Soil- An Introduction

Soils are complex mixtures of 45% minerals, 25% water, 5% organic matter and 25% air with a diverse range of organisms and materials of biological origin. Soil is known as skin of earth capable of supporting plant life and is vital to life on earth. Organic materials in and on the soil are broken down and transformed – mainly by soil organisms – into nutrient elements, which are, in turn taken up by plants and micro-organisms. Soils are one of the main global reservoirs of biodiversity, more than 40% of living organisms in terrestrial ecosystems are associated during their life-cycle directly with soils. It has been estimated that 1 gram of soil contains up to 1 billion bacteria cells, comprising tens of thousands of taxa, up to 200 metres of fungal hyphae, and a wide range of organisms including nematodes, earthworms and arthropods.

Fig.1 Amount of microorganism in one gram of soil

Soil biodiversity is defined as the variety of life belowground, from genes and species to the communities they form, as well as the ecological complexes to which they contribute and to which they belong, from soil micro-habitats to landscapes (FAO, 2020). Soil biodiversity enables self-perpetuating ecosystem functions that fuel specialized processes such as:

- soil structure maintenance;
- nutrient cycling;
- carbon transformations; and
- the regulation of pests and diseases.

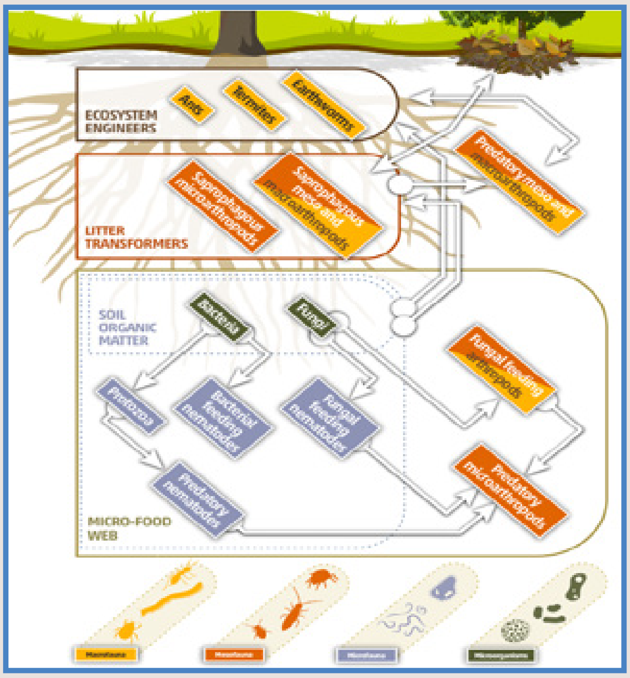

Fig.2 Classification of soil microorganism

The nutrients required for the plant travel through multiple soil layers by means of foragers, tunnelers, and ground-nesting insects including beetles, ground-nesting bees, ants, and termites, and detritivores like nematodes, springtails, earthworms, millipedes, and woodlice. These organisms transform decaying material and minerals into usable forms, cycle nutrients, and increase soil fertility.

- Soil organisms vary from 20 nm to 20-30 cm in body width and are traditionally divided into four size classes:
- Microbes (20 nm to 10 µm) including virus, bacteria, Archaea, fungi
- Microfauna (10 µm to 0.1 mm) like soil protozoa and nematodes
- Mesofauna (0.1 mm to 2 mm) are soil microarthropods (e.g., mites, springtails, enchytraeids, apterygota, small larvae of insects).
- Macrofauna (2 mm to 20 mm) are large soil invertebrates (e.g., earthworms, woodlice, ants, termites, beetles, arachnids, myriapods, insect larvae) and Megafauna (greater than 20 mm) are vertebrates (mamalia, reptilian and amphibia). They create spatial heterogeneity on the soil surface and in its profile through movement.

Soil Microorganisms and Microfauna

Soil microorganisms are bacteria, actinomycetes, fungi, algae, protozoa and viruses present in the soil. Their interaction influences soil fertility. The loss in the soil microbial diversity results in a significant decrease in potential nitrification and denitrification activities, greenhouse gas fluxes and pesticide mineralization capacity. The reduction in microbial diversity has been shown to impact on soil respiration.

Bacteria: Bacteria are organisms with the single-celled, therefore, microscopic. It is estimated that the Earth hosts approximately 2.5×10^{30}cells. They are decomposers, eating dead plant material and organic waste. By doing this, the bacteria release indispensable nutrients for life that other organisms could not access. The bacteria do this by changing the nutrients from inaccessible to usable forms. Bacteria play key roles in carbon transformations and nutrients cycling, improving the soil fertility and regulate soil structure and create healthy soil environments (biological regulation) to protect plants from pathogenic agents and increase crop yields. Symbiotic and free-living (non-symbiotic) nitrogen fixing bacteria (Rhizobium), found in most (undisturbed) soil types, can convert atmospheric nitrogen to ammonia, which nitrifiers convert into nitrate that is readily assimilated by plants.

