An introduction to

Soil

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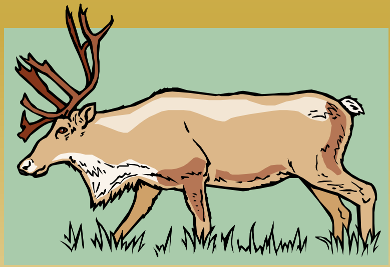

It’s always good to start with a definition . . .

Here is one rather standard definition of **soil**.

> The weathered outer layer of Earth's crust, composed of weathered rock materials and organic matter, with pores filled with air and water, supporting plants, bacteria, fungi, invertebrates, and other forms of life.

Termite mounds, Zimbabwe


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Agriculture – Nebraska, USA.


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Saline soils – California, USA


US Dept of Ag. Scott Bauer CC0

Aspects of soil health

Soil scientists consider three main aspects of soil health. The usual discussions of these are in the context of agriculture. A perfectly normal desert soil might be considered unhealthy from an agricultural perspective.

Physical health is a function of soil texture and structure as they relate to crop production. Soils might be in poor physical health because they are compacted or eroded, or because they have too much clay, or too much or too little water retention.

Chemical health is related to the availability of a variety of nutrients and the ability to retain nutrients, pH, salinity, and presence of any toxins.

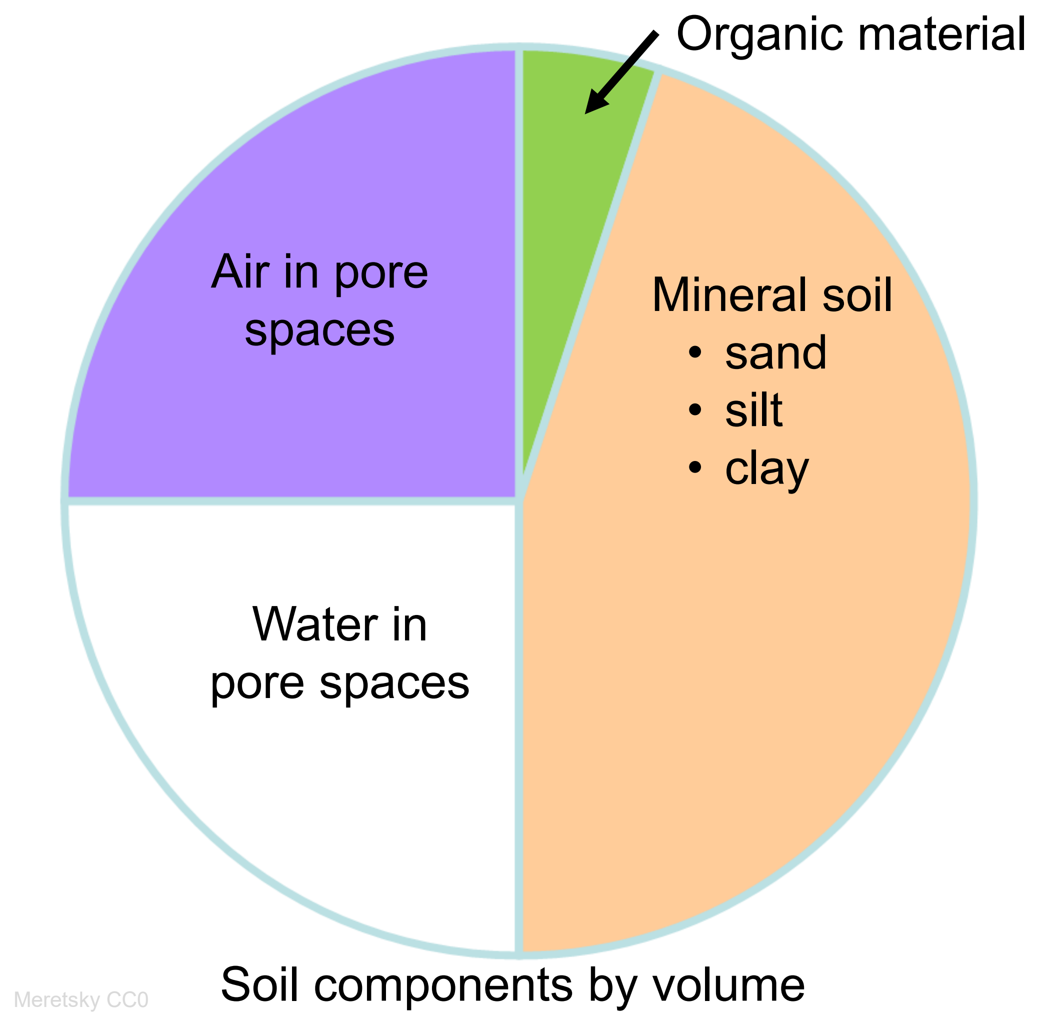
Biological health is a function of the soil ecosystem and its ability to support healthy crop growth. The community of soil organisms contribute to decomposition of dead material, nutrient cycling, GHG emissions and C sequestration, soil structure, water balance, support for plant growth, and suppression of plant diseases.

