BMP UNIVERSITY

TEXAS A&M AGRILIFE EXTENSION

Agriculture, Horticulture, Landscape and Environmental Best Management Practices Education and Training Program

Soil BMPs

Module 1: Nature, Functions, and Properties of Soils Overview

EO3: Environmental Functions of Soils

Environmental Functions of Soils

- Plant nutrient supply
- Water movement and storage
- Organic matter (carbon) deposition and decomposition
- Habitat for living organisms

- Plant nutrient supply

16 Essential Elements for Plant Growth

Boron	Iron	Phosphorus
Calcium	Magnesium	Potassium
Carbon	Manganese	Sulfur
Chlorine	Molybdenum	Zinc
Copper	Nitrogen	
Hydrogen	Oxygen	

Structural Elements

Primary Macros

Secondary Macros

Micronutrients

- Plant nutrient supply

TABLE 1: Form, source, mode of uptake and major functions of the 16 plant essential nutrients.

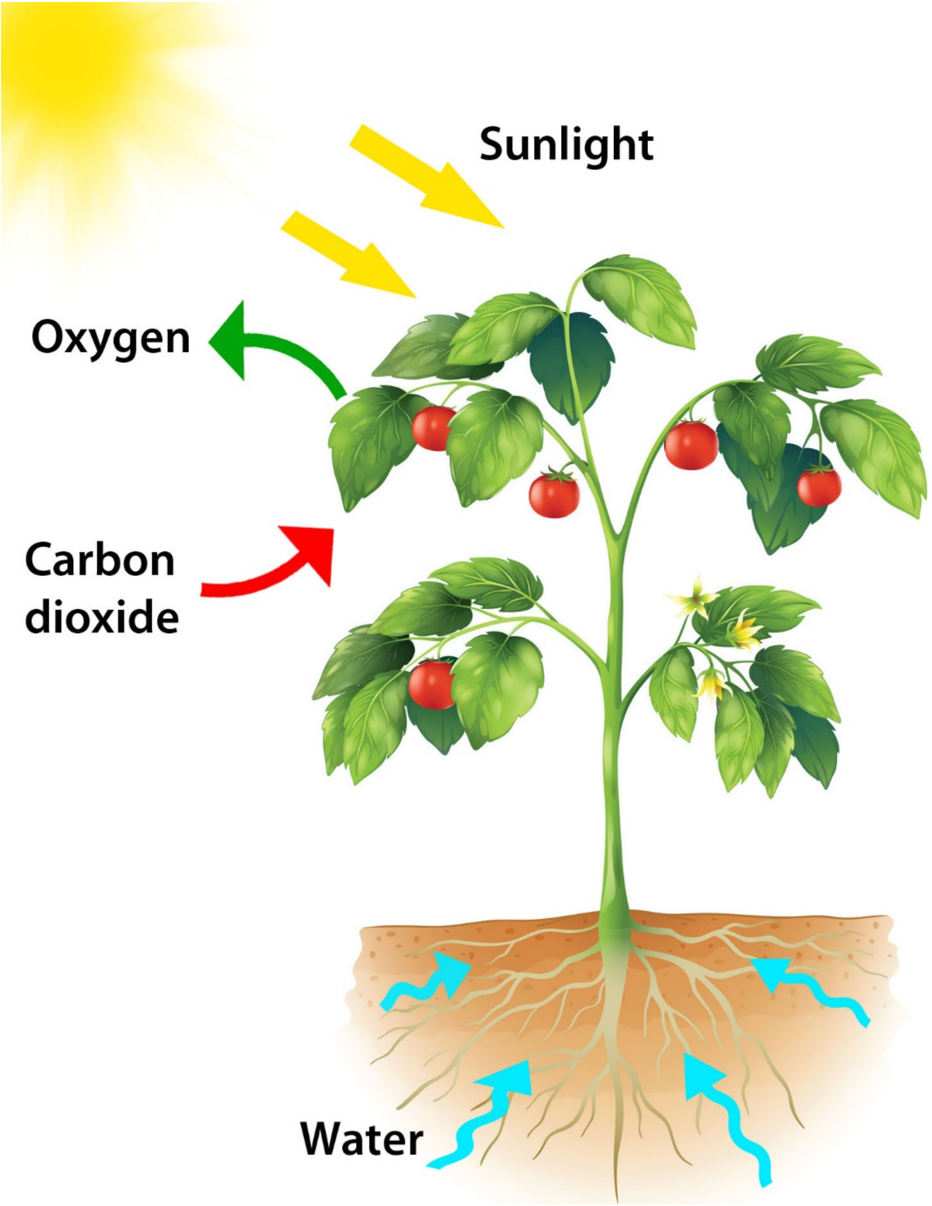
Nutrient family	Nutrient	Percentage of plant	Form taken up by plants (ion)	Primary mode of uptake*	Major functions in plants
Primary	Carbon	45	Carbon dioxide (CO_2), bicarbonate (HCO_3^-)	Open somates	Plant structures
	Oxygen	45	Water (H_2O)	Mass flow	Respiration, energy production, plant structures
	Hydrogen	6.0	Water (H_2O)	Mass flow	pH regulation, water retention, synthesis of carbohydrates
	Nitrogen	1.75	Nitrate (NO_3^-), ammonium (NH_4^+)	Mass flow	Protein/amino acids, chlorophyll, cell formation
	Phosphorus	0.25	Dihydrogen phosphate ($H_2PO_4^-$, HPO_4^{2-}), phosphate (PO_4^{3-})	Diffusion	Cell formation, protein syntheses, fat and carbohydrate metabolism
	Potassium	1.5	Potassium ion (K+)	Diffusion	Water regulation, enzyme activity
Secondary	Calcium	0.50	Calcium ion (Ca^{2+})	Mass flow	Root permeability, enzyme acitivity
	Magnesium	0.20	Magnesium ion (Mg^{2+})	Mass flow	Chlorophyll, fat formation and metabolism
	Sulfur	0.03	Sulfate (SO_4^{2-})	Mass flow	Protein, amino acid, vitamin and oil formation
Micro	Chlorine	0.01	Chloride (Cl^-)	Mass flow	Chlorophyll formation, enzyme activity, cellular development
	Iron	0.01	Iron ion (Fe^{2+}, Fe^{3+})	Diffusion	Enzyme development and activity
	Zinc	0.002	Zinc ion (Zn^{2+})	Diffusion	Enzyme activity
	Manganese	0.005	Manganese ion (Mn^{2+})	Diffusion	Enzyme activity and pigmentation
	Boron	0.0001	Boric acid (H_3BO_3), borate (BO_3^{3-}), tetraborate (B_4O_7)	Mass flow	Enzyme activity
	Copper	0.0001	Copper ion (Cu^{2+})	Diffusion	Enzyme activity
	Molybdenum	0.00001	Molybdenum ions ($HMoO^{4-}$, MoO_4^{2-})	Mass flow	Enzyme activity and nitrogen fixation in legumes

* In some cases other modes are possible, but primary mode represents mode by which most of the nutrient is taken up

Structural elements
Supplied through photosynthesis

- Carbon (C)
- Hydrogen (H)
- Oxygen (O)

These elements are important in many plant functions but a large amount are dedicated to structures such as cell walls (cellulose) and energy (sugars).



Primary Macronutrients
Supplied by soil

- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)

Primary macronutrients are required by plants in the greatest quantities (behind water) of any other nutrient.

Secondary Macronutrients
Supplied by soil

- Calcium (Ca)
- Magnesium (Mg)
- Sulfur (S)

Secondary macronutrients are required by plants in great quantities, but generally less than those of the primary macronutrients

Micronutrients
Supplied by soil

- Boron (B)
- Chlorine (Cl)
- Copper (Cu)
- Iron (Fe)
- Manganese (Mn)
- Molybdenum (Mo)
- Zinc (Zn)

Micronutrients are needed in relatively tiny amounts compared to the macronutrients, but are still absolutely ‘essential’.

- Plant nutrient supply

Where do the nutrients in soil come from?

Note: It is important to recognize that plants can only take up nutrients that are dissolved in water (in this case the soil water, or soil solution). Plants cannot take up a solid, undissolved nutrient.

Minerals: Soil minerals may weather and dissolve to release soluble nutrients. Potassium, iron, magnesium, and calcium are predominantly supplied from mineral sources.

