Microbiota of tree roots

Let's build a tree house! But what is holding the tree up?

Image by Jeremy Bishop, via Pexels.com

Ana V. Lasa

Microbiology of Agroforestry Ecosystems, Department of Soil and Plant Microbiology, Estación Experimental del Zaidín, Consejo Superior de Investigaciones Científicas (CSIC), Granada, Spain.

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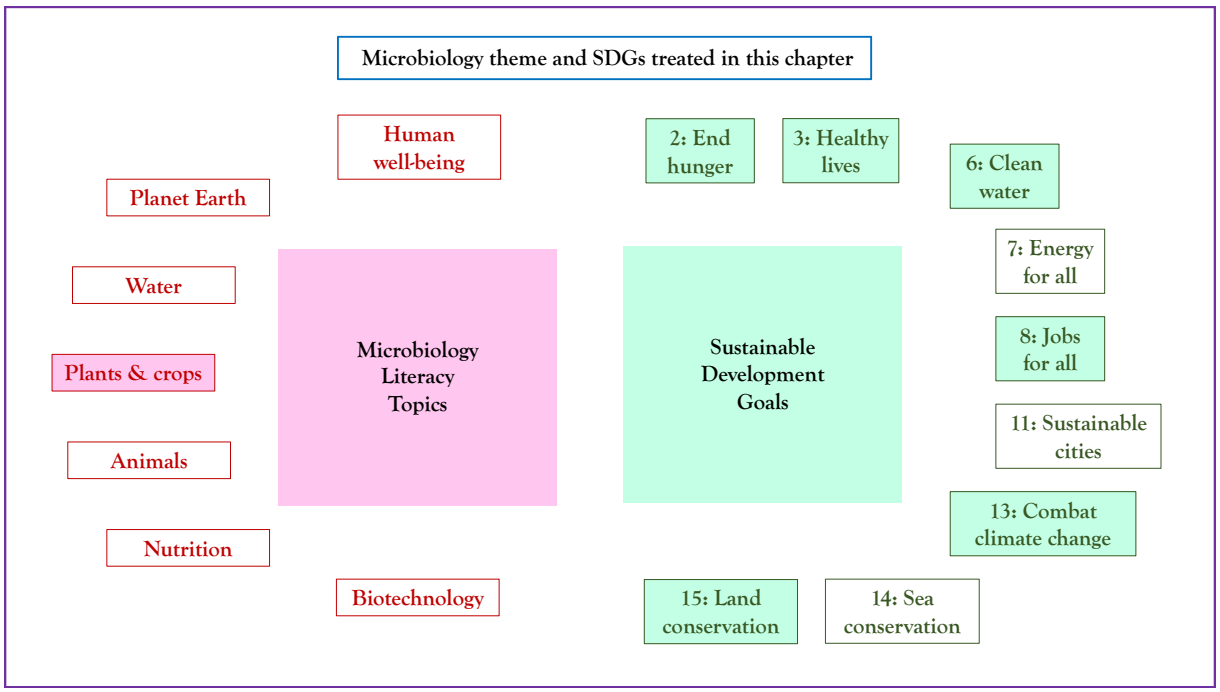
Storyline

It is impossible to know exactly how many trees there are in the world, although it has been estimated that there are close to three trillion. While this might seem a lot, it is not because prior to human civilization, the Earth hosted about six trillion trees. And we are losing 15 billion trees each year to satisfy certain human needs, such as paper, timber and food production, farmland expansion, and so forth. The loss of so many trees has significant negative impacts on our planet and human well-being, because trees[1] provide a range of important services: they are a great source of products (timber, firewood, fiber, animal and human food, such as nuts, and even medicines) and provide non-commercial benefits such as oxigen production, soil protection, hydrological regulation, atmospheric carbon fixation, and enhancement of recreational spaces.

