Microbial Ecology and Environmental Biotechnology

Introduction to Microbial Ecology

Microbial ecology is the study of the relationships between microorganisms and their environment. These relationships include the basic factors affecting growth and survival of microorganisms, such as pH, temperature, salt concentration, oxygen and carbon dioxide concentrations, and growth factors synthesized by other bacteria. Microbial ecology also deals with the relationships between various microorganisms, such as the interactions between the various members of a microbial community within an environmental site.

Microorganisms play important roles in the biogeochemical cycling of carbon, nitrogen, oxygen, sulfur, phosphorus and other factors in the environment. Microorganisms also contribute significantly to pollutant degradation in the environment. Environmental biotechnology is concerned with the exploitation of this potential of microbes for restoring and managing the quality of the natural environment.

Fundamental Concepts in Microbial Ecology

Microbial ecology is the study of the interactions of microorganisms with their environment, each other, and with other organisms. Microbial ecology seeks to understand the diversity of microbial species within communities, their activities and relationships with the environment, and the manner in which they influence biogeochemical processes. The notion that microorganisms are of utmost importance in the environment was clearly recognized as early as the 1930s during the formative years of microbial ecology. Investigation of microorganisms in the context of the environment is known as microbial ecology and such a discussion should begin by defining the magnitude and scope of microbial ecology and the historical development of the discipline.

Microorganisms can be largely responsible for any alteration in the natural ecology of the system. It is a pertinent fact that the life-support systems of the broader categories of flora and fauna mainly depend on microorganisms. Although the study of microorganisms and their natural habitats has acquired the name of microbial ecology only recently, a reference in general terms to microorganisms in water, soil, and air was made more than 2000 years ago by

Hindu Vedic and Greek manuscripts. Different types of life processes are also being performed by microorganisms, such as nitrogen fixation, oxygen production by the processes of photosynthesis, biodegradation, and nutrient recycling. They also play an important role in the mineralization of organic wastes in the ecosystem.

1. Microbial Diversity

Microbial Ecology is the study of the relationships between microorganisms and their environments. The field emerged in the mid-Eighteenth Century with the works of Antoine van Leeuwenhoek and M. Schleiden, and grew rapidly after the works of Louis Pasteur. Today, Microbial Ecology combines molecular biology techniques with environmental sciences, dissecting the diversity of microorganisms in their role as the major agents of biogeochemical cycles.

Environmental Biotechnology emerged in the early Twentieth Century, based on the discoveries of Louis Pasteur and Sergei Winogradsky. These founders of Microbial Ecology demonstrated natural purification processes carried out by microorganisms. Today, Environmental Biotechnology exploits these natural microbial metabolic routes to remediate contaminated systems, which accelerates the use of microbial agents in bioremediation, wastewater treatment, biodegradation of plastics, bioaugmentation, biotransformation of recalcitrant compounds, and microbial fuel cells.

2. Microbial Interactions

The survival and existence of species depend on interactions, being physiological or ecological. Trophic, symbiotic, co-existence, and antagonistic relationships are the fundamental relations. The ecological relation that exists between two different species for food is called trophic. One species benefits while the other loses food. For example, a carnivore depends on other animals as food. A symbiotic relation is when two different species live closely in a physiological relationship. For example, mycorrhizal fungi help plants to absorb nutrients from the soil. A co-existence relation is when two or more living organisms live together without disturbing each other. For example, different bacteria in the soil, each species occupies a particular environment, for example, Bacillus at pH 8.5, Clostridium at pH 5.5, exhibiting optimal co-existence relation.

3. Nutrient Cycling

Microbial Ecology is defined as the study of interactions that occur among microorganisms and between microorganisms with their environment, where they are affected by both physical and biological influences. Microorganisms have a prominent place in the living world because of their diversity, wide abundance, wide distribution, diverse habitat and enormous biological activities. Microorganisms play an important role in the circulation of nutrients in the ecosystem. Environmental Microbiology is a relatively new field, which deals with the microorganisms present in different environments, aquatic or terrestrial, natural or artificial. It therefore aims at describing the structure and functioning of microbial communities in relation to the particular biotope that they occupy.

The interface between environmental microbiology, microbial ecology and environmental biotechnology often provides insights into microbial secretion of extracellular enzymes and bioactive molecules, and ways to exploit these for the development of environmental biotechnology processes. Such interactions exploit the vast metabolic potential of microorganisms that allows them to exploit virtually all environments. The discovery of genes that regulate the physiological function of microorganisms can perhaps be applied in increasing the ability of microbes to degrade toxic substrates from the environment. Today, environmental biotechnology is a subject which encompasses all these areas of microbial activity as well as many other associated areas

Role of Microorganisms in Soil Health

Soil is a complex dynamic system, a living matrix of minerals, water, air, and innumerable organisms interacting to create an environment capable of growing plants and sustaining life on earth. The soil microbiome encompasses the bacteria, fungi, archaea, protists, and viruses inhabiting soil. The role of the microbiota in maintaining soil's ability to function is shown by the rapid degradation of soil functions and erosion of fertile soil once the soil microorganism community has been destroyed. Soils function in plant production by providing support for the plant, supplying nutrients, air, and moisture, buffering against fluctuations in temperature and moisture, regulating the dynamics of plant diseases, and participating in elemental cycling.

