CHAPTER-2

BACTERIA AND ARCHAEA

The Bacteria and Archaea comprise a diverse group of single-celled, prokaryotic organisms which live in the soils of every ecosystem -from warm, moist, densely vegetated soils to the deserts and grasslands. They are the smallest of all the cellular organisms that live in soil. Only the viruses which exist not as cells, are smaller.

Despite their small size, the bacteria and archaea exhibit a greater variety of metabolic capabilities than any other groups of organisms and play crucial roles in soil formation, organic matter decomposition, remediation of contaminated soils, biological transformations of mineral nutrients and interactions with plants and plant diseases.

CLASSIFICATION

Although there is currently no universally accepted system for classifying these diverse microorganisms, each species does have one officially recognized name.

The most widely accepted system for classifying these single-celled, prokaryotic microorganisms is described in Bergey's Manual of Determinative Bacteriology.

Bergey's Manual places them in the kingdom *Prokaryotae* and describes four divsions on the basis of walls the cells possess.

Division I: *Gracilicutes*

Prokaryotes with Gram-negative cell wall.

Division II: *Firmicutes*

Prokaryotes with Gram-positive cell wall

Division III: *Tenericutes*

Prokaryotes that have no cell wall, commonly called mycoplasmas.

Division IV: *Medosicutes*

Prokaryotes with walls that do not contain the bacterial polymer peptidoglycan.

Division I-III (*Gracilicutes, Firmicutes and Tenericutes*) are placed in the domain Bacteria and division IV (*Medosicutes*) in Archaea. Although these two domains of life differ radically in many fundamental properties as given below in the Table 1, yet the generic term bacteria (note lower case) is commonly applied to both groups of prokaryotes. The Gram negative and Gram positive bacteria are the most abundant cellular organisms found in soil. The Archaea include microorganisms that grow in harsh environments (extreme halophiles and thermophiles) and strictly anaerobic methanogens, which can reduce carbon dioxide to methane gas. Archaea resemble Bacteria and have some genes that are similar to bacterial genes, but they also contain other genes that are more like what are found in eukaryotes. Furthermore, they have some genes that are not like any found in anything else.

Table 1: Differences between the Bacteria and Archaea

Character	Bacteria	Archaea
Lipids in membrane	Ester-linked , straight-chain fatty acids	Ether-linked, branched chain aliphatics
Cell walls	Peptidoglycan-muramic acids	Variety, no muramic acid
Transfer RNA	Thymine present	Thymine absent
Ribosome, response to Chloramphenicol Kanamycin Anisomycin	 Sensitive Sensitive Insensitive	 Insensitive Insensitive Sensitive
DNA-dependent, RNA polymerase Number of enzymes Structure Rifamicin sensitivity	 One Simple subunit Sensitive	 Several Complex subunit Insensitive

The primary taxonomic unit in bacterial classification is the *species* which can be defined as "a collection of strains that share many features in common and differ considerably from other strains". In bacteriology, a *strain* is a culture of cells descended from a single pure isolate.

Most microbiologists prefer to assign bacteria to descriptive groups that do not reflect a formal taxonomic ranking. The characteristics commonly used to classify bacteria are given in Table 2.

Table 2. Characteristics commonly used to classify bacteria

Characteristic	Description
Cellular morphology	Size, shape, and arrangement of cells; staining reactions; presence or absence of specific structures.
Chemical characteristics	Chemical nature of cellular constituents.
Cultural characteristics	Nutritional and environmental requirements for growth; appearance of cultures in liquid or solid media.
Metabolism	Chemical reactions carried out by cells to satisfy nutritional and energy requirements.

Antigenic characteristics	Distinctive chemical components of cells that react specifically with antibodies produced by animal.
Genetic characteristics	Base composition and nucleotide sequence of chromosomal or plasmid DNA.
Pathogenicity	Ability to produce disease in plant or animal hosts.
Ecological characteristics	Normal habitat and distribution of the organism in nature, interactions with other organisms.

STRUCTURE AND FUNCTION OF BACTERIAL CELLS

Cell Shapes:

Most soil bacteria live as single cells, though some species form long, slender, branching filaments. These are divided into different groups on the basis of shapes.