Actinomycetes: Actinomycetes are soil microorganisms like both bacteria and fungi, and have characteristics linking them to both groups. Actinomycetes give soil its characteristic smell. *Actinomycetes* secrete antibiotics that kill or inhibit the growth of plant pathogens, providing a healthy environment for plant growth.

Fungi: Fungi are a highly diverse group of organisms with estimates on the total number of species ranging from 0.8 to 3.8 million. Soil fungi have fundamental ecological roles as decomposers, mutualists, or pathogens of plants and animals. Fungi drive soil carbon cycling and mediate mineral nutrition of plants in both natural and anthropogenic ecosystems. Along with the main functions of carbon transformations, nutrient cycling, soil structure formation and biological regulation, fungi are also key players in the fight against climate change and land degradation. Some fungi can attach themselves to plant roots in a beneficial relationship called mycorrhizal. The fungi help the plant by giving it needed nutrients and the fungi recieve carbohydrates from the plant; the same food that plants give to humans. On the other hand, fungi can recieve food by being parasites and attaching themselves to plants or other organisms for exploitation. Both mutualistic symbionts (mycorrhizal fungi) and saprophytic fungi living at the root-soil interfaces, the rhizosphere, or in the plant-associated soil, are recognized as essential drivers of nutrient cycling, availability and capture. Saprotrophic fungi are recognized for their abilities to propel nitrogen fixation and phosphorus mobilization, two fundamental processes for sustaining plant productivity.

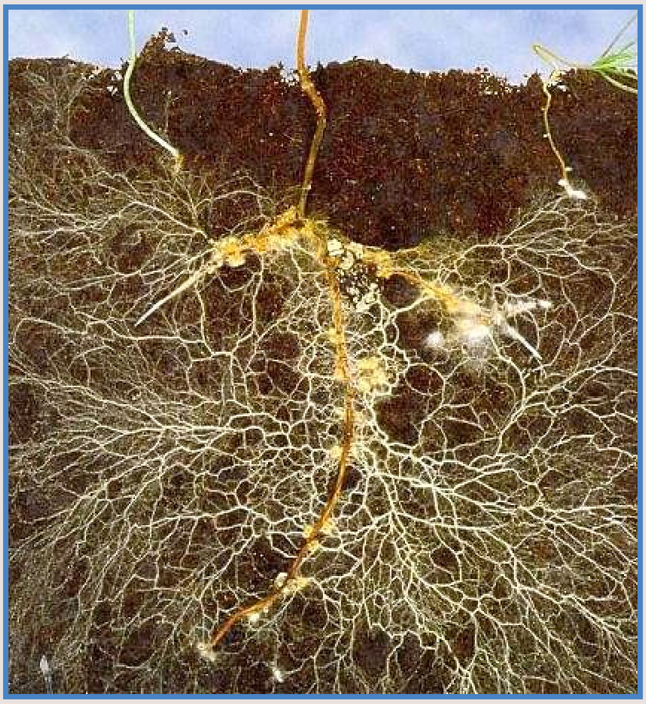

Fig.3 Soil fungus

Algae: Algae are microscopic free-living, symbiotic organisms capable of oxygenic photosynthesis. Algae are present in most of the soils where moisture and sunlight are available. In temperate region, algal biomass can reach up to 500 kg ha^{-1}. Algae play an important role in the fixation of CO^2 and the production of organic carbon compounds as well as in the release of O_2 into the soil. Algae are also involved in the biomineralization of carbon dioxide by calcium carbonate precipitation. The algae contribution of nitrogen-fixing to the soil nitrogen pool reaches 30 kg/ha. Algae excrete a variety of substances (including enzymes, growth factors, phytohormones, toxins, and antibiotics) which influence the development of other soil organisms.

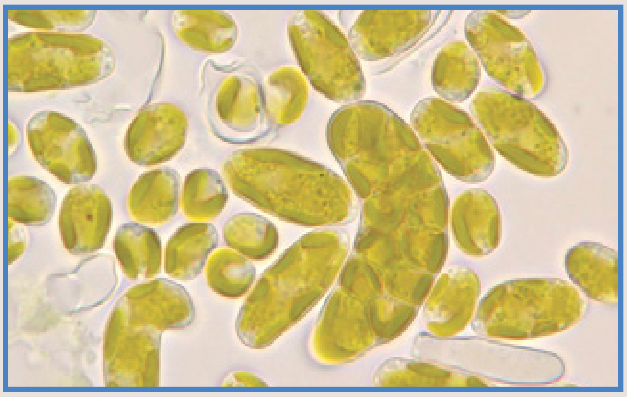

Fig.4 Soil Algae

Protozoa: These are colourless, single-celled animal-like organisms. They are larger than bacteria, varying from a few microns to a few millimetres. Their population in arable soil ranges from 10,000 to 100,000 per gram of soil and they are abundant in the surface soil. Protozoa derive their nutrition from feeding or ingesting soil bacteria and, thus, they play an important role in maintaining microbial/bacterial equilibrium in the soil. Some protozoa have been recently used as biological control agents against organisms that cause harmful diseases in plants.