All the beneficial services (also known as "ecosystem services") trees provide are largely dependent upon one of their organs: the root system and the microorganisms associated with it. Without the microorganisms, the roots would not fulfil their functions, trees could not survive, and therefore neither could we.

The Microbiology and Societal Context

The microbiology: plant microbiome; plant-microorganism interactions; root system; rhizosphere; plant microbial biotechnology; forestry. *Sustainability issues*: plant crop; food security and quality; better use of farmlands; sustainable forestry practices; health; food supply; economy; employment; climate change.



[1] There are different types of trees: those which are part of temperate, tropical and boreal forests (pines, oaks, etc), crop trees such as olive trees or fruit trees, and ornamental trees, which can be found in cities or parks (urban trees).

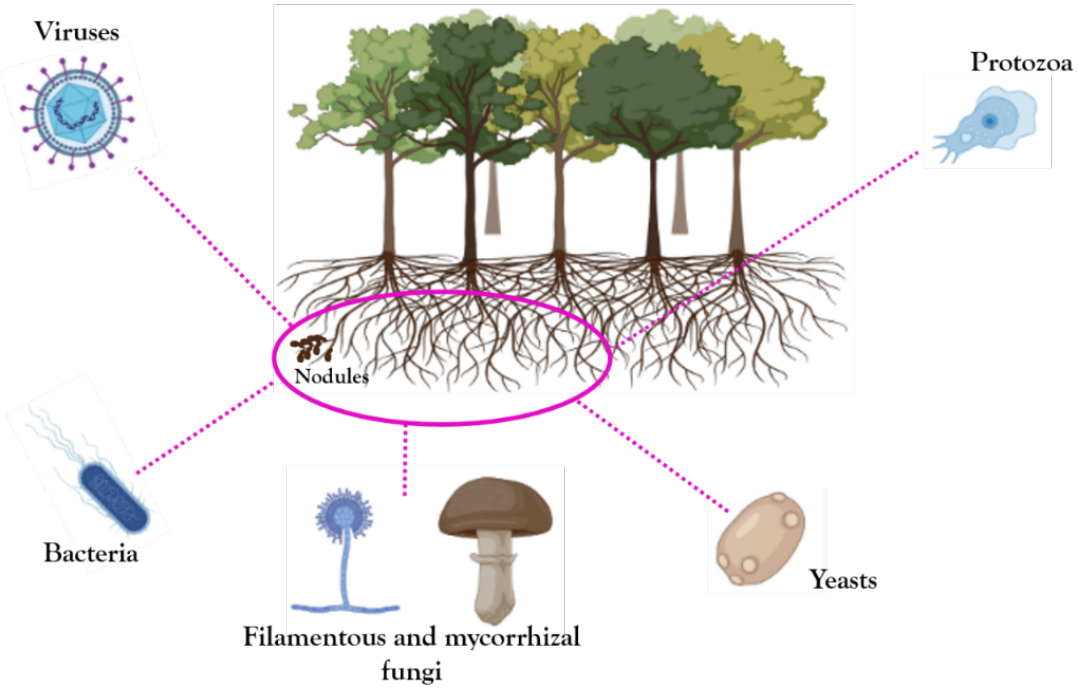
Microbiota of tree roots: the Microbiology

1. ***The root system supports the entire plant.*** The root system is considered a plant organ since it is physically and functionally distinct from the other parts, and plays essential roles. It acts as a *vacuum cleaner*: it absorbs water and nutrients directly from the soil and channels them into the stem to be distributed to all the other organs of the tree: the leaves, flowers, fruits, etc. Some of the nutrients collected are accumulate in the roots during the colder months of the year, so roots are also food storehouses.

In addition, roots help to keep the whole tree standing because they anchor the tree to the ground: this reduces the probability of trees uprooting in extreme weather conditions, such as strong wind, downpours, snow, etc. To picture this in your mind, think about the excellent root-supporting function in a giant sequoia: without a magnificient root system, the weight of a trunk that can reach a diameter of up to 10 m could not be supported.