1. Bacilli (Bacillus): Rod-shapes cells
2. Cocci (Coccus): Spherical cells
3. Spirilla (Spirillum): Twisted or spiral-shaped rods
4. Actinomycetes: Slender, branching filaments

Some bacteria that live in aquatic environments or in animal hosts exhibit additional shapes. e.g.

5. Vibrios: Curved rods
6. Spirochetes: Corkscrew-shaped cells
7. Sheathed bacteria: Long, slender filaments of rod-shaped cells enclosed within a sheath.

Cell Grouping:

In some species of bacteria , particularly among the cocci, individual cells often do not separate after undergoing cell division. Instead, the cells remain attached to one another and exhibit characteristic types of cell grouping.

1. Streptococci: Cocci, which consistently divide longitudinally, form chains of cells called streptococci.
2. Staphylococci: Cocci that divide randomly form irregular clusters of cells called staphylococci.

   A few species of cocci form planar packets of four cells, known as tetrads, or cuboidal packets of eight or more cells.

3. Streptobacilli: Some of the rod-shaped bacteria that remain attached end-to-end following cell division form chains of cells called streptobacilli.

4. Palisade: In some of the bacilli, the cells may align side-by-side rather than end-to-end, forming an arrangement called a palisade.

Cell Structure:

The bacteria differ from other major groups of soil microbes in their distinctive cell structure and mechanism of genetic recombinatin. Bacteria are prokaryotic. They are much smaller than the eukaryotic soil microbes-the fungi, algae, protozoa and microscopic animals. The bacteria lack the complex array of membrane bound organelles found in eukaryotes.

<u>Cytoplasmic membrane:</u>

As in all living cells, the cytoplasm of a bacterial cell is enclosed within a cytoplasmic membrane (also called cell membrane). The cytoplasmic membrane is a fluid structure consisting of two layers of phospholipid molecules oriented so that the lipids face one another in the interior of the membrane.

The cytoplasmic membrane is the site of many essential functions in bacterial cells.One essential function of the cytoplasmic membrane is to transport nutrients into the cell, and waste products and certain types of enzymes out of the cell. Another essential function of the cytoplasmic membrane is to generate the energy that a bacterial cell needs to survive and grow.

<u>Cell wall:</u>

A rigid cell wall surrounds the cytoplasmic membrane of all soil bacteria. Microbiologists divide the domain Bacteria into two large groups based upon the type of cell wall that they possess. These groups are as below:

1. Gram-positive (G^+): The cell wall in G^+ bacteria is a single thick layer composed largely of a rigid polymer called peptidoglycan.
2. Gram-negative (G^-): The cell wall of G^- bacteria has a more complex structure. A relatively thin layer of peptidoglycan surrounds the cytoplasmic membrane. The peptidoglycan layer is, in turn, enclosed within a second membrane known as the outer membrane. Numerous lipoprotein molecules anchor the outer membrane to the peptidoglycan layer.

A gel-like periplasm fills the space between the cytoplasmic membrane and outer membrane of a G^- bacterium. Periplasmic protein performs several key functions in G- bacteria, such as catalysing the initial steps in hydrolysis of food molecules, transporting substances from the outer membrane to the cytoplasmic membrane.

The primary function of cell wall is to confer osmotic protection to soil bacteria. The concentration of dissolved substances in the cytoplasm of a bacterial cell is much higher than the concentration of dissolved substances in the soil solution. As a result, water diffuses into the cells and would cause the cells to burst if they were not enclosed by a rigid wall.

Bacterial chromosome:

The chromosome, or nucleoid, of a bacterial cell consists of a single, circular double-stranded DNA molecule which is suspended directly in the cytoplasm. Unlike the nucleus of a eukaryotic cell, the nucleoid in a bacterial cell is not enclosed within a nuclear envelope. The chromosome contains the essential genetic information of a bacterial cell.

Most, if not all, bacteria possess one or more small DNA molecules called plasmids in addition to the DNA of the chromosome. Plasmids are circular molecules, like the DNA of the nucleoid, but they are much smaller and contain much less information than the nuclear DNA. Plasmids are dispersed throughout the cytoplasm of a bacterial cell and can replicate even when the cell itself is not reproducing. As a result, bacterial cells may contain multiple copies of one or more plasmids.

