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Forest Life Under Control of Microbial Life

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1. Introduction

Microbial life has been present for at least 3,500 million years, and the earth itself was only formed about 4,600 million years ago. "For much of its history, Earth was a planet of microbes. Even today, microbes dominate the living world in terms of biomass and number". Microbes play numerous key roles in global change, often as silent partners in human activities such as agriculture, mining and water treatment and also microbes are responsible for transforming many of the Earth's most abundant compounds, and thus are central to global changes causing concern (Kenneth Todar 2009).

In the magic world of microorganisms you will wonder how microbes tiny as they are but considered the engines that keep the wheel of life turning. Without microorganisms, the ecosystems of the world would collapse and die. However, it is quite clear that microbe's life can destroy other livings life, one of such livings life is the forest life. Although microorganisms can destroy trees, in contrast, a healthy, balanced community of microorganisms is extremely important for trees health. You will wonder if you think deeply of theses tiny organisms how are world's worst diseases caused by microbes can turned into weapons of mass destruction, on the other hand how microbes can offer a great deal of hope for solving many of the problems our world faces.

The microorganisms are at the bottom of the food chain. Their survival is essential for the survival of all the other species. Loss of forest microbes, however, would have a severe effect throughout the entire forest ecology. The forest is dependent upon the actions of microbes, to sustain the base-level of food supply. Microbes dispose of dead matter by decaying and rotting it. They provide nutrients both from their by-products and from themselves, for other usually larger and more complex life-forms - they are food. Many species of plant could consequently suffer extinction, if microbial populations were destroyed or degraded. Although microbes are numerous and there are many species, they can be sensitive to the smallest of environmental change - changes in water acidity, levels of sunlight, toxins, etc. They can be quite fragile. However, they and their diversity are keys to the survival of the forest. http://www.theguardians.com/Microbiology/gm_mbr10.htm

The microbial world of the forest, though lacking the appeal of the more exotic larger creatures, should be regarded as just as important as any other forest population. Therefore efforts should be directed towards understanding and preserving their habitat and the way they interact with the forest environment.

In this chapter you will recognize the positive face of microorganisms that offer exchangeable benefits with trees and the negative face that exert damage on trees. Microbes are weapon with two faces, therefore we do not need sterile life from microbes but we need to spread beneficial microbes against pathogenic microbes, because the former have magical effects on overcoming the later problems via antagonism activity. To realize how microbial life can control forest life you need a journey in the forest for understanding the relation between trees and microbes, moreover for understanding the aspects of microbial interactions with trees.

But before going in both journeys try to imagine what if we loose forests:

Forests offer watershed protection, timber and non-timber products, and various recreational options. Forests prevent soil erosion help in maintaining the water cycle, and check global warming by using carbon dioxide in photosynthesis. Forest lands are instrumental in the beauty and spiritual impact of our landscape. If the forest disappears, the entire ecosystem begins to fall apart, with dire consequences for all of us.

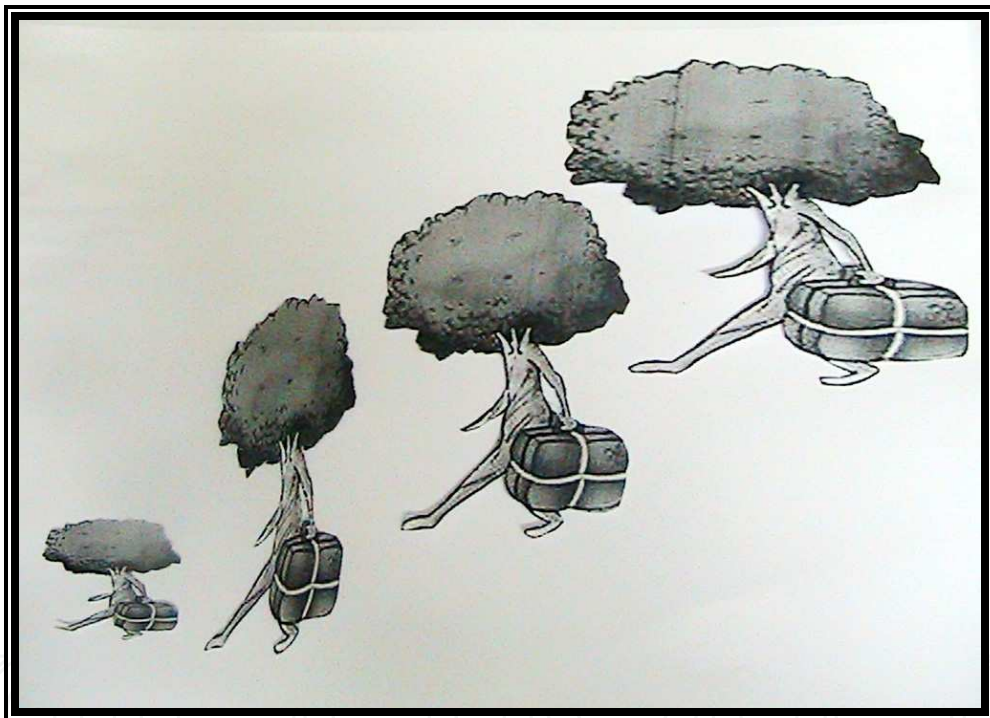


Fig. 1. Funny photo illustrates the disappearance of trees due to their anger from human activities.

Now let's start our journey in the forest and in the microbial world.

2. Journey in the forest

No exciting journey more than that in the forest. In the forest world you can see an area with a high density of trees. It functions as habitats for organisms, hydrologic flow modulators, and soil conservers, constituting one of the most important aspects of the biosphere. A typical forest is composed of the overstory (or upper tree layer of the canopy) and the understory. The understory is further subdivided into the shrub layer, herb layer, and

sometimes also moss layer. In some complex forests, there is also a well-defined lower tree layer. Although a forest is classified primarily by trees a forest ecosystem is defined intrinsically with additional species such as fungi.

Forests can be classified in different ways and to different degrees of specificity. One such way is in terms of the "biome" in which they exist, combined with leaf longevity of the dominant species (whether they are evergreen or deciduous). Another distinction is whether the forests composed predominantly of broadleaf trees, coniferous (needle-leaved) trees, or mixed (Martin et al 2007).

1. Boreal forests occupy the sub arctic zone and are generally evergreen and coniferous.
 2. Temperate zones support both broadleaf deciduous forests (e.g., temperate deciduous forest) and evergreen coniferous forests (e.g., Temperate coniferous forests and Temperate rainforests). Warm temperate zones support broadleaf evergreen forests, including laurel forests.
 3. Tropical and subtropical forests include tropical and subtropical moist forests, tropical and subtropical dry forests, and tropical and subtropical coniferous forests.
- Physiognomy classifies forests based on their overall physical structure or developmental stage (old growth or second growth).
 - Forests can also be classified more specifically based on the climate and the dominant tree species present, resulting in numerous different forest types (e.g., Ponderosa pine/Douglas-fir forest)

In the following figures you can see some examples of forests classification



Old growth forest



Spiny forest



Conifer forest

temperate deciduous forest

Fig. 2. Photos for different types of forest adopted from forest Wikipedia, the free encyclopedia

In temperate deciduous forest, the weather may range from cold with moderate amounts of snow to warm and rainy. Because of their moderate temperatures and other factors, these are ideal places for certain types of bacteria. The tropical rainforests are the richest places in the world in terms of biodiversity. A larger variety of microorganisms live in rainforest than anywhere else. Rainforest organisms have been found to possess amazing properties that are of potential benefit to mankind. Rubber, medical products and treatments, food-stuffs such as potatoes, chocolate and spices all originate from the rainforests. The rain forest has acid soil due to the volume of water moving through the soil.

