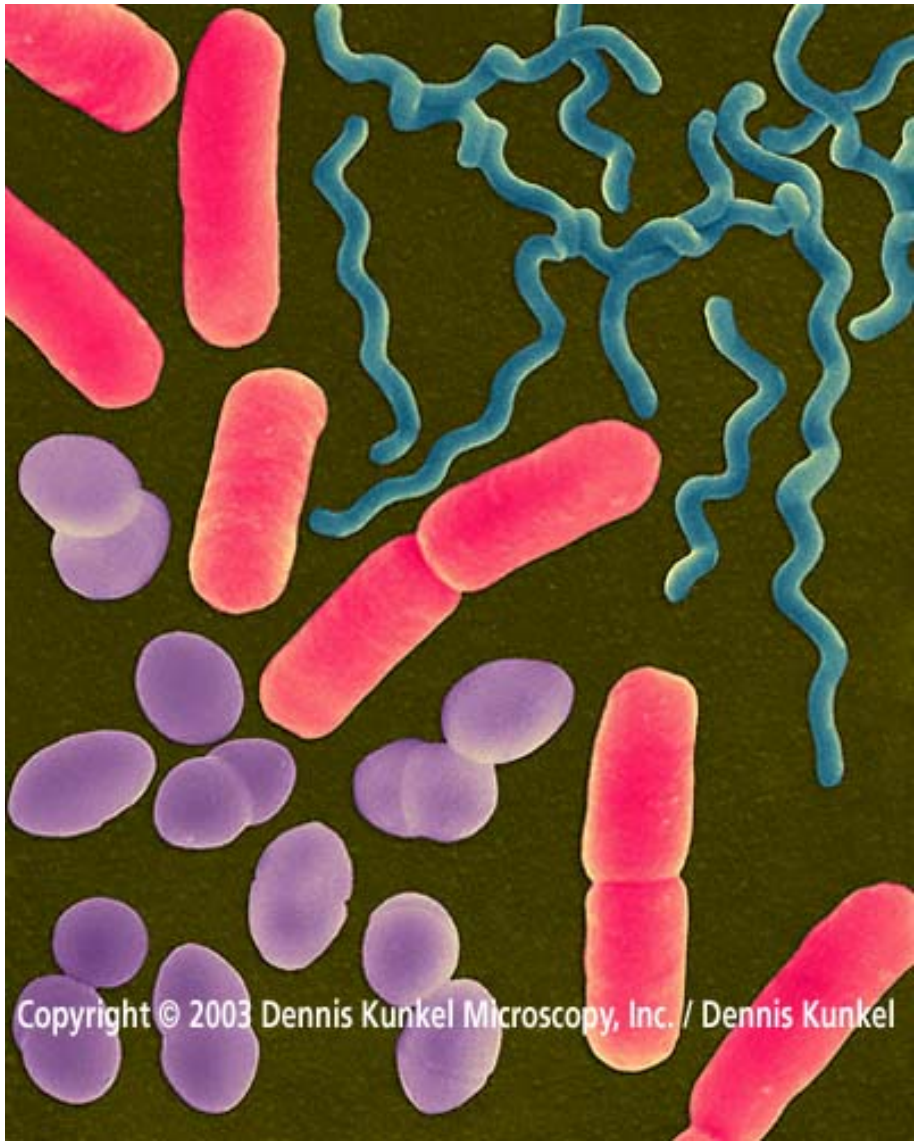
- A healthy soil food web controls disease
  - Not all soil organisms are beneficial
  - A large, diverse community controls problem organisms
  - Competition keeps pathogens in check

Nitrogen Cycling



Bacteria
"Chemosynthesizers"

- The most numerous and varied
- Primary decomposers
- Feeding bacteria
  - Rhizosphere
  - Surfaces of OM



Aerobic Bacteria

In the presence of oxygen

Keep pathogenic bacteria in check

Play a role in breaking down toxins and pollutants

Crucial role in nutrient recycling

- Carbon – release CO_2
- Sulfur – make plant-available
- Nitrogen

Bacteria (cont.)