Viruses: Soil viruses are of great importance, as they may influence the ecology of soil biological communities through both an ability to transfer genes from host to host and as a potential cause of microbial mortality. Consequently, viruses are major players in global cycles, influencing the turnover and concentration of nutrients and gases. Viruses rely on host cell machinery for replication, such that a free viral particle is biologically inert and subject to biological and environmental degradation. Evidences has shown that virus supports direct and indirect contributions to soil carbon and nutrient cycling.

Protist: - A protist is any eukaryotic organism that is not an animal, plant, or fungus. Soil protists include amoeba, ciliates and flagellates. Their numbers can exceed hundreds of thousands of individuals in one gram of soil. Protist predation releases nutrients (especially nitrogen) from bacteria, making it available for plant uptake. Protists have been proposed as a potential biocontrol agent, for instance by reducing the abundance of plant pathogens.

Nematodes: - Nematodes (or roundworms) are the most abundant group of animals in soils and in aquatic systems, representing around 80 percent of all animals on Earth. Nematodes are ubiquitous in aquatic sediments, glaciers and soils worldwide (Kionte and Fitch, 2013), with an estimated global population of 4.40 x 10^{20} individuals in soils alone. Nematodes fill a number of trophic roles in soils, including as bacterivorous and/ or fungivorous grazers, predators of other nematodes and smaller animals, plant-feeders, omnivores and parasites of both animals and plants. Nematodes are important in soil carbon (C) dynamics. Globally, it is estimated that soil nematodes respired 110 Mt carbon which is equal to approximately 15 percent of the carbon released from fossil fuels. Studied shows that nematodes significantly increases net N (+25 percent) and net P (+23 percent) availability, as well as plant biomass production (+9 percent) compared to their absence.

Fig.5 Soil Nematode

Mesofauna

Mites:- The free-living soil mites (**Acari**) are highly diverse in soil systems, with roughly 80,000 species. The total abundance of mites varies among biomes from around 20,000 to 200,000 individuals per m^2. Mites are generally found in higher numbers in soils with considerable amounts of organic matter and prefer soils with higher soil moisture content and lower pH. Predatory mites are the most important predators of

Fig.6 Soil Mite

the soil micro- and mesofauna, feeding voraciously on nematodes, enchytraeids and microarthropods. Mites enhance the growth of fungi in leaf litter, stimulate the soil enzyme activity and the recovery of soil microbial communities. Mites can accumulate heavy metals (Zn, Cu, Cd, Pb) to very high internal concentrations.

Springtails:- Springtails (Collembola) are microarthropods that are just a few millimetres in size and are commonly named springtails because of an obvious forked jumping organ called a furca that helps them jump to avoid predators. Springtails are among the most abundant arthropods in the world, and in most terrestrial ecosystem they occur at densities between 10 000 and 100,000 individuals per square metre. There are around 8,000 described species world-wide and the biomass is usually in the range of 80–200 mg m^{-2} . Springtails directly and indirectly regulate the soil microbial activity and nutrient cycling. They directly accelerate organic matter decomposition by ingestion of organic material (such as litter and animal excrements) and by producing faeces forming the humus. Springtails play a role in transferring litter-derived C into the soils through interactions with the fungal assemblages. Springtails has contrasting effect on the distribution of calcium, magnesium and potassium within the soil layers. Springtails can stimulate fungal growth, induce the increase of fungal decomposing activity in soils and increase the mobilization of nutrients that were locked in fungal biomass.

Fig.7 Soil Springtails

Macrofauna

Ants:- Ants comprise a single insect family (Formicidae), sister to the Apoidea (honeybees), within the insect order Hymenoptera. There are some 20,000 ant species accounting for around 10% of the planets animal biomass, from which some 15,000 are described. It forms a cavity in soil with numerous chambers. Ants are effective predators and modify soil chemical properties by increasing the amounts of organic matter, P, K and N in the mounds and physical properties by transporting food and soil materials during feeding and mound and gallery construction. Ants are major predators of

Fig.8 Ant

small invertebrates, and they provide several ecosystem services in agrosystems, such as plant pollination, soil bioturbation, bioindication, and the regulation of crop-damaging insects.