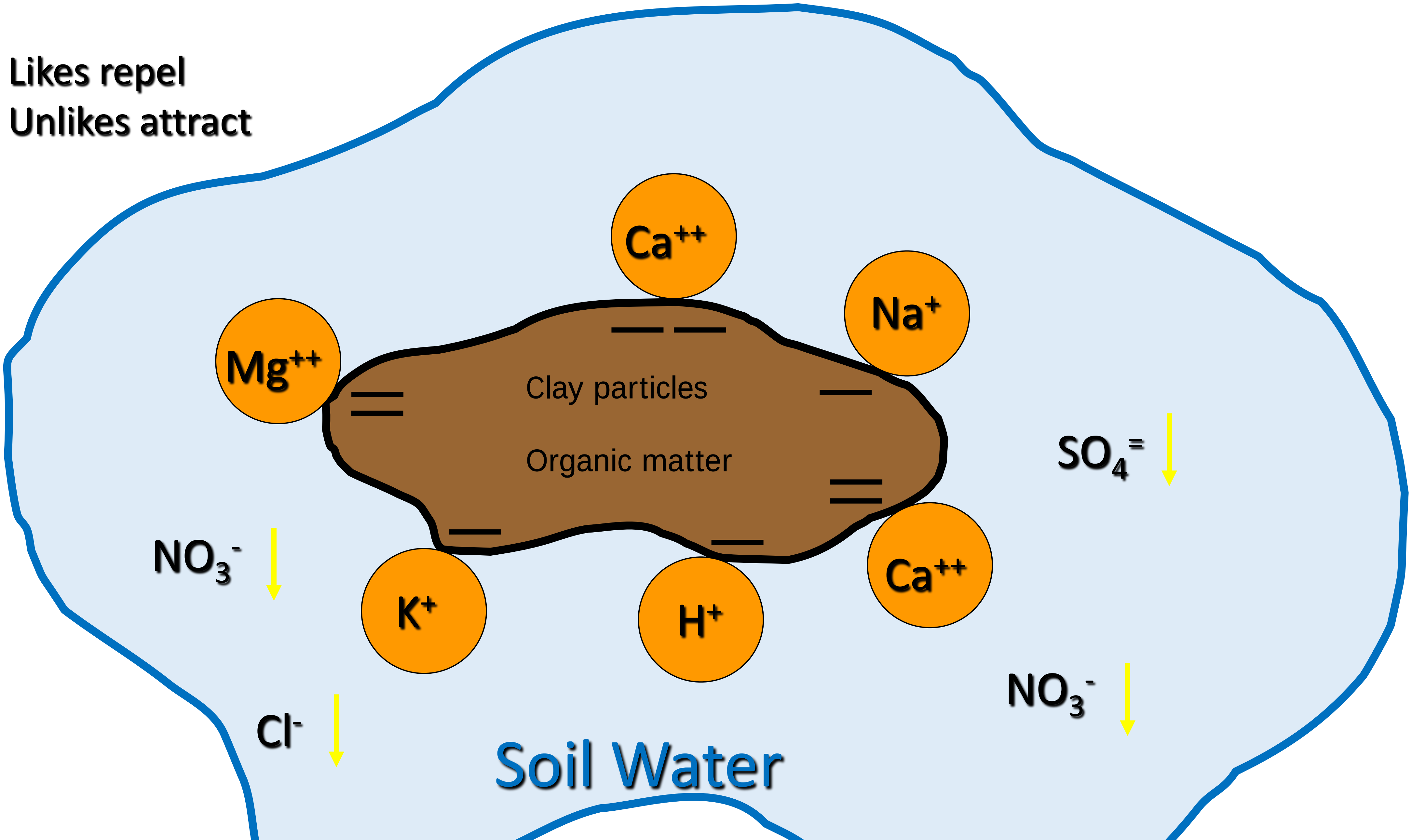
Organic matter: breakdown of soil organic matter (SOM) releases many nutrients formerly incorporated into the tissue of living organisms. Breakdown of SOM is called *Mineralization.* Mineralization is largely carried out by microorganisms, although chemical processes and sunlight play smaller but important roles. A soil with good organic matter content (3-5%) can turn over nutrients such as sulfur, zinc, and copper through mineralization in amounts that obviate the need for fertilizers.

Both soil minerals and SOM may provide a storage and release mechanism for nutrients called **Cation Exchange Capacity (CEC)**

- Plant nutrient supply

Cation Exchange Capacity

- Likes repel
- Unlikes attract



- Plant nutrient supply

Cation Exchange Capacity

Where do the nutrients in soil come from?
On the surfaces of very small mineral particles (clays from EO1), the surface area to volume ratio allows the expression of negative charges on the actual surface of the particle. Negative charges on the surface attract positively charged nutrients (+ ↔ -). This is a property of clays, and not of silts and sands. Therefore, sandy soils have far less CEC than clayey soils

A bit about ions before we move on.
Ions are electrically charged chemical species. They can be atoms (elements) or molecules (assemblages of atoms). There are two types of charges: positive (+) and negative (-). Well really 3 if you count zero charge. But only positive and negative charged chemical species are considered to be ions. This is because ions are either attracted to or repelled by each other or by other things with charges, like clay particles or organic matter functional groups.

Positive ions are called **cations.** Negative ions are called **anions**.

Salts are a special class of compounds that are made up of associated (+) and (-) ions. Their bonds are typically weaker than other types of compounds and subject to separation or 'dissolution' when introduced to water. When dissolved, nutrients that form salts may become plant available.

- Plant nutrient supply

Cation Exchange Capacity

Where do the nutrients in soil come from?

When nutrients adsorb to clay surfaces as in slide 8, they are removed from solution and held temporarily safe from uptake or loss from the soil. As the soil solution loses nutrients to plant uptake, diffusion demands that some portion be released to satisfy the need to maintain equilibrium, thus resupplying the plant available nutrients in solution.

Organic matter can provide cation exchange capacity through a different mechanism. Chemical functional groups at the end of carbon chains in SOM molecules have a negative charge that attracts cations just like the negative charges on clay surfaces. However, SOM can provide 5 x the CEC per gram compared to clay particles.

Bottom line: Soil nutrient storage and supply increases with clay and organic matter content because of cation exchange capacity

Pathways of nutrient loss from soils

Nutrients are not only supplied by soils, but may also be lost in or away from soils. This causes problems with providing nutrient to plants, and also causes problems when nutrients migrate away from the fields they are placed in as fertilizer. Nutrients that make it to other fields or even surface and ground waters cause imbalances in ecosystems and even have catastrophic effects on plant, animal, and human health.

Leaching: As water percolates downward through the soil profile, it can carry dissolved nutrients (and other chemicals) far enough to contaminate aquifers that supply wells for drinking water. Over application of nitrogen is a common cause of nitrate contamination in well water. (slide 12)

Runoff: Nutrients may easily runoff from the surface of soil and be transported by rapidly moving water to nearby rivers, lakes, and oceans. Phosphorus and nitrogen in particular cause a phenomenon called ***<u>Eutrophication</u>*****.** Excess nutrients in surface waters promote the rapid growth of plants and algae at the water surface. Once the nutrients are consumed, the plants and algae die off, to be consumed by bacteria that require oxygen to decompose the carbon from the dead tissue. The increased use of oxygen asphyxiates fish and other organisms in those waters, leading to mass mortality events.

Pathways of nutrient loss from soils

Volatilization: Nitrogen fertilizers containing urea or ammonium (or ammonia) are subject to losses of ammonia through the release of ammonia gas.

- Ammonia (NH_3^0) may be dissolved in water or it may exist as a gas. Ammonia gas is easily lost from soil into the atmosphere.
- Ammonium (NH_4^+) is easily and rapidly converted to NH_3^0 as the pH of soil rises above 7.8.
- Urea is rapidly converted to ammonium by enzymes released by bacteria and fungi in the soil