- Biofilm (bacterial slime)
  - Prefer alkaline soil pH of 7 or greater
  - Enough bacteria can keep the pH at the desired level in the rhizosphere
  - Used for moving through the soil
  - Protective barrier

Fungi

- Yeasts – little presence in soil
- Molds – important in humus formation
- Fusarium & Aspergillis
- Penicillium
- Mycorrhizae (hyphae & mushrooms)
- Endophytes - live inside plants

Fungi

- **The primary decay agents in the SFW**
- **Break down a wide range of organic matter**
  - Lignin and cellulose
  - Chitin shells of insects
  - Bones of animals
- **Scout for and find nutrients, bind them up**

Fungi

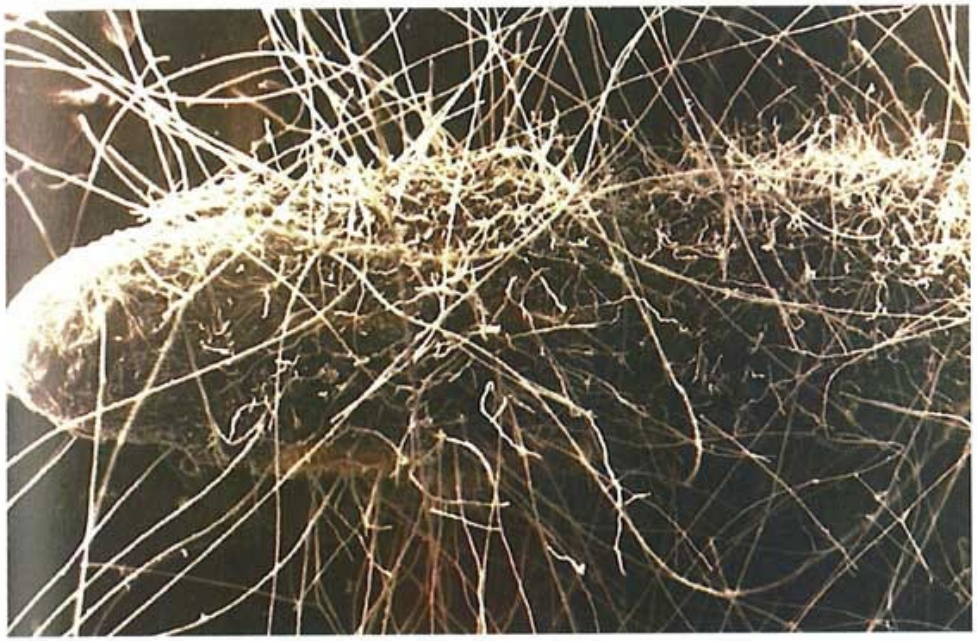
- Decomposers
- Nutrient cyclers
- Soil structure builders
- Beneficial symbionts
- Prevent and cause diseases

Fungi

Reproduce by dispersing spores from fruiting bodies (mushrooms)

Mychorrhizae

- **Hyphae grow end-to-end creating strands**
- **Masses create mycelia**



Mycorrhizal fungi, extending from a root—and increasing the plant's ability to obtain nutrients and water. Courtesy Mycorrhizal Applications, www.mycorrhizae.com.

Mycorrhizae

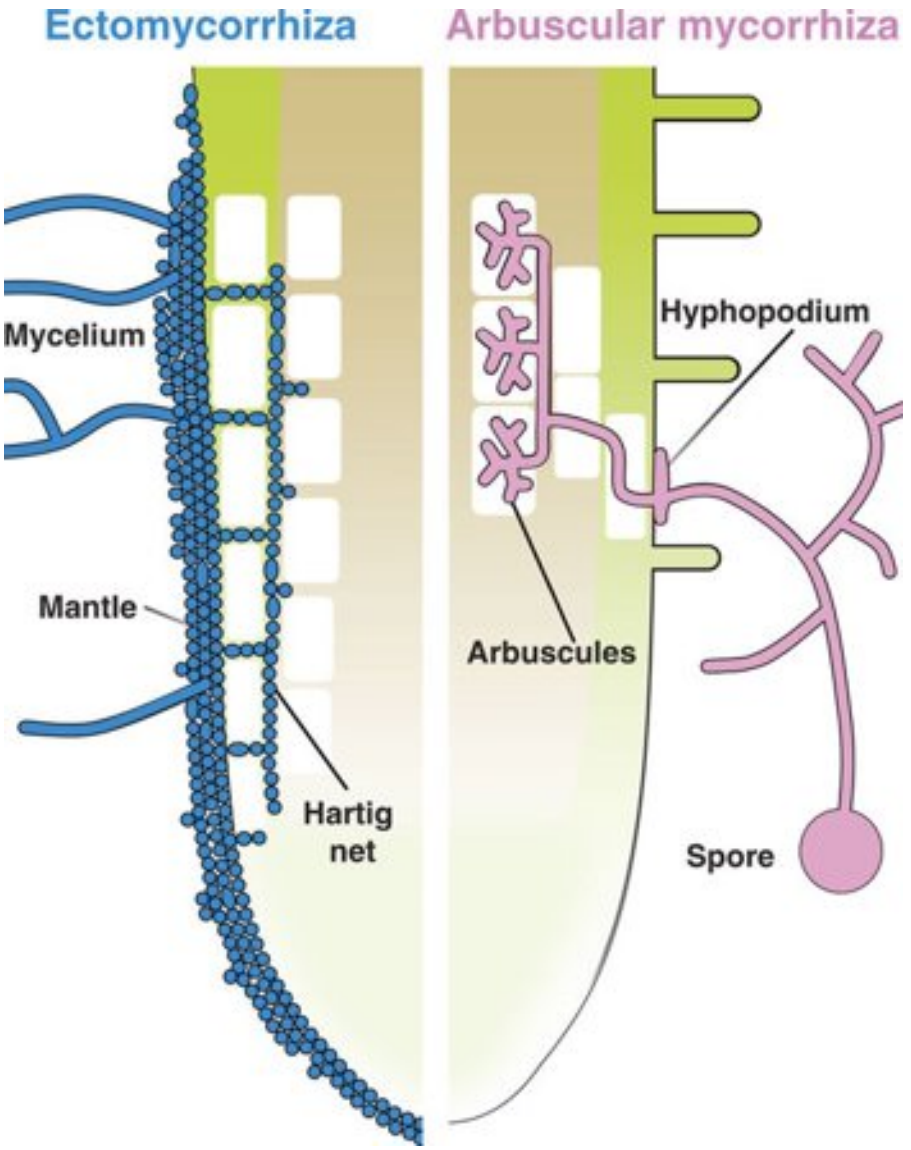
- A fungus which grows in association with the roots of a plant in a symbiotic or mildly pathogenic relationship
  - Hyphae grow end-to-end creating strands
  - Masses create mycelia
- Able to grow significant distances to locate food sources
- Transports nutrients through the hyphae, cell to cell
- Hyphae tubes provide paths for air, water and bacteria