3. Journey in microbial world

If you have given a microscope you can enter a whole world of "inner space", you will find it really quite fascinating. You will find it fascinating enough to decide to make the study of these tiny forms of life your life's work. You will discover that the basic structure of microbe is unicellular but although that, many species of microbes live together in diverse communities, in the same way that trees, flowers, fish, birds and bugs interact. Earth is a microbial planet-always has been, and always will be. <http://www.voanews.com/english/news/a-13-2009-02-13-voa31-68673292.html>. But what is the origin of microbes and how it related to the plants?

Kenneth Todar (2009) told us the origin of microbes' story as follows: when life arose on Earth about 4 billion years ago, the first types of cells to evolve were prokaryotic cells. For approximately 2 billion years, prokaryotic-type cells were the only form of life on Earth. The

primitive earth's atmospheric gases, such as ammonia (NH_3), hydrogen (H_2) and hydrogen sulfide (H_2S) could be oxidized to produce energy that allowed conversion of CO_2 to cellular (organic) material. As organic material developed, it became the substrate to support the growth and metabolism of other cells that use simple organic compounds as their source of energy. The use of inorganic chemicals as a source of energy is called **chemolithotrophy**; the use of organic chemicals as energy sources is called **chemoheterotrophy**. Thus, chemolithotrophy and chemoheterotrophy were the first two types of metabolism to evolve. An important group of archaea that were involved in this process were the **methanogens**, which grow by using H_2 as an energy source and CO_2 as a carbon source, resulting in the production of the simplest of all organic molecules, methane (CH_4). Archaea and bacteria probably arose from a universal ancestor but are thought have split early during the evolution of cellular life into the two groups of prokaryotes that we recognize today. **Photosynthesis** (metabolism which uses of light as an energy source) developed in bacteria about 3.2 billion years ago. The first type of photosynthesis to appear is called **anoxygenic photosynthesis** because it does not produce O_2 . Anoxygenic photosynthesis preceded **oxygenic photosynthesis** (plant-type photosynthesis, which produces atmospheric O_2) by half a billion years. However, oxygenic photosynthesis also arose in prokaryotes, specifically in a group of bacteria called **cyanobacteria**, and existed for millions of years before the evolution of plants. As molecular oxygen (O_2) began to appear in the atmosphere, organisms that could use O_2 for respiration began their evolution, and "aerobic" respiration became a prevalent form of metabolism among bacteria and some archaea.

Even was the above story true or imaginary, at least it gives us outline about the probable origin of microbes and how could plant may originated from them .Also it may explain the underlying mechanisms behind the interactions between plants (trees) and microbes which are still poorly known.

Microorganism is the technical name of microbe. It means an organism of microscopic or submicroscopic size they are grouped or classified in various ways. Most microbes belong to one of four major groups: bacteria, viruses, fungi, or protozoa. The most important groups for forest are fungi, bacteria and viruses. Therefore these three groups will be described here to some extent in details.

3.1 What are fungi?

Fungi are a distinct kingdom of organisms that are neither plants nor animals. The basic fungal vegetative structure is the microscopic hyphae, a thread like-tube that maybe separated into cells by the formation of cross-walls (septa). Unlike plants and animals, fungi absorb all their food from external sources. The hyphae grow through or on their food substrate and sometimes form a visible mycelium. Many fungi are saprophytic or parasitic (callan et al 2001). There is considerable variation in the structure, size, and complexity of various fungal species. For example, fungi include the microscopic yeasts, the molds seen on contaminated bread, and the common mushrooms.

Fungi can be recognized by the following five characteristics:

1. The cells of fungi contain nuclei with chromosomes (like plants and animals, but unlike bacteria).

2. Fungi cannot photosynthesize (they are heterotrophic, like animals)
3. Fungi absorb their food (they are osmotrophic)
4. They mostly develop very diffuse bodies made up of a spreading network of very narrow, tubular, branching filaments called hyphae. These filaments exude enzymes, and absorb food, at their growing tips. Although these filaments are very narrow, they are collectively very long, and can explore and exploit food substrates very efficiently.
5. They usually reproduce by means of spores, which develop on, and are released by, a range of unique structures (such as mushrooms, cup fungi, and many other kinds of microscopically small fruiting bodies).

3.2 What are bacteria?

Bacteria are large domain of single-cell, prokaryote microorganisms. Typically a few micrometers in length, bacteria have a wide range in shape ranging from spheres to rods and spirals. Bacteria are ubiquitous in every habitat on Earth, growing in soil, acidic hot springs, radioactive waste (Fredrickson et al 2004), water, and deep in the Earth's crust, as well as in organic matter and the live bodies of plants and animals. There are typically 40 million bacterial cells in a gram of soil and a million bacterial cells in a milliliter of fresh water; in all, there are approximately five nonillion (5×10^{30}) bacteria on Earth (Whitman et al 1998), forming a biomass on Earth, which exceeds that of all plants and animals (Hogan 2010). Bacteria are vital in recycling nutrients, with many steps in nutrient cycles depending on these organisms, such as the fixation of nitrogen from the atmosphere and putrefaction. However, most bacteria have not been characterized, and only about half of the phyla of bacteria have species that can be grown in the laboratory (Rappé and Giovannoni 2003). After the discovery that prokaryotes consist of two very different groups of organisms that evolved independently from an ancient common ancestor, these two groups called Bacteria and Archaea <http://en.wikipedia.org/wiki/Bacteria>

Many bacteria can move using a variety of mechanisms: flagella are used for swimming through water; bacterial gliding and twitching motility move bacteria across surfaces; and changes of buoyancy allow vertical motion (Bardy and Jarrell 2003). Flagella are semi-rigid cylindrical structures that are rotated and function much like the propeller on a ship.

Swimming bacteria frequently move near 10 body lengths per second and a few as fast as 100. This makes them at least as fast as fish, on a relative scale (Dusenbery 2009).

Bacterial species differ in the number and arrangement of flagella on their surface; some have a single flagellum (monotrichous), a flagellum at each end (amphitrichous), clusters of flagella at the poles of the cell (lophotrichous), while others have flagella distributed over the entire surface of the cell (peritrichous). The bacterial flagella is the best-understood motility structure in any organism and is made of about 20 proteins, with approximately another 30 proteins required for its regulation and assembly (Dusenbery 2009). The flagellum is a rotating structure driven by a reversible motor at the base that uses the electrochemical gradient across the membrane for power (Macnab 1999). This motor drives the motion of the filament, which acts as a propeller.

3.3 What are viruses?

A virus is a small infectious agent that can replicate only inside the living cells of organisms. Most viruses are too small to be seen directly with a light microscope. Viruses infect all

types of organisms, from animals and plants to bacteria and archaea. Virus particles consist of two or three parts: the genetic material made from either DNA or RNA, long molecules that carry genetic information; a protein coat that protects these genes; and in some cases an envelope of lipids that surrounds the protein coat when they are outside a cell. <http://en.wikipedia.org/wiki/Virus>. Viruses spread in many ways; viruses in plants are often transmitted from plant to plant by insects that feed on the sap of plants, such as aphids

Viruses are very small (submicroscopic) infectious particles (virions) composed of a protein coat and a nucleic acid core. They carry genetic information encoded in their nucleic acid, which typically specifies two or more proteins. Translation of the genome (to produce proteins) or transcription and replication (to produce more nucleic acid) takes place within the host cell and uses some of the host's biochemical "machinery". Viruses do not capture or store free energy and are not functionally active outside their host. They are therefore parasites (and usually pathogens) but are not usually regarded as genuine microorganisms.