Physical and Chemical Aspects of Soil

Types of soil aggregates

USDA NRCS. Public domain.

Soil components

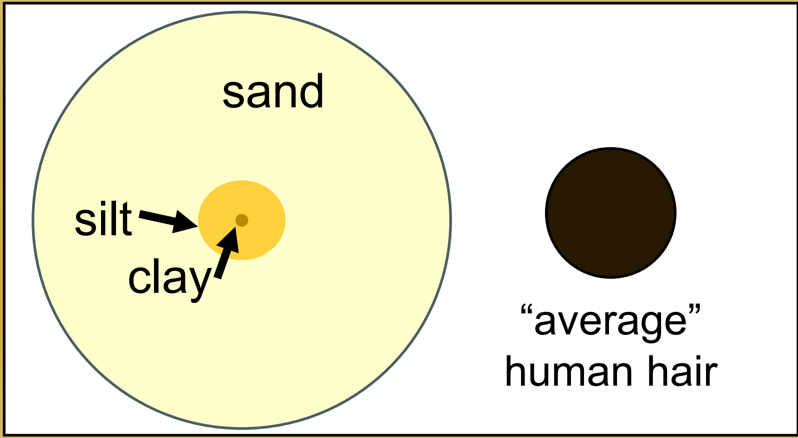


Soil components by volume

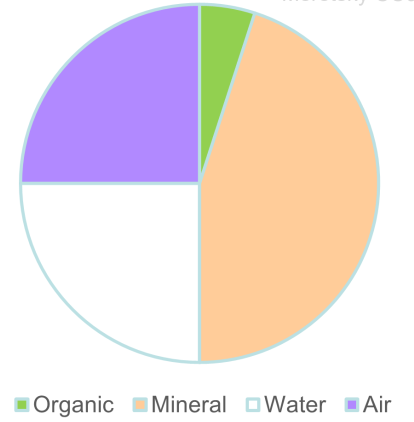
Soil components help to determine soil structure and texture.

The pie chart represents an agriculturally ideal soil. Soils in the real world vary considerably.

Natural soils that do not resemble ideal agricultural soils are not broken or dysfunctional. Many natural soil types are not good for agriculture!



Water travels very easily through sand, fairly easily through silt, and only slowly through clay.



Pore spaces in soil hold water and air. In an ideal agricultural soil, it’s about 50-50 water and air.

Roots need air to breath and plants need water for structural support and circulation of nutrients.

Mineral soil – clay, silt, and sand particles – is derived from the underlying bedrock and material blown or washed into the site. As it decomposes, it provides nutrients. Clay particles are slightly charged and so can lightly bind some nutrients, which helps to hold them against being carried away by water. Crumbs or *aggregates* of soil that contain a lot of clay can also enclose organic material, protecting it from decomposition. Page/slide 4 has images of some kinds of aggregates.