Mycorrhizae (cont.)

- 90-95% of plants have associations with mycorrhizae
- Symbiotic relationship with plant roots
- Convert insoluble nutrients in to plant-available forms
  - Phosphorus
- Exchange nutrients for exudates
- Waste provides nitrogen

Mycorrhizae

- **Symbiotic relationship with plant roots**
- **Convert insoluble nutrients in to plant-available forms**
- **Phosphorus**
- **Exchange nutrients for exudates**
- **Waste provides nitrogen**



Mycorrhizae

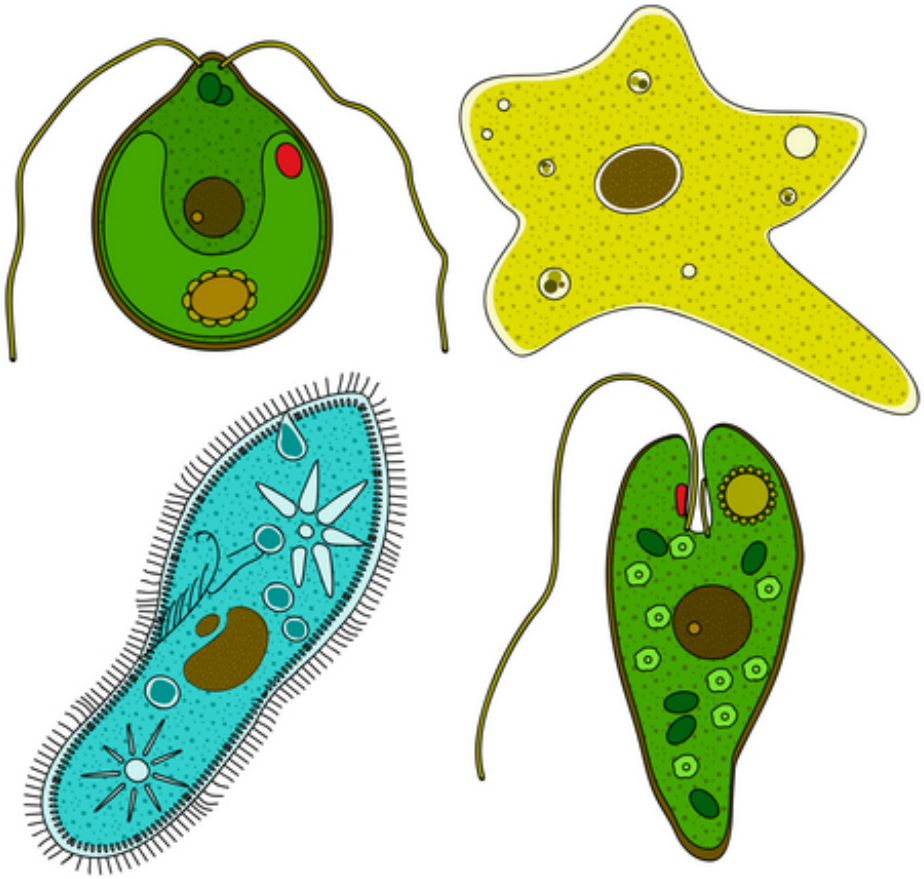
- Unlock, retrieve and transport minerals
  - Phosphorus
  - Calcium
  - Magnesium
  - Zinc
  - Iron
  - Copper

