

Soil Health

Uncle: Why do you collect compost in your garden and dig it into the soil? And why do you like worms so much?



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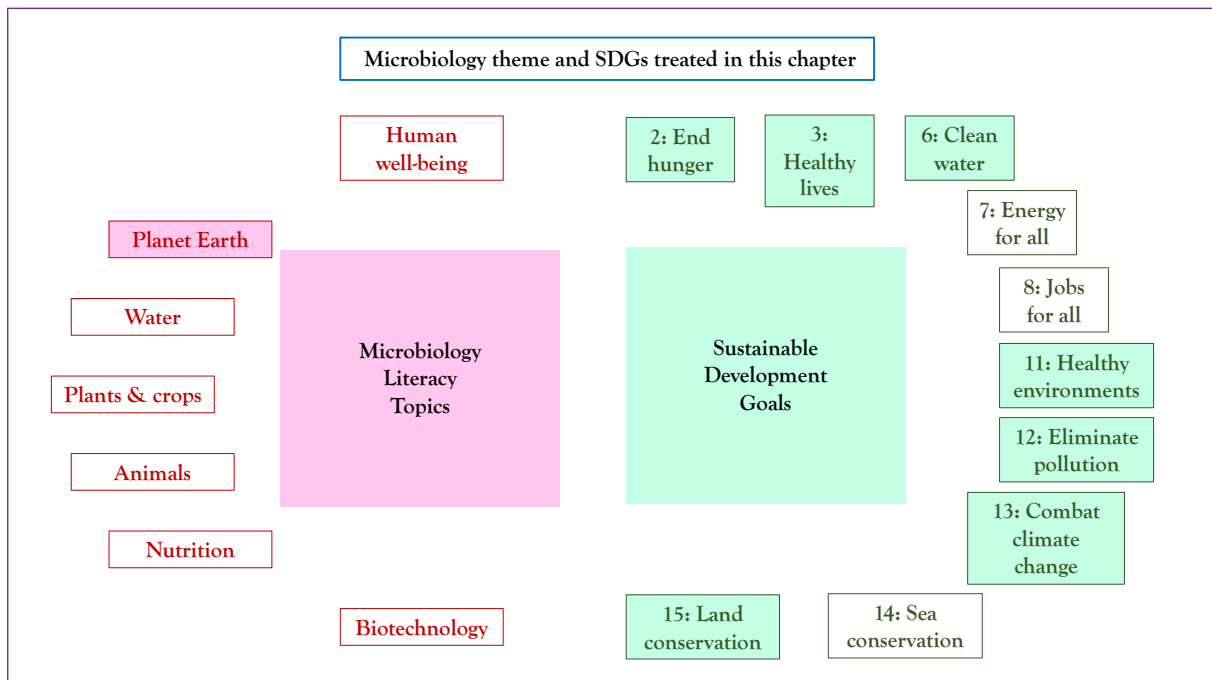
Soil Health

Storyline

Soil is often seen as dirt that simply provides a more or less stable substrate for plant roots. Microbes and soil fauna are rather known for their detrimental effects to the health of humans, animals and plants. The bad reputation of soil-dwelling organisms comes from unpleasant bacteria like *Bacillus anthracis*, the causal agent of anthrax, plant pathogenic fungi like several *Fusarium* species, which can cause dramatic losses in crop production, or pests like phylloxera, which destroyed most European vineyards in the late 19th century. The vast majority of the tremendous soil-borne biodiversity is, however, not dangerous to humans, animals or plants. On the contrary, biodiversity is essential for soil functioning, nutrient cycling and plant health. Knowledge of the complex processes and interactions between soil-borne organisms and the many other constituents of soils are essential for the protection of healthy soils and the prevention of losses through erosion, degradation, sealing and pollution. Many topics addressed in this chapter are dealt with in more detail in other chapters, which gives the reader the possibility to have a closer look at selected aspects of the complex soil life.

The Microbiology and Societal Context

The microbiology: soil microorganisms and their roles in soil ecosystem services; nitrogen cycling; plant:microbe symbioses; plant pathogens and suppressive soils; composting. *Sustainability issues:* soil health and food production; agrochemicals and human health; clean water; climate change.



