SOIL ORGANIC MATTER

Soil organic matter consists of a wide range of materials derived from living organisms that range from undecomposed plants and animal tissues through to transitional products of decomposition to the relatively stable brown to black materials that bears no resemblance to plant and animal tissues from which they originated. The latter group i.e. the highly stable dark coloured organic matter which has no resemblance to original plants and animal parts is what is defined as Humus. Besides the remains of plants and animals at various stages of decomposition, are the organisms that live in the soil, the soil biomass, which are part of the soil organic matter. Soil organic matter is the totality of organic materials in the soil that includes both living and non living components. The living component of soil organic matter is called soil biomass.

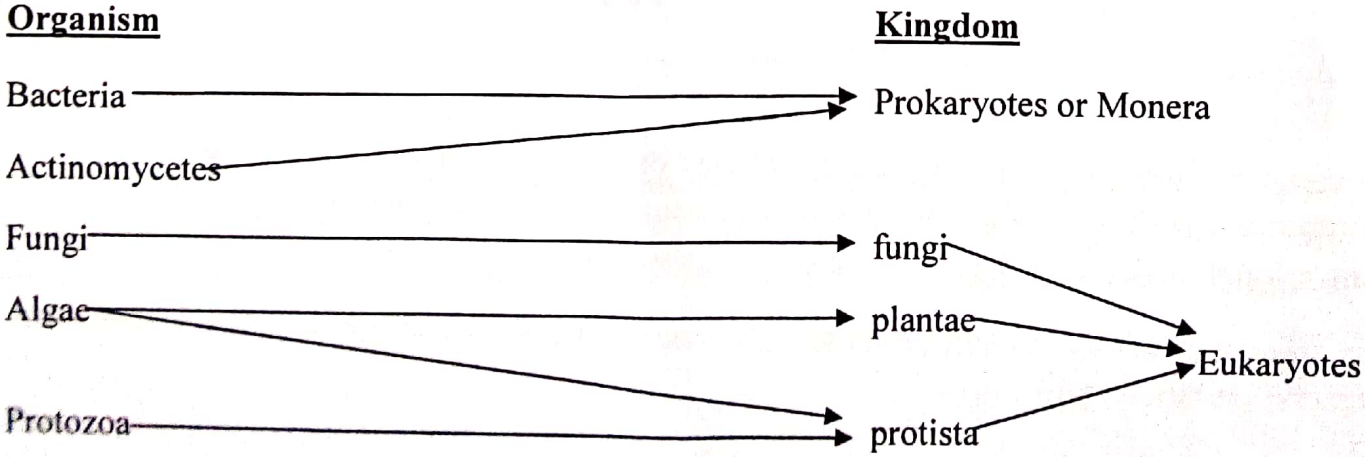
Soil Biomass

Soil biomass refers to the living organisms that are found in the soil, which range from microscopic materials such as bacteria, through invertebrates such as earthworms, to vertebrates such as moles, mice and other rodents that live in the soil. While these organisms play an important role in the formation and functioning of soils, the group that perhaps plays a significant role are the tiny organisms that cannot be observed by unaided eye, the microorganism. The microorganisms found in the soil constitute what is known as soil microorganism. The main soil microorganisms found in the soil are;

1. Bacteria
2. Fungi
3. Actinomycetes
4. Algae
5. Protozoa

Soil Microorganisms

The five main groups of microorganisms belong to four main Kingdoms, as indicated below



Bacteria and Actinomycetes are prokaryotic organisms whose cells have a nucleus that is not surrounded by a nuclear membrane and have few organelles, none of which are surrounded by membranes. They have cells with a relatively primitive cell composition.

Fungi, Algae and Protozoa are eukaryotic organisms with cells containing nucleus materials surrounded by a nuclear membrane. They also have specialized organelles such as mitochondria, surrounded by membranes.

Subdivision of Microorganisms on Basis of Nutrition

Microorganisms are subdivided into two classes based on their mode of nutrition, more precisely based on their source of carbon, and on energy. Organisms that obtain their carbon from inorganic compounds i.e synthesizes own organic requirements are termed Autotrophs. Organisms that obtain their carbon from preformed organic compounds are termed Heterotrophs. Organisms that obtain their energy from the sun or sunlight are called Phototrophs, while those that use energy from chemical compounds (organic or inorganic) are called Chemotrophs.