Slime Molds

- Found with rotting organic matter
- Engulf food and digest internally

Protozoa aka Threadworms

- Widespread and numerous
- Get their nutrients eating bacteria, fungi and other protozoa
- 3 basic models
  - Amoebae
  - Ciliates
  - Flagellates



Protozoa (cont.)

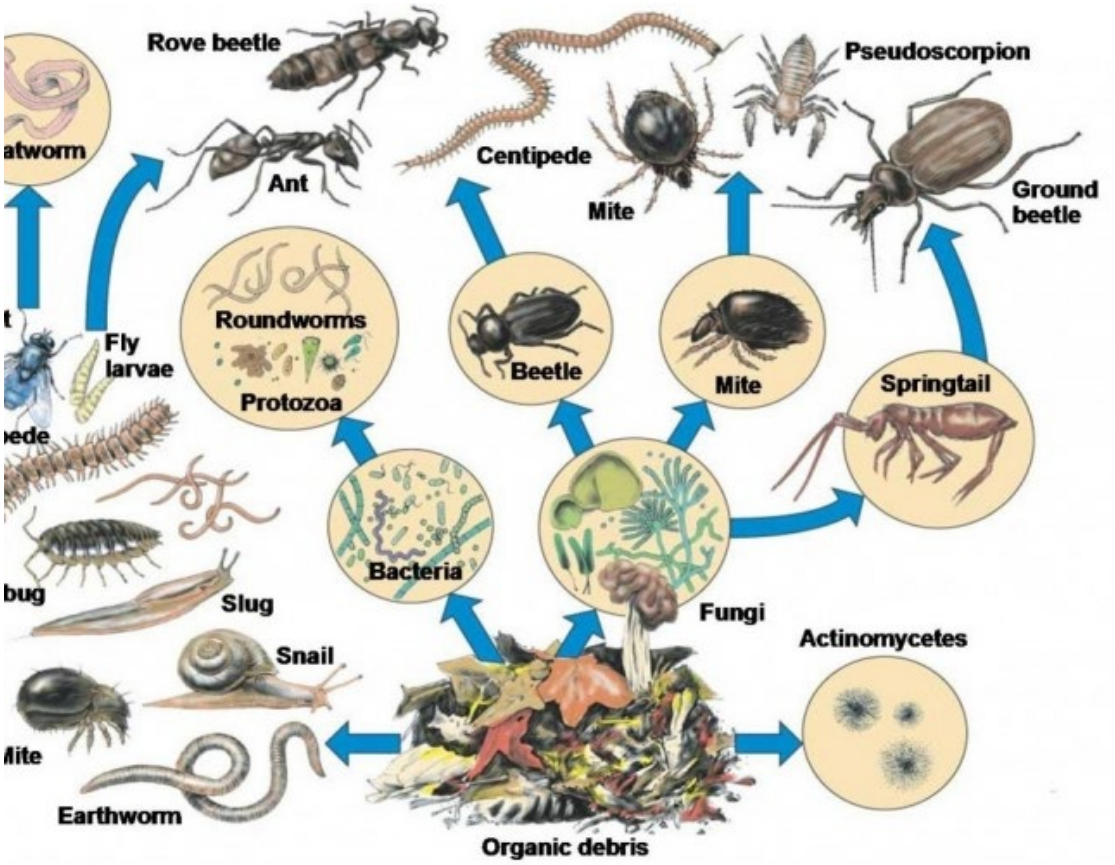
Their waste contains carbon and mineralized compounds

~80% of N required by plants comes from protozoa poop

Worms need a healthy population

Nematodes

- Non-segmented, round worms
  - Minerlize nutrients contained in bacteria and fungi
  - Most not visible to the naked eye
  - Require more porous soil



Arthropods

- Greek for “segmented feet”
- Chitinous exo-skeletons
  - Shed their skins
- Food for other SFW members
- Mix and aerate the soil
- Poop adds to SOM
- Shredders, predators and soil aerators
  - Majority are shredders (chew up OM)