There are beneficial as well as harmful activities of the soil microbial communities. Mutualistic interactions with other soil biota support nutrient cycling, increase stress tolerance, and control of plant pests. Symbiotic interactions with plant roots, such as mycorrhiza and nitrogen-fixing bacteria, can account for a significant part of plant nutrition. Several groups of soil microorganisms convert otherwise unavailable nutrients into forms that can be taken up and used by plants. Soil microorganisms also play a role in maintaining soil structure and help plants relieve abiotic stress. On the other hand, certain members of the soil microbial community may cause various plant diseases.

1. Soil Microbiome

Biodiversity forms the foundation for ecosystem functioning, and it includes all levels of life, ranging from genes and species to ecosystem-level diversity across the landscape. An ecosystem contains a number of species interacting with one another, thus forming complex communities where various types of relationships exist. Natural biodiversity offers countless potential sources of metals and minerals, drugs, foods, cosmetics, and more. Notably neglected are the genetic resources of microbes. A cursory glance at the natural products of life on earth suggests that biodiversity is an unimaginably complex superposition of biological building blocks. The general term “biological resources” or “bioresources” encompasses gene-pools, biological species, populations, and any biotic component of ecosystems with actual or potential use or value to humans.

Soil is a major resource, vital to agriculture and hence to the sustenance of human civilization; the soil microbiome is considered the second genome of the plant. Along the crop cycle, plants recruit microbes from the soil, especially the root soils, and among these, it is the roots that exert a more specific role in recruiting and selecting for microorganisms from the environment, through an active and selective root exudation of compounds. Properties such as protection against pathogens and pests, tolerance to and remediation of abiotic stresses, and help in improving nutrient uptake are paramount for reaching good crop yields. There is growing interest in elucidating the relations between bacteria and plants in order to assess their impact on plant growth and crop production: such research will also help the development of sustainable agriculture.

2. Plant-Microbe Interactions

Microorganisms are involved in numerous symbiotic relationships with plants, encompassing effects that range from beneficial to detrimental. The diversity of these relationships spans mutualistic associations with rhizobia and arbuscular mycorrhizal fungi to interactions with agents of plant disease, pathogenic nematodes, and other harmful organisms. Within the soil system, virtually all microbial phyla can be detected, underscoring the extensive microbial biodiversity present. Plant-associated microorganisms undertake an array of roles, including the absorption of nutrient elements from the soil, prevention of phytopathogenic infections via antibiosis or parasitism, and biotransformation of contaminants.

Engineered microorganisms are frequently employed in bioremediation processes due to their capacity to degrade and detoxify hydrocarbons and herbicides in diesel-contaminated soils. Several drought-tolerant bacterial strains—namely Bacillus, Nocardioides, Arthrobacter, Microbacterium, and Ensifer—are also capable of degrading complex aromatic substances found in diesel-contaminated soils, thereby enhancing hydrocarbon biodegradation under conditions of water stress. Further, biofertilization strategies harness nitrogen-fixing bacteria, mycorrhizal fungi, and other constituent members of the soil microbiome to promote plant growth in metal-contaminated soils.

Microbial Ecology in Aquatic Systems

Water is an essential component of nature and the sources such as rivers, lakes, seas and oceans are the habitats of numerous plants and animals as well as microorganisms. Secondary metabolites of microorganisms play an important role in the biogeochemistry of aquatic environment. Microorganisms are the base of the food chain in aquatic ecosystem. The water currents take the materials from the surface to the deep sea and vice versa. In the aquatic systems where there is plenty of oxygen, the carbonaceous wastes are oxidized to carbon dioxide. In the subsoil of the oceans and seas of tropical and temperate countries, the temperature remains between 2 and 8 °C and mostly the environment is aerobic. However, in the Antarctica, the environment is mostly anaerobic due to the presence of a thick layer of ice and oxygen has been consumed by the activity of microbes. In many fresh water systems also there is an oxygen depletion and consequently anaerobic microbes take over the functions of aerobic microbes.

1. Freshwater Ecosystems

Microbial ecology is the study of the interactions of microorganisms with one another and with the environment. These interactions are diverse and influence how they survive and reproduce, making them ideal subjects for ecological principles. Microbial ecology has application in environmental management and restoration as well. Although already important in many environmental technologies, such as wastewater treatment, the field is advancing rapidly because of emerging threats posed by human activities such as global warming and chemical pollution.

Environmental biotechnology is a subset of the broader field of biotechnology and makes use of various microbes for the removal of pollutants from the environment. It utilises the metabolic processes of microorganisms to transform polluting substances into non- polluting products. Environmental biotechnology is any application of biotechnology used to study or manipulate the relationships of living organisms with respect to their environment. It deals with the application of living organisms such as microbes to the environment. It also deals with the exploitation of the activities of the microbes and other microorganisms to protect the environment. It is also called public health biotechnology. Environmental biotechnology applications to environmental management include bioremediation of polluted environments, solid waste management, construction of microbial fuel cells, etc. The diversity of microbes involved in environmental biotechnology is huge because of the diversity of environmental pollutants and also the alarming variety of environmental habitats.

2. Marine Ecosystems

Transverse trench profiles in the North-East Atlantic characterize Southern European coasts. The concentration of organic matter and nutrients in Hessian Bay, Greece, in the eastern Mediterranean region, shows marked differences. Organic matter in the sediments is mostly of marine origin, which is contrasted by the much younger sedimentary environment of the adjacent Messenian Bay. Despite the large variations in total organic matter and nitrogen content, their spatial distribution coincides roughly with a diatom-silica distribution pattern. The C/N ratio of these surficial sediments points to a considerable contribution of organic matter from terrigenous sources. Organic matter concentrations are greatest along the coast and at the shelf break, the latter of which coincides with the highest phytoplankton densities measured in the surface water.