Based on their mode of obtaining carbon and energy, living organism can be classified into four groups summarized in the Table below;

		Carbon Source	
		Inorganic (CO_2)	**Organic**
		Autotrophs	**Heterotrophs**
Energy Source	**Phototrophic** (use light energy)	**Photoautrophic** e.g plants, bacteria, algae	**Photoheterotrophic** e.g bacteria
	Chemotrophic (use chemical energy)	**Chemoautotrophic** e.g bacteria such as nitrosomonas and nitrobactor	**Chemoheterophic** e.g most bacteria, fungi and protozoa

A further classification of microorganisms is based on terminal electron acceptors used when the organisms are respiring. Microorganisms that use oxygen as the terminal electron acceptor during respiration are termed as being aerobic or have aerobic respiration.

Microorganisms that use organic products (intermediate breakdown products as terminal electron acceptors) are termed fermentors.

Microorganisms that use inorganic compounds as terminal electron acceptors during respiration are termed as anaerobic organisms.

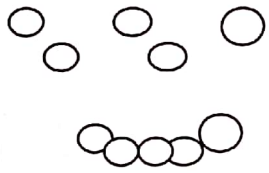
Some organisms can switch electron acceptor between oxygen and inorganic compounds. These are termed as facultative anaerobic organisms.

Summary of Properties, Adaptation and Importance of Major Groups of Soil Microorganisms

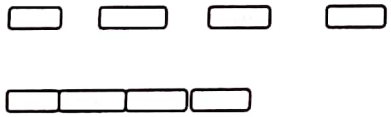
1. Bacteria

Bacteria are unicellular, procaryotic microorganisms, which are very abundant in soils. They are usually the most abundant microorganisms in soils. Bacteria are usually classified on the basis of the shape of their cells. The 3 main groupings of bacteria based on shape are:

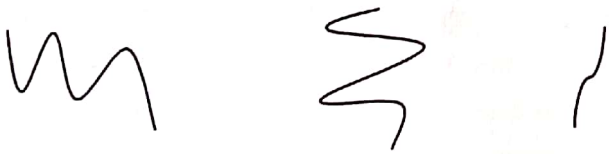
i. Cocci or Coccus (Singular) - for bacteria that have round shaped cells



ii. Bacilli or Bacillus (Singular) - for bacteria with rod-shaped.



iii. Spirilli – Spirillus (Singular) for spiral shaped bacteria cells



Nutrition

Bacteria vary widely in their mode of nutrition. Some are autotrophic while others are heterotrophic. Bacteria are the mostly widely adapted organisms. Bacteria are equally well adapted to wide range of environmental conditions. Some are aerobic, others anaerobic, and some facultative.

Environmental conditions favorable for bacteria

1. Most common soil bacteria are better adapted to neutral to alkaline soil condition, and do not thrive under very acid conditions.
2. Most bacteria in soils are aerobic and are therefore favored by well aerated conditions, though anaerobic bacteria are also present.
3. Warm conditions, generally are favorable for the survival of many soil organisms, therefore, cold environments tend to lower the activity of bacteria in soils.
4. Moisture conditions – all microbes need water for survival, moist well aerated soils are more favorable for the survival of most bacteria.
5. Organic matter – since most bacteria are heterotrophs they need organic matter for their survival. Therefore, soils with high organic matter contents are generally more favorable for the survival of bacteria.