Arthropods

Microarthropods

Can only be seen under magnification

Macroarthropods

Mites and springtails recycle 30% of leaves and woody debris

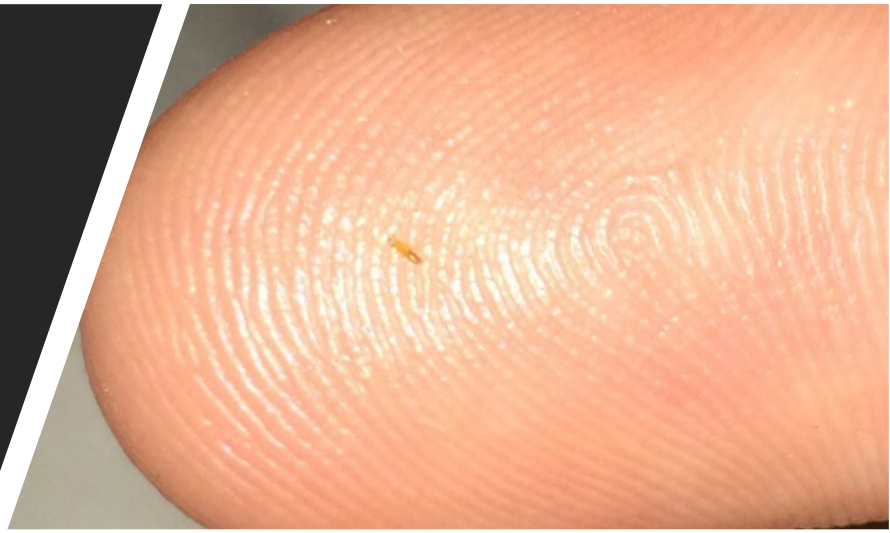
In the absence of OM, they will feed on living matter

Soil Mites

- **2 primary types**
  - **Oribatid mites**
    - Found mostly in debris
    - Major recyclers and decomposers
  - **Gamasid mites**
    - Predatory; feed on other arthropods
    - Major indicator of soil health

Springtails

- Healthy soil: 100 per square inch
- Feed on bacteria, fungi and decaying OM
- Favorite food of mites



Termites and Ants

- **Both are shredders**
- **Termites eat cellulose-containing OM**
  - ❖ **Make available to bacterial and fungi**
- **Construction of tunnels aerates and mixes soil and transports microbes**

Earthworms

- Healthy soil contains 10-50 per sf
- Master shredders
- Aerate soil, increase porosity
- Help with soil aggregation
- Increase water-holding capacity
- Move OM and microorganisms
- Increase microbial population
- Aid plant root growth
- Increase fertility

Earthworms (cont.)

- **Vermicastings**
  - ❖ **50% higher in OM than soil without worms**
  - ❖ **7 x richer in phosphate**
  - ❖ **10 x available potash**
  - ❖ **5 x nitrogen**
  - ❖ **3x available magnesium**
  - ❖ **1.5 x calcium**

Humus

Humus is vital to soil health

- Improves the physical and chemical properties
- Improves biological health
- molecules that are too complex and large for soil organisms to decompose

What is it?

- Bacteria and fungi produce slime so they don’t get washed away; this stuff binds mineral particles together
- Fungal hyphae physically bind particles and clods together

Benefits of the Soil Food Web

- **A healthy soil food web controls disease**
  - Not all soil organisms are beneficial
  - A large, diverse community controls problem organisms
  - Competition keeps pathogens in check
- **Eliminate or reduce the need for:**
  - Fertilizers
  - Pesticides
  - Herbicides
  - Fungicides
- **Improved water- and air-holding capacity**
- **Healthier, more productive plants**

Benefit Soil Structure

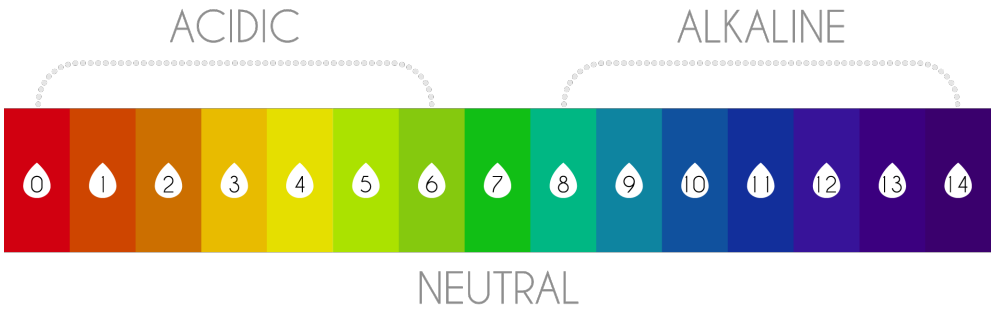
- **Bacteria and fungi produce slime so they don’t get washed away; this stuff binds mineral particles together**
- **Fungal hyphae bind particles and clods together**

Bacteria + fungi =

Protozoa
+ nematodes =

The Soil Food Web (cont.)