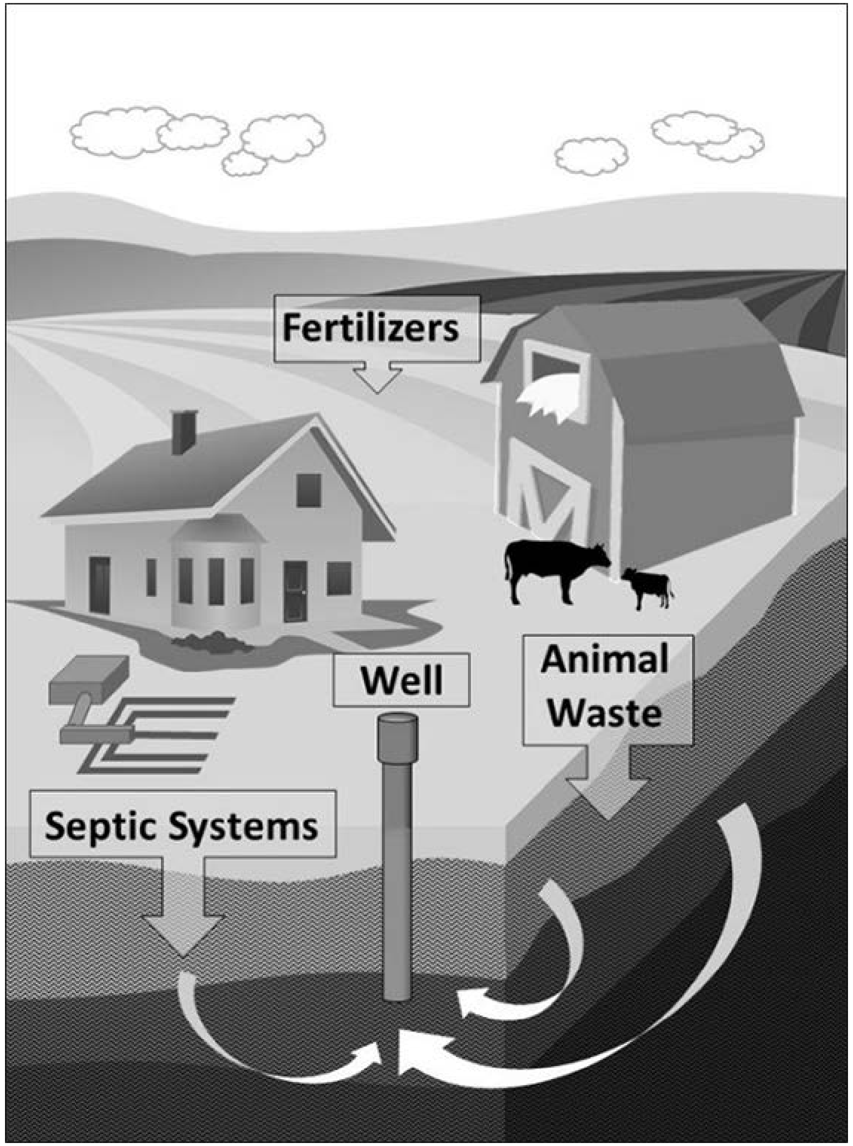
Erosion: Wind and water can carry massive amounts of soil away from fields. Mixed with the soil are nutrients both free and adsorbed that can be transported thousands of miles away in extreme cases.

- Plant nutrient supply

Drinking water with concentrations of nitrate above 10 mg/L can cause immediate health problems.

Nitrates in drinking water sources can drastically increase treatment costs. Nitrate-removal systems supply costs can rise from 5-10 cents per 1000 gallons to over $4 per 1000 gallons.

Following recommended practices in nutrient management can vastly reduce contamination of groundwater supplies for drinking water.



- Plant nutrient supply

Nutrient escapes (losses) from soils have diverse and wide ranging effects on the U.S. economy, impacting tourism, property values, commercial fishing, recreational businesses and other segments of the economy that depend on clean water. Eutrophication leads to algal blooms and fish kills in major waterways of the U.S. each year.

Drinking water costs

It can cost billions of dollars to clean up polluted water bodies. Every dollar spent on protecting sources of drinking water saves in water treatment costs.

- Water movement and storage

We discussed in EO1 how texture affects water movement and storage. We'll build on and provide a little more detail in this section.

Water holding capacity - this is the amount of water that a soil can hold against the force of gravity. This is different than maximum potential water content (the amount of water held when all void volumes are filled with water). This is also called saturated water content. Gravity will drain some of this water, and soils will retain more than half depending on pore size distribution. Pore sizes > 0.05 mm are too large to hold water against the force of gravity.

- Smaller macropores and micropores that hold onto water are associated with the clay fraction of soils. Therefore, clayey soils have greater WHC than sandy soils.
- WHC is most frequently expressed as volume of water / volume of soil, or as mass of water / mass of soil, or sometimes just percent (%)

Soil hydraulic conductivity - this term describes the capacity of a soil to transmit water. Water flows downward and horizontally through soils. During times of high evaporative demand, water may move upward through soils as well. Water flow (or flux) is the ***volume*** of water passing through a cross sectional ***area*** of soil per unit ***time***.

- **Volume (V)** is 3 dimensional. Think of a cube or a sphere. Units may be cubic feet.
- **Area (A)** is 2 dimensional. Think of a square or a circle. Units may be square feet.
- **Time (t)** is time. Units may be seconds, or minutes, or hours.

The dividend of 3D unit and a 2D unit (e.g. V/A) is a 1 dimensional unit. In this case V/A gives **length (L).**

- Therefore, the dimensions of flux are (V/A) / t = L / t. So we wind up with units like feet per day, or inches per hour

- Water movement and storage

Soil texture and organic matter affect both water holding capacity and conductivity.

WHC

Soils with more clay content (up to a point) hold more water against the force of gravity, while sandy soils hold less. This means that sands have less capacity to supply plants with water and must be replenished more frequently if plants are to grow well. Notice that a clay may hold less than a silt loam. This is because a silt loam has a good distribution of both small macropores and micropores, whereas the clay is dominated by micropores only.

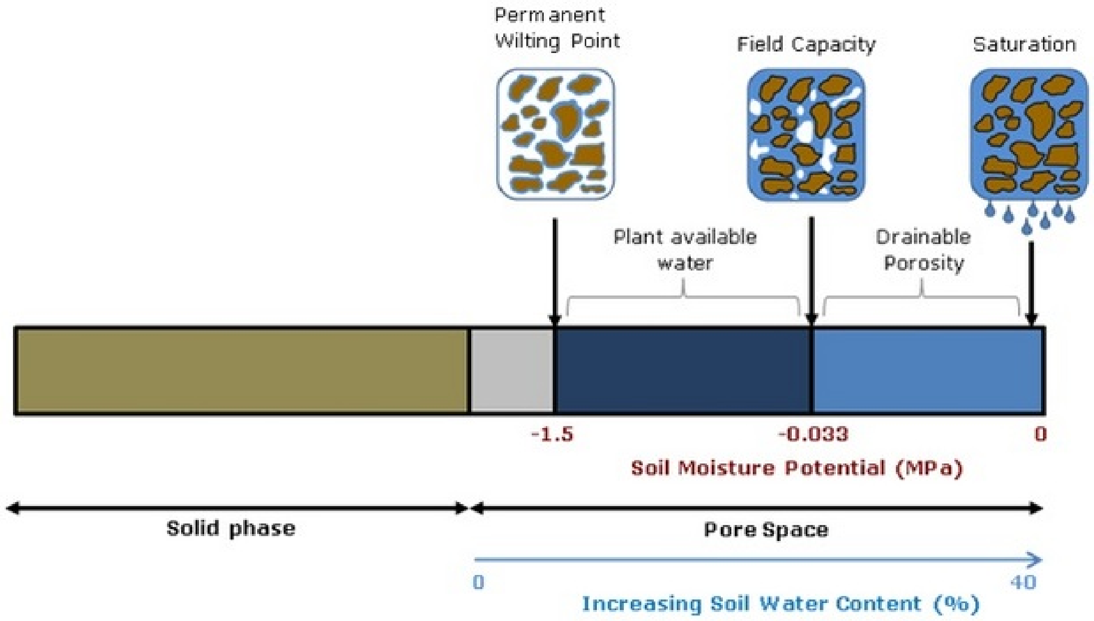
Some textural classes from the soil texture triangle and their relative water holding capacities.

Loamy Sand	Loam	Silt Loam	Clay
0.12 g / g	0.27 g / g	0.40 g / g	0.35 g /g

Organic matter has a much higher water retention potential than clay particles. A good rule of thumb is 5x the amount. So a small amount of SOM can add a lot of water holding power.

The way that soils hold water is by exerting a negative pressure through adhesive force. This pressure in soils is called soil water potential. We use units of pressure to describe soil water potential, such as Pascals (Pa), MegaPascals (Mpa), or Bars. There are three important states of soil water to learn

1. **<u>Saturation</u>**: when all soil voids are full, there is no pressure exerted and the potential is zero (e.g. 0 MPa). Plant growth will be generally limited at saturation due to limited oxygen supply to root cells.
2. **<u>Field Capacity</u>:** when a soil has been drained by gravity, the pressure exerted is equal to the downward force of gravity. The soil water potential at this state is -0.33 MPa. Plant growth is fairly good at this water state. Roots have ample access to water and oxygen.
3. **<u>Permanent Wilting Point</u>:** there is a point where water content becomes so low that the soil exerts a greater negative pressure on water than plant roots can overcome. Water may be present, but is no longer accessible by plants. This occurs at potentials of -1.5 MPa and lower.