Importance in Soils

Bacteria play a number of important roles in the soil. Amongst the prominent roles played by bacteria in soils are:

1. Decomposition of organic matter
   Bacteria are involved in the decomposition of various organic compounds in the soil. This decomposition leads to the release – or mineralization of nutrients that were present in soil organic matter into the soil as free inorganic ions or compounds. They thus play an important role in the cycling of nutrients.
2. Nitrogen fixation (biological nitrogen fixation)
   Bacteria are involved in the conversion of atmospheric nitrogen into forms that can readily be utilized by plants. This conversion of atmospheric N into forms that can be used by plants is called Nitrogen fixation. A number of bacterial species are involved. They include free living species (i.e bacteria able to fix N alone) such as Azotobacter and Clostridium and symbiotic bacteria (bacteria that fix N in association with plants, such as Rhizobium, which are known to fix N, in association with leguminous plants.
3. Cause diseases (Pathogens)
   Bacteria are a well known cause of a number of diseases in both plants and animals, which result in great economic losses.

2. Actinomycetes

Actinomycetes are a special group of multi-cellular bacterial that form a network of hyphae similar to those observed in fungi. Their individual cells are about the same size as bacteria in width but they form branched filaments and are sometimes called ray fungi, though they are prokaryotic unlike fungi which are eucaryotic.

Nutrition and Adaptation

Most actinomycetes are heterotrophic and aerobic. They are more adapted to drier conditions than bacteria and therefore tend to be more active in drier soils than bacteria that thrive better in wet soil conditions. Actinomycetes are better adapted to slightly acid to alkaline conditions and do not survive under acidic soil conditions.

Importance in Soils

1. Actinomycetes are important in the decomposition and humification of organic residues. They are able to decompose more resistant organic compounds.
2. Some species of actinomycetes cause diseases. E.g. the disease potato scab is caused by actinomycetes.
3. Source of antibiotics – a number of actinomycetes produces chemicals that are able to kill microorganisms such as bacteria. These chemicals are known as antibiotics. Actinomycetes are used to produce a variety of antibiotics.

3. Fungi

Fungi are multi-cellular eucaryotic organisms belonging to the kingdom of fungi. Many fungi form a network of filaments known as hyphae that give rise to a mesh of such filaments known as mycelium. Some fungi, such as yeast do not form filamentous structures .

Adaptations

1. Most fungi are heterotrophs, and thus feed on organic materials. Many species are parasitic on plants and soils, and the non parasitic species, saprophytes attacks and decompose a variety of substances in soils, including complex organic plant materials such as cellulose and lignin
2. Most of the fungi are aerobic, and thus requires the presence of oxygen to survive, though a few are anaerobic. The absence of oxygen in the soil or in water logging conditions sharply limits the growth of most fungi. The activities of fungi are therefore limited in water logged soils.
3. Fungi are much more adapted to acidic conditions that bacteria and actinomycetes. In acidic conditions fungi tend to be the more dominant active soil microorganism.

Importance of Significance in Soils

1. Fungi are very important in decomposition organic matter in soils. They are better adapted to degrading more complex organic materials such as cellulose and lignin.
2. Fungi sometimes colonize the surface of plants and form fungus-roots associations known as mycorhizae (myco= fungus, rhizae=roots). The formation of mycorhizae is a symbiotic one,

in which the fungus gets food from roots, and in turn assists the plant roots in extracting nutrients from the soil, such as phosphorus. Plants with mycorhizae are able to grow in literally infertile soils and soils with adverse chemicals compared to plants without mycorhizae.

3. Fungi also cause disease to plants and animals. They can cause serious losses in crop yield. Fungal attacks are common in very wet and moist environments.

4. Protozoa

Protozoa are unicellular eucaryotic microorganisms. In soils protozoa plays an important role in controlling the population of bacteria. The particular species of protozoa tend to selectively feed on specific species of bacteria. They are mainly predators of bacteria.

Some bacteria exist as parasites in insects. Insects such as termites have the ability to degrade a wide range of organic compounds because of the presence of certain species of protozoa in their digestive systems, which have enzymes that are able to degrade various complex organic compounds.

5. Algae

Algae are the simplest green plants which may be unicellular or short filaments. These organisms are not as numerous as bacteria, actinomycetes or fungi. Algae have a distinctively green pigmentation due to the presence of chlorophyll although the colour may be masked by other pigments. They are photosynthetic organisms that require sunlight. Algae are photoautotrophic in nutrition as they have the ability to use light as an energy source. Carbon is obtained from the atmosphere as carbon dioxide. Some species of algae are heterotrophs which use oxidation of organic carbon as the source of energy.