- **<u>Trees, shrubs and perennials</u>**
  - Prefer fungal-dominated soils
  - Fungi make the soils more acid (lower pH)
- **<u>Veggies, annuals and grasses</u>**
  - Prefer bacteria-dominated soils
  - Bacterial slime create more alkaline soils (higher pH)



- **Plants control the pH**
  - pH determines how nitrogen is made available

Reptiles, Mammals & Birds

- **Dung is recycled in to nutrients**
- **Feet spread microbes**
- **Birds indicate that arthropods, worms, and larvae are present**

The Effects of Chemical Fertilizers

- **Synthetic NPK fertilizer**:
  - Reduces soil production of plant-available nitrogen
  - Slows production of exudates
  - Slows down or even halts humus formation (i.e., carbon storage)
  - Microbe populations decline
  - Decline of populations of bacteria and fungi affect all the other organisms down the food line, including worms
  - Worms are irritated by chemical fertilizers

The Effects of Chemical Fertilizers

- **Chemical fertilizers**
  - Deteriorate soil structure
  - Decrease water-holding capacity
  - Increase salts in the soil
  - Increase the presence of pathogens and pests

Rototilling

- **Breaks up fungal hyphae**
- **Destroys worms**
- **Pulverizes arthropods**
- **Destroys soil structure**
- **Reduces air- and water-holding capacity**

Soil Building

- The product of a self-reinforcing, positive feedback loop.
  - Soil decline is also a self-reinforcing loop that can result in catastrophic soil loss

"The proper care and feeding of soil organisms demands close attention to managing soil organisms." – Soul of the Soil

Building the Soil

First priority: Restore/build a diverse soil food web

- **3 primary strategies:**
  - **Building and Maintaining Humus**
  - **Compost**
  - **Mulching**

Building the Soil

- **No matter what your soil or climate, improving the soil food web will improve your soil**
  - Improve soil structure
  - Improve nutrient availability and retention
  - Improve water-holding capacity and drainage
  - Minimize pests and diseases
  - Provide the right pH at the root zone

Amendments for Building and Maintaining the Soil Food Web

- **Compost**
- **Mulch**
- **Compost Tea**
- **Mycorrhizal Fungi**
- **Other Amendments**
  - Bio-char
  - Rock dust

Compost

- **Art/science of mixing various OM in a pile and allowing it to decay in to stable humus**
  - **High in microbial life & microarthropods**
  - **Use to inoculate your soil**
  - **NO tainted or toxic materials**
    - No herbicides
    - No pesticides
    - No fungicides
- **Initial soil prep: 12 cubic yards per 1,000 square feet (4”)**
- **Annually: Place ¼” to 1” around your plants**

Animal Manures

- Contributes significantly to SOM
- Stimulates humification of other OM
- Aged at least 6 months
- Best added to compost

Green Manures

- Any crop that is chopped & dropped before maturity to improve the soil
  - Compost in place
  - Biomass – perennial grasses & legume sod crops
  - Nitrogen - legumes
- Especially effective for heavy and compacted soils with little OM
- Spring-planting and fall-planting mixes

Cover Crops

- Planted along side and under plants
- Suppress growth of weeds
- Attract and feed beneficials
- Can add biomass and fix nitrogen
- Shade the soil