Cytoplasmic structures:

The cytoplasm of a bacterial cell lacks the complex array of membrane-bound organelles which fills the cytoplasm of eukaryotic microbes. Nonetheless, it is a region of intense biochemical activity. Much of this activity is mediated by the thousands of *ribosomes* that fill the cytoplasm. Ribosomes are small particles composed of granular proteins and ribosomal RNA which catalyse protein synthesis. They often form structures known as *polysomes* when a bacterium is actively synthesizing proteins. Bacterial ribosomes are smaller than the ribosomes in the cytoplasm of eukaryotic microbes, and they do not attach to the membranes of an endoplasmic reticulum (prokaryotes do not have an endoplasmic reticulum).

Many bacteria store nutrients in the cytoplasm when an excess supply of the nutrients is available in the soil. The nutrients are stored as droplets or granules called *inclusions* which can later be hydrolysed when the nutrient supply becomes depleted.

Endospores:

A few species of bacteria, most notably the members of genera Bacillus and clostridium, produce a unique structure called endospore in response to nutrient depletion or other environmental stresses. Unlike the reproductive spores produced by the fungi and actinomycetes, bacterial endospores do not serve to increase the number of individuals in a population. Endospores are survival structures, not reproductive structures. Each bacterial cell in a population of spore formers is transformed into a single endospore during a period of stress. When favorable conditions for growth return, each endospore germinates to form a single cell, so there is no increase in the number of individuals in the population. Endospores are specially constructed to enable a bacterial population to withstand harsh environmental conditions, including extremely high temperature, desiccation (drying), radiation, and exposure to toxic chemicals. Recently, scientists succeeded in reviving endospores which were from 25-40 million years old.

Surface structures;

Bacterial cells possess a variety of surface structures which play important roles in their activities in soil. An organism's survival in soil often depends on its ability to adhere to the surface of soil particles or to the cells of other organisms with which it forms a mutualistic or antagonistic association. Many soil bacteria produce structures known as *pili* (singular, *pilus*) or *fimbriae* (singular, *fimbria*) which enable them to adhere to surface. Both structures are slender protein filaments which extend through the cell wall into the surrounding medium. Fimbriae are shorter and more numerous than *pili*. A special type of *pilus*, known as *sex pilus*, enables compatible cells to adhere and draw together during conjugation.

Bacteria must contend with wide fluctuations in the moisture content of soils, and they must avoid predation by larger soil microbes and infection by lytic viruses in order to survive. Many species excrete a layer of polysaccharides and glycoproteins, or *capsule*, onto the cell surface to satisfy these requirements. The structure and consistency of the capsule varies from a thin slime layer to a thick gel, depending on the species of the bacteria and the type and availability of organic nutrients in the soil. The capsule enables the organism to avoid desiccation and masks surface structures that phagocytic microbes would otherwise recognize and engulf the bacteria and that viruses would use to initiate infection. Thick, sticky capsules may also play a role in the attachment of bacterial cells to surfaces and in the formation of biofilms.

Many soil bacteria have the ability to swim in the soil solution from one location to another known as motility. Depending on soil moisture conditions, motility enables unattached bacteria to move from a site where conditions are less favorable for growth to a site where conditions are more favorable, though the distances travelled through are not great. Most motile bacteria swim by rotating a long, slender, helically shaped protein filament called a *flagellum (*plura*l flagella*). Some species of bacteria produce a single flagellum, whereas others produce two or more in various characteristic arrangements. Flagella are anchored to the cytoplasmic membrane and extend outward through the cell wall into the surrounding medium.

Movement of bacteria towards a chemical attractant (such as an essential nutrient or a more favorable oxygen concentration), or away from a chemical repellent (such as toxic substances or an unfavorable pH), is referred to as *chemotaxis*.