Soil Health: The Microbiology

1. **Microbes are a fundamental constituent of soil.** All terrestrial ecosystems are built upon soil, which is a complex mixture of minerals, dead organic matter, water, gases and a multitude of organisms. All kinds of living beings thrive and prosper in the soil: microbes like archaea, bacteria, fungi and protists, animals like insects, worms and mammals (e.g. moles) and finally plants via their roots. Together, the organisms not only inhabit the soil but contribute to its generation, its turnover and its functions. A very small but nevertheless infamous fraction of soil microbes can cause human diseases, e.g. *Bacillus anthracis*, the causal agent of anthrax, or the fungus *Histoplasma capsulatum*, which can infect the lungs. Soil harbours, however, a tremendous biodiversity with extremely high species numbers and a high biomass. Soil microbial biomass can amount to ca. 2 tons per hectare in a temperate grassland, while earthworms and insects amount to ca. 15-20 kg/ha. And most of the soil-borne organisms do no harm to humans but support nutrient cycling and have positive impacts on plant growth.

2. **All soils are different.** When comparing a forest to a wheat field to a rice field, it becomes obvious that the soils are very different, but it is more extreme than this, because in fact it is difficult to find two soils that are the same. Differences not only occur horizontally between sites, but also vertically as you can see when you dig a hole into the ground. Often distinct horizons become visible with differences in texture and colour (see Figure 1). Each soil type has its own specific history. Parent rock material, water table, climate, vegetation, fauna, land management, soil dwelling organisms and their complex interactions, all contribute to the different soil types. Similar to plants, belowground organisms have preferences for certain soil types. Earthworms are found in neutral soils but are absent from the acidic soils in conifer forests. The edible scarletina bolete (current scientific name *Neoboletus erythropus*) is mainly found in deciduous or coniferous woodland on acidic soil, while the similarly-looking lurid bolete (current scientific name *Suillellus luridus*) prefers broad-leaved woodlands on calcareous soils. Both fungi form an underground mycelial network, which associates with roots of trees for the benefit of both partners - a symbiotic interaction known as ectomycorrhiza (Figure 1e). Consequently, ectomycorrhizal fungi thrive in forests but not in grassland. To allow a description and comparison of soils from all over the world, an international standard for soil classification has been developed, the so-called World Reference Base (WRB).

3. **Functions of soil.** Soil is mostly known as a carrier for the aboveground vegetation, which can be e.g. a forest, a garden or an agricultural crop. Soil also provides mineral nutrients to the plant. Processes of nitrogen turnover is of such an importance and complexity that it deserves a separate paragraph (see below), but many other minerals like phosphorous, potassium, calcium, magnesium etc. are stored in the soil and are used by plants, animals and microbes for their nutrition. Many of the minerals in soil need microbial activities to set free the nutrients they contain so that they can be taken up efficiently by plant roots. For example, most elements are stably bound in a crystal structure and are not soluble in water. By secretion of organic acids, microbes can solubilize phosphates and make them available to the plant. Ectomycorrhizal fungi can actually drill microscopic holes into stones and thereby directly contribute to the process of weathering. They obtain the energy they need for this through their symbiotic interactions with plant roots, which supply sugars from photosynthesis to the fungus. In turn, the plant gets minerals from the rocks. A more detailed description of nutrient cycles and the microbial contribution to these cycles is given in dedicated chapters (cycles of carbon, phosphorous, sulfur and metals, respectively). Life on earth is only possible with the microbial contribution to all nutrient cycles! Soil can, however, do much more than providing a growth substrate for plants.

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It provides us with a manifold of ecosystem services, which are often only recognised when malfunctions disrupt the services (see chapter on The Global Soil Crisis Issue).

