Definition of Soil Microbiology & Soil in view of Microbiology

Definition:

It is branch of science/microbiology which deals with study of soil microorganisms and their activities in the soil.

Soil:

It is the outer, loose material of earth's surface which is distinctly different from the underlying bedrock and the region which support plant life. Agriculturally, soil is the region which supports the plant life by providing mechanical support and nutrients required for growth. From the microbiologist view point, soil is one of the most dynamic sites of biological interactions in the nature. It is the region where most of the physical, biological and biochemical reactions related to decomposition of organic weathering of parent rock take place.

Components of Soil:

Soil is an admixture *of* five major components viz. organic matter, mineral matter, soil-air, soil water and soil microorganisms/living organisms. The amount/ proposition of these components vary with locality and climate.

1. **Mineral / Inorganic Matter:** It is derived from parent rocks/bed rocks through decomposition, disintegration and weathering process. Different types of inorganic compounds containing various minerals are present in soil. Amongst them the dominant minerals are Silicon, Aluminum and iron and others like Carbon, Calcium Potassium, Manganese, Sodium, Sulfur, Phosphorus etc. are in trace amount. The proportion of mineral matter in soil is slightly less than half of the total volume of the soil.
2. **Organic matter/components:** Derived from organic residues of plants and animals added in the soil. Organic matter serves not only as a source of food for microorganisms but also supplies energy for the vital processes of metabolism which are characteristics of all living organisms. Organic matter in the soil is the potential source of N, P and S for plant growth. Microbial decomposition of organic matter releases the unavailable nutrients in available from. The proportion of organic matter in the soil ranges from 3-6% of the total volume of soil.
3. **Soil Water:** The amount of water present in soil varies considerably. Soil water comes from rain, snow, dew or irrigation. Soil water serves as a solvent and carrier of nutrients for the plant growth. The microorganisms inhabiting in the soil also require water for their metabolic activities. Soil water thus, indirectly affects plant growth through its effects on soil and microorganisms. Percentage of soil-water is 25% total volume of soil.
4. **Soil air (Soil gases):** A part of the soil volume which is not occupied by soil particles i.e. pore spaces are filled partly with soil water and partly with soil air. These two components (water & air) together only accounts for approximately half the soil's volume. Compared with atmospheric air, soil is lower in oxygen and higher in carbon dioxide, because CO_2 is continuous recycled by the microorganisms during the process of decomposition of organic matter. Soil air comes from external atmosphere and contains nitrogen, oxygen CO_2 and water vapour (CO_2 > oxygen). CO_2 in soil air (0.3-1.0%) is

more than atmospheric air (0.03%). Soil aeration plays important role in plant growth, microbial population, and microbial activities in the soil.

5. **Soil microorganisms:** Soil is an excellent culture media for the growth and development of various microorganisms. Soil is not an inert static material but a medium pulsating with life. Soil is now believed to be dynamic or living system.

Soil contains several distinct groups of microorganisms and amongst them bacteria, fungi, actinomycetes, algae, protozoa and viruses are the most important. But bacteria are more numerous than any other kinds of microorganisms. Microorganisms form a very small fraction of the soil mass and occupy a volume of less than one percent. In the upper layer of soil (top soil up to 10-30 cm depth i.e. Horizon A), the microbial population is very high which decreases with depth of soil. Each organisms or a group of organisms are responsible for a specific change / transformation in the soil. The final effect of various activities of microorganisms in the soil is to make the soil fit for the growth & development of higher plants.

Living organisms present in the soil are grouped into two categories as follows.

1. Soil flora (micro flora) e.g. Bacteria, fungi, Actinomycetes, Algae and
2. Soil fauna (micro fauna) animal like eg. Protozoa, Nematodes, earthworms, moles, ants, rodents.

Relative proportion / percentage of various soil microorganisms are: Bacteria-aerobic (70%), anaerobic (13 %), Actinomycetes (13%), Fungi /molds (03 %) and others (Algae Protozoa viruses) 0.2-0.8 %. Soil organisms play key role in the nutrient transformations.

Scope and Importance of Soil Microbiology

Living organisms both plant and animal types constitute an important component of soil. Though these organisms form only a fraction (less than one percent) of the total soil mass, but they play important role in supporting plant communities on the earth surface. While studying the scope and importance of soil microbiology, soil-plant-animal ecosystem as such must be taken into account. Therefore, the scope and importance of soil microbiology, can be understood in better way by studying aspects like

1. Soil as a living system
2. Soil microbes and plant growth
3. Soil microorganisms and soil structure
4. Organic matter decomposition
5. Humus formation
6. Biogeochemical cycling of elements
7. Soil microorganisms as bio-control agents
8. Soil microbes and seed germination
9. Biological N_2 fixation
10. Degradation of pesticides in soil.