NUTRITION AND METABOLISM OF SOIL BACTERIA

Nutritional Requirements:

Bacteria have many of the same nutritional requirements as higher organisms. A *nutrient* is any substance that a bacterium must obtain from its surroundings to survive and grow. Some nutrients are assimilated into cellular constituents, while others are transformed to obtain energy. Substances required in large quantities are called *macronutrients*. These elements often occur as structural components of the biological molecules that are abundant in bacterial cells: Carbohydrates, proteins, lipids, and nucleic acid. Carbon is required in the greatest amount, followed by nitrogen, phosphorous, and sulfur. Water is generally not regarded as nutrient in the same sense as these elements, yet it is essential for all living cells and it serves as the primary source of hydrogen and oxygen. These elements account for about 95% of the dry mass of bacterial cells. Potassium, sodium, calcium, and magnesium are also required in substantial quantities.

Micronutrients are required in lesser amounts (a few ng g^{-1} dry mass). These elements often serve as structural components or activators of specific enzymes in bacterial cells. Iron is the micronutrient that is usually required in the greatest amount. Others include cobalt, zinc, molybdenum, copper and manganese.

Some

Some bacteria can synthesize all necessary cellular constituents and obtain energy for growth using a single carbon source and a few mineral nutrients. Others have more complex nutritional requirements. Many soil bacteria require specific organic compounds that they are unable to synthesize from simple straight materials. Organic nutrients of this type are called *growth factors* and are usually classified into one of the following categories:

Amino acids (precursors of protein synthesis)

Purines and pyrimidines (precursors for nucleic acid synthesis) and

Vitamins (precursors for the synthesis of certain enzymes)

Sources of Carbon and Energy:

Bacteria are classified into different groups on the basis of carbon and energy requirements which are discussed below.

Chemoheterotrophs:

Most soil bacteria are chemoheterotrophs. They obtain energy by oxidizing the organic matter in soils and use the products of energy metabolism or other organic compounds as sources of carbon for growth. Most of these bacteria are *saprophytes* which feed on nonliving plant and animal residues or on humic substances in soils. A few species are *symbionts* or *pathogens* which invade the tissues of other living organisms. Symbiotic bacteria feed on organic compounds in the tissues of a host organism and usually benefit the host. Pathogenic bacteria harm the hosts whose tissues they invade, thereby causing disease.

Photoheterotrophs:

These are the bacteria which use light as source of energy and organic compounds as source of carbon. These include green sulfur bacteria and purple non-sulfur bacteria.

Photoautotrophs:

Several genera of soil bacteria are photoautotrophs. They capture light energy and use it to synthesize carbohydrates (photosynthesis) with carbon dioxide as their source of carbon. The *cyanobacteria* resemble eukaryotic algae (and plants) in the manner in which they use light energy and water to fix carbon dioxide (forming oxygen in the process). The green bacteria produce green photosynthetic pigments and use reduced sulfur compounds (sulfide or thiosulfate) or hydrogen gas as electron donors. The purple bacteria produce purple photosynthetic pigments and are divided into two groups:

i) purple sulfur bacteria which use reduced sulfur compounds, hydrogen , or organic compounds as electron donors

ii) Purple non-sulfur bacteria which generally do not use reduced sulfur as an electron donor and oxidize hydrogen or organic compounds when growing photoautotrophically.

Chemoautotrophs:

Several important groups of soil bacteria are chemoautotrophs, also known as *lithotrophs*. They obtain energy by oxidizing reduced inorganic compounds in soil and use carbon dioxide as their source of carbon to synthesize carbohydrate.

Two groups of chemoautotrophic bacteria, collectively known as nitrifying bacteria, obtain energy by oxidizing inorganic nitrogen in soil:

i) The *ammonia-oxidizing bacteria* (*Nitrosomonas* and related genera) obtain energy by oxidizing ammonia (NH_3) to nitrite (NO_2^-).

$$2NH_3 + 3O_2 \rightarrow 2NO_2 + 2H^+ + 2H_2O$$

ii) The *nitrite-oxidizing bacteria* (*Nitrobacter* and related genera) which obtain energy by oxidizing nitrite to nitrate (NO_3^-). They usually accompany ammonia-oxidizing bacteria in soils.

$$2NO_2 + O_2 \rightarrow 2NO_3^-$$

The *sulfur-oxidizing bacteria* obtain energy by oxidizing sulfides, elemental sulfur, or thiosulfate. The oxidation of these substances results in the production of substantial amounts of sulfuric acid, significantly lowering the pH of the microenvironment in which sulfur oxidation occurs. Several sulfur-oxidizing bacteria are *obligate acidophlies* that not only tolerate the acid they produce but are actually unable to grow at pH greater than 4.