Most viruses are restricted to a particular type of host. Some infect bacteria, and are known as bacteriophages, whereas others are known that infect algae, protozoa, fungi (mycoviruses), invertebrates, vertebrates or vascular plants. However, some viruses that are transmitted between vertebrate or plant hosts by feeding insects (vectors) can replicate within both their host and their vector. This web site is mostly concerned with those viruses that infect plants but we also provide some taxonomic and genome information about viruses of fungi, protozoa, vertebrates and invertebrates where these are related to plant viruses. (Brüssow et al 2004).

4. Relation between forest and microbes

The forest support multitudes of microbial life in many different relationships with the plants that grow there. Life in a forest is self-sustaining and does not require fertilization. In a natural forest setting, leaves, needles and foliage fall and gradually decompose creating a natural fertility process and nutrient source for trees. In an urban or residential environment, the leaf litter that would eventually decompose and provide natural fertilizers for trees is cleared away. Grass is planted under trees which supports a large bacterial component in direct conflict with trees normal association with fungi.

All rainforests (tropical, subtropical and temperate) are under threat from human activity at the present time. They are being destroyed at an alarming rate that could potentially lead to many different types of environmental catastrophe, not only in the local forest zone, but globally. The greatest threats come from deforestation (tree removal by various means and for various purposes) and mining.

Deforestation may be done to create farmland, to build hydro-electric plants, to sell the lumber, or through careless or accidental burning.

Rainforest microbes are extremely efficient at breaking down and recycling waste organic matter - the leaf litter and layers of detritus on the ground. As a result, almost no nutrients reach the forest soil and it is consequently poor. Removal of the trees the soil to dry out and the little humus that allows it exists to deteriorate. This causes the rainforest microbes to die and the soil becomes largely inert, biologically. (http://www.theguardians.com/Microbiology/gm_mbr10.htm)

There is no doubt that microorganisms are the foundation of the cycles that take the essential elements of life from the soil to the tree, they influencing tree growth but they can destroy forests which offer watershed protection, timber and non-timber products, and various recreational options. The forests which prevent soil erosion help in maintaining the water cycle, and check global warming by using carbon dioxide in photosynthesis. The forest lands which are instrumental in the beauty and spiritual impact of our landscape. If the forest disappears, the entire ecosystem begins to fall apart, with dire consequences for all of us.

One of the most important findings so far in the literature indicates that the substitution of a forest area for an area of cultivated plants could reduce the diversity of the bacteria associated with the surface of leaves by more than 99 % (Ekelund et al 2009).

Although microorganisms can destroy trees, in contrast, a healthy, balanced community of microorganisms is extremely important for trees health. Some of these organisms protect trees from disease-causing organisms that would otherwise infect trees. Microbes are weapon with two blades or coin with two faces, one negative face and one positive face.

4.1 Positive face of microbes

The positive face represents the group of microorganisms which exerts influence on health of trees. Those who has positive power; they always engaged with growing or benefit strategy of trees. Their purpose is not to dominate but to get exchangeable benefits. We can call them non-pathogenic microbes. Scientists (ecologists, biologists etc) explain the interactions or the interdependence between the different forest species by means of two terms: Symbiotic relationships and nitrogen cycle.

Symbiotic Relationship between two or more species is called:

Mutualism, if the relationship is beneficial for both of them.

Commensalism, if the relationship is beneficial for one species and neutral to the other, that is, neither beneficial nor harmful for the other species.

Parasitism, if the relationship is beneficial for one species and harmful for the other species.

Neutralism, if there is no relationship between the species.

Amensalism, if the relationship is harmful for one species and neutral to the other.

Synnecrosis, if the relationship is harmful for both the species.

Nitrogen cycle: All living organisms require nitrogen compound for getting their necessary nutrients. Even though air contains nitrogen in abundance-79% by volume, it cannot be used by organisms directly. It is an inert gas and needs to be converted into usable forms of nutrients for the "users"- whether they are plants, trees by processing, either by natural biological process or by man made industrial processing. After the "users" consume their nutrients and eject their excrements to the atmosphere, they must be further acted upon by the natural biological process or the industrial processing to recycle the excrements back into nitrogen again before it can be passed on to the atmosphere. Plants require nitrogen compound in the form of ammonia, urea etc. They get them from the soil through their roots by absorption. "Nitrogen-fixing" bacteria like rhizobia and mycorrhizae fungi enable the roots of the trees and plants to get the required nitrogen compound from the soil (Jenkins and Groombridge 2007)

As mentioned before, the most important groups for forest are fungi, bacteria and viruses; therefore in this chapter you will recognize the positive and the negative face of each microbial group separately.

This is a **mutually beneficial symbiotic relationship between the trees and the fungi**, since the plants get their nutrients from the soil through the fungi and mycorrhizal fungi get their nutrients in the form of sugars, starches, proteins etc from the plant roots.

4.1.1 Positive face of fungi

There are two main types of fungi associated with trees and they are:

- **Decomposers**, which are associated with wood, leaf litter, plant and animal matter.
- **Food gathering, or mycorrhizal fungi**, which form symbiotic relationships with the roots of trees.

Fungi form a key component of the microbial populations influencing tree growth and uptake of nutrients. In addition to increasing the absorptive surface area of their host tree root systems, the hyphae of these symbiotic fungi provide an increased area for interactions with other microorganisms, and an important pathway for the translocation of energy-rich plant assimilates to the soil.

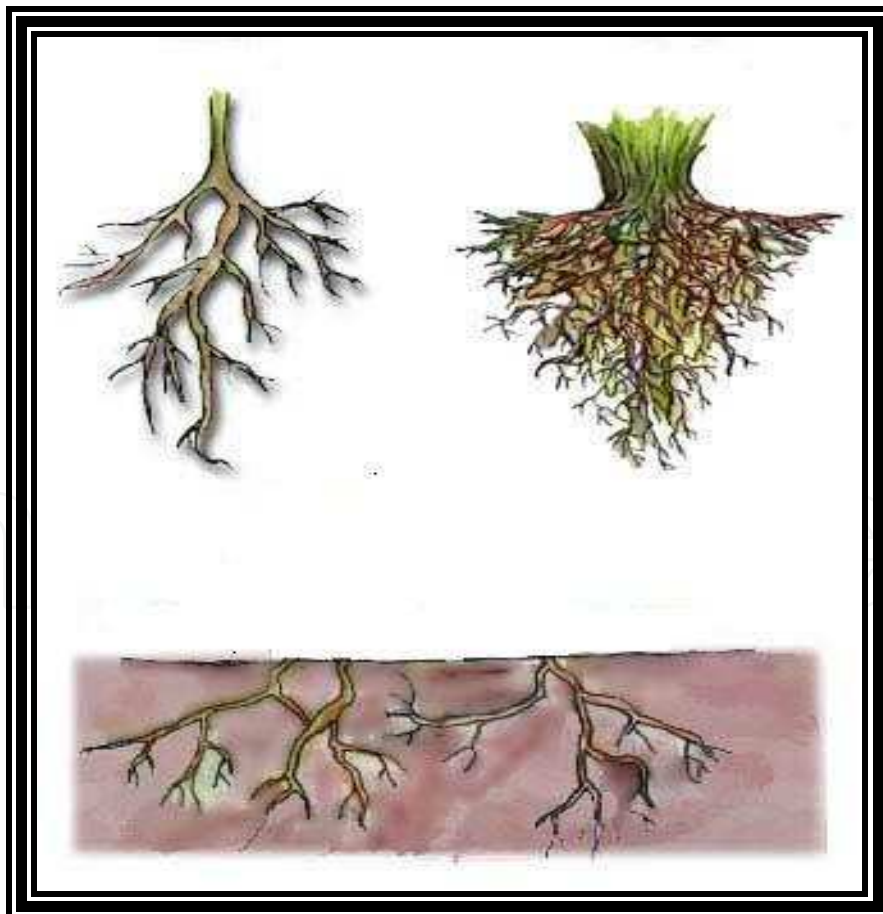


Fig. 3. Rhizosphere is the zone of soil in which interactions between living plant roots and micro-organisms are found.