1. Soil as a living system: Soil inhabit diverse group of living organisms, both micro flora (fungi, bacteria, algae and actinomycetes) and micro-fauna (protozoa, nematodes, earthworms, moles, ants). The density of living organisms in soil is very high i.e. as much as billions / gm of

soil, usually density of organisms is more in cultivated soil than uncultivated / virgin land and population decreases with soil acidity. Top soil, the surface layer contains greater number of microorganisms because it is well supplied with Oxygen and nutrients. Lower layer / subsoil is depleted with Oxygen and nutrients hence it contains fewer organisms. Soil ecosystem comprises of organisms which are both, autotrophs (Algae, BOA) and heterotrophs (fungi, bacteria). Autotrophs use inorganic carbon from CO_2 and are "primary producers" of organic matter, whereas heterotrophs use organic carbon and are decomposers/consumers.

2. Soil microbes and plant growth: Microorganisms being minute and microscopic, they are universally present in soil, water and air. Besides supporting the growth of various biological systems, soil and soil microbes serve as a best medium for plant growth. Soil fauna & flora convert complex organic nutrients into simpler inorganic forms which are readily absorbed by the plant for growth. Further, they produce variety of substances like IAA, gibberellins, antibiotics etc. which directly or indirectly promote the plant growth

3. Soil microbes and soil structure: Soil structure is dependent on stable aggregates of soil particles-Soil organisms play important role in soil aggregation. Constituents of soil are viz. organic matter, polysaccharides, lignins and gums, synthesized by soil microbes plays important role in cementing / binding of soil particles. Further, cells and mycelial strands of fungi and actinomycetes, Vormicasts from earthworm is also found to play important role in soil aggregation. Different soil microorganisms, having soil aggregation / soil binding properties are graded in the order as fungi > actinomycetes > gum producing bacteria > yeasts. Examples are: Fungi like *Rhizopus, Mucor, Chaetomium, Fusarium, Cladasporium, Rhizoctonia, Aspergillus, Trichoderma* and Bacteria like *Azofobacler, Rhizobium Bacillus*and *Xanlhomonas.*

4. Soil microbes and organic matter decomposition: The organic matter serves not only as a source of food for microorganisms but also supplies energy for the vital processes of metabolism that are characteristics of living beings. Microorganisms such as fungi, actinomycetes, bacteria, protozoa etc. and macro organisms such as earthworms, termites, insects etc. plays important role in the process of decomposition of organic matter and release of plant nutrients in soil. Thus, organic matter added to the soil is converted by oxidative decomposition to simpler nutrients / substances for plant growth and the residue is transformed into humus. Organic matter / substances include cellulose, lignins and proteins (in cell wall of plants), glycogen (animal tissues), proteins and fats (plants, animals). Cellulose is degraded by bacteria, especially those of genus *Cytophaga*and other genera *(Bacillus, Pseudomonas, Cellulomonas, and Vibrio Achromobacter)* and fungal genera *(Aspergillus, Penicilliun, Trichoderma, Chactomium, Curvularia)*. Lignins and proteins are partially digested by fungi, protozoa and nematodes. Proteins are degraded to individual amino acids mainly by fungi, *actinomycetes* and *Clostridium.* Under unaerobic conditions of waterlogged soils, methane are main carbon containing product which is produced by the bacterial genera (strict anaerobes) *Methanococcus, Methanobacterium* and *Methanosardna.*

5. Soil microbes and humus formation: Humus is the organic residue in the soil resulting from decomposition of plant and animal residues in soil, or it is the highly complex organic residual

matter in soil which is not readily degraded by microorganism, or it is the soft brown/dark coloured amorphous substance composed of residual organic matter along with dead microorganisms.

6. Soil microbes and cycling of elements: Life on earth is dependent on cycling of elements from their organic / elemental state to inorganic compounds, then to organic compounds and back to their elemental states. The biogeochemical process through which organic compounds are broken down to inorganic compounds or their constituent elements is known "Mineralization", or microbial conversion of complex organic compounds into simple inorganic compounds & their constituent elements is known as mineralization.

Soil microbes play important role in the biochemical cycling of elements in the biosphere where the essential elements (C, P, S, N & Iron etc.) undergo chemical transformations. Through the process of mineralization organic carbon, nitrogen, phosphorus, Sulfur, iron etc. are made available for reuse by plants.

7. Soil microbes and biological N_2 fixation: Conversion of atmospheric nitrogen in to ammonia and nitrate by microorganisms is known as biological nitrogen fixation.

Fixation of atmospheric nitrogen is essential because of the reasons:

1. Fixed nitrogen is lost through the process of nitrogen cycle through Denitrification.
2. Demand for fixed nitrogen by the biosphere always exceeds its availability.
3. The amount of nitrogen fixed chemically and lightning process is very less as compared to biologically fixed nitrogen
4. Nitrogenous fertilizers contribute only 25% of the total world requirement while biological nitrogen fixation contributes about 60% of the earth's fixed nitrogen
5. Manufacture of nitrogenous fertilizers by "Haber" process is costly and time consuming.