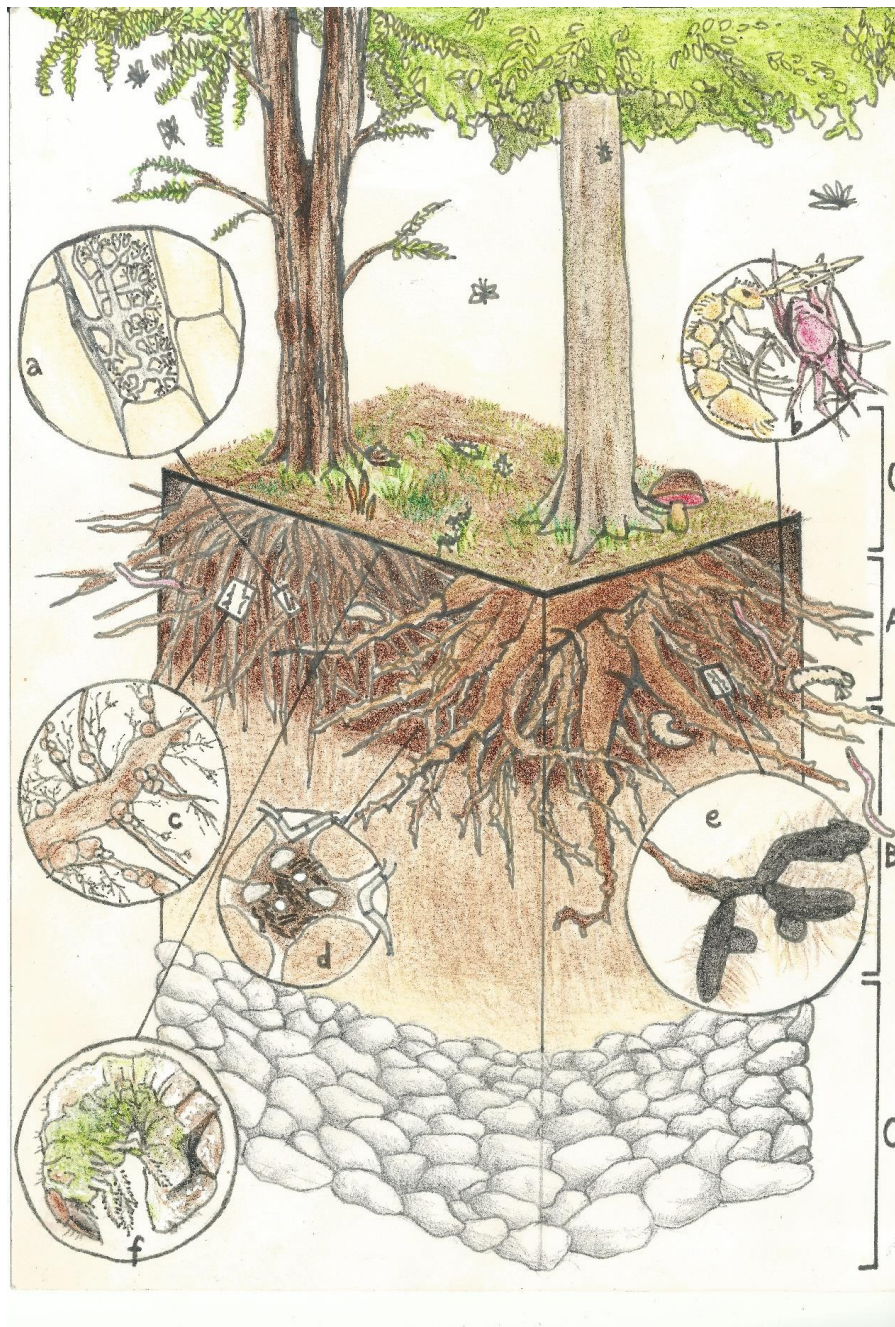


Figure 1. Soil is made of layers or horizons, as indicated by upper case letters to the right (O: organic layer; A: topsoil; B: subsoil; C: parent material). Soil is inhabited by a multitude of different organisms, e.g. earthworms, springtails and mites (insert b) and microorganisms like fungi and bacteria (d). Microbes promote aggregate stability by holding and gluing particles together, contribute to nutrient cycling and are engaged in a multitude of interactions with other organisms, e.g. as arbuscular mycorrhizal fungi (a), ectomycorrhizal fungi (e), as insect pathogens colonizing larvae (f) or as nitrogen-fixing rhizobia in root nodules (c). Drawing by Anastasia Zinner.

Soils can store huge amounts of water. And water is purified during its passage through soil by gravity. To do so efficiently, soils must have pores that are big enough that water can enter and small enough that it is retained by capillary forces. Ideally, mineral particles are glued together by organic material like plant litter that has been converted to humus by the action of insects,

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earthworms and microbes (Figure 1d). Further aggregate stability is provided by an extensive belowground network of fungal hyphae. Meanwhile the microbes purify the water by assimilating and converting substances that otherwise would contaminate the groundwater.

In mountainous areas, forests protect slopes from rockfall and landslides. Roots from healthy trees contribute to a major extent to slope stabilization, and they are supported by **understory** vegetation and by highly diverse microbial and soil faunal activities that stabilize the soil. Most ecosystem services (Table 1) are directly or indirectly linked to the activity of microbes and other soil dwelling organisms. Most microbes depend on plant **root exudates** or on input of organic matter, which can be decomposed and which thereby feeds the microbes. Consequently, it is often the humus content that is a good indicator for a healthy soil that can fulfil many of its functions.

Many contaminants like heavy metals or toxic chemicals have negative impacts on plants, microbes, insects, worms, and other organisms living in the soil (see chapters on Pollutants). Disruption of terrestrial ecosystems by severely inhibiting growth of plants and of belowground organisms can have detrimental effects leading to erosion, soil loss, contamination of nearby ecosystems (e.g. water bodies) etc. Unfortunately, some soils are also contaminated with toxic substances such as pesticides. Many soil microorganisms have the capacity to degrade recalcitrant compounds and are being used to remediate soils.