Traditionally, the influence of plant assimilates on microbial communities has been defined in relation to the rhizosphere, the narrow zone of soil surrounding living roots. The rhizosphere is characterized by increased microbial activity stimulated by the leakage and exudation of organic substances from the root.

Many fungi develop only on dead or dying trees and are not pathogens. These fungi are Saprophytes and are living on dead tree tissues or organic debris as opposed to pathogens which usually gain their sustenance from living trees as Parasites. Other fungi, especially certain mushroom, are actually beneficial to trees. Many of these types of fungi form highly specialized, mutually beneficial associations called Mycorrhizae with the roots of living trees. In these associations the fungi receive sugar and other dietary essentials from the trees, and in return enhance the tree's ability to extract phosphorus and other nutrients from the soil. (Grayston et al 1997).

There is relationship between ancient trees and fungi and it is a very close one. Within the woodland ecosystem, fungi play an important role in recycling nutrients and in individual trees- within and between cells, from the leaves in the canopy down to the root hairs. As a tree ages the relationship between trees and fungi remains the same but the species may change. Fungi can be extremely long lived, perhaps even everlasting, as some species are known to grow continuously. Each tree creates a unique and dynamic support system for fungi and, contrary to previous opinion, it is likely that rather than being detrimental to the tree, fungi actually prolongs its life. <http://www.ancient-tree-hunt.org.uk/ancienttrees/treeecology/fungi.htm>

4.1.2 Positive face of bacteria

In the forest you can not only see fungi but also bacteria. Certain bacteria are efficient at breaking down inorganic minerals into nutrients. This process, called mineral weathering, is especially important in acidic forest soils where tree growth can be limited by access to these nutrients. Mineral-weathering bacteria can release necessary nutrients such as iron from soil minerals. This gives trees with increased concentrations of mineral-weathering microbes an advantage over other trees.

You also can see cyanobacteria on large long trees. Cyanobacteria are more abundant in mosses high above the ground, and that they "fix" twice much nitrogen as those associated with mosses on the forest floor.

Mycorrhizal fungi are beneficial fungi that act as a secondary root system for trees, plants and shrubs. This secondary root system provides up to a 700% increase in the plant's ability to absorb important nutrients and water. In nature, certain species of beneficial bacteria promote healthy plant growth and soil fertility. These "good" bacteria are called rhizobacteria and displace harmful soil life that may be present. While common in natural settings, their populations are often very low in urban and residential landscapes, nursery potting soils and other man-made landscapes (Grayston et al 1997).

There is an inherent difficulty in determining whether mycorrhizosphere bacteria are specifically associated with roots or mycorrhizal fungi, or they simply form opportunistic associations with a range of other organisms. But as the following figures indicate, presence of bacteria in the soil either in root zone or other is very important for healthy growth.



Fig. 4. Plant without Bacteria modified photo from <http://www.ganesh-tree.com/>



Fig. 5. Plant with Bacteria modified photo from <http://www.ganesh-tree.com/>

Actually it is interesting to mention that there are bacteria live within the plant tissue naturally and they called endophytes, their role inside the plants still unknown but scientists expected that these bacteria improve plant growth, therefore scientists succeeded

to isolate different types of bacteria like *Enterobacter*, *Burkholderia*, etc and tested the addition of these type of bacteria to different trees, they observed that microbe- supplemented trees grew faster. Scientists also sequenced the genes of these bacteria for production of plant growth promoting enzymes, hormones, and other metabolic factors that might help explain how the bacteria improve plant growth. (Safihy et al 2009)

The relation between microbes and trees is very complicated

Each tree species has its own distinct and unique community of hundreds of species of bacteria, the function of these microorganisms in the forest's normal dynamics could be much more important than originally thought. The bacterial community varies not only in relation to the various species of trees, but also based on the location of trees in different environments, taking into consideration, for example, the position of trees within a given forest or comparison of the same plant species in forest that are distant from each other.

The surfaces of tree leaves, trunks and roots contain complex biofilms comprised of diverse microorganisms that interact amongst themselves, with the plant, with animals and the atmosphere. Each plant species has a unique set of bacteria associated with it. And each part of the plant has a different community. On the leaf, bark or root, the same bacterial species are not repeated (Castro 2011).

Based on information obtained using molecular technology, the scientists believed that cultivated plants would probably have a much lower quantity and different type of associated bacteria than those found on forest species. A comparison has been made utilizing soybean, sugarcane and eucalyptus. Surprisingly, the cultivated plants and forest trees are statistically very similar in terms of the estimated diversity and wealth of bacterial species. Nevertheless, the types of bacteria that live on the leaves of cultivated plants are very different from those that live on plants in the forest.

The role of bacterial community in the forest maybe due to that, nitrogen is an essential element for plant growth and is not found in the forest soil. In order to maintain the forest, the nitrogen must come from the environment. Nitrogen is captured from the air by microorganisms that live on tree leaves and bark (Castro 2011).

Why do plants in the forest rarely get sick? Probably because they have the natural protection of the microorganisms that are living there. When a plant is domesticated and grown in large monocultures, it rapidly loses the capacity to inhibit growth of pathogenic microorganisms, and with this, the results are outbreaks of disease on plantations. Protecting the plant could be one of the other functions that other bacteria have (Castro 2011)

Another explanation for importance of bacteria is, forest litter bacteria are especially important for completion of organic matter mineralization. Bacterial contribution to the decomposition process is complementary to that of other microbiota. Some studies have examined bacterial interrelations with the abundance and/or activity of other biota, e.g. fungi and forest litter composition, fungi and actinomycetes (Alek hina *et al.* 2001), fungi and nematodes (Mikola and Sulkava 2001), fungi and microarthropods, fungi and protozoa, fungi, algae, testate amoebae and microarthropods. However, it seems that field research on forest litter bacteria quantitatively assessing the whole complex of ecological interactions with the abundance and/or activity of fungi, protozoa (flagellates, ciliates, amoebae), nematodes, microarthropods, and forest litter composition is not common (Frouz *et al.* 2001).

4.1.3 Positive face of virus

In nature there is no positive face of virus as the word virus is Latin word referring to poison and other noxious substances. But in laboratory, Scientists can use and manipulate the viral genome for insertion of desirable genes into plants by using the viral lysogenic mechanism.

5. Negative face of microbes

The negative face represents the group of microorganisms which exerts damage on trees. Their purpose is to dominate and damage. We can call them pathogenic microbes.

On contrast to the importance of such microbes to forest life, each year millions of dollars worth of valuable timber and other tree resources are lost because of invasive microbial tree diseases. Diseases are caused by a variety of factors or agents which are divided into two general groups: non-living (abiotic) and living (biotic). Biotic agents are called Pathogens. These pathogens usually are fungi, bacteria and viruses. We have to know some common types of disease problems affecting trees.