The numbers of soil microorganisms carry out the process of biological nitrogen fixation at normal atmospheric pressure (1 atmosphere) and temp (around 20 °C).

Two groups of microorganisms are involved in the process of BNF.

A. Non-symbiotic (free living) and B. Symbiotic (Associative)

Non-symbiotic (free living): Depending upon the presence or absence of oxygen, non-symbiotic N_2 fixation prokaryotic organisms may be aerobic heterotrophs (*Azotobacter, Pseudomonas, Achromobacter)* or aerobic autotrophs *(Nostoc, Anabena, Calothrix, BGA)* and anaerobic heterotrophs *(Clostridium, Kelbsiella. Desulfovibrio)* or anaerobic Autotrophs *(Chlorobium, Chromnatium, Rhodospirillum, Meihanobacterium etc)*

Symbiotic (Associative): The organisms involved are *Rhizobium, Bradyrhizobium* in legumes (aerobic): *Azospirillum* (grasses), Actinonycetes frantic (with *Casuarinas,* Alder).

8. Soil microbes as biocontrol agents: Several ecofriendly bioformulations of microbial origin are used in agriculture for the effective management of plant diseases, insect pests, weeds etc. eg: *Trichoderma* sp and *Gleocladium* sp are used for biological control of seed and soil borne diseases. Fungal genera *Entomophthora, Beauveria, Metarrhizium* and protozoa *Maltesia grandis. Malameba locustiae* etc are used in the management of insect pests. Nuclear polyhydrosis virus (NPV) is used for the control of *Heliothis* /American boll worm. Bacteria

like *Bacillus thuringiensis, Pseudomonas* are used in cotton against Angular leaf spot and boll worms.

8. Degradation of pesticides in soil by microorganisms: Soil receives different toxic chemicals in various forms and causes adverse effects on beneficial soil micro flora / micro fauna, plants, animals and human beings. Various microbes present in soil act as the scavengers of these harmful chemicals in soil. The pesticides/chemicals reaching the soil are acted upon by several physical, chemical and biological forces exerted by microbes in the soil and they are degraded into non-toxic substances and thereby minimize the damage caused by the pesticides to the ecosystem. For example, bacterial genera like *Pseudomonas, Clostridium, Bacillus, Thiobacillus, Achromobacter etc.* and fungal genera like *Trichoderma, Penicillium, Aspergillus, Rhizopus, and Fusarium* are playing important role in the degradation of the toxic chemicals / pesticides in soil.

9. Biodegradation of hydrocarbons: Natural hydrocarbons in soil like waxes, paraffin's, oils etc are degraded by fungi, bacteria and actinomycetes. E.g. ethane (C_2H_6) a paraffin hydrocarbon is metabolized and degraded by *Mycobacteria, Nocardia, Streptomyces Pseudomonas, Flavobacterium* and several fungi.

Current Topics in soil microbiology:

Following are some of the important research interests that the soil microbiologists are pursuing:

- Symbiotic nitrogen fixation
- Organic matter decomposition (waste removal and composting)
- Mineral nitrogen transformations (nitrification, denitrification and ammonification)
- Rhizosphere studies (root/soil/microorganism interactions)
- Soil enzymes (ureases, cellulases, ligninases, phosphatases)
- Biodegradation and bioremediation
- Metal transformations
- Carbon cycling
- Greenhouse gases and atmospheric pollution (production of methane, carbon dioxide, nitric oxide, nitrous oxide)
- Release and monitoring of genetically engineered microorganisms (GEM)
- Microbial ecology

Subsurface microbial activity.

Types of Microorganisms in Soil

Living organisms both plants and animals, constitute an important component of soil. The pioneering investigations of a number of early microbiologists showed for the first time that the soil was not an inert static material but a medium pulsating with life. The soil is now believed to be a dynamic or rather a living system, containing a dynamic population of organisms / microorganisms. Cultivated soil has relatively more population of microorganisms than the fallow land, and the soils rich in organic matter contain much more population than sandy and eroded soils. Microbes in the soil are important to us in maintaining soil fertility / productivity, cycling of nutrient elements in the biosphere and sources of industrial products such as enzymes, antibiotics, vitamins, hormones, organic acids etc. At the same time certain soil microbes are the causal agents of human and plant diseases.

The soil organisms are broadly classified in to two groups viz soil flora and soil fauna, the detailed classification of which is as follows.

Soil Organisms

A. Soil Flora

a) Microflora: 1. Bacteria 2. Fungi, Molds, Yeast, Mushroom 3. Actinomycetes, Stretomyces 4. Algae eg. BGA, Yellow Green Algae, Golden Brown Algae.