Organic material in soil is mostly from dead plants and a bit from dead animals, dead fungi, dead bacteria, etc. Organic material contains pore spaces and can absorb some water. It provides nutrients as it decomposes, and it also can lightly bind nutrients, as clay does.

Organic material, being organic, contains abundant C. C in soil is C that is not in the atmosphere, and some C - either because it is very difficult to decompose, like some kinds of wood, or because it has been trapped on or inside clay aggregates – stays in soil for long periods. Agricultural techniques that conserve C in the soil are part of nature-based solutions to climate change.

Parent material

Parent material is the rock from which the inorganic parts of soil derive.

Parent material may come from local bedrock or may be rock carried in by water, winds or glaciers. Mineral soil components (sand, silt, clay) may also be carried by water, wind or glaciers.

Different parent materials give different characteristics to the soils that form from them.

https://geology.utah.gov/map-pub/survey-notes/geosights/sand-mountain/

This sandstone from the deserts of Utah (USA) is weathered by wind and rain to the sand dune that lies at its feet.

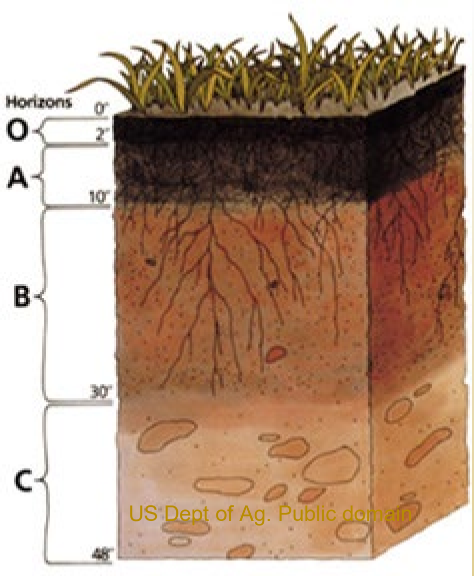

US National Park Service, Victoria Shauf, Public domain

The granite that underlies much of New England and eastern Canada degrades into a sandy, acid, soil. Acid soils leach nutrients and sandy soils are often dry. The best farming in this region is in river valleys that collect organic material that retains nutrients and water better.
Acadia National Park, Maine.

In contrast, limestone degrades into a nutrient-rich soil with a rather high clay component and a neutral or slightly basic pH. In Indiana, soils over limestone are often good for farming, but tend to be dry.
Limestone in McCormick’s Creek State Park, Indiana.


Meretsky, CC0

A soil profile is composed of horizons



US Dept of Ag. Public domain

Over long periods of time, undisturbed soils develop differentiated layers (horizons) that are most influenced by plant life and organic material at the top and horizons most influenced by the bedrock – the parent material – at the bottom. The full set of horizons is called a soil profile.

Different kinds of soil have characteristic profiles.

Deserts with sparse vegetation may have no obvious organic layer on top, while grasslands may have quite thick organic layers, for example.

As plants die, they create a layer of organic material which is mixed into the soil by burrowing mammals, earth worms, and other, larger soil life, as it decomposes.

Rainfall and melting snow dissolve out some of the nutrients and carry them deeper into the soil, along with dissolved minerals and fine clay particles.

Below the reach of most rainfall, the soil is mostly degraded mineral soil from the bedrock, with little organic material, few roots, and a less active soil community.

Disturbed areas such as mountainous terrain lack the stable conditions needed to develop soil profiles.

Soil components affect many aspects of soil

The recipe of sand, silt, clay, and organic material in a particular soil affects soil characteristics.

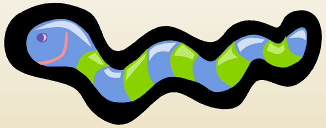
Water moves quickly into (**infiltration**) and through (**percolation**) sandy soils, but more slowly through clay soils.