2. ***Roots and the soil attached to them: who is there*?** Not only the roots are important, but also the soil that is closely attached to them, which is called rhizosphere. Although it may seem that the rhizosphere is a hostile or lifeless environment, it hosts a wide diversity of microorganisms (microbiome or microbiota): in fact, it is one of the terrestrial environments which harbors the greatest number of different microbes. Among them, we can find many types of bacteria, for instance some that establish symbiotic relations with trees (both the tree and bacteria depend on and benefit from each other) and form nodules or lumps inside which they live and provide beneficial compounds to the host tree (Box 1).

Box 1. Microorganisms inhabiting the rhizosphere soil of trees.



Other symbiotic microorganisms are the mycorrhizal fungi, which penetrate or live on the surface of the roots and form a mantle of roots and fungi that can extend over a great surface of the soil, increasing the tree nutrient absorption area. You have probably seen a mushroom close to a tree in a forest: it is probably a type of mycorrhizal fungus.

The fungus *Amanita muscaria* growing in a pine forest establishing symbiotic association with pine trees. Photo: Ana V Lasa.

Yeasts (single-celled fungi) also inhabit the rhizosphere soil, as well as nematodes or microscopic worms that can also have beneficial effects on the trees. However, some of them are enemies of the trees. Soil viruses should also not be ignored: they are the most abundant life form entities on Earth and are predators of other microorganisms living in the same environment, for example, bacteria.

3. Rhizosphere microbiota: what are they doing there?

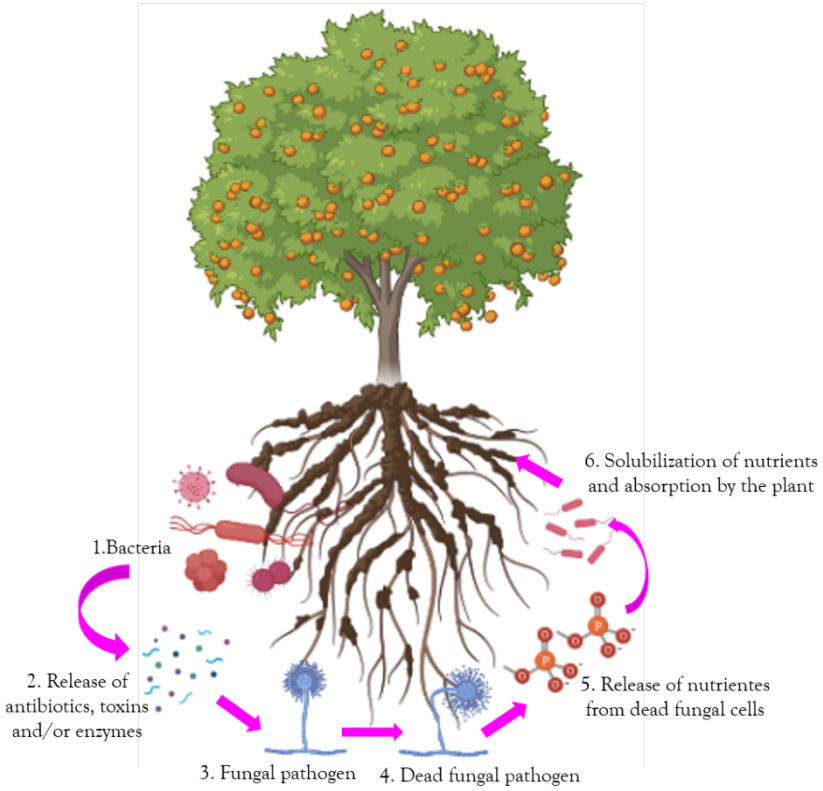
a. Microorganisms can cause serious tree diseases. Trees can become ill, like humans and animals do. In many cases, the entry pathway of the pathogen into the tree is the tree roots. The root microbiota mostly consists of beneficial microorganisms, although roots can also harbor pathogens that include certain bacteria, fungi, viruses, nematodes, etc.

When trees become ill, they develop symptoms which sometimes can be observed in the roots or in other parts of the tree. This is the case of the root rot caused by different fungi, a disease that can be identified by the poor growth of the tree, wilted leaves, and weak branches.

In most root diseases, roots cannot do their job, so they become weak and the tree may even die. Root tree diseases should not be overlooked, since the infectious illness can be transmited to one tree to another, and spread along a big forest or a cultivated area such an apple or peach orchard.

b. Microorganisms can also prevent tree disease. The rhizosphere also contains microorganisms that are able to prevent infections by pathogens. Some bacteria have developed the ability to produce compounds that limit the growth of the pathogens such as antibiotics (similar to those we take when we are ill), toxins that directly kill the pathogens, or enzymes (proteins that carry out many essential functions for cells) that dissolve the cell wall or the "skin" of the fungal cells and therefore kill them (Box 2). Moreover, microorganisms can stimulate the inmune system of the plants, which prepares them to face the attack of further pathogens. Therefore, microorganisms can be applied to tree roots to prevent tree infectious diseases.

Box 2. Example of an antibiosis phenomenon and nutrient cycling in the rhizosphere



c. The survival of the trees depends on rhizosphere microbiota. In addition to disease prevention, microorganisms inhabiting the rhizosphere play other important roles relevant to the health of trees. They can dissolve nutrients that are not available for the plant and thereby improve tree nutrition by making the nutrients more soluble in the soil. Some microorganisms produce plant hormones called phytohormones which are necessary for tree growth and for several processes such as tree flowering or fruit production. They also contribute to field survival by promoting the tolerance of the trees to environmental stresses, such as those caused by high temperatures or low rainfall patterns. All these properties make microorganisms excellent candidates for adding to the trees as if they were fertilizers (biofertilizers).

d. The structure of the tree roots and quality of the surrounding soil depends on their associated microbiota. Due to microbial activity (specially mycorrhizal fungal activity), roots can vary their morphology. When they stablish symbiotic interactions with mycorrhizal fungi, the soil surface covered by roots increases. Other microorganisms can decompose the litter and dead wood, which promotes the addition of new nutrients, water and oxygen to the soil, thereby improving its quality.

Relevance for Sustainable Development Goals (SDG) and Grand Challenges

The utilization of tree products, microbial biofertilizers and the importance of the root system relate to several SDG, including:

- **Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture.** Healthy trees producing food crops, such as apples, cherries, olives, nuts, have better crop yields and quality than those of unhealthy trees and those infected by pathogenic microorganisms. This in turn will improve food security. In

addition, a good balance of nutrients in the rhizosphere (commonly achieved by a healthy microbiome) is synonymous with fruits of higher nutritional value.

- **Goal 3: Ensure healthy lives and promote well-being for all at all ages**: Forests contribute to healthy lives of humans and promote well-being in different ways, for instance, by creating an oxygen-rich atmosphere or by going for a walk through a forest. By maintaining a healthy rhizosphere microbiota and therefore healthy forests, our physical and mental health can improve due to the activities we can do there, which would mean savings for the health budgets and a benefit to our life quality.
- **Goal 6**: **Ensure availability and sustainable management of water and sanitation for all.** If rhizosphere microorganisms are applied to tree crops instead of high amounts of chemical fertilizers or pesticides, irrigation water receives fewer contaminants and there is less pollution of run-off water. On the other hand, the large scale production of microorganisms as agrobiochemicals is a high water consumption process, so this may be more difficult to achieve.
- **Goal 8**: **Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.** The use of fertilizers based on beneficial microorganisms (biofertilizers) could support economic growth in several ways. Firstly, the development of biofertilizers involves many different businessess (research, product development, marketing, transportation