1. Bacteria is again classified in **I) Heterotrophic** eg. symbiotic & non - symbiotic N2 fixers, Ammonifier, Cellulose Decomposers, Denitrifiers **II) Autrotrophic** eg. Nitrosomonas, Nitrobacter, Sulphur oxidizers, etc.

b) Macroflora: Roots of higher plants

B. Soil Fauna

a) Microfauna: Protozoa, Nematodes

b) Macrofauna: Earthworms. moles, ants & others.

As soil inhabit several diverse groups of microorganisms, but the most important amongst them are: bacteria, actinomycetes, fungi, algae and protozoa. The characteristics and their functions / role in the soil are described in the next topics.

Soil Microorganism: Bacteria

Amongst the different microorganisms inhabiting in the soil, bacteria are the most abundant and predominant organisms. These are primitive, prokaryotic, microscopic and unicellular microorganisms without chlorophyll. Morphologically, soil bacteria are divided into three groups viz *Cocci* (round/spherical), (rod-shaped) and *Spirilla I Spirllum* (cells with long wavy chains). *Bacilli* are most numerous followed by Cocci *and Spirilla in* soil.

The most common method used for isolation of soil bacteria is the "dilution plate count" method which allows the enumeration of only viable/living cells in the soil. The size of soil bacteria varies from 0.5 to 1.0 micron in diameter and 1.0 to 10.0 microns in length. They are motile with locomotory organs flagella.

Bacterial population is one-half of the total microbial biomass in the soil ranging from 1,00000 to several hundred millions per gram of soil, depending upon the physical, chemical and biological conditions of the soil.

Winogradsky (1925), on the basis of ecological characteristics classified soil microorganisms in general and bacteria in particular into two broad categories i.e.**Autochnotus** (Indigenous species) and the **Zymogenous** (fermentative). **Autochnotus** bacterial population is uniform and constant in soil, since their nutrition is derived from native soil organic matter (eg. *Arthrobacter* and *Nocardia* whereas **Zymogenous** bacterial population in soil is low, as they require an external source of energy, eg. *Pseudomonas & Bacillus.* The population of Zymogenous bacteria increases gradually when a specific substrate is added to the soil. To this category belong the cellulose decomposers, nitrogen utilizing bacteria and ammonifiers.

As per the system proposed in the Bergey's Manual of Systematic Bacteriology, most of the bacteria which are predominantly encountered in soil are taxonomically included in the three orders, Pseudomonadales, Eubacteriales and Actinomycetales of the class Schizomycetes. The most common soil bacteria belong to the genera *Pseudomonas, Arthrobacter, Clostridium Achromobacter, Sarcina, Enterobacter* etc. The another group of bacteria common in soils is the Myxobacteria belonging to the genera *Micrococcus, Chondrococcus, Archangium, Polyangium, Cyptophaga.*

Bacteria are also classified on the basis of physiological activity or mode of nutrition, especially the manner in which they obtain their carbon, nitrogen, energy and other nutrient requirements. They are broadly divided into two groups i.e. a) Autotrophs and b) Heterotrophs

1. Autotrophic bacteria are capable synthesizing their food from simple inorganic nutrients, while heterotrophic bacteria depend on pre-formed food for nutrition. All autotrophic bacteria utilize Co2 (from atmosphere) as carbon source and derive energy either from sunlight (photoautotrophs, eg. *Chromatrum. Chlorobium. Rhadopseudomonas* or from the oxidation of simple inorganic substances present in soil (chemoautotrophs eg. *Nitrobacter, Nitrosomonas, Thiaobacillus).*
2. Majority of soil bacteria are heterotrophic in nature and derive their carbon and energy from complex organic substances/organic matter, decaying roots and plant residues. They obtain their nitrogen from nitrates and ammonia compounds (proteins) present in soil and other nutrients from soil or from the decomposing organic matter. Certain bacteria also require amino acids, B- Vitamins, and other growth promoting substances also.

Functions / Role of Bacteria:

Bacteria bring about a number of changes and biochemical transformations in the soil and thereby directly or indirectly help in the nutrition of higher plants growing in the soil. The important transformations and processes in which soil bacteria play vital role are: decomposition of cellulose and other carbohydrates, ammonification (proteins ammonia), nitrification (ammonia-nitrites-nitrates), denitrification (release of free elemental nitrogen), biological fixation of atmospheric nitrogen (symbiotic and non-symbiotic) oxidation and reduction of sulfur and iron compounds. All these processes play a significant role in plant nutrition,