Organic mulches

- Wood chips
- Leaves and pine needles
- Grass clippings
- Straw

Organic Matter Matters

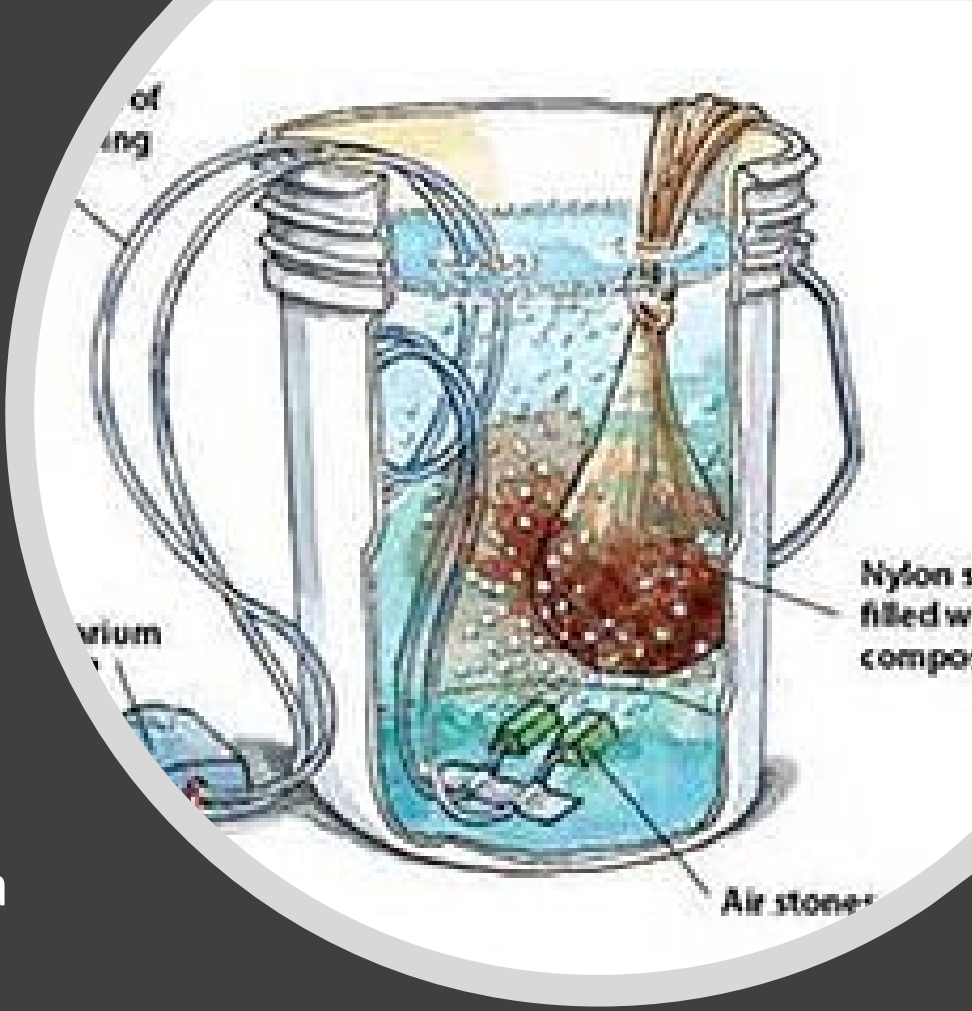
"Each 1 percent increase in soil organic matter helps soil hold 20,000 gallons more water per acre."

Mulch

- Anything placed on the soil to
  - Reduce evaporation
  - Prevent weed growth
  - Insulate roots
- Provides a home for beneficial organisms
- Place on top of compost 3-4” thick
- Taper away from plant stems and trunks

Compost Tea

- Actively Aerated Compost Tea (AACT)
- Helps put microbiology in the soil or on plants
- Stretches the use of compost a lot farther
- It is not compost leachate, extract or manure tea (anaerobic mixtures)



Landscape Fabrics

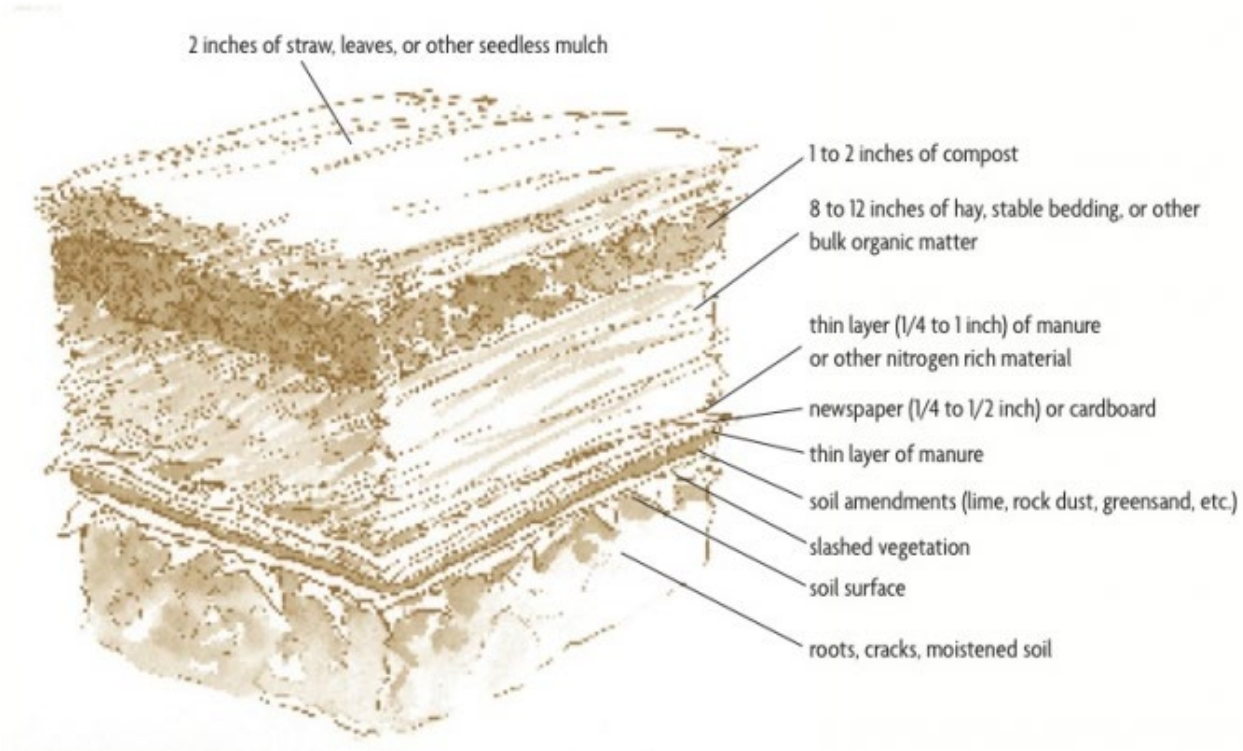
- Synthetic fabrics create a bacterial environment beneath that “weed-protected” surface;
- Compost and Mulch decomposition slows to a standstill and no longer feeds the soil
- Ground beneath becomes more compacted