Clay soil can hold the most water, but it holds it so tightly that plant roots cannot easily access much of it. A mix of sand, silt, clay and organic material – a loamy soil – holds less water, but more of it is accessible to plants, and these soils are better for farming.

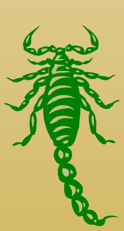
Organic materials can absorb a lot of water fairly quickly. Wetland soils, with their deep organic layers of rotting marsh vegetation, are useful for flood protection for this reason. During drought, they will dry more slowly, providing additional resilience.

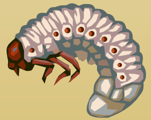
Clays and organic material can lightly bind positively charged nutrients such as potassium (K^+), calcium (Ca^{+2}), and magnesium (Mg^{+2}) ions. But in acidic soils, the binding sites that could hold nutrients are taken up by H^+ ions, and nutrients are more easily lost in rainwater and snowmelt. Acidic soils are nutrient-poor soils.

Sandy soils are typically acidic, and water also moves through them easily, rather than being absorbed. Because they are nutrient-poor and tend to dry quickly, they often don’t have a lot of organic material, which could otherwise help with both nutrients and water-holding capacity.



The life that is the party in the soil

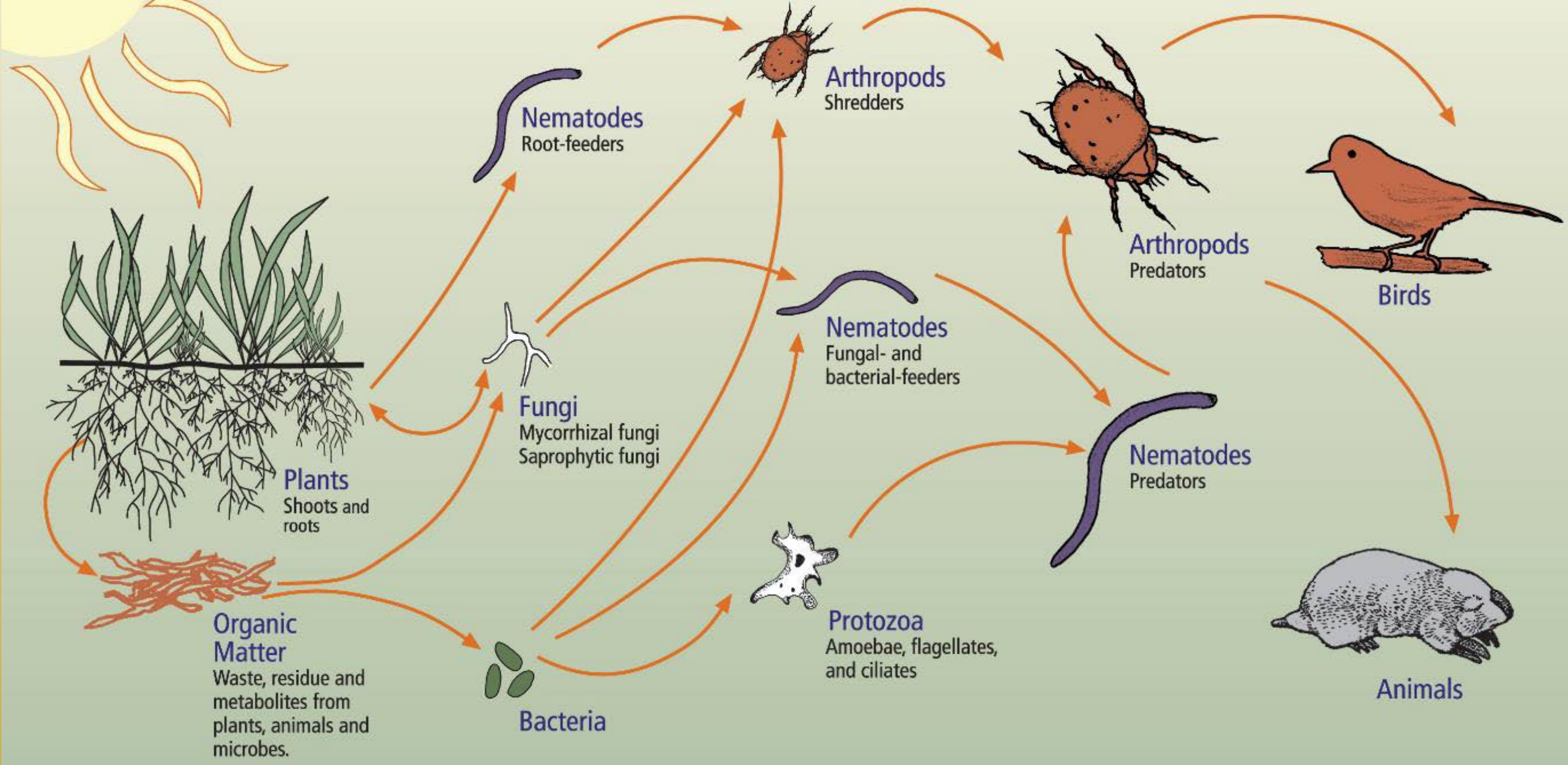




Biological Aspects of Soil

The Soil Food Web

Note: Arthropods are a major group of macroinvertebrates. Nematodes are mostly microinvertebrates. Note the multiple roles for both groups.



Plants
Shoots and roots

Organic Matter
Waste, residue and metabolites from plants, animals and microbes.

Nematodes
Root-feeders

Fungi
Mycorrhizal fungi
Saprophytic fungi

Bacteria

Arthropods
Shredders

Nematodes
Fungal- and bacterial-feeders

Protozoa
Amoebae, flagellates, and ciliates

Arthropods
Predators

Nematodes
Predators

Birds

Animals

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

The players – the big species

Species burrowing in or traveling in the soil that mix soil and leave fur, feathers, scales, skin, urine and feces – they “fluff up” the soil, maintaining pore spaces.

- Larger mammals, small mammals, amphibians and reptiles, burrowing owls, many insects and other macroinvertebrates.