Table 1. An overview of important services provided by terrestrial ecosystems (Millennium Ecosystem Assessment)

Supporting	Provisioning	Regulating	Cultural
Habitat for organisms	Food	Climate Regulation	Aesthetic
Decomposition	Freshwater	Water regulation	Spiritual
Nutrient cycling	Fuel	Disease regulation	Educational
Soil formation	Wood, fibre	Pest regulation	Recreational
Primary production	Genetic resources	Water purification	
Water cycling	Medicinal resources	Erosion regulation	

4. ***Microbes keep the global nitrogen cycle turning.*** Details of the complex nitrogen cycle are depicted in Figure 2. Although the major part of our atmosphere consists of nitrogen, this element is a limiting factor for plant growth in most ecosystems. Atmospheric dinitrogen (N_2) is unreactive and hence unusable for most organisms on earth because of the strength of the triple bond between the two atoms. Some **archaea** and especially bacteria have, however, developed a system to reduce dinitrogen to ammonium, which can then be incorporated into biomass (e.g. N_2 -fixing rhizobia in **root nodules** of legumes, see Figure 1c and Figure 2). Once incorporated into biomass, nitrogen is distributed to other organisms along the food chain. When organisms die or plant litter falls to the ground, nitrogen-containing compounds like amino acids, amino sugars, proteins, nucleic acids, chitin etc. are decomposed and utilized by insects, worms and microbes, and nitrogen is eventually stored in more or less stable humus.

Parts of organically bound nitrogen can also be **mineralized** to ammonium, which either serves again as a nitrogen source for the synthesis of biomass, or it is converted to nitrate. The latter process is called **nitrification** and can only be performed by selected groups of archaea and bacteria. The oxidation of ammonia to nitrate supplies the nitrifiers with the energy necessary for the reduction of carbon dioxide (CO_2) to incorporate the carbon into biomass. This

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chemoautotrophic process of carbon dioxide assimilation is similar to the photosynthesis in plants, where the energy for the assimilation is provided by light.

Nitrate, the end-product of nitrification, can again be assimilated by microbes or plants, or it can be used under conditions of limiting oxygen by many microbes as an alternative electron acceptor to oxygen. Nitrate therefore allows respiration in the absence of oxygen. The nitrate is then converted to the potent greenhouse gas nitrous oxide (N_2O) or to dinitrogen (N_2) – which thereby closes the nitrogen cycle. Both end-products of nitrate respiration – nitrous oxide and dinitrogen – are gases and are therefore lost from soil ecosystems. The whole process is therefore consequently termed denitrification.