Algae are moderately adaptable to environmental change and persist in unfavourable conditions such as alkaline and arid soils. These microorganisms are abundant in habitats with adequate moisture and where light is accessible. Algae are found in abundance in the flooded soils of swamps and they can be found on the surface of poorly drained soils and in wet depressions. Algae may also occur in relatively dry soils, and they form mutually beneficial relationships with other organisms.

Through photoautotrophic nutrition, algae are involved in the generation of organic matter from inorganic substances. Algae also contributes to improved soil structure and erosion control.

Soil Microbial Activity

The microorganisms discussed in the preceding section play an important role in the transformation of organic matter in the soil, and in the cycling of nutrients contained in organic

matter. The activity of microorganisms in soils is an important measure of the "health" of a soil. Soils with high microbial activity generally tend to be more fertile than soils with low microbial activity.

There are many methods of measuring microbial activity in soils. The most common are measurement that relate to the respiration occurring in soils. Since most soil microorganisms are aerobic, the amount of aerobic respiration occurring in a soil is a useful guide to the microbial activity in a soil.

The aerobic decomposition of organic matter is usually associated with consumption of oxygen, and evolution of carbon dioxide as indicated in the grossly simplified reaction below;

$$CH_2O\ (s) + O\ (g) \longrightarrow CO_2\ (g) + H_2O\ (l)$$

Organic matter Oxygen Carbon dioxide Water

The activity of microorganisms in a soil can thus be related to the loss of organic matters, or consumption of oxygen or to the evolution of carbon dioxide under aerobic conditions.

Non Living Fraction of Soil Organic Matter

Most of the organic matter in soils is derived from remains of plant materials. Therefore, plant materials are the main parent materials of soil organic matter. In addition, remains of microorganisms constitute a significant part of soil organic matter. Under the influence of living organisms in the soil, the remains of plants, animals and microbes are transformed into new compounds.

The main constituents of mature plants include, compounds soluble in ether such as fats, and waxes, and compounds soluble in ethanol and water such as amino acids, sugars and organic acids, hemicellulose, cellulose, lignin, proteins and inorganic salts. Simple sugars, amino acids, most proteins and polysaccharides such as hemicellulose are readily decomposed and are quickly utilized by microorganisms in soils with a matter of hours to a few days. Large macro molecules take longer to degrade as they must first be broken down into simpler units before they can be utilized by microbes. Compounds such as lignin and cellulose, require organisms with ability to release enzymes that can degrade them, to be decomposed. Fungi play an important role in the degradation as such materials as they have specialized enzymes to degrade lignin and cellulose.

The Decomposition Process

Organic matter decomposition occurs in different stages. Microorganisms such as earthworms and other soil animals help reduce the size of fresh organic residues in the soil. Further transformations are carried out by enzymes produced by microorganisms.

The first materials to be decomposed are the sugars, amino acids, proteins, and organic acids. Some of the carbon from these materials are synthesized into microbial cells, while some carbon is lost as CO_2, and some remain as by products such as NH_3, organic acids and other intermediates.

As time progresses, more complex plant parts such as cellulose and lignin are attacked and degraded by actinomycetes and fungi. Bacteria are usually early decomposers of more readily decomposable materials.

Each stage of decomposition of soil organic matter involves partial conversation of carbon from organic matter to CO_2 and synthesis of microbial cells. In addition some new organic compounds are synthesized in the soil by microorganisms. The composition of these new compounds is different from that of the original material from which the compounds were derived. These new compounds are what are called humus.

Soil organic matter consists of two major groups of compounds; the unhumified substances which includes undecomposed remains of plants, and soil microorganisms, and the humified substance or material. The humified materials are materials that do not show any resemblance to the plant or animal remains from which they originated from even when viewed under a light microscope.