Thiobacillus thiooxidans $2S^0 + 3O_2 + 2H_2O \rightarrow 2SO_4^{2-} + 4H^+$

Thiobacillus ferrooxidans $2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$

$4Fe^{2+} + 4H^+ + O_2 \rightarrow 4Fe^{3+} + 2H_2O$

Thiobacillus denitrifican $5S^0 + 6KNO_3 + 2H_2O \rightarrow K_2SO_4 + 4KHSO_4 + 3N_2$

The *hydrogen-oxidizing bacteria* normally grow as chemoheterotrophs when organic substances are available in the soil. In the absence of an oxidizable organic substrate, they can oxidize hydrogen for energy and synthesize carbohydrates with carbon dioxide as their source of carbon.

$$2H_2 + O_2 \rightarrow 2H_2O$$

$$2H_2 + NAD^+ \rightarrow NADH + H^+$$

Table 3. Major nutritional groups of soil bacteria.

Nutritional classification	Carbon sources	Energy sources	Representative groups
Chemoheterotrophs	Organic	Organic	Saprophytic bacteria Most symbiotic bacteria
Photoautotrophs	Carbon dioxide	Light energy	Cyanobacteria Green bacteria Purple bacteria
Chemoautotrophs	Carbon dioxide	Inorganic	Nitrifying bacteria Sulfur-oxidizing bacteria Hydrogen-oxidizing bacteria

Oxygen Requirements:

Oxygen concentrations in soils can vary widely from one microsite to another. Bacteria in a macropore filled with air may find plenty of oxygen to respire aerobically, while just a few millimeters away bacteria in a micropore filled with water may encounter strict anaerobic conditions. Oxygen concentrations can also vary widely with time, as soils undergo periods of saturation with water which may lead to temporary hypoxic or anoxic conditions and periods of dryness. It is not surprising, then, that soil bacteria exhibit a full range of adaptations to different oxygen concentrations.

Obligate aerobes:

Many soil bacteria are obligate aerobes. Obligate aerobes obtain energy exclusively by aerobic respiration and can only grow in microsites where oxygen is available to use as a terminal electron acceptor.

Obligate anaerobes:

These cannot survive in the microsites where oxygen is available because they lack the enzymes that are needed to rid themselves of the toxic products (hydrogen peroxide and superoxide) that are initially formed when oxygen serves as an electron acceptor. Obligate anaerobes grow exclusively in anaerobic microsites, obtaining energy either by fermentation or by anaerobic respiration.

Soil microbiologists recognize several groups of obligate anaerobes that generate energy by anaerobic respiration:

i) The *sulfate-reducing bacteria* use sulfate as a terminal electron acceptor and produce hydrogen sulfide as a gaseous waste product. Along with the sulfur oxidizers, these bacteria play an important role in sulfur cycle.

$$SO_4^{2-} + 8e^- + 10H^+ \rightarrow H_2S + 4H_2O$$

ii) The *methanogenic bacteria* use carbonate as a terminal electron acceptor and produce methane as a gaseous waste product. The *acetogenic bacteria* also use carbonate as a terminal electron acceptor, but produce acetic acid as a waste product rather than methane.

$$CO_3^{2-} + 8e^- + 10H^+ \rightarrow CH_4 + 3H_2O$$

$$2CO_3^{2-} + 8e^- + 12H^+ \rightarrow CH_3COOH + 4H_2O$$

<u>Facultative anaerobes:</u>

Many soil bacteria can grow either in the presence or absence of oxygen called as Facultative anaerobes. These bacteria respire aerobically when oxygen is available, but can alter their metabolism to grow anaerobically in the absence of oxygen. Some facultative anaerobes shift to fermentative metabolism under anaerobic conditions, whereas others shift to anaerobic respiration using nitrate or other inorganic compounds as the terminal electron acceptor. In either case aerobic respiration is the preferred mode of metabolism because it provides the bacteria with more energy than either fermentation or anaerobic respiration.