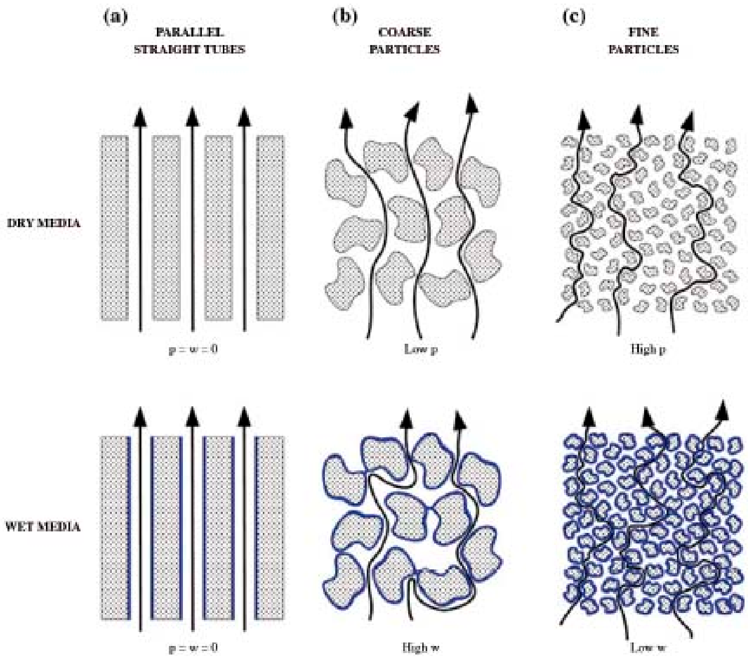
- Water movement and storage

Soil texture and organic matter affect both water holding capacity and conductivity.

Conductivity

Water movement in soil is strongly influenced by the soil water potential, whether it arises from clay particles or from organic matter. Flow is also affected by the ‘tortuosity’ of the pathway through the soil. Think of the soil as a granular porous medium where the water must flow not strictly ‘through’ as it would an empty pipe, but ‘around’ every single particle through the spaces in between them. Sandy soils provide a relatively straight pathway. Clayey soils are more tortuous. Soils with well developed structure tend to facilitate more rapid flow and drainage by preserving macroporosity.

- When there is a change in texture between two soil horizons, whether from sand to clay or vice / versa, a barrier to water flow is created. This is a very important concept. We will cover this idea specifically a little later in the course.
- When soil becomes compacted, macroporosity, voids between particles, decreases. Tortuosity increases. Hydraulic conductivity decreases.



Source: Thorbjorn et al. (2008).

The more tortuous the pathway, the slower the rate of flow of water through a soil. Tortuosity reduces conductivity

Permeability Class	Permeability Rate (cm / hr)	Textural Class
Very Slow	<0.13	Clay
Slow	0.13-0.5	Sandy clay, Silty clay
Moderate	2.0-6.3	Fine sandy loam, Loam, Silt
Rapid	12.7-25.4	Sand, Sandy loam
Very Rapid	>25.4	Coarse sand

- Water movement and storage

Soil texture and organic matter affect both water holding capacity and conductivity.

Drainage

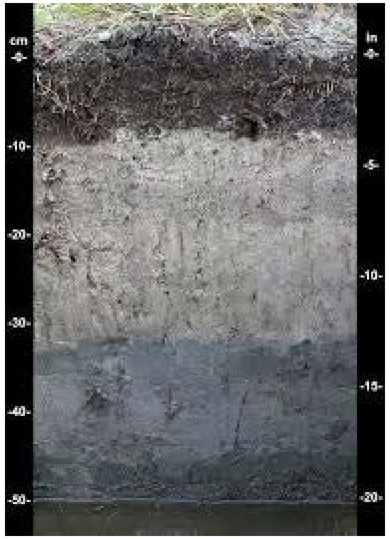
The rate at which water drains from the soil profile is probably the component of conductivity or flow that concerns us most in agricultural and urban environments. Poorly drained soils remain saturated or wetter longer than well drained soils. This is of particular interest when planning the timing of irrigation for crops and lawns. Compacted soil, or compacted layers in soils, slow down water due to reductions in macroporosity and increased tortuosity.

Some tips for observation

- ❑ Poorly drained soils will exhibit colors associated with poor oxygenation
  - The color development is called "redoxymorphic features" after the biological organic matter decomposition processes that occur under limited or no oxygen to accept electrons during cellular respiration
  - Iron (Fe) and manganese (Mn) in soil are used by bacteria as electron acceptors, changing their valence state from Fe^{3+} to Fe^{2+} and Mn^{4+} to Mn^{3+} respectively. Iron changes to the rust or reddish orange color. Manganese changes to a gunmetal blue or black color.
  - When these colors appear in soil horizons, it is a strong indication that this activity has occurred because of poor drainage.

NRCS pic of iron redoximorphic features

NRCS pic of Mn redoximorphic features



NRCS pic of well drained soil

- Soil Organic Matter: Deposition and Decomposition

How does organic matter get into soil?

Soil organic matter (SOM) is any material produced originally by living organisms (monera, protista, plants, animals, fungi, bacteria, archeae).

Most SOM comes from plant matter, which is made of carbon (C), oxygen (O), hydrogen (H), nitrogen (N), potassium (K), and the other nutrients covered in lesson EO2. The carbon and nutrients in organic matter are very important to the environmental function of soils, including carbon sequestration, greenhouse gas emission, and fertility.

SOM is made up of formerly, but not currently, living things. You will find many sources that include living bacteria and fungi in SOM. This course does not take that viewpoint. Therefore, SOM begins with materials that may be very fresh. Eventually SOM will have been stabilized through many transformations in the soil, or will exist on some point along the decay spectrum. On the way to stabilization, most organic matter will have been converted by heterotrophic microorganisms to carbon dioxide (CO_2) and released back into the atmosphere.

- Fresh SOM, such as crop residue or grass clippings, is considered to be **"Active"**
- Humus is a form of SOM considered to be **"Stable"**

There are benefits to SOM towards the environmental functions of soils.

- Storage and provision of plant nutrients (associated with the stable fraction)
- Promotion of soil structure and tilth (associated with the active fraction)
- Prevention of erosion (associated with both fractions)

Tilth - the soil's general suitability to support plant root proliferation. A soil with proper tilth exhibits friability, a low degree of compaction, a balanced distribution of macro and micropores, allows diffusion of oxygen throughout, and holds sufficient water for plant growth while maintaining good drainage. Potential tilth differs by soil, and is a function of texture, structure, fertility, organic matter, and biology.

- Soil Organic Matter: Deposition and Decomposition

Decomposition of SOM

Organic matter is broken down naturally by biological, chemical, and physical processes in soil.
Shredders - invertebrates such as worms and insects in the soil, even birds and insects above the soil surface physical breakdown larger, coarse organic particles (>1 mm) into smaller ones. They often consume portions of this material, processing it as food and excreting it latter as waste.
Heterotrophs - micro-organisms that cannot make assimilate carbon from CO2 as plants do, must acquire their carbon from the breakdown of much smaller SOM particles, even down to individual organic molecules. There are ***aerobic heterotrophs*** that require oxygen to respire everywhere in soils. Bacteria and fungi are two important types of organisms that include many aerobic heterotrophs in their numbers. These organisms 'eat' the carbon and other nutrients in organic matter and they 'breathe' out carbon dioxide (CO_2). The taking up of carbon and nutrients into their living biomass temporarily prevents it from being released as CO_2 or as plant available nutrients. However, both carbon and nutrients will eventually be released as the organisms' life cycle is completed. At this point, the cycle begins again, and the materials may be consumed, released, or stabilized. As long as carbon and nutrients are in a living organism, the potential for cycling within the soil and eventually becoming stable organic matter and or plant food persists.

When oxygen is limiting, ***anaerobic heterotrophs,*** or even heterotrophic organisms that are flexible ***facultative anaerobes*** (can switch back and forth), begin to dominate in the soil. This happens most often during saturated conditions. Generally, the rates at which anaerobes decompose SOM is much slower than those of anaerobes. The process that uses oxygen is much more efficient in terms of energy produced.

The decomposition of organic matter that leads to inorganic plant available nutrients is called ***"<u>Mineralization</u>"***

Rates of mineralization by heterotrophic are affected by a number of environmental and other conditions.