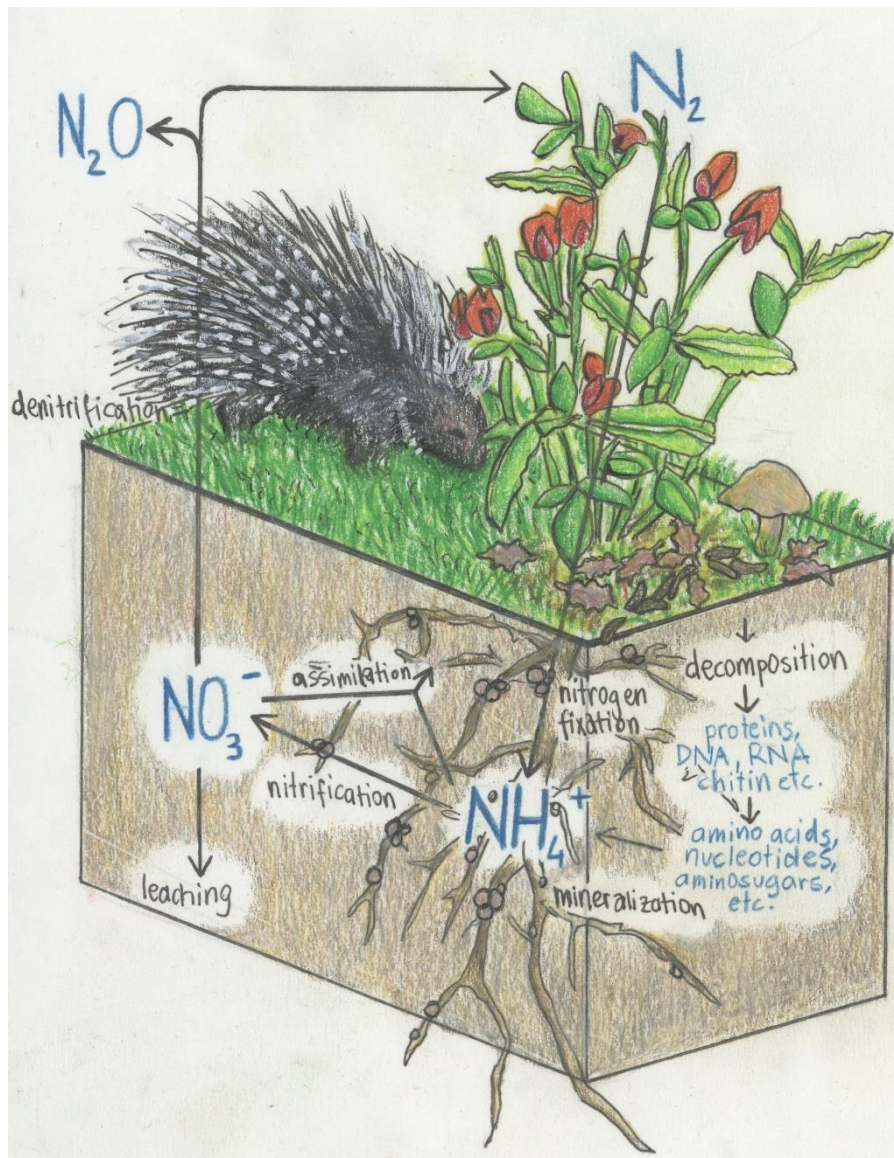


Figure 2. The Nitrogen Cycle. Not all details of the full nitrogen cycle are shown. Drawing by Anastasia Zinner.

Nitrogen that has been assimilated by the plant and is incorporated into biomass can enter the soil again after decomposition of plant litter by soil fauna, fungi, bacteria and archaea. Complex polymers like proteins or nucleotides are converted into their monomers and can

subsequently by mineralized to ammonium. Alternatively, plant biomass is eaten by herbivores, and the nitrogen is finally given back to the soil through the deposition of feces.

Nitrate that is not assimilated or denitrified may be translocated together with soil water to deeper soil layers and finally to the groundwater, from where it can enter drinking water supply systems or water streams and lakes. Unbalanced systems, where surplus amounts of nitrogen from manure or chemical fertilizers are added, which cannot be assimilated or converted by plants and microbes, result in groundwater contamination and eutrophication of ponds, lakes, rivers and coastal waters. Degraded land is not able to retain nitrogen. Considerable amounts of soil nitrogen are lost through denitrification to the atmosphere or through leaching to groundwater with all the negative consequences.

The nitrogen cycle is among the most complex nutrient cycles and is naturally linked to all other nutrient cycles, especially the carbon and the phosphorous cycles. In the absence of microbes, the nutrient cycles would come to a halt and so would life on earth.

5. Supporting plant health, nutrition and resilience. Many soil microorganisms are attracted by root exudates, which serve as an important nutrient source, and colonize the rhizosphere or even the interior of plants. These communities are highly important in providing plant nutrients or protecting the plant against pathogens or unfavourable conditions.

Some microbes engage in symbiotic interactions with plants: rhizobia can colonize root nodules of legumes (Figure 1c), where dinitrogen is converted to ammonium and incorporated into organic molecules. Arbuscular mycorrhizal fungi (Figure 1a) colonize the roots of many plants, including most crops like wheat, maize, tomatoes, potatoes etc. Some important crops remain however non-mycorrhizal, like members of the Brassicaceae (cabbage, rape seed etc.). Arbuscular mycorrhizal fungi grow into the soil surrounding the root. The fine fungal hyphae have better access to nutrients and they are especially effective in mining for phosphate. Mineral nutrients are transported to the plant root, where they are exchanged against carbohydrates from the plant. By improving plant nutrition, arbuscular mycorrhizal fungi can also increase plant resistance against abiotic and biotic stresses, like drought or pathogen attack.

Most trees in temperate and boreal forest ecosystems form a so-called ectomycorrhiza (Figure 1e) with a highly diverse group of fungi. Most of the year, the hyphal network of ectomycorrhizal fungi remains inapparent under the surface of the soil. But, under favourable conditions, fruiting bodies are formed by some fungi to produce high numbers of spores that can be dispersed by the wind. Some fruiting bodies of ectomycorrhizal fungi are among the most delicious mushrooms, like the edible bolete (*Boletus edulis*) and the chanterelles (yellow: *Cantharellus cibarius*; black: *Craterellus cornucopioides*) as well as non-edible or even toxic fungi.