<u>Aerotolerant anaerobes:</u>

The *aerotolerant* bacteria grow both under aerobic and anaerobic conditions, but do not shift from one mode of metabolism to another as conditions change. They lack the electron transport protein that function in aerobic and anaerobic respiration and obtain energy exclusively by fermentation. Because they do not form toxic products by using oxygen as an electron acceptor, aerotolerant anaerobes are not poisoned by oxygen in the same manner as obligate anaerobes.

Habitats:

Bacteria exhibit an exceptional variety of adaptations that enable them to survive and grow in habitats that no other organisms can tolerate. It has already been discussed that bacteria, through their various modes of energy metabolism, can grow in aerobic or anaerobic environments.

Bacteria can tolerate temperature extremes far beyond those tolerated by other organisms. These can be classified into following different groups on this basis.

Mesophiles:

Most soil bacteria are Mesophiles that grow optimally at temperatures in the range of 15 to 35 °C.

Thermophiles:

Some species of bacteria, known as thermophiles, survive and often thrive at temperatures in excess of 40 to 50^{o}C (and as high as 100^{o}C). Most eukaryotes cannot survive temperatures above 45^{o}C. Thermophllic bacteria typically produce heat-stable enzymes and structural proteins that do not denature at elevated temperatures.

Psychrophiles:

Some species of bacteria, known as Psychrophiles, have adapted to grow optimally at temperatures below 15^{o}C. These psychrophilic bacteria often synthesize large quantities of unsaturated fatty acids that maintain the fluidity of the cytoplasmic membrane at low temperatures.

Several species of bacteria thrive best at particular pH, and are classified into following groups on this basis.

Acidophiles:

Some species of bacteria thrive in acidic soils that predominate in regions with high precipitation. Some, such as the sulfur-oxidizing bacteria, tolerate extremely low pH that severely inhibits normal enzymatic activity. These Acidophiles maintain a neutral cytoplasmic pH by actively transporting H^{+} ions out of the cell.

Alkalophilic:

These grow at pH as high as 10.5 in arid and semi arid regions and use a similar strategy (ion pumps as by Acidophiles) for this purpose. Actinomycetes frequently predominate in alkaline soils because of their tolerance to high pH.

Poor drainage and rapid surface evaporation in arid regions often lead to the formation of saline soils with stressful osmotic potential that inhibits the growth of many microbes. Many species of bacteria have adapted to saline or arid environments by developing enzymes that function in solutions of high ionic strength or by accumulating solutes in the cytoplasm to compensate for the low water potential of the soil solution.

Halophiles:

Bacteria that can tolerate high salt concentrations are called halophiles.

Xerophiles:

Bacteria that tolerate dry habitats are called Xerophiles.

INTERACTIONS WITH OTHER ORGANISMS

Bacteria exhibit a broad spectrum of interactions with one another and with other soil microorganisms, ranging from neutral relationships at the center of the spectrum to symbiotic interactions at one extreme or antagonistic interaction at the other. Probably the most common type of interaction among soil microbes is *competition*. Bacteria, fungi, protozoa, and microscopic animals compete for water, food, shelter, and other vital resources that are present in short supply.

Beneficial interactions involving soil bacteria are also common. Decomposition of the complex constituents of soil organic matter, for instance, typically requires the cooperative activity of diverse community of microorganisms. One population may break down a complex substrate to an intermediate product that a second population can use as its source of carbon or energy for growth. Bacteria may have a negative impact on one another and on other soil microbes by producing antibiotics or other substances that harm the organisms living nearby.

Bacteria also have important interactions with plants. They colonize plant roots in greater numbers than any other group of soil microbes and profoundly influence plant growth and productivity in natural and agricultural ecosystems. Bacteria may increase he availability of inorganic nutrients in soils by mineralizing soil organic matter and solubilizing soil minerals, and that they may compete with plants for those same nutrients through the process of immobilization. Many bacterial species influence plant growth directly by producing hormones or toxins that stimulate or impede root function and morphology. A few species, e.g. Rhizobium, Bradyrhizobium, and Frankia, form intricate mutualistic symbiosis with selected plant species, while other bacteria produce disease in plants that they infect. Most of the bacteria that colonize plant roots are harmless saprophytes that feed on the organic nutrients in root exudates and protect the plant from infection by competing with pathogens for nutrients, water, and places to attach to the root, or by excreting substances that directly inhibit the pathogen. Several species of bacteria are currently being investigated as potential biological control agents because of their ability to inhibit the growth of plant pathogens.