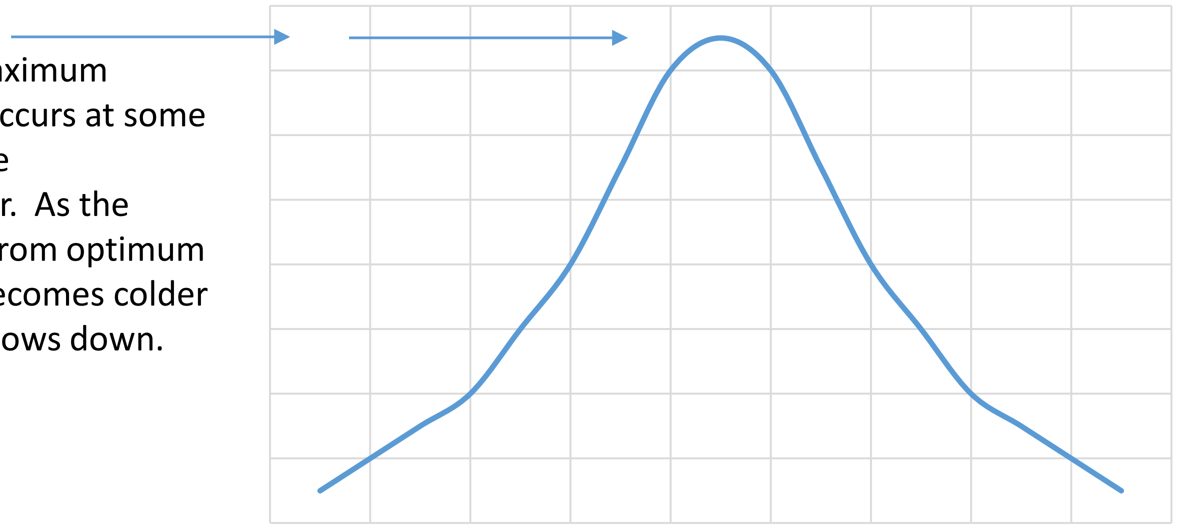
- Temperature
- Water potential
- Soil texture
- Soil pH
- Number and type of organisms
- Quality of the organic matter. simple molecules like sugars are mineralized more rapidly that complex molecules like waxes that require more energy to break down. Lignin, common component of plant cell walls, is an example of a complex organic structure that is very slow to break down
- Soil disturbance

- Soil Organic Matter: Deposition and Decomposition

Influence of Environmental Factors on SOM Mineralization

Warmer wetter soils tend to mineralize organic matter more rapidly than dry cool soils.
Bacteria are mineralize organic matter more rapidly than fungi. Bacteria are more rapid at soil pH values in the alkaline range (e.g. 8-9), whereas fungi tend to be more rapid at acid pH values between 5 and 6. This may be due to decreased competition from bacteria at lower pH values.
In general, the environmental factors temperature, water potential, and soil pH follow a pattern in terms of rate response to changes in that factor (below)

There is always a maximum potential rate that occurs at some optimal value for the environmental factor. As the factor moves away from optimum (e.g. temperature becomes colder or hotter) the rate slows down.



Environmental Factor (ex: Temperature, Soil pH, Water potential)

- Soil Organic Matter: Deposition and Decomposition

Influence of Soil Texture

Coarse soils (sands) tend to mineralize organic matter more quickly. Clay particles will sorb organic molecules onto their surfaces, protecting them from attack by heterotrophs.

Quality of Organic Matter

What the SOM is made up of matters when it comes to heterotrophic decomposition rates.

C:N ratio idea: Because heterotrophic micro-organisms use nitrogen in their proteins, they must have a certain amount of N to go along with the carbon they break down and assimilate. If the organic material itself has far less N per unit C, then mineralization proceeds very slowly, as the microorganisms do not have enough total N and C to grow and reproduce. The ratio of C:N is an important determinant in the rate of progress for mineralization of SOM.

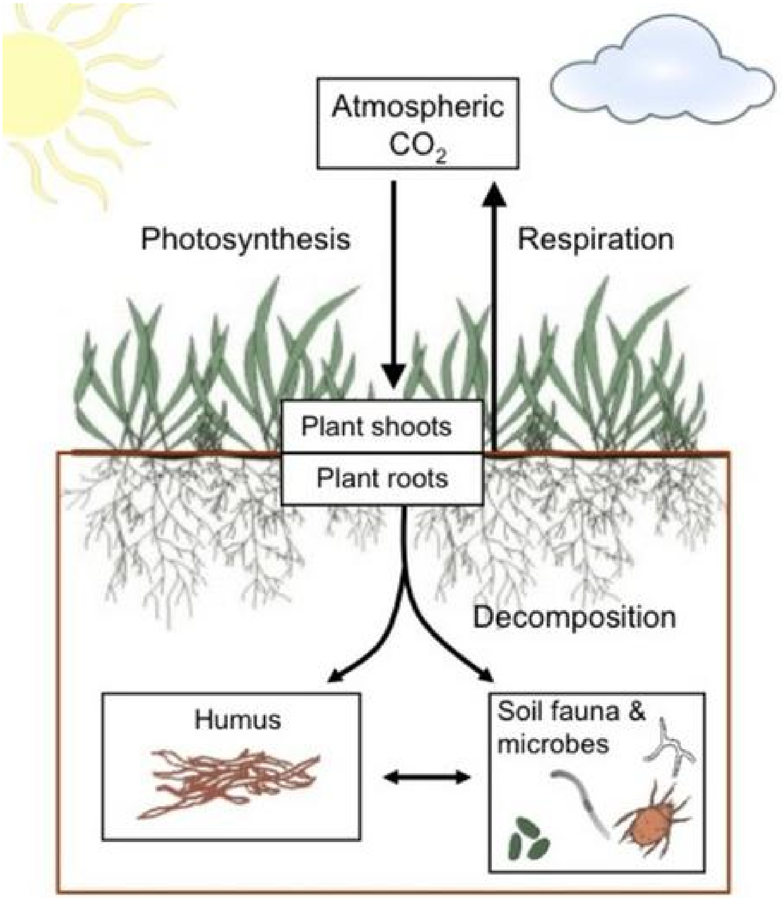
- Exception: If an N source is available outside of the organic material (e.g. N fertilizer added to soil), then micro-organisms may assimilate this external N to continue driving the SOM decomposition at the rate allowed by all other factors.
- This case will be covered in more detail in later sections on N fertilizer management.

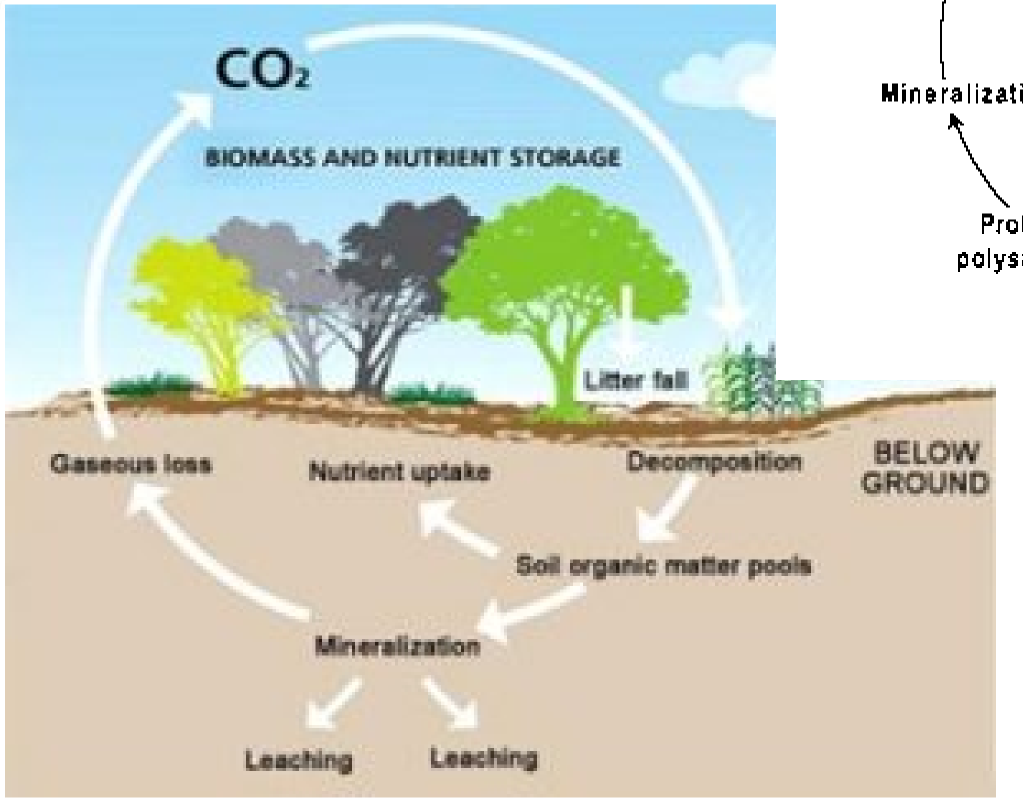
Type of Carbon is important. The cells of living organisms are made up of different kinds of carbon. Sugars are rapidly decomposed with little energy required and much released. Consequently these types of compounds are the first to be metabolized. Proteins take more energy, but have a very favorable C:N ratio (~3:1). Plant cell wall components cellulose and hemicellulose, which have wider C:N ratios (30-35:1), also contain chemical bonds which require more energy to break. Lignin, a material that fills the spaces in plant cell walls between cellulose and hemicellulose, contains almost no nitrogen at all. Therefore, the more lignin present in an organic material, the less of it can be mineralized, and at a slower rate.