Viruses and bacteria are important causes of plant and tree disease in many parts of the world. The diseases that caused by bacteria are, leaf and shoot infections, bacterial canker, fire blight, wetwood, scorchs and yellows. The most important bacterial forest diseases are scorchs and yellows. Viral diseases in trees are unimportant except in certain cases, for the effects are often subtle. Their Symptoms are often confused with mineral deficiency, ozone damage, or drought. Many fungi associated with tree diseases. One group of fungus-like organisms and three main groups of fungi are associated with diseases of forest trees. Some species are associated with diseases of roots, cankers, leaf blights, needle casts and vascular wilts-, leaf spots and anthracnose.

Microbial diseases	Other diseases
<ol style="list-style-type: none"> 1) Fruiting bodies of a canker fungus - signs of canker infections 2) Heart rot (internal) and sporophore of a heart rot fungus at a broken branch stub 3) Sporophore of a butt-rot fungus at base of tree 4) Sporophores of a root rot fungus arising from a damaged root 5) Crown gall - a gnarled swelling ("tumor") caused by a bacterium 6) Severed root resulting from construction damage - site of entry for root and butt-rot fungi 	<ol style="list-style-type: none"> 1) Leaf spots - a foliage disease 2) Twig dieback - evidence of cankers and/or stress and decline 3) Mistletoe - a parasitic seed plant 4) Wilt - evidence of moisture deficiency, vascular wilt disease or root rot 5) Vascular streaking (internal) - evidence of vascular wilt disease 6) Branch canker at a branch stub 7) Nematode damage to small tree roots lesions (upper) and galls (lower)

Table 1. Some common types of disease problems affecting trees

5.1 Negative face of fungi

Fungal diseases can quickly destroy a healthy tree. Deciduous, fruit bearing, ornamental and evergreen trees are all susceptible to fungal diseases. Some varieties of trees are hardier than others, but still can become infected with a fungal disease. A fungus invades the tree when a spore germinates on a tree and eventually spreads and feeds on the host tree. Fungi can cause damage for trees or other plants by different ways, each fungus has its own method for invading tree but some trees have their own tricks for defense and here are some examples for such bad invasion:

*Some fungi like *Verticillium dahliae* produces microsclerotia (thick-walled viable fungal cells) that can survive in soil for many years and invade the tree directly through the root system or through root wounds (Hiemstra and Harris 1998; Tjamos et al. 2000). The fungus spreads in the vascular tissue via spores, produces toxins that kill cells, and blocks the trees ability to transport nutrients and water. The tree in turn produces defense compounds that attempt to isolate infected cells to limit fungal movement in the tree. The isolation of infected vascular tissue reduces the flow of water from the roots upward. Symptoms of Verticillium wilt can develop any time during the growing season. Leaves may wilt in portions of the canopy or on scattered branches and may become chlorotic and necrotic (faded green, yellow, or brown); branch dieback may occur, and a general decline of the tree ensues.



Photo of *Verticillium dahliae* adopted from en.wikipedia.org/wiki/Verticillium_dahliae

*Several species of fungi like *Aureobasidium apocryptum* (synonym *Kabatiella apocrypta*) and *Colletotrichum gleosporioides*. The fungus over winters on diseased leaf or stem tissue, and produces infectious spores in the spring. During cool, rainy periods of spring, the fungal spores are carried by wind and rain to newly emerging leaves of trees. Symptoms on infected leaves appear as scattered dead areas (red, black, brown, or tan) developing along and between leaf veins. These lesions may enlarge rapidly and kill large areas of leaf tissue. Leaves may become distorted, and significant leaf drop can occur in late spring. Severe infection can result in extensive defoliation. The fungus can infect beyond the leaf surface into twigs causing cankers, which may eventually kill small branches (Berry 1985).



Photo of anthracnose: (*Aureobasidium apocryptum*) adopted from www.ipmimages.org

*The fungus *Neonectria galligena* causes a disease known as Nectria canker, this fungus is slowly growing pathogen usually does not kill the tree, but reduces the value of the tree for veneer and weakens the tree causing breakage at the point of the canker on the main stem. The fungus overwinters in the callus (wound-closing) tissue produced by the tree in response to infection. Infections occur on twigs, branches, and trunks in spring or early summer during moist periods, and the spores are dispersed by wind or rain. Infection occurs naturally through leaf scars or through wounds from improper pruning, storm damage, frost cracks, and other mechanical damage. Symptoms of Nectria canker appear as dark, water-soaked, depressed areas of the bark on stems or branches. Infected small twigs may become girdled, wilt, and die suddenly. The tree responds to infection by trying to isolate the fungus by the production of a ridge of callus tissue. As the fungus continues to grow from these perennial cankers into healthy wood, the tree produces another ridge of callus tissue. Concentric ridges of callus tissue then develop over time producing a round or elongated target like canker on the tree. This canker disease grows slowly when the tree is dormant or under stress, and kills the bark, cambium, and outer sapwood (Sinclair and Lyon 2005).



Photo of *Neonectria galligena* adopted from <http://donsgarden.co.uk/homepages>

**Eutypella parasitica* is the fungus that causes a disease known as Eutypella canker. This disease causes mortality by girdling trees and the elliptical perennial cankers are entry points for decay fungi. The resulting decay and malformation of the trunk of the tree results in wood useless for veneer and makes the tree susceptible to wind breakage. Symptoms of Eutypella canker large, tar-like spots surrounded by yellow-orange zones appear on the upper surface of the leaves.



Photo of *Eutypella parasitica* adopted from www.forestyimages.org

*Other types of fungi known as decay fungi cause stem trunk, root, and butt rots. The fungi develop slowly in trees and their presence may only be evident once trees start to die or produce conks. *Inonotus glomeratus* causes a white to light brown, spongy canker rot. Branch stubs or wounds are the primary entry point for infection by this canker rot fungus. *Phellinus igniarius* causes trunk rot. *Climacodon septentrionalis* infects through wounds and causes a spongy white rot. Decay is extensive by the time conks appear. *Ganoderma lucidum* causes a butt and trunk decay, and *Laetiporus sulphureus* more commonly causes rot in butt and stem.



Photo of *Inonotus glomeratus* adopted from <http://www.herbarium.iastate.edu/fungi/index.html>

*Sapstreak disease is a disease caused by the fungus *Ceratocystis virescens* (Houston 1993). The fungus produces a distinctive banana oil odor; noticeable if profuse sporulation is found. Infection occurs through roots, buttress roots, or lower stem wounds. Symptoms of sapstreak disease are a sparse crown with unusually small leaves. Branch dieback occurs, trees may fail to leaf-out the next year, or the tree may die suddenly. The diseased wood has a yellow-green stain with red flecks that darkens after exposure to air, and eventually turns to a light brown.

*Armillaria root disease is a destructive disease of the roots and butts of trees and the fungus most often associated with this disease is *Armillaria mellea* (Shaw and Kile 1991), although other species (*A. calvescens*, *A. gallica*, *A. ostoyae*, and *A. sinapina*) have been reported to be associated with this disease. Trees infected with *Armillaria* can have reduced growth, rapid mortality, wood decay (white rot), and susceptibility to wind throw. *Armillaria* can infect non-wounded root systems of trees, and the fungus spreads from tree to tree through roots, and via rhizomorphs which infect intact bark. These fungi produce a honey-colored mushroom around the base of the tree in late summer or fall during moist periods. Disease caused by *Armillaria* species contribute to tree decline by the interaction with other factors such as site, tree age, drought, insects, etc.

*Pecan scab is the most serious disease of pecan and is caused by the fungus *Cladosporium caryigenum*. The fungus overwinters on infected shucks, leaves, leaf petioles, and stems. In the spring, during periods of warm, rainy weather, spores germinate and are dispersed long distances by rain and wind. Disease symptoms first appear on immature leaves, leaf petioles, and nut shucks as small, olive-green spots that turn black. Leaf infections do not cause serious defoliation (Kromroy 2004).