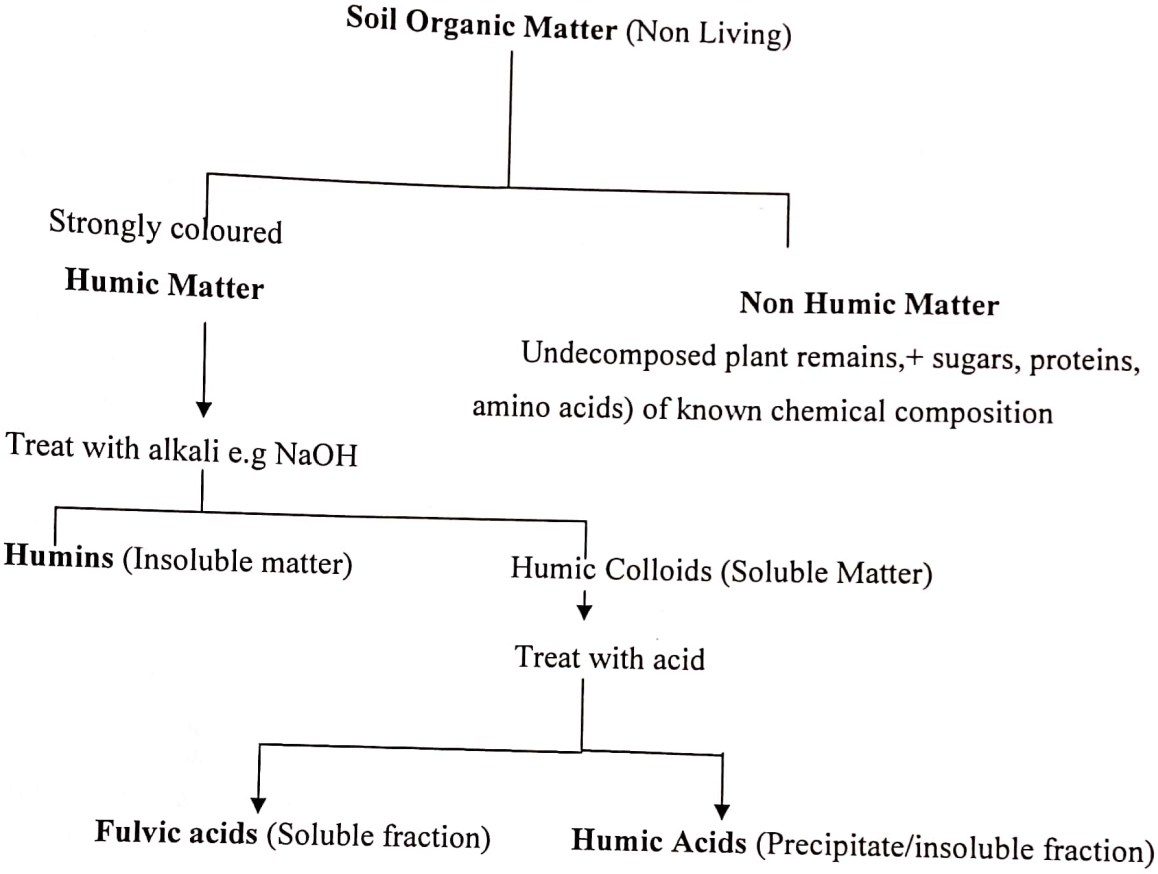
The humified materials are the most active fraction of soil organic matter. They include humic materials and non humic materials. The non-humic materials include; carbohydrates, proteins, lipids and organic acids whose chemical formula can be written precisely.

The humic materials – are substances with more complex structures that are formed in the soil. The humic materials are subdivided into fractions based on their solubilities in alkali and acid solutions, into:

i. Humin
ii. Fulvic acid
iii. Humic acid

The following chart shows the fractionation of soil organic matter.

Fractionation of Soil Organic Matter



Humus is thus the decomposition product of plant, animal and microbial remains in soils, which is composed of materials that have no visual resemblance with original tissues of plants, animals or microbes. It consists of non-humic materials, which consists of organic compounds of known chemical compositions and humic materials that consist of complex organic compounds synthesized within the soil. The humic substances are further subdivided into humin, fulvic acid and humic acid.