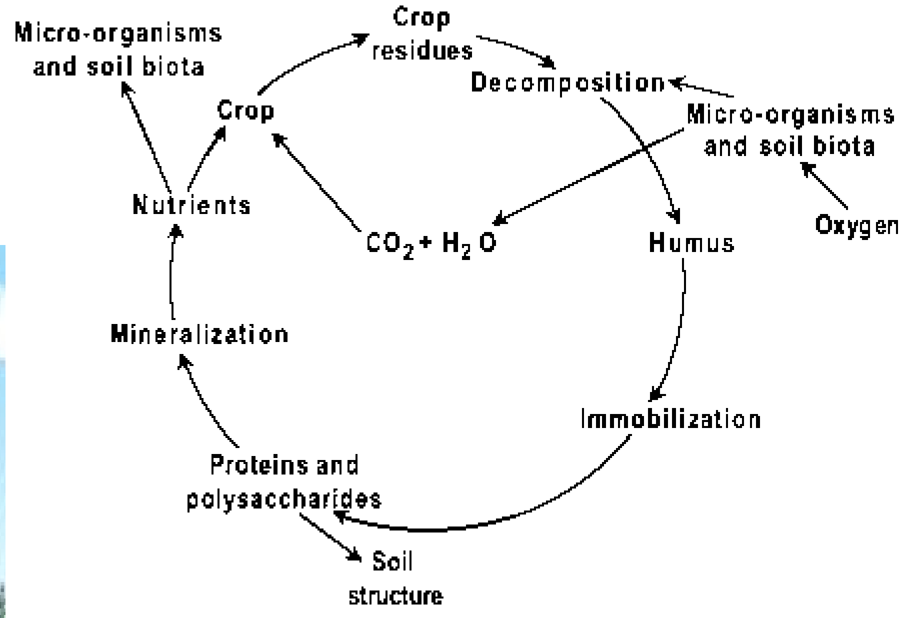
Other plant nutrients contained in organic matter are released during mineralization. The rate of their release is directly tied to the rate of decomposition. Except for the case of potassium (K), which is not bound in organic material, but exists as a dissolved ion in the solutions (water) that makes up living things

C:N ration	Relative Rate of Decomposition
<20:1	Fast
20:1-30:1	Slow
>30:1	Very slow

- Soil Organic Matter: Deposition and Decomposition





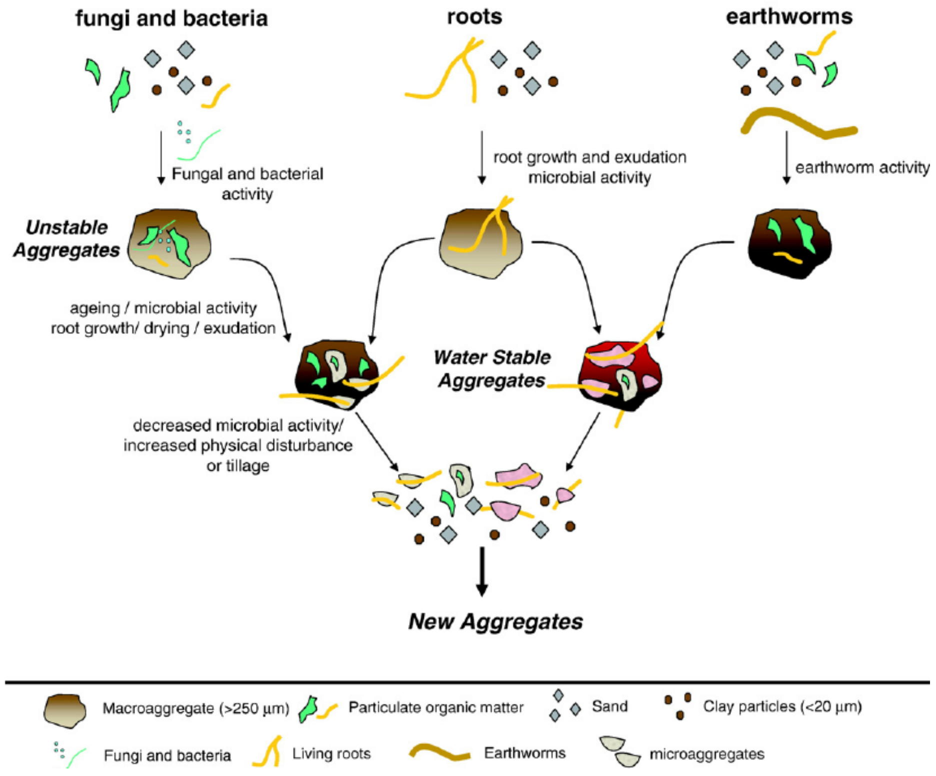


- Habitat for living organisms

Complex web of interactions

Soil organic matter provides the chemical carbon source for many microorganisms (called heterotrophs) and is food for larger organisms such as macro-invertebrates that include insects and worms. Living plant roots and soil organisms of all sizes excrete materials (acids, proteins, enzymes, and wastes) which serve many purposes.

- Binding or aggregation of clay particles together to build soil structure and tilth
- Provision of food sources for other organisms
- Cycling of nutrients in and out of living organic biomass to prevent loss
- Improve supply of nutrients to plants
- Suppression of detrimental or pathogenic organisms