Soil-borne plant pathogens and suppressive soils. Soil-borne microbes mostly come to the public attention as pathogens of humans, animals or plants. In agriculture, fungal pathogens can cause severe losses, and some of them are soil-borne and are especially difficult to eradicate. The fungus *Gaeumannomyces graminis*, which causes take-all disease in wheat, barley, rye and other related grasses, is one of these examples. It starts from infecting the root and then grows inside the plant upwards. Most of its lifetime the fungus is therefore independent of nutrients in the soil and instead directly takes all the nutrients from the plant. During propagation inside the plant, the fungus starts blocking the vessels and infected plants exhibit reduced growth and soon die. Monocultivation of susceptible crops initially leads to an increase in diseased plants, as *Gaeumannomyces graminis* can build up a bigger inoculum in the soil from infected plant debris. After a few years, often a reduction in disease incidence is observed, the so-called take-all disease decline. Soon after the initial description of take-all disease decline, it became clear that soil-borne microbes are responsible for the observed effect. In a series of field and laboratory experiments it was found

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out that fluorescent pseudomonads (Gram-negative bacteria), which can produce the antibiotic 2,4-diacetylphloroglucinol (DAPG), are the main players in disease reduction. *Geaumannomyces graminis*, in turn, was shown to be especially sensitive to DAPG. Soils that inhibit the infectious cycle of *Geaumannomyces graminis* are called **disease-suppressive** soils. Interestingly, it was observed that in these soils the pathogen is still present but causes less disease manifestation on wheat or other susceptible grains.

6. **Composting.** During growth, plants not only fix carbon from atmospheric CO₂ in their biomass but also accumulate mineral nutrients like nitrogen, potassium, magnesium etc. After death of the plant or parts of the plant (e.g. leaves, in leaf litter), the biomass serves as a food and energy source for many organisms including microbes. Arthropods like beetles and their larvae, ants, springtails etc. begin the process of litter disassembly. Fungi are especially well adapted to the breakdown of complex organic molecules like lignin, cellulose, hemicellulose, chitin, starch etc. by a highly efficient protein secretion system. Enzymes for the digestion of the polymers are secreted to the environment and the small molecules resulting from the breakdown are subsequently taken up into the cell. Bacteria and archaea on the other hand are especially well adapted to the use of nutrients even at very low concentrations due to highly efficient uptake systems.

Earthworms mix partially decomposed plant debris with mineral particles and redistribute it throughout the soil. The earthworm gut constitutes a specific environment, where archaea, bacteria, fungi, protists and even nematodes thrive. Constant humidity, low oxygen content and high concentrations of organic substances promote the growth of a specific subset of microbes, including amongst others denitrifying, fermentative bacteria. It is actually the microbes in the gut that break down the organic matter ingested by the earthworm. The important contribution of earthworms to the process of soil formation has already been acknowledged by Charles Darwin in a book that provides a detailed description and interpretation of 40 years of observations and experiments.

Through the concerted action of soil-borne organisms, major nutrients in the plant debris become mineralized and are thereby made again available to plants. A substantial fraction is transformed into microbial biomass, and can enter into more or less stable humus pools, which as such can fulfil several functions like carbon storage, **soil aggregate** stabilization, water storage etc.

Decomposition is a natural process, which occurs wherever plant material accumulates, albeit at highly different rates depending on the climatic conditions. Under warm and humid conditions in the tropics it is an extremely fast process, while in the boreal forests it is extremely slow. Recently, an easy method has been developed, through which decomposition of plant material can be easily determined via the so-called Teabag index. Commercially available teabags are buried in the ground. After incubation for three months the teabags are recovered, dried and weighed. The weight-loss gives a good estimate of the microbial decomposition process.

Composting can, however, also be carried out under controlled conditions. Some companies are specialized in this business and run composting plants, where waste products from agriculture are converted to substrates that can be used for the growth of plants and as **fertilizer**. During the composting process, the high microbial activity produces heat that leads to an increase in temperature. Only specially adapted thermophilic microbes can survive these conditions. Most gardens also have a designated corner, where plant litter is collected and allowed to rot until it is converted to fertile compost, which can be distributed to flowers and vegetables to improve their growth. Nowadays composting is even done in households in the form of **vermicomposting**, which can convert kitchen garbage into a valuable fertilizer for pot plants.

Relevance for Sustainable Development Goals and Grand Challenges

Considering the important role of microorganisms for soil health and functioning, soil microbiology relates to a number of SDGs as outlined below:

- **Goal 2: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.** Healthy soils are key for a sustainable food production, that minimizes soil erosion, land degradation and pollution of soil, water and atmosphere. Sustainable agriculture has the potential to nourish the growing population all over the world with healthy food, but is based on the availability of healthy soils.

- **Goal 3: Ensure healthy lives and promote well-being for all at all ages.** Healthy soils reducing the necessity to apply harmful agrochemicals are a key requirement to provide a healthy, plant-based diet.