THE ACTINOMYCETES

The actinomycetes constitute specialized group of bacteria that occurs in soils throughout the world. The term actinomycetes (*actinis*, meaning "ray" and *myces,* meaning "fungus") is a misnomer. Despite their placement with bacteria, the relation of actinomycetes to fungi is apparent in the formation of an aerial mycelium, although much smaller than that of fungi and the production of abundant asexual spores called *conidia* which give the colony a powder or chalky appearance. However, their resemblance to fungi is strictly morphological. The actinomycetes are classified with bacteria because they:

- are prokaryotic,
- contain peptidoglycan in their cell walls,
- are sensitive to lysozyme which degrades the polysaccharide backbone of the peptidoglycan,
- are sensitive to antibacterial but not antifungal antibiotics, and
- Possess flagella typical of bacterial flagella in the few species that show motility.

The actinomycetes include the microorganisms that produce colonies ranging from those typical of bacteria, such as species of *Mycobacterium* and *Corynebacterium,* to those that produce the tough, leathery mycelium characteristic of S*treptomyces* species.

The actinomycetes play important roles in soils and other environments such as compost piles. They are important agents in the degradation of organic materials in soil and contribute to the formation of stable humus. Recent research indicates that they, along with certain fungi, may play an important role in the degradation of lignin. They are also responsible for certain animal, plant, and human diseases.

The actinomycetes are often described as slow-growing organisms. For this reason, culture plates are often incubated for one or two weeks to allow differentiation of the actinomycetes colonies. Although they do not compete well with the faster-growing bacteria and fungi for readily available carbon substrates, they are thought to be important in mineralizing carbon and nitrogen formed during the early stages of decomposition, such as fungal cell walls. Many actinomycetes are good chitin degraders and simply because actinomycetes are "late colonizers" should not detract from the vital roles they play in the degradation processes and in the formation of humus.

Perhaps one of the most outstanding characteristics of the actinomycetes is their ability to produce antibiotics. Streptomycin, neomycin, erythromycin, and tetracycline are a few of the medically important antibiotics derived from species of *Streptomyces*.

Actinomycetes tend to respond to environmental influences like bacteria. However, there are some exceptions. Actinomycetes tend to become more abundant in soils subjected to prolonged drying. This shift toward numerical dominance in generally attributed to the ability of actinomycetes to produce conidia which withstand desiccation well. Thus, while more sensitive organisms are inhibited / killed due to low-moisture stress, actinomycetes persists. The conidia also confer a slight tolerance to increased soil temperature. Though most of the actinomycetes are Mesophiles, Thermophllic actinomycetes are important in the high-temperature transformations of organic substrates during composting. As a group, the actinomycetes tend to be sensitive to low pH. In general, as the soil pH decreases to 6.0 their number declines and below pH 5.0 they are almost absent.

Figure 1: Common shapes and grouping of soil bacteria: a) rods, occurring as single cells, in chains (streptobacilli), and palisade arrangement; b) cocci, occurring as single cells and in chains (streptococci), irregular clusters (staphylococci); c) spirilla; d) streptomyces, an actinomycete, with chains of spores.

Figure 2: Generalized structure of bacterial cell: CM= cytoplasmic membrane, CW= Cell wall, N: nucleoid, In= Inclusion, Me= mesosome, R= ribosome occurring in the form of a polysome, Fi= fimbria, P= pilus and F= flagellum.

Figure 3: Structure of Gram-negative (a) and Gram-positive (b) bacterial cytoplasmic membranes and walls. CM= cytoplasmic membrane, PG= peptidoglycan, LP= lipoprotein, OM= outer membrane, LPS= lipopolysaccharide, p= porin, and TA= teichoic acid