Termites:- Termites constituting up to 75% of the insect biomass and 10% of all terrestrial animal biomass in the tropics. Termites have been considered as tropical analogs of earthworms since they process large amounts of litter. Termites are categories as wood-feeding species, plant- and humus-feeding species, and fungus growers. Termites play a very important role in the soil formation and decaying of dead plant material and thereby nutrient circulation. Soil feeding mites consume organic matter mixed with the mineral particles and the plant that are not degraded by the microorganism. Termites consume up to 1,500 kg ha^{-1} dry litter annually, including most woody litter, and a staggering 50% of grass litter and a considerable amount of mammalian dung. Hence, they have substantial impacts on decomposition, and consequently carbon and nutrient cycling in the agroecosystems. Termites play an important role in the decomposition of litter on the ground, the regulation of soil structure, soil organic matter (SOM) and nutrient cycling, water dynamics, soil erosion, plant growth, and overall biodiversity

Fig.9 Termites

Earthworm:- Arable soils typically contain 150–350 earthworms per m^2 and high populations (>400 earthworms per m^2) are linked to significant benefits in plant productivity. Earthworms alone can construct up to 8,900 km of channels per hectare, decreasing soil erosion by 50% via increased soil porosity and water infiltration. Earthworms can produce 40–250 tonnes of casts per hectare per year. Some can produce up to 2,500 tonnes of casts per hectare per year. Earthworms pierce the ploughing pan, so improving water infiltration and offering new paths for root penetration.

- Earthworms can be classified as epigeic, endogeic, or anecic based on their positioning in the soil horizon and associated morphological and behavioural traits.

Fig.10 Earthworm

- Epigeic earthworms are mostly small bodied, darkly pigmented, and agile species with high reproductive rates and rapid life cycles that live in organic substrates where they feed on decaying organic matter.
- Anecic species are generally larger and produce relatively stable burrows, and feed on surface-deposited organic matter such as dead leaves. They have particularly large impacts on the soil structure and fragmentation of organic matter.
- Endogeic species live in deeper soil horizons where they feed on soil organic matter. The anecic species have particularly large impacts on soil structure and the fragmentation and redistribution of organic matter within the soil matrix.
- Earthworms substantially stimulates soil processes, aid in mineral weathering and enhances the carbon and nutrient mineralization through their direct impacts on litter decomposition and indirectly through their interactions with the microbes. Earthworms can therefore both increase and decrease bulk density, soil porosity, and aggregation.

Millipedes:- Global estimate of described millipedes is about 12,000 species (out of a total estimate 80,000 species) distributed in all the continents except for Antarctica. Millipedes are soil specialists living on the ground, in shallow sub-terranean habitats, among the leaf-litters or in the soil which consume organic materials. They play an important role in breaking down plant and animal debris (detritus) and are excellent for the soil, eating up to 10 percent of the leaf litter in compost. Millipedes also benefit other soil organisms, working together to turn mulch and debris into nutrient-rich soil. They recycle nutrients at a much higher rate than natural decomposition. Millipede can also perform the same function as the earthworm, also a soil invertebrate, which has gained popularity for use in producing organic fertiliser.

Fig.11 Millipede

Centipedes:- The approximately 3,000 species of centipedes feed predominantly on decaying organic matter and are predominant predators. Centipedes consume a tremendous amount of soil-dwelling larvae. Their tunneling aerates the soil, allowing water and nutrients to reach the roots of plants and grasses. Centipedes are generally long, flattened, sometimes large-bodied animals that actively hunt and eat other invertebrates (and occasionally small vertebrates) in the litter. They have large jaw-like structures (forcipules) with poison glands at their base (predators).

Fig.12 Centipede

Beetles:- Beetles represent almost one-fourth of all described species in soil with approximately estimated 3-5 million species and 370,000 identified being saprophagous, phytophagous and predators. Most soil-dwelling beetle species are brown or black color ecosystem engineer able to increase the soil fertility, due to their high diversity of feeding habits, live in humus, leaf litter, decomposing roots and logs, other rotting organic matter, dung, carrion, and in the fruiting bodies of many types of fungi, where they significantly contribute to decomposition processes. Staphylinidae (rove beetles) feed on small insects and mites that infest the plants and sometimes on rotting vegetation, as well insects in the soil and on plant roots. Both the immature larvae and the adult beetles prey on other insects. Dung-beetles play a crucial role by burying dung and dig subvertical galleries like earthworms filled with large pellets of dung. beetle), includes species that are mostly predacious and have a role as biological regulators of crop pests.

Fig.13 Dung beetles

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