*Anthracnose is a fungal leaf spot of pecan caused by *Glomerella singulata*. The spores are spread in spring and early summer during rainy periods. Symptoms start as brown to black sunken lesions on the leaves and shucks. Cream- to salmon-colored spores in concentric rings may also appear on the shucks. *Gnomonia* leaf spot caused by the fungus *Gnomonia caryae* is characterized by reddish-brown (liver colored) circular spots.

*Botryosphaeria canker (branch dieback) results from infection by the fungus *Botryosphaeria dothidea* and is most often associated with stressed trees. Trees affected with this canker disease exhibit leaf wilting on twigs and branches. The infected branch turns black, cankers enlarge, and the pith of the branch is black or dark brown. This fungal disease infects through natural openings in the bark or through pruning wounds. The fungus is dormant in the winter, and spores are spread by wind in the spring. Cankers will girdle and kill twigs and branches. Twig death is usually generalized within a tree, and stress may be caused by defoliation from other pathogens, drought, or shading (Sinclair and Griffiths 1994).

*Phytophthora root rot incited by the fungus-like organism *Phytophthora cinnamomi* is a soil-borne pathogen that causes root and collar rot. Symptoms appear as root lesions that develop upward in the trunk. The pathogen spreads by spores that can be carried over large distances by water and in soils. Infection occurs through the roots, causes root cell death (rotting), and therefore prevents transport of water from the roots. Moderate levels of soil compaction and moisture contribute to the susceptibility of root rot on American chestnut (*Castanea dentata*) seedlings (Rhoades et al. 2003). Root rot reduces tree vigor and causes mortality.

*Chestnut blight is a devastating disease caused by the fungus *Cryphonectria parasitica* (Anagnostakis 2000). The fungus enters through cracks or wounds in the bark and eventually kills the cambium. The fungus is spread by wind, rain, insects, and birds. Airborne spores carried by birds and insects that visit colonized bark "account" for overland spread of the fungus.

*Heart rot caused by the sulfur fungus, *Laetiporus sulfureus*, is a brown heart rot of living trees that will also decay dead trees. The fungus can invade through bark wounds and dead branch stubs. Symptoms include a slightly depressed or cracked bark in areas of the tree with dying branches. Massive clusters of bright, sulfur-yellow to orange, shelf-like conks are produced annually (usually in fall), and become brittle and white with age (Sinclair and Lyon 2005).

5.2 Negative face of bacteria

Not only fungi have the ability to invade trees but so do bacteria. But diseases caused by bacteria are not much as those of fungi and here are some of bacterial diseases.

*Bunch disease is caused by a *phytoplasma* [related to gram-positive bacteria] (Davis and Sinclair 1998) that may be transmitted from tree to tree by insects (leafhoppers). The pathogen can also be transmitted through grafts. Symptoms of bunch disease are branches with excessive lateral stem growth and compacted growth of leaves on these stems (witches'-broom). Upright shoots form on the trunks and main branches. Bunch disease is very obvious in the spring and early summer as the diseased shoots leaf out earlier than non-infected shoots. Symptoms may occur throughout the tree or be limited to individual branches. Terminal branches infected with bunch disease do not produce a normal crop of nuts. Branches may fail to go dormant in the fall and be killed by frost or winter injury.

*Bacterial leaf scorch affects some trees *Xylella fastidiosa* (Wells et al. 1987) is a gram-negative bacterium that lives in an infected tree's water conducting tissue (xylem) and is transmitted to other healthy trees by insects that feed on xylem fluid, such as leafhoppers, treehoppers, and possibly spittlebugs. The bacterium multiplies in the xylem tissue and, together with the overproduction of defense compounds produced by the tree in response to infection physically, blocks the xylem. Water transport then becomes limited to leaves, branches, and roots. Symptoms of bacterial leaf scorch first appear in late summer to early fall and can be identified by a characteristic marginal leaf scorch (Gould and Lashomb 2005). Leaves develop an irregular pattern of light and reddish brown tissue separated from green tissue by a yellow halo. As the disease progresses, leaves curl and drop prematurely, branches die, and the tree declines. Symptoms of other physiological or cultural problems can be mistaken for bacterial leaf scorch.

*Ash yellow is a disease caused by a *phytoplasma* (bacteria-like organism lacking a cell wall) that inhabits the phloem (Griffiths et al. 1999) and substantially reduces growth, induces premature decline, and death of *Fraxinus* spp. Both green (*F. pennsylvanica*) and white (*F. americana*) ash are susceptible to ash yellows, in addition to other ash species. The *phytoplasma* is spread by phloem-feeding insects such as leafhoppers (Hill and Sinclair 2000). The *phytoplasma* is introduced into the phloem tissue, via the insect saliva, and spreads throughout the tree killing the tissue. Symptoms of ash yellows include small, chlorotic leaves growing in tufts at the end of branches, branch dieback, bark cracks, thin chlorotic

crowns, epicormic sprouting (along branches or at ground level), early fall coloration, loss of dominant growth habit, general decline, and witches' brooms (cluster of spindly shoots) on the trunk of the tree.

*Bacterial blight caused by the bacterium *Xanthomonas arboricola*. The bacterium overwinters in twig cankers, and dormant buds and catkins. The bacteria invade new young shoots, leaves, catkins, and fruit through natural openings, wounds, or insect damaged areas. During periods of spring rainfall or wet weather, conditions are suitable for bacterial infection. Symptoms of bacterial blight on young walnut shoots appear as black spots or lesions. The lesions may girdle the shoot and extend into the pith to form cankers. The blight causes small, irregular-shaped brown to black spots on all tissues of the leaves (midrib, veins, rachis, and petiole). Unless infection is severe, defoliation does not usually occur and most infected leaves remain on the tree. Infected catkins turn black and become shriveled and distorted (Bentz and Sberald 2001).

5.3 Negative face of virus

Viruses cause many important plant diseases and are responsible for huge losses in crop production and quality in all parts of the world. Infected plants may show a range of symptoms depending on the disease but often there is leaf yellowing (either of the whole leaf or in a pattern of stripes or blotches), leaf distortion (e.g. curling) and/or other growth distortions (e.g. stunting of the whole plant, abnormalities in flower or fruit formation).

Some important animal and human viruses can be spread through aerosols. The viruses have the "machinery" to enter the animal cells directly by fusing with the cell membrane (e.g. in the nasal lining or gut).

By contrast, plant cells have a robust cell wall and viruses cannot penetrate them unaided. Most plant viruses are therefore transmitted by a vector organism that feeds on the plant or (in some diseases) are introduced through wounds made, for example, during cultural operations (e.g. pruning). A small number of viruses can be transmitted through pollen to the seed while many that cause systemic infections accumulate in vegetative-propagated crops. The major vectors of plant viruses are insects. This forms the largest and most significant vector group and particularly includes, **aphids** which transmit viruses from many different genera, including *Potyvirus*, *Cucumovirus* and *Luteovirus*. *Potato virus* <http://www.dpvweb.net/intro/index.php>

Viruses differ from fungi and bacteria in that they do not produce spores or other structures capable of penetrating plant parts. Since viruses have no active methods of entering plant cells, they must rely upon mechanically caused wounds, vegetative propagation of plants, grafting, seed, pollen, and being carried on the mouth parts of chewing insects. Some viruses are introduced into plants through small wounds caused by handling and by insects chewing on plant parts. Once the virus enters the host, it begins to multiply by inducing host cells to form more virus (Viruses do not cause disease by consuming or killing cells but rather by taking over the metabolic cell processes, resulting in abnormal cell functioning. Abnormal metabolic functions of infected cells are expressed. Infected plants serve as reservoirs for the virus and the virus can be transmitted easily (either mechanically or by insects) to healthy plants (Pfleger and Zeyen 2008).