Species traveling in the soil that eat things that live in or travel through the soil

- Voles and others – small mammals that eat roots
- Moles – small mammals that eat worms and other soft-bodied invertebrates
- Predator macroinvertebrates

Species that live in the soil and fragment and digest decomposing material

- Worms and other macroinvertebrates

Eastern mole eating an earthworm.
Arkansas Game and Fish Commission

Burrowing owl
http://www.birdphotos.com CC BY

Damage to roots from pine voles. Photo credit: Paul Bachi, University of Kentucky Research and Education Center, Bugwood.org

The players – the small species – microinvertebrates and microbes

These species live in the soil. Many require a moist environment and live in the water layer that lines pore spaces. This layer is maintained by capillary action – the same thing that causes water or blood to rise in a narrow-diameter, glass capillary tube. It is the last water to disappear under dry conditions, but it will disappear.

Species that live in the soil as predators

- **Nematodes** and single-celled protozoa such as amoebas

Decomposer microbes, including fungi that form visible threads (hyphae)

- Fungi (broadly pH tolerant), bacteria (intolerant of acidic soils)

Plant-partnering fungi that receive sugary exudates (secretions) from plant roots and act as root extensions to bring water and nutrients to plants, but also are decomposer fungi.

- **Mycorrhizal fungi**

Root herbivores

- Nematodes and other micro-invertebrates

Disease organisms

- Bacteria, fungi, viruses …

If you counted all the animals on earth, nematodes would be 80% of them. They are everywhere and play many roles.

More than 95% of plant species partner with mycorrhizal fungi, including most crops.

The Trustees of the Royal Botanic Gardens, Kew. CC BY

Fungal hyphae (the individual threads of fungi) form a mass called a mycelium.

Mycorrhizal fungi are connected directly to plant roots; they either create a sheathe around each individual root or growing directly into root cells. They deliver water and nutrients, including nutrients the fungi liberate from organic material by acting as decomposers.

The sheathing types of mycorrhizal fungi also protect roots against disease organisms.

Life helps to create soil from raw materials

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The tree roots that are slowly dismantling bits of one of the temples of Angor Wat in Cambodia and the lichens slowly etching their way into the boulder in the Canadian tundra secrete acids that eventually break down rock. Plant roots also slide into small cracks and then grow, which breaks rock faster.

Insects fragment larger pieces of organic material into smaller pieces. Fungi and bacteria decompose organic material into its mineral components. These decomposers are a vital part of nutrient cycles, allowing nutrients locked up in plant and animal tissues to be freed into the soil and water where they can be taken up by plants and continue to cycle through the world.

Soil life helps to determine soil structure, with **bioglues**. Earthworms excrete large volumes of processed organic matter that is coated in mucous – they process tons of soil per acre per year. Plant roots excrete sticky, sugary secretions to feed their fungal partners. Microbes also produce sticky secretions. All these sticky bioglues, together with the naturally sticky nature of clay particles in soil help to clump soil into the crumb-like structures called aggregates that we saw earlier.

Aggregate clumps provide some protection against erosion. They can also enclose organic material, protecting it from decomposition, and keeping C out of the atmosphere.

Plant roots and fungal hyphae help to bind soil, as well, providing additional protection against erosion.

Soil life also modifies texture structure by movement in soil. Earthworm burrows and the aggregates formed by earthworm “poop” help to maintain pores that bring air down to plant roots, allow water to infiltrate into the soil and percolate through the soil, and provide tracks for plant roots to follow, for faster, deeper growth and easier access to deeper soil water. Digging and burrowing by other species also loosens soil, preventing and reducing soil compaction and improving water-holding capacity and water movement. Good water retention with some drainage offers good protection against both drought and floods.

Previously mentioned microbial services to plants

Bioglues create soil structure, which reduce erosion, promotes soil aggregates and supports pore spaces that provide water and air and improve water retention.

Decomposition of organic material increases nutrient availability.

Mycorrhizal fungi increase nutrient and water availability for partner plants, which feed them sugars in exchange.

Some mycorrhizal fungi physically decreasing access to pathogens by covering plant roots.

Additional microbial services to plants

Some microbes can fix N_2 out of the atmosphere (N_2 is not useful to plants) into nitrogen compounds that plants can use.

“Healthy” microbes decrease levels of pathogens by competing with them for space and (some species) producing antibiotics.

Microbes increase soil C sequestration. First, they promote aggregates that enclose organic material and prevent decomposition, retaining the C in the soil. Second, the C in dead microbes tends to resist decomposition and is an important fraction of soil organic carbon.

Not all soils are hospitable to a wide range of soil organisms.

Many soil organisms need near-neutral or slightly basic soil conditions. Acidic soils, such as those of the boreal forests and some tropical forests, have lower soil biodiversity. Rates of decomposition are also lower, because the bacterial decomposers are not present. Fungi tolerate acidic soils and become the primary decomposers in such soils.

Soft-bodied, larger creatures like worms and salamanders need moist soil to survive and may die during drought.

Microscopic life like nematodes and microbes need some water in soil, too – just a layer along the boundaries of the pore spaces. Some microinvertebrates are more able than worms and salamanders to use dormancy or become encysted or produce eggs that tolerate severe conditions so that the species can persist at sites where water becomes unavailable.

We will discuss ecosystems functions at length, in the later chapters. The next slide reviews functions – ecological and other functions – that soils can perform.

Soil functions

Soils deliver ecosystem services that enable life on Earth

2015
International Year of Soils
fao.org/soils-2015

Carbon sequestration

Water purification and soil contaminant reduction

Climate regulation

Nutrient cycling

Habitat for organisms

Flood regulation

Source of pharmaceuticals and genetic resources

Foundation for human infrastructure

Provision of construction materials

Cultural heritage

Provision of food, fibre and fuel

Food and Agriculture Organization of the United Nations

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