Process/reaction	**Bacterial genera**
Cellulose decomposition (celluloytic bacteria) most cellulose decomposers are mesophilic	a. Aerobic : *Angiococcus, Cytophaga, Polyangium, Sporocytophyga, Bacillus, Achromobacter, Cellulomonas* b. *anaerobic: Clostridium Methanosarcina, Methanococcus*
Ammonification (Ammonifiers)	*Bacillus, Pseudomonas*
Nitrification (Nitrifying bacteria)	*Nitrosomonas, Nilrobacter Nitrosococcus*
Denitrification (Denitrifies)	*Achromobacter, Pseudomonas, Bacillus, Micrococcus*
Nitrogen fixing bacteria	a Symbiotic- Rhizobium, *Bradyrrhizobium* b Non-symbiotic: aerobic – Azotobacter *Beijerinckia* (acidic soils), anaerobic-*Clostridium*

Bacteria capable of degrading various plant residues in soil are :

Cellulose	***Hemicelluloses***	***Lignin***	***Pectin***	***Proteins***
Pseudomonas	Bacillus	Pseudomonas	Erwinia	Clostridium
Cytophaya	Vibrio	Micrococcus		Proteus
Spirillum	Pseudomonas	Flavobacteriumm		Pseudomonas
Actinomycetes	Erwinia	Xanthomonas		Bacillus
Cellulomonas		Streptomyces		

Soil Microorganism – Actinomycetes

These are the organisms with characteristics common to both bacteria and fungi but yet possessing distinctive features to delimit them into a distinct category. In the strict taxonomic sense, actinomycetes are clubbed with bacteria the same class of Schizomycetes and confined to the order Actinomycetales.

They are unicellular like bacteria, but produce a mycelium which is non-septate (coenocytic) and more slender, tike true bacteria they do not have distinct cell-wall and their cell wall is without chitin and cellulose (commonly found in the cell wall of fungi). On culture media unlike slimy

distinct colonies of true bacteria which grow quickly, actinomycetes colonies grow slowly, show powdery consistency and stick firmly to agar surface. They produce hyphae and conidia / sporangia like fungi. Certain actinomycetes whose hyphae undergo segmentation resemble bacteria, both morphologically and physiologically.

Actinomycetes are numerous and widely distributed in soil and are next to bacteria in abundance. They are widely distributed in the soil, compost etc. Plate count estimates give values ranging from 10^4 to 10^8 per gram of soil. They are sensitive to acidity / low PH (optimum PH range 6.5 to 8.0) and waterlogged soil conditions. The population of actinomycetes increases with depth of soil even up to horizon 'C' of a soil profiler They are heterotrophic, aerobic and mesophilic (25-30 ^c) organisms and some species are commonly present in compost and manures are thermophilic growing at 55-65° c temperature (eg. Thermoatinomycetes, Streptomyces).

Actinomycetes belonging to the order of Actinomycetales are grouped under four families viz Mycobacteriaceae, Actinomycetaceae, Streptomycetaceae and Actinoplanaceae. Actinomycetous genera which are agriculturally and industrially important are present in only two families of Actinomycetaceae and Strepotmycetaceae.

In the order of abundance in soils, the common genera of actinomycetes are Streptomyces (nearly 70%), Nocardia and Micromonospora although Actinomycetes, Actinoplanes, Micromonospora and Streptosporangium are also generally encountered.

Functions / Role of actinomycetes:

1. Degrade/decompose all sorts of organic substances like cellulose, polysaccharides, protein fats, organic-acids etc.
2. Organic residues / substances added soil are first attacked by bacteria and fungi and later by actinomycetes, because they are slow in activity and growth than bacteria and fungi.
3. They decompose / degrade the more resistant and indecomposable organic substance/matter and produce a number of dark black to brown pigments which contribute to the dark colour of soil humus.
4. They are also responsible for subsequent further decomposition of humus (resistant material) in soil.
5. They are responsible for earthy / musty odor / smell of freshly ploughed soils.
6. Many genera species and strains (eg. Streptomyces if actinomycetes produce/synthesize number of antibiotics like Streptomycin, Terramycin, Aureomycin etc.
7. One of the species of actinomycetes *Streptomyces scabies* causes disease "Potato scab" in potato.

Soil Microorganism – Fungi

Fungi in soil are present as mycelial bits, rhizomorph or as different spores. Their number varies from a few thousand to a few -million per gram of soil. Soil fungi possess filamentous mycelium composed of individual hyphae. The fungal hyphae may be aseptate /coenocytic (Mastigomycotina and Zygomycotina) or septate (Ascomycotina, Basidiomycotina & Deuteromycotina).

As observed by C.K. Jackson (1975), most commonly encountered genera of fungi in soil are; *Alternaria, Aspergillus, Cladosporium, Cephalosporium Botrytis, Chaetomium, Fusarium,*

Mucor, Penicillium, Verticillium, Trichoderma, Rhizopus, Gliocladium, Monilia, Pythium, etc. Most of these fungal genera belong to the subdivision Deuteromycotina / Fungi imperfeacta which lacks sexual mode of reproduction.