Symptoms and effects of viral diseases:

As mentioned before symptoms are often confused with mineral deficiency, ozone damage, or drought. Many say that viral diseases in trees are unimportant, for the effects are often subtle.

- leaves are mottled with necrotic and chlorotic lesions,
- ring spots, and yellowing
- Effects:
 - stunted growth
 - decreased photosynthesis and increased respiration
 - reduction in cold tolerance
 - rarely, death results

<http://www.forestpathology.org/bacteria.html>

Viruses are widespread pathogens in agriculture crops and weeds; the latter are considered important reservoir of viruses. Therefore, it can be expected that they are also present in forest ecological system. Viruses can be the cause of severe disease of non woody and woody plants. Thousands of viruses' diseases have been described worldwide. A considerable number of viruses have caused epidemic in agriculture crops when environmental conditions, host range and other factors were favorable. Information of viruses' diseases of forest tree is rare. One reason may be that, the interest of research in forest pathology was traditionally focused on insect damage and fungal diseases. A second reason is the technical difficulty of demonstrating, isolating and transmitting viruses in woody plants. And last but not least, the economic importance of loss of a relatively small number of forest trees has been considered as negligible compared with agricultural crops such as fruit trees (Nienhaus 1985).

It can be stated that a number of viruses are inciting factors for decline of forest trees. Viruses are predisposing factors leading to early senescence reduces the regeneration capacity of the host plant and the juvenile metabolic vigor is lost. Under abiotic stress conditions the infected trees have less potential for recovery from inciting factors than non infected trees.

After reading the negative face of microbes for trees, the question arises here is to which degree the potential for recovery of infected trees, the answer might be in the following section.

6. Control of plant disease

Diagnosis of plant problems can be a difficult and at times impossible task but it is important. Therefore, the goal is a correct diagnosis so that management procedures can be implemented successfully.

As mentioned above, plant diseases are caused mainly by fungi, bacteria and viruses. Therefore plant diseases need to be controlled.

Different approaches may be used to prevent, mitigate or control plant diseases. One of such approach is using chemicals. Today, there are strict regulations on using chemicals;

consequently, some researchers have focused their efforts on developing alternative inputs to synthetic chemicals for controlling diseases. Among these alternatives are those referred to as biological control? The terms “biological control” equal “biocontrol” have been used in plant pathology.

But what is biological control? It is the suppression of damaging activities of one organism by one or more other organisms, often referred to as natural enemies. In plant pathology, the term applies to the use of microbial antagonists to suppress diseases.

Biological control offers an environmentally friendly approach to the management of plant disease. The microbiologists and plant pathologists try to gain a better knowledge of biocontrol agents, to understand their mechanisms of control and to explore new biotechnological approaches. A screening approach was developed to assess the potential of plant-associated bacteria to control plant pathogens. The study of plant-associated bacteria and their antagonistic potential is important not only for understanding their ecological role and the interaction with plants and plant pathogens but also for any biotechnological application. Plant-associated bacteria can be used directly for biological control of soil borne plant pathogens or indirectly for the productions of active substances (Doaa et al 2008).

As biocontrol of plant disease involves the use of an organism or organisms to reduce disease, several microorganisms have shown potentialities as biological control agents against important plant diseases caused by soil-borne pathogens. They are *Pseudomonas fluorescens* against the take-all disease of wheat caused by *Gaeumannomyces graminis*, *Erwinia caratovora* infection of wheat, *Thielaviopsis basicola* infection of tobacco and damping off caused by *Pythium* in cotton; *Bacillus subtilis* against *Fusarium roseum* wilt of com; *Trichoderma harzianum* against *Alternaria spp.* infection of radish; *Penicillium oxalicum* against root rot of peas; non-pathogenic *Fusarium oxysporum* against *Fusarium* wilt of cucumber; *Trichoderma viride* against *Verticillium* wilt of tomatoes; *Cytophaga sp.* against damping off of conifer seedlings; *Bacillus sp.*, *Penicillium sp.*, and *Alcaligenes sp.* against crown gall disease of cherry seedlings caused by *Agrobacterium tumefaciens*; *Chaetomium globosum* against damping off of sugar beets; *Pseudomonas putida* against *Fusarium solani* wilt of beans; *Bacillus sp.* and *Pseudomonas sp.* against *Fusarium oxysporum* wilt of carnations. <http://www.microbiologyprocedure.com/microbial-products-influencing-plant-growth/biological-control-of-plant-diseases.html>

Here are photos for how can one microorganism kill other microorganism to assess the potential of microbes to control plant pathogens, adopted from previous work for the author. Over the past one hundred years, research has repeatedly demonstrated that phylogenetically diverse microorganisms can act as natural antagonists of various plant pathogens (Cook 2000). The interactions between microorganisms and plant hosts can be complex. Interactions that lead to biocontrol can include antibiosis, competition, induction of host resistance, and predation (Cook and Baker 1983). However, fewer isolates can suppress plant diseases under diverse growing conditions and fewer still have broad-spectrum activity against multiple pathogenic taxa. Nonetheless, intensive screens have yielded numerous candidate organisms for commercial development. Some of the microbial taxa that have been successfully commercialized and are currently marketed as EPA-registered biopesticides in the United States include bacteria belonging to the genera *Agrobacterium*, *Bacillus*, *Pseudomonas*, and *Streptomyces* and fungi belonging to the genera *Ampelomyces*, *Candida*, *Coniothyrium*, and *Trichoderma* <http://www.plantmanagementnetwork.org/pub/php/review/biocontrol/>