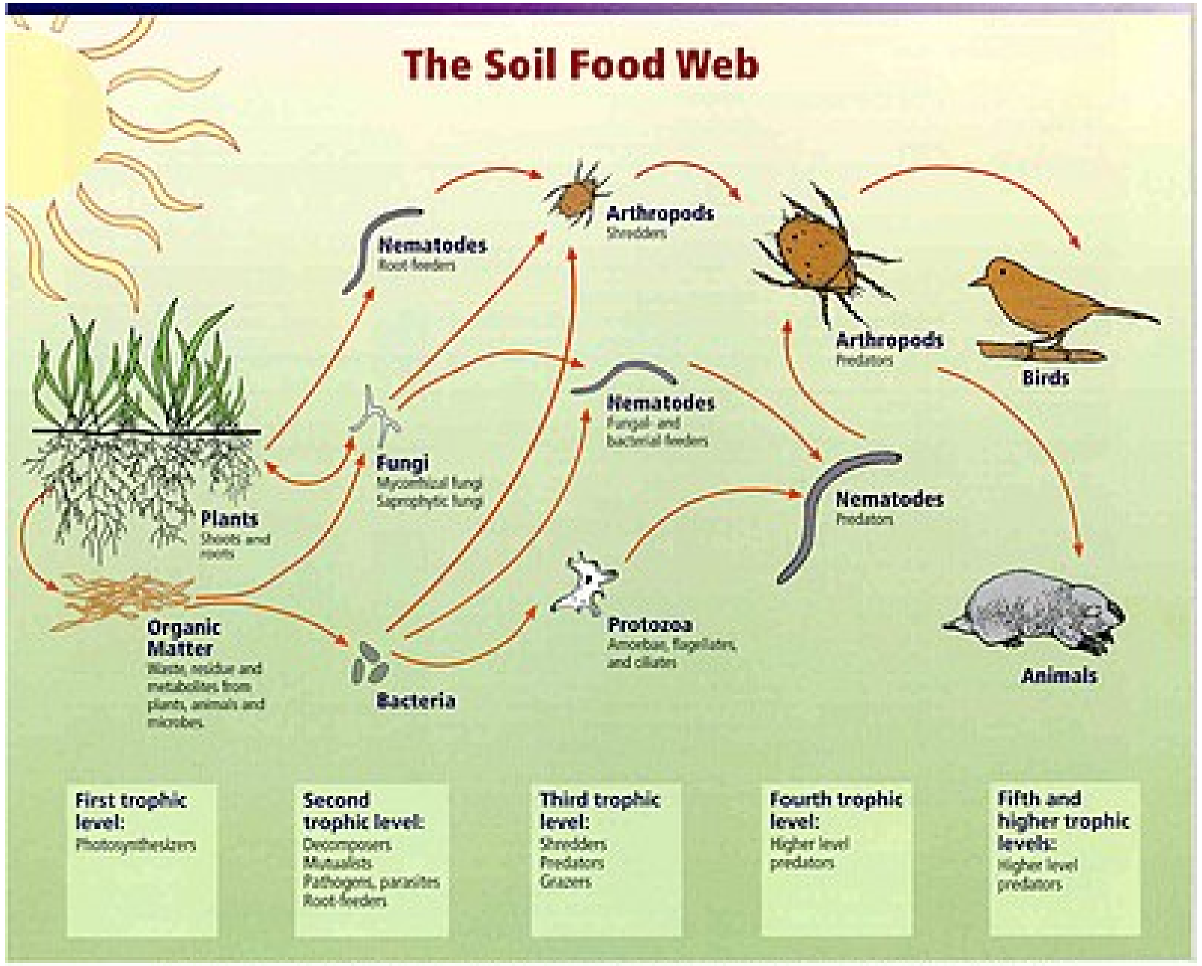


Major features of soil ecology

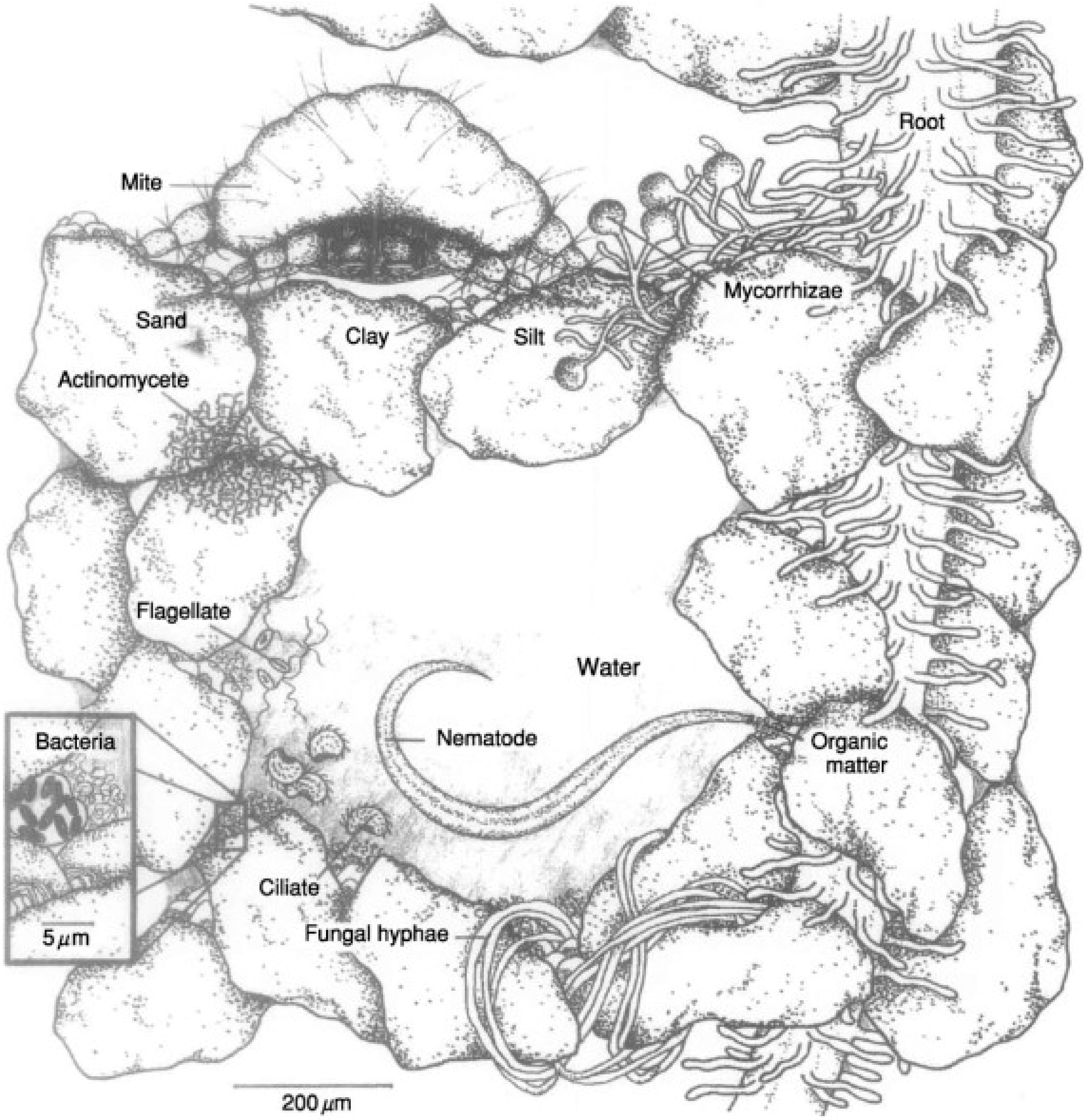
1. Soils contain twice as much carbon as the plant vegetation that grows up from it.
2. Though the soil habitat at first appears dominated by microscopic life, many organisms are not. In fact some soil fungal organisms are among the largest living things on the planet.
3. We may currently only be aware of < 5% of the species that live in soil.
4. Food webs do not follow traditional above ground rules. There are many omnivores and generalists present. Extremes lead to dominance without predation.
5. There are a multitude of scales due to macro- and microporosity volumes. This leads to a multitude of sub habitat divisions
6. Soils take thousands of years to form. This legacy profoundly influences the biology. Sometimes more than the plant life.

- Habitat for living organisms

Food web and habitat images



Relationships between soil food web, plants, organic matter, and birds and mammals
Image courtesy of USDA Natural Resources Conservation Service
http://soils.usda.gov/sqi/soil_quality/soil_biology/soil_food_web.html



- Habitat for living organisms

Food web and habitat images

Types of organisms

1. Microflora (<10µm)
    - Bacteria
    - Fungi
    - Actinomycetes
    - Algae
2. Microfauna (<0.1mm)
    - Protista
    - Nematodes
3. Mesofauna (0.1mm-2.0mm)
    - Enchytraeids
    - Mites
    - Springtails
4. Macrofauna (>2.0 mm)
    - Earthworms
    - Insects
    - Millipedes
    - Slugs
    - Snails
    - Mammals, reptiles, & amphibians

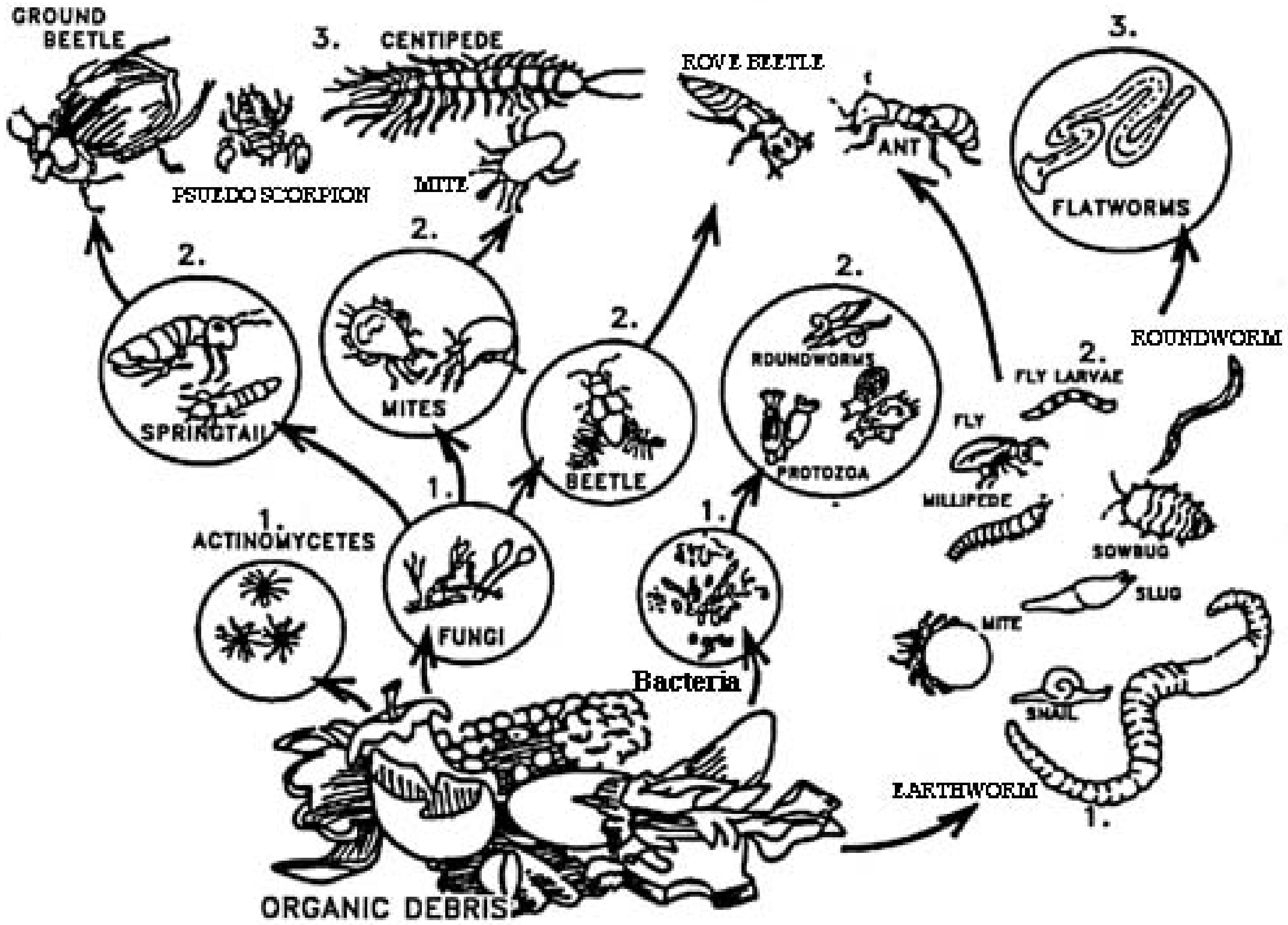
A selection of organisms in soil communities[51].