As these soil fungi are aerobic and heterotrophic, they require abundant supply of oxygen and organic matter in soil. Fungi are dominant in acid soils, because acidic environment is not conducive / suitable for the existence of either bacteria or actinomycetes. The optimum PH range for fungi lies-between **4.5 to 6.5.** They are also present in neutral and alkaline soils and some can even tolerate PH beyond 9.0

Functions / Role of Fungi

1. Fungi plays significant role in soils and plant nutrition.
2. They plays important role in the degradation / decomposition of cellulose, hemi cellulose, starch, pectin, lignin in the organic matter added to the soil.
3. Lignin which is resistant to decomposition by bacteria is mainly decomposed by fungi.
4. They also serve as food for bacteria.
5. Certain fungi belonging to sub-division Zygomycotina and Deuteromycotina are predaceous in nature and attack on protozoa & nematodes in soil and thus, maintain biological equilibrium in soil.
6. They also plays important role in soil aggregation and in the formation of humus.
7. Some soil fungi are parasitic and causes number of plant diseases such as wilts, root rots, damping-off and seedling blights eg. *Pythium, Phyiophlhora, Fusarium, Verticillium*etc.
8. Number of soil fungi forms mycorrhizal association with the roots of higher plants (symbiotic association of a fungus with the roots of a higher plant) and helps in mobilization of soil phosphorus and nitrogen eg. Glomus, *Gigaspora, Aculospora,* (Endomycorrhiza) and *Amanita, Boletus, Entoloma, Lactarius* (Ectomycorrhiza).

Soil Microorganism – Algae

Algae are present in most of the soils where moisture and sunlight are available. Their number in soil usually ranges from 100 to 10,000 per gram of soil. They are photoautotrophic, aerobic organisms and obtain CO2 from atmosphere and energy from sunlight and synthesize their own food. They are unicellular, filamentous or colonial. Soil algae are divided in to four main classes or phyla as follows:

1. Cyanophyta (Blue-green algae)
2. Chlorophyta (Grass-green algae)
3. Xanthophyta (Yellow-green algae)
4. Bacillariophyta (diatoms or golden-brown algae)

Out of these four classes / phyla, blue-green algae and grass-green algae are more abundant in soil. The green-grass algae and diatoms are dominant in the soils of temperate region while blue-green algae predominate in tropical soils. Green-algae prefer acid soils while blue green algae are commonly found in neutral and alkaline soils. The most common genera of green algae found in soil are: *Chlorella, Chlamydomonas, Chlorococcum, Protosiphon* etc. and that of diatoms are *Navicula, Pinnularia. Synedra, Frangilaria.*

Blue green algae are unicellular, photoautotrophic prokaryotes containing Phycocyanin pigment in addition to chlorophyll. They do not possess flagella and do not reproduce sexually. They are common in neutral to alkaline soils. The dominant genera of BGA in soil are: *Chrococcus,*

Phormidium, Anabaena, Aphanocapra, Oscillatoria etc. Some BGA possess specialized cells known as **"Heterocyst"** which is the sites of nitrogen fixation. BGA fixes nitrogen (non-symbiotically) in puddle paddy/water logged paddy fields (20-30 kg/ha/season). There are certain BGA which possess the character of symbiotic nitrogen fixation in association with other organisms like fungi, mosses, liverworts and aquatic ferns *Azolla, eg Anabaena-Azolla* association fix nitrogen symbiotically in rice fields.

Functions / role of algae or BGA:

1. Plays important role in the maintenance of soil fertility especially in tropical soils.
2. Add organic matter to soil when die and thus increase the amount of organic carbon in soil.
3. Most of soil algae (especially BGA) act as cementing agent in binding soil particles and thereby reduce/prevent soil erosion.
4. Mucilage secreted by the BGA is hygroscopic in nature and thus helps in increasing water retention capacity of soil for longer time/period.
5. Soil algae through the process of photosynthesis liberate large quantity of oxygen in the soil environment and thus facilitate the aeration in submerged soils or oxygenate the soil environment.
6. They help in checking the loss of nitrates through leaching and drainage especially in un-cropped soils.
7. They help in weathering of rocks and building up of soil structure.

Soil Microorganism – Protozoa

These are unicellular, eukaryotic, colorless, and animal like organisms (Animal kingdom). They are larger than bacteria and size varying from few microns to a few centimeters. Their population in arable soil ranges from l0,000 to 1,00,000 per gram of soil and are abundant in surface soil. They can withstand adverse soil conditions as they are characterized by **"cyst stage"** in their life cycle. Except few genera which reproduce sexually by fusion of cells, rest of them reproduces asexually by fission / binary fission. Most of the soil protozoa are motile by flagella or cilia or pseudopodia as locomotors organs. Depending upon the type of appendages provided for locomotion, protozoa are

1. Rhizopoda (Sarcondia)
2. Mastigophora
3. Ciliophora (Ciliata)
4. Sporophora (not common Inhabitants of soil)

Class-Rhizopoda: It **c**onsists protozoa without appendages usually have naked protoplasm without cell-wall, pseudopodia as temporary locomotory organs are present some times. Important genera are *Amoeba, Biomyxa, Euglypha*, etc.

Class Mastigophora: It belongs to flagellated protozoa, which are predominant in soil. Important genera are: *Allention, Bodo, Cercobodo, Cercomonas, Entosiphon Spiromonas, Spongomions* and *Testramitus.* Many members are saprophytic and some possess chlorophyll and are autotrophic in nature. In this respect, they resemble unicellular algae and hence are known as "Phytoflagellates".

The soil protozoa belonging to the class ciliate / ciliophora are characterized by the presence of cilia (short hair-like appendages) around their body, which helps in locomotion. The important soil inhabitants of this class are *Colpidium, Colpoda, Balantiophorus, Gastrostyla, Halteria, Uroleptus, Vortiicella, Pleurotricha* etc.

Protozoa are abundant in the upper layer (15 cm) of soil. Organic manures protozoa. Soil moisture, aeration, temperature and PH are the important factors affecting soil protozoa.

Function / Role of Protozoa

1. Most of protozoans derive their nutrition by feeding or ingesting soil bacteria belonging to the genera *Enterobacter, Agrobacterium, Bacillus, Escherichia, Micrococcus,* and *Pseudomonas* and thus, they play important role in maintaining microbial / bacterial equilibrium in the soil.
2. Some protozoa have been recently used as biological control agents against phytopathogens.
3. Species of the bacterial genera viz. *Enterobacter* and *Aerobacter* are commonly used as the food base for isolation and enumeration of soil protozoans.
4. Several soil protozoa cause diseases in human beings which are carried through water and other vectors, eg. Amoebic dysentery caused by *Entomobea histolytica.*

Factors Affecting Distribution, Activity and Population of Soil Microorganisms

Soil microorganisms (Flora & Fauna), just like higher plants depends entirely on soil for their nutrition, growth and activity. The major soil factors which influence the microbial population, distribution and their activity in the soil are:

1. Soil fertility
2. Cultural practices
3. Soil moisture
4. Soil temperature
5. Soil aeration
6. Light
7. Soil pH (H-ion Concentration)
8. Organic matter
9. Food and energy supply
10. Nature of soil
11. Microbial associations.

All these factors play a great role in determining not only the number and type of organism but also their activities. Variations in any one or more of these factors may lead to the changes in the activity of the organisms which ultimately affect the soil fertility level. Brief account of all these factors influencing soil micro flora / organisms and their activities is activities are discussed paragraphs.

1. Cultural practices (Tillage): Cultural practices viz. cultivation, crop rotation, application of manures and fertilizers, liming and gypsum application, pesticide/fungicide and weedicide application have their effect on soil organism. Ploughing and tillage operations facilitate aeration in soil and exposure of soil to sunshine and thereby increase the biological activity of organisms,

particularly of bacteria. Crop rotation with legume maintains the favorable microbial population balance, particularly of N2 fixing bacteria and thereby improve soil fertility.

Liming of acid soils increases activity of bacteria and actinomycetes and lowers the fungal population. Fertilizers and manures applied to the soil for increased crop production, supply food and nutrition not only to the crops but also to microorganisms in soil and thereby proliferate the activity of microbes.

Foliar or soil application of different chemicals (pesticides, fungicides, nematicides etc.) in agriculture are either degraded by the soil organisms or are liable to leave toxic residues in soil which are hazardous to cause profound reduction in the normal microbial activity in the soil.

2. Soil fertility: Fertility level of the soil has a great influence on the microbial population and their activity in soil. The availability of N, P and K required for plants as well as microbes in soil determines the fertility level of soil. On the other hand soil micro flora has greater influence on the soil fertility level.

3. Soil moisture: It is one of the important factors influencing the microbial population & their activity in soil. Water (soil moisture) is useful to the microorganisms in two ways i.e. it serve as source of nutrients and supplies hydrogen / oxygen to the organisms and it serve as solvent and carrier of other food nutrients to the microorganisms. Microbial activity & population proliferate best in the moisture range of 20% to 60%. Under excess moisture conditions / water logged conditions due to lack of soil aeration (Oxygen) anaerobic microflora become active and the aerobes get suppressed. While in the absence of adequate moisture in soil, some of microbes die out due to tissue dehydration and some of them change their forms into resting stages spores or cysts and tide over adverse conditions. Therefore optimum soil moisture (range 20 to 60 %) must be there for better population and activity of microbes in soil.

4. Soil temperature: Next to moisture, temperature is the most important environmental factor influencing the biological physical & chemical processes and of microbes, microbial activity and population in soil. Though microorganisms can tolerate extreme temperature (such as - 60 ° or + 60 u) conditions, but the optimum temperature range at which soil microorganisms can grow and function actively is rather narrow.