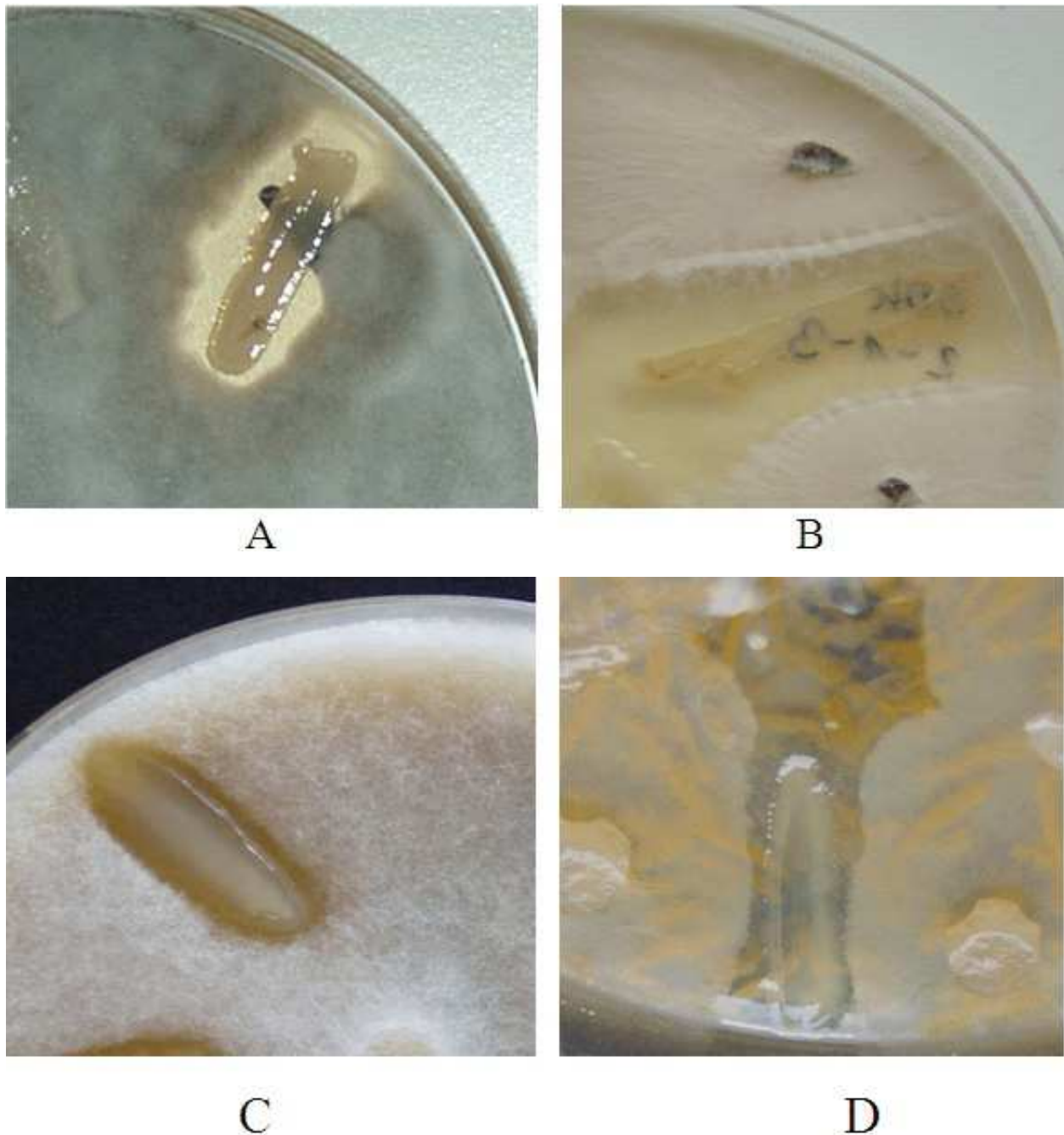


Fig. 6. Antagonistic activity of *Paenibacillus polymyxa* against plant pathogens, A (*Phoma betae*), B (*Rhizoctonia solani*), C (*Pythium ultimum*), D (*Aphanomyces cochlioides*). (Adopted from Doaa et al 2008)

Screening is a critical step in the development of biocontrol agents. The success of all subsequent stages depends on the ability of a screening procedure to identify an appropriate candidate. Many useful bacterial biocontrol agents have been found by observing zones of inhibition in Petri plates. However, this method does not identify biocontrol agents with other modes of action such as parasitism, induced plant resistance, or some forms of competition.

Screening methods for parasitism include burying and retrieving propagules of the pathogen to isolate parasites. For competition, methods include looking for microbes that quickly colonize sterilized soil and have the ability to exclude other organisms that attempt to invade the space, and looking for microbes that colonize the infection court. Primary screens for new biocontrol microbes are still undertaken (Larkin and Fravel 1998) and it seems likely that continued prospecting will be required to diversify the potential applications of biocontrol as well as replace more widely used biocontrol products should resistance develop.

7. Probable mechanisms of biocontrol

The phenomenon of disease suppressive soils has fascinated plant pathologists for decades. Observed in many locations around the world, suppressive soils are those in which a specific pathogen does not persist despite favorable environmental conditions, the pathogen establishes but doesn't cause disease, or disease occurs but diminishes with continuous monoculture of the same crop species. The phenomenon is believed to be biological in nature because fumigation or heat-sterilization of the soil eliminates the suppressive effect, and disease is severe if the pathogen is re-introduced.

There are three main mechanisms by which one microorganism may limit the growth of another microorganism: antibiosis, mycoparasitism, and competition for resources. Antibiosis is defined as inhibition of the growth of one microorganism by another as a result of diffusion of an antibiotic. Antibiotic production is very common among soil-dwelling bacteria and fungi, and in fact many of our most widely used medical antibiotics (e.g., streptomycin) are made by soil microorganisms. Antibiotic production appears to be important to the survival of microorganisms through elimination of microbial competition for food sources, which are usually very limited in soil.

Another mechanism of biocontrol is destructive mycoparasitism. This is parasitism of a pathogenic fungus by another fungus. It involves direct contact between the fungi resulting in death of the plant pathogen, and nutrient absorption by the parasite.

Microorganisms compete with each other for carbon, nitrogen, oxygen, iron and other micronutrients. **Nutrient competition** is likely to be the most common way by which one organism limits the growth of another, but demonstrating that this is actually responsible for biological control is quite challenging.

In most terrestrial habitats, microbial competition for the soluble form of iron, Fe^{3+} , is keen. Some fungi and bacteria produce very large molecules called siderophores which are efficient at chelating Fe^{3+} . Individual strains can have their own particular siderophores and receptors which can bind Fe^{3+} in such a way that the iron becomes inaccessible to other microorganisms, including pathogens. In some cases, siderophore production and competitive success in acquiring Fe^{3+} is the mechanism by which biocontrol agents control plant diseases. Siderophores produced by certain strains of *Pseudomonas* have been implicated in disease suppression of several fungal diseases, but none of these biocontrol organisms have yet been developed commercially. [http://www.understanding the mechanisms of biocontrol](http://www.understandingthe mechanisms of biocontrol).

8. Recommendation

It is critical that effective safe means of controlling and eliminating many of these invasive tree diseases must be found and applied. Major challenges include reducing pathogen without

affect biodiversity, as the microbial communities in the forest systems will be modified due to tillage, herbicides and pesticides. Microbial diversity in these systems will be reduced and the functional consequences of this loss of diversity are still uninvestigated but may alter plants life style. Increased environmental awareness has progressively led to a shift from conventional intensive management to the opposite direction.

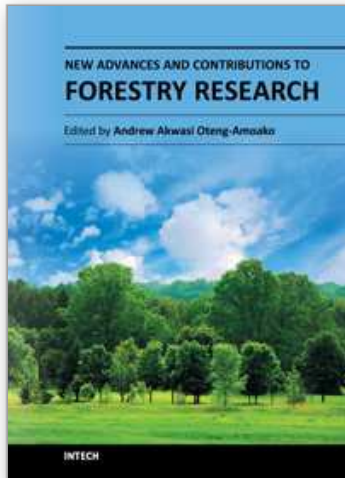
We do not need sterile life from microbes but we need to spread beneficial microbes against pathogenic microbes, because the former have magical affects on overcoming the later problems via antagonism activity.

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New Advances and Contributions to Forestry Research

Edited by Dr. Dr. Andrew A. Oteng-Amoako

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New Advances and Contributions to Forestry Research consists of 14 chapters divided into three sections and is authored by 48 researchers from 16 countries and all five continents. Section Whither the Use of Forest Resources, authored by 16 researchers, describes negative and positive practices in forestry. Forest is a complex habitat for man, animals, insects and micro-organisms and their activities may impact positively or negatively on the forest. This complex relationship is explained in the section Forest and Organisms Interactions, consisting of contributions made by six researchers. Development of tree plantations has been man's response to forest degradation and deforestation caused by human, animals and natural disasters. Plantations of beech, spruce, Eucalyptus and other species are described in the last section, Amelioration of Dwindling Forest Resources Through Plantation Development, a section consisting of five papers authored by 20 researchers. New Advances and Contributions to Forestry Research will appeal to forest scientists, researchers and allied professionals. It will be of interest to those who care about forest and who subscribe to the adage that the last tree dies with the last man on our planet. I recommend it to you; enjoy reading it, save the forest and save life!

How to reference

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