- **Goal 6: Ensure availability and sustainable management of water and sanitation for all.** A substantial part of the world population obtains drinking water from groundwater resources. The passage of surface water through soil leads to purification and removal of unwanted contaminants (e.g. nitrate, pesticides etc.) by microbial activities. Reducing the input of harmful agrochemicals will also reduce leaching of harmful compounds into groundwater and thereby overall improve water quality.

- **Goal 11: Make cities and human settlements inclusive, safe, resilient, and sustainable.** Urban farming and gardening are current trends improving the climate in cities and contributing to local food production. Also here, healthy soils hosting diverse microorganisms are important to enable sustainable and chemical-free production of food.

- **Goal 12: Ensure sustainable consumption and production patterns.** Healthy soils, in which microorganisms are key elements, are key to sustainable production and consumption. Sustainable agricultural production is based on microbial activities and interactions such as nutrient cycling, organic matter build-up, supporting plant health, nutrition and resilience.

- **Goal 13: Take urgent action to combat climate change and its impacts** by regulating emissions and promoting developments in renewable energy. Soils are both sources and sinks of potent greenhouse gases (e.g. carbon dioxide, methane, nitrous oxide) through the action of microbes. The production of inorganic fertilizers or pesticides is highly energy-demanding and reducing their application will contribute to combating climate change. Furthermore, the availability of healthy soils will be key to resilient plant production under challenging situations such as under conditions affected by climate change

- **Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.** Microorganisms are a key element in maintaining important soil functions, such as nutrient cycling or the build-up of soil structure. Microbial diversity in soil is therefore crucial for promoting the sustainable use of terrestrial ecosystems and to prevent land degradation. Reforestation after major disturbances, or the reclamation of degraded land, often makes use of ectomycorrhizal fungi that promote survival of young trees under challenging conditions.

Potential Implications for Decisions

1. *Individual*

a. Which products do I buy in the supermarket? Considering soil health aspects, including soil biodiversity, may lead to buying products produced by sustainable or organic farming practises making best use of microbial activities.

2. *Policy*

a. Does our pricing system consider the benefits related to sustainable production and maintenance of soil microbial diversity? Or in other words does the consumer have to pay for non-sustainable production leading to environmental damage and a reduction in biodiversity (including soil microorganisms).

b. Loss of soil health and microbial diversity / functioning related to greenhouse gas emission

c. Loss of soil health and microbial diversity / functioning related to losing resilience of the plant-soil system (e.g. to environmental stress or disturbance)

Pupil participation

1. *Class discussions on how different food products are produced* and what are the implications on soil microbial diversity and functioning

2. *Pupil stakeholder awareness*

a. Discuss different agricultural soil treatments (tillage, application of compost etc.) and the consequences on soil microorganisms

b. Discuss about plant disease-causing and beneficial or important microorganisms

c. Discuss about SOM (e.g. litter degradation in autumn)

3. *Exercises*

a. Make your own compost and discuss processes taking place

b. Bury litter teabags in different soils and observe degradation (www.teatime4science.org)

c. Sample legume plants (e.g. soybean) from a field and have a closer look at nodules containing active N₂-fixing bacteria

The evidence base, further reading and teaching aids

Soil Borne Human Diseases:

<https://publications.jrc.ec.europa.eu/repository/bitstream/111111111/22432/2/lbna24893enn.pdf>

Soil types: <http://www.fao.org/3/i3794en/I3794en.pdf>

Suppressive soils: https://apsjournals.apsnet.org/doi/10.1094/PHYTO-03-17-0111-RVW?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%20%20pubmed

Exercises: <https://www.sciencebuddies.org/>

Soil Microbiology and soil health: https://www.youtube.com/watch?v=3-fFpd_7Egw

Soil Health, microbial diversity and plant growth: <https://www.youtube.com/watch?v=bbNRvltavfY>

Living in the soil: <https://www.secs.com.es/wp-content/uploads/2020/10/Living-in-the-soil-English-2016.pdf>

Soil science in school: [IUSS - IUSS GO TO SCHOOL \(iuss-goes-to-school.org.mx\)](http://iuss-goes-to-school.org.mx)

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Scoop on soil: [Scoop on Soil \(illinois.edu\)](http://soilillinois.edu)

Soils for kids: [Home | Soils 4 Kids](http://soils4kids.org)

Big Compost Experiment: <https://www.bigcompostexperiment.org.uk>

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Glossary

Alternative electron acceptor: an electron acceptor is a chemical entity that accepts electrons transferred to it from another compound. It is an oxidizing agent that, by virtue of its accepting electrons, is itself reduced in the process. A frequent electron acceptor is oxygen, alternative electron acceptors include, nitrate, iron (III), manganese (IV), sulfate or carbon dioxide.