Depending upon the temperature range at which microorganisms can grow and function, are divided into three groups i.e. psychrophiles (growing at low temperature below 10 °C) Mesophiles (growing well in the temp range of 20 ° C to 45° C) and thermopiles (can tolerate temperature above 45° C and optimum 45-60°C).

Most of the soil microorganisms are mesophilic (25 to 40 °) and optimum temperature for most mesophiles is 37° C. True psychrophiles are almost absent in soil, and thermopiles though present in soil behaves like mesophiles. True thermopiles are more abundant in decaying manure and compost heaps where high temperature prevails.

Seasonal changes in soil temperature affect microbial population and their activity especially in temperate regions. In winter, when temperature is low (below 50° C), the number and activity of microorganisms falls down, and as the soils warms up in spring, they increases in number as well as activity. In general, population and activities of soil microorganisms are the highest in spring and lowest in winter season.

5. Soil air (Aeration): For the growth of microorganisms better aeration (oxygen and sometimes CO2) in the soil is essential. Microbes consume oxygen from soil air and gives out

carbon dioxide. Activities of soil microbes is often measured in terms of the amount of oxygen absorbed or amount of Co2 evolved by the organisms in the soil environment. Under high soil moisture level / water logged conditions, gaseous exchange is hindered and the accumulation of Co4 occurs in soil air which is toxic to microbes. Depending upon oxygen requirements, soil microorganisms are grouped into categories viz aerobic (require oxygen for like processes), anaerobic (do not require oxygen) and microaerophilic (requiring low concentration / level of oxygen).

6. Light: Direct sunlight is highly injurious to most of the microorganisms except algae. Therefore upper portion of the surface soil a centimeter or less is usually sterile or devoid of microorganisms. Effect of sunlight is due to heating and increase in temperature (More than 45°)

7. Soil Reaction / Soil PH: Soil reaction has a definite influence / effect on quantitative and qualitative composite on of soil microbes. Most of the soil bacteria, blue-green algae, diatoms and protozoa prefer a neutral or slightly alkaline reaction between PH 4.5 and 8.0 and fungi grow in acidic reaction between PH 4.5 and 6.5 while actinomycetes prefer slightly alkaline soil reactions. Soil reactions also influence the type of the bacteria present in soil. For example nitrifying bacteria *(Nitrosomonas & Nitrobacter)* and diazotrophs like *Azotobacter* are absent totally or inactive in acid soils, while diazotrophs like *Beijerinckia, Derxia,* and sulphur oxidizing bacteria like *Thiobacillus thiooxidans* are active in acidic soils.

8. Soil Organic Matter: The organic matter in soil being the chief source of energy and food for most of the soil organisms, it has great influence on the microbial population. Organic matter influence directly or indirectly on the population and activity of soil microorganisms. It influences the structure and texture of soil and thereby activity of the microorganisms.

9. Food and energy supply: Almost all microorganisms obtain their food and energy from the plant residues or organic matter / substances added to the soil. Energy is required for the metabolic activities of microorganisms. The heterotrophs utilize the energy liberated during the oxidation of complex organic compounds in soil, while autotrophs meet their energy requirement form oxidation of simple inorganic compounds (chemoautotroph) or from solar radiation (Photoautotroph). Thus, the source of food and energy rich material is essential for the microbial activity in soil. The organic matter, therefore serves both as a source of food nutrients as well as energy required by the soil organisms.

10. Nature of Soil: The physical, chemical and physico-chemical nature of soil and its nutrient status influence the microbial population both quantitatively and qualitatively. The chemical nature of soil has considerable effect on microbial population in soil. The soils in good physical condition have better aeration and moisture content which is essential for optimum microbial activity. Similarly nutrients (macro and micro) and organic constituents of humus are responsible for absence or presence of certain type of microorganisms and their activity. For example activity and presence of nitrogen fixing bacteria is greatly influenced by the availability of molybdenum and absence of available phosphate restricts the growth of *Azotobacter.*

11. Microbial associations / interactions: Microorganisms interact with each other giving rise to antagonistic or symbiotic interactions. The association existing between one organism and another whether of symbiotic or antagonistic influences the population and activity of soil microbes to a great extent. The predatory habit of protozoa and some mycobacteria which feed on bacteria may suppress or eliminate certain bacteria. On the other hand, the activities of some of the microorganisms are beneficial to each other. For instance organic acids liberated by fungi,

increase in oxygen by the activity of algae, change in soil reaction etc. favors the activity or bacteria and other organisms in soil.

12. Root Exudates: In the soil where plants are growing the root exudates also affects the distribution, density and activity of soil microorganism. Root exudates and sloughed off material of root surfaces provide an abundant source of energy and nutrients and thus directly or indirectly influence the quality as well as quantity of microorganisms in the rhizosphere region. Root exudates contain sugars, organic acids, amino acids, sterols, vitamins and other growth factors which have the profound effect on soil microbes.