CEC of Organic Matter and Sources of Charge on Soil Matter

Humus is known to be responsible for a lot of the beneficial effects of soil organic matter on the physical and chemical properties of soil. The high cation exchange capacity of soil organic matter is associated with the humic fraction of the soil. Most of the negative charge on soil organic matter is associated with carboxylic acid groups (R – COOH) and phenolic groups associated with the humic fractions.

The carboxylic groups tend to dissociate when the pH of the soil increases resulting in a negative charge whose magnitude is strongly associated with the pH of the soil solution.

Role and Function of Soil Organic Matter

Soil organic matter, particularly humus contributes to the fertility or productivity of soils through its positive effect on the chemical, physical and biological properties of the soils.

1. Effect on nutrient availability

Soil organic matter serves as a reservoir of nitrogen (N), phosphorus (P), sulfur (S) and many other plant nutrients. The conversion of organic N, P and S to inorganic minerals forms (NH_4^+, NO_3^-, PO_4^{3-}, SO_4^{2-}) occurs through the influence of the activity of microorganisms, which are in turn influenced by environmental factors that affect microbial activity, such as temperature, moisture and pH. It is also affected by the ratio of these nutrients to carbon (i.e. C/N ratio, C/P ratio and C/S ratio) in the material being decomposed.

The conversion of organic forms of a nutrient or element to its inorganic form is referred to as mineralization, while the conversion of an element or nutrient from its inorganic to organic form is called immobilization. Immobilization and mineralization always occurs in soils.

Organic N, P, S or other nutrient $\longleftrightarrow$ NH_4^+, NO_3^-, PO_4^{3-}, SO_4^{2-} or inorganic form of other nutrients

Mineralization and immobilization are by products the decomposition of soil organic matter. When microbes are able to obtain the level of nutrients they require from the organic material, any excess nutrient present in the organic form will be released into the soil in inorganic form. The nutrient in question is said to be mineralized. It is the mineralized nutrients (nutrients present in inorganic form) that are readily available for pant intake.

On the other hand, if the organic material being decomposed contains less of a nutrient, than required by the decomposing microorganisms, the microorganisms will utilize any inorganic form of that nutrient present in the soil, and incorporate it into their bodies. This conversion of inorganic forms of nutrients into microbial cells is called immobilization and it leads to a reduction of the available nutrients for plants in that soil.

The ratio of carbon to the other nutrients determines whether mineralization or immobilization of the nutrients will occur. There are certain critical levels of these ratios above or below which mineralization or immobilization of the nutrients will occur.

In general, a high carbon: other nutrient ratio will lead to immobilization of that nutrient while a low carbon: other nutrient ratio will promote mineralization of the nutrient, when the organic material is decomposed.

As a general role net mineralization (i.e. gain of mineral forms of the nutrient by the soil will occur at

C/N ratio < 20:1
C/P ratio < 200:1
C/S ratio < 200:1

Net immobilization of the nutrients will occur when
C/N ratio ≥ 30:1
C/P ratio ≥ 300:1
C/S ratio ≥ 400:1

Intermediate ratios lead to neither a gain nor loss of the inorganic form of nutrient.

2. Organic matter is a source of energy for both macro and microorganisms.

The activity of microbes is affected and related in a general way to humus content of a soil. Low organic matter contents result in low activity of living organisms in the soil and consequently to lower levels of benefits associated organisms that live in soils.

3. Soil physical properties

Humus plays an important role in determining the structure of soils. Humus serves as a binding agent for soil particles that result in the formation of soil aggregates. The formation of aggregates improves the aeration of the soil, the water holding capacity of the soils as well as the permeability of the soils (i.e. the ability of the soil to allow water and air to pass through it). Water is thus better able to enter and percolate through the soil.

4. Resistance to erosion

Humus through the ability to bind soil particle together enhances the soils' resistance to erosion. The formation of lager pores between aggregates allows water to percolate through the soil, without breaking it into individual grains that can easily be moved away.

5. Contribution to cation exchange capacity and buffering capacity

Humus contributes to the CEC of soils and also to the ability of soils to resist sudden changes in pH, due to the presence of function groups that have the capacity to release H^- ions when pH increases or to adsorb H^+ ions when the pH decreases.