Improving Your Soil

- **Sheet Mulching**
  - As simple as a layer of newspapers topped by 8 to 12” of nearly any mulch material

Improving Your Soil

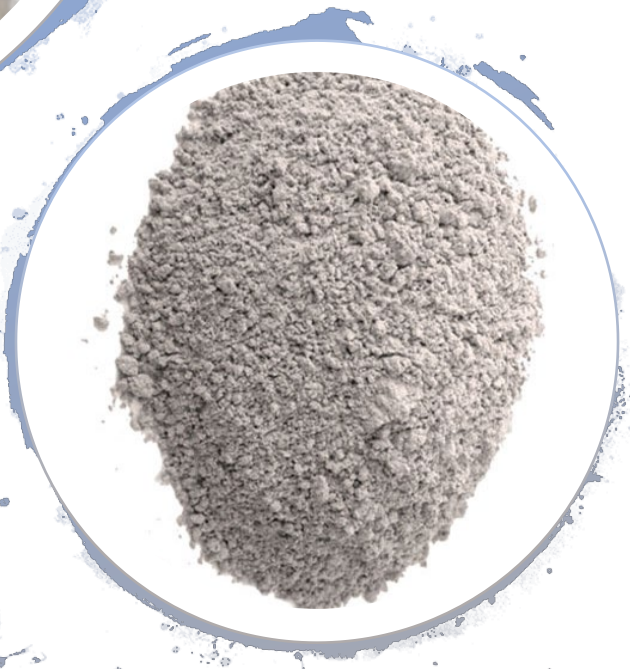
Toby Hemenway's Bomb-proof Sheet Mulch



Improving Your Soil

- **Buying Nutrients**
  - Mineral nutrients are needed to replace those removed by the harvest of crops
    - Organic fertilizer
  - Natural materials won't create imbalances in soil ecosystem

Improving Your Soil



- **Mineral Nutrient Sources**
  - **Rock powders**
    - Purported to provide slow-acting remineralization
  - **Bio-char**
    - **Best used in the making of compost**
- **Getting the SFW working will resolve many deficiencies**

A Sample Soil Food Web Calendar

Yard and garden care isn't just about plants

Spring

- Get you compost piles cooking
- Apply compost to landscape and garden areas
- Refresh mulch under trees and shrubs
- Apply soybean meal (microbe food) @ 4 lbs./100 s.f.

Sample Soil Food Web Calendar

- **Summer**
  - **Compost veggie garden soil with green mulch (fresh grass clippings)**
    - Reapply every two weeks or so
  - **Replenish mulches as needed**

Sample Soil Food Web Calendar

- **Fall**
  - **If green mulch is available, use in veggie beds**
  - **Gather up and store leaves**
  - **Apply organic microbial food (soybean meal, powdered malt, oatmeal, oat bran, powdered baby oatmeal*)**

Sample Soil Food Web Calendar

- **Winter**
  - **Read good garden articles online and books**

The Soil Food Web

- **“No One Ever Fertilized an Old Growth Forest”**
  - **No one has ever fertilized the forests around us, yet they thrive**
  - **You can reap the benefits with less work**
- **Gardening with the Soil Food Web is a natural!**

UCCE
El Dorado Master Gardeners

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