(a) root fungi	(b) decomposer fungi	(c) bacteria	(d) nematode	(e) tardigrade
(f) collembolan	(g) mite	(h) worm	(i) millipede	(j) centipede
(k) earthworm	(l) ants	(m) woodlice	(n) flatworm	(o) mole

- Habitat for living organisms

Food web and habitat images

Types of organisms



From Aggie Horticulture https://aggie-horticulture.tamu.edu/earthkind/landscape/dont-bag-it/chapter-1-the-decomposition-process/

Soil organisms

- Habitat for living organisms

Types of organisms that live in soils
Microflora
Bacteria
All bacteria are microscopic one-celled organisms. Typical sizes are around 1 µm, though cell shapes may be circular, oval, square-ish, or oblong ‘rectangles’. A gram of soil may contain between 100 million and 1 billion bacterial cells. The total mass of bacteria per acre is potentially more than one ton.

Functional groups of soil bacteria

1. Decomposers. Heterotrophs (organisms that derive nutrition from organic carbon sources) breakdown SOM, converting the potential energy it contains into useful forms for the rest of the soil food web, and releasing CO_2 as a byproduct.
2. Mutualists. Form partnerships with plants that benefit both organisms.
3. Pathogens. Deleterious to plants and causative agents of disease
4. Lithotrophs. and Chemoautotrophs. Organisms that obtain energy from sources other than carbon. Many bacteria can use compounds of nitrogen, sulfur, iron, or hydrogen instead of carbon.

Role of soil bacteria
Bacteria cycle nutrients, preventing loss from the system. These nutrients are incorporated into active living biomass and are therefore temporarily unavailable. However, they have more potential to remain in the root zone for future plant use than not. Bacteria excrete a variety of compounds that serve to bind soil particles and promote aggregate formation. Aggregates improve water percolation through and retention by soils.

Some bacteria are aerobic (require oxygen). Other bacteria only operate under low or no oxygen (anaerobic) conditions. Some bacteria can switch between aerobic and anaerobic metabolism. Because of this versatility, there are few conditions under which bacteria are not active in soils.

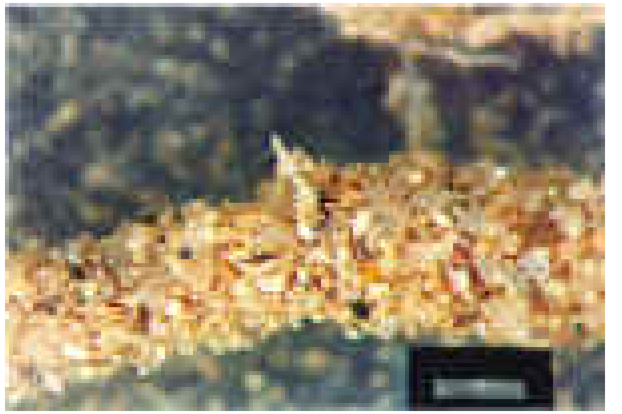
- Habitat for living organisms

Types of organisms that live in soils
Microflora
Fungi
Many fungi are strictly microscopic, though many grow structures that are easily visible with the naked eye. Some fungi are multi-cellular, and some are single celled organisms. A structure typical of fungi is the hyphae, long threads which elongate through the soil. Hyphae may grow tens of feet long.

Functional groups of soil fungi
1. Decomposers. Saprophytic fungi convert SOM into fungal biomass and release CO_2. This group produces organic acids as wastes during metabolism, which serve to increase stable soil humus.
2. Mutualists. Arbuscular mycorrhizal fungi (AMF) are a well known example of endomycorrhizae (fungi that live partially inside plant tissue) that exchange nutrients and carbohydrates with plants. AMF are known to increase phosphorus supply to plants, and are reported to improve biotic and abiotic stress tolerances. Ectomycorrhizae are fungi that live mostly outside the plant but interact with root tips of woody plants to exchange nutrients and carbohydrates.
3. Pathogens and parasites. This group can cause disease or death when the colonize roots and/or whole plants. Root rot and powdery mildew are examples.

Role of soil fungi
Fungi, like bacteria, cycle nutrients and exude compounds that 'glue' soil particles together. Fungi are aerobic only, but they have a tolerance for conditions that bacteria are not as well suited to adapt to. Long thread like hyphae can bridge and access isolated water pockets during times of drought. Fungi tend to tolerate low pH soils better than bacteria, and dominate when bacterial activity decreases under acidic conditions.

Mycorrhizal fungi link root cells to soil particles; sand grains are bound to a root by hyphae from endophytes (fungi similar to mycorrhizae), and by polysaccharides secreted by the plant and the fungi.



Credit: Jerry Barrow, USDA-ARS Jornada Experimental Range, Las Cruces, NM. Please contact the Soil and Water Conservation Society at pubs@swcs.org for assistance with copyrighted (credited) images.

- Habitat for living organisms

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- Habitat for living organisms

Types of organisms that live in soils
Microflora
Actinomycetes
Nontaxonomic term applied to soil microorganisms that breakdown resistant organic materials (e.g. chitin, lignin). They are gram positive simple prokaryotes that can form hyphae or mycelium like those of fungi

Algae
Algae occur in all environments. Some are prokaryotes and some are eukaryotes. They play an important role in primary and secondary plant community succession through early stage colonization of soils. Algae are often involved in nitrogen fixation, and stabilization of aggregates.

Prokaryote vs. Eukaryote: What's the difference?

Prokaryote - single celled organism that has no distinct nucleus with a membrane nor other specialized organelles. Bacteria are prokaryotes

Eukaryote - single or multi cellular organism in which DNA is contained (as chromosomes) in a distinct nucleus.

- Habitat for living organisms

Types of organisms that live in soils
Microfauna (<0.1mm)
Protista - unicellular water dwelling organisms. Protists predate on bacteria, filling an important niche in the soil food web

Nematodes - microscopic roundworms < 0.5µm. Functional groups include:

1. Plant feeding root herbivore species (can cause crop damage)
2. Bacteria and fungi feeders
3. Predatory and omnivorous species

Mesofauna (0.1mm-2.0mm)
Enchytraeids are related to earthworms (class Oligochaeta) and they look like small, white or transparent earthworms. Functionally, they breakdown organic matter and are also microbial feeders and are therefore an important component of the decomposition system in soils.

Mites are the smallest (usually less than 1 mm), and also the most diverse group of arthropods in soil and therefore show a very wide range of feeding habits and lifestyles. The presence of these microarthropods markedly increases decomposition rates across a range of environments.

Collembola, also known as springtails, also have a central role in soil food webs and affect decomposition processes. They are small (less than 6 mm in length) wingless insects in the subclass Apterygota. Different collembola species are specialised for different microhabitats in soil and litter and are quite susceptible to desiccation unless they remain in a moist environment.

- Habitat for living organisms

Types of organisms that live in soils
Macrofauna (>2.0 mm)
A wide range of insects inhabit the soil for all or part of their life cycle. In many case insect species simply use the soil for the egg or pupal stages of the life cycle. Larvae of beetles, flies and ants are common; in addition woodlice, centipedes and millipedes are found in all life stages in soil. A number of these species are root herbivores and thus affect a range of above ground plant processes.

Any animal that inhabits the soil for a substantial portion of its lifecycle or spends a large part of its day underground may be said to habitate in the soil. This includes some snakes, moles, voles, lizards, earthworms and more.

Macrofauna modify the soil physical environment through digging and tunneling. They also perform and important first step as decomposers by consuming larger pieces of organic matter whole or by shredding them into smaller pieces that are easier for other decomposers to handle.


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