Arbuscular mycorrhizal fungi: are symbiont fungi which penetrate the cortical cells of plant roots and show several plant beneficial activities. Small, tree-like structures - so-called arbuscules (see Figure 1a) - are formed by the symbiotic fungus inside root cortical cells for exchange of nutrients between the

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Archaea: represent a specific domain within Prokaryota (like Bacteria), have a similar cell size as bacteria, but possess unique genes and metabolic pathways, which are more similar to Eukaryota
Assimilated: assimilation is referred to as the process in which the living organisms integrate the nutrients from various external resources and utilizes them to satisfy the energy demands required to stay alive.

Calcareous soil: is a soil that has high levels of both magnesium carbonate and calcium that reduce acidity in the soil. Calcareous soil can have a coarse to fine texture as well as differing levels of sand, silt or clay.

Coniferous woodland: is predominantly made up of conifer trees

Ectomycorrhiza: a type of mycorrhiza, typical of temperate and boreal trees, in which the symbiotic fungus forms a layer on the outside of the roots of the plant (see Figure 1e).

Eutrophication: a process by which pollution from such sources as sewage effluent or leachate from fertilized fields causes a lake, pond, or fen to become over-rich in organic and mineral nutrients, so that algae and cyanobacteria grow rapidly and deplete the oxygen supply

Deciduous woodland: contain trees with broad leaves such as oak, beech and elm

Denitrification: is a microbially facilitated process where nitrate (NO_3^-) is reduced and ultimately produces molecular nitrogen (N_2) through a series of intermediate gaseous nitrogen oxide production

Disease-suppressive soil: soil in which plant pathogens cause little or no disease due to activities of the resident microbial community

Fertilizer: is a chemical or natural substance that is added to the soil or plants to supply them with nutrients.

Humus: is the part of soil which consists of dead plants that have begun to decay

Protist: is any eukaryotic microbe that is not an animal, plant or fungus

Mineralized: mineralization refers to the conversion of organic substances to inorganic derivatives

Mycelial network: mycelium is the vegetative part of a fungus or fungus-like bacterial colony, consisting of a mass of branching, thread-like hyphae, which usually form a network.

N_2 -fixing rhizobia: specialized symbiotic bacteria, which are able to fix the nitrogen from the air and convert it to ammonia.

Nitrification: the oxidation of an ammonia compound into nitric acid, nitrous acid, or any nitrate or nitrite, mediated by specialized bacteria or archaea

Nutrient cycling: in the nutrient cycle, the usage of the nutrients in the environment, their movement and the processes their recycling are described. Important nutrients include carbon, oxygen, hydrogen, phosphorus and nitrogen are required to be recycled for the existence of organisms.

Pesticides: chemical substances which are applied to protect the plant from disease and pests

Rhizosphere: is the narrow region of soil or substrate that is directly influenced by root secretions

Root exudates: are compounds released by plant roots containing sugars, amino acids and other compounds providing nutrients to soil microorganisms

Root nodule: a swelling on the root of a leguminous plant, such as the pea or clover, that contains N_2 -fixing rhizobia (see Figure 1c)

Soil aggregate: is made up of soil particles of different sizes held together by both the attraction of soil particles and the binding of organic matter between soil particles

Soil degradation: is the decline in soil condition caused by its improper use or poor management, usually for agricultural, industrial or urban purposes

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Soil erosion: is the displacement of the upper layer of soil; it is a form of soil degradation. This natural process is caused by the dynamic activity of erosive agents, that is, water, ice (glaciers), snow, air (wind), plants, animals, and humans. In accordance with these agents, erosion is sometimes divided into water erosion, glacial erosion, snow erosion, wind (aeolean) erosion, zoogenic erosion and anthropogenic erosion

Soil horizon: is a layer parallel to the soil surface whose physical, chemical and biological characteristics differ from the layers above and beneath

Soil pollution: is the presence of toxic chemicals (pollutants or contaminants) in soil, in high enough concentrations to pose a risk to human health and/or the ecosystem

Soil sealing: is the destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.)

Sustainable Development Goals: were adopted by all United Nation Member States in 2015 as a universal call to action to end poverty, protect the planet and ensure that all people achieve peace and prosperity by 2030.

Terrestrial ecosystem: is a land-based community of organisms and the interactions of biotic and abiotic components in a given area.

Understory: comprises plant life growing beneath the forest canopy without penetrating it to any great extent, but above the forest floor.

Vermicomposting: is a type of composting in which certain species of earthworms are used to enhance the process of organic waste conversion and produce a better end-product. It is a process utilizing microorganisms and earthworms. Earthworms feeds the organic waste materials and passes it through their digestive system and gives out in a granular form (cocoon) which is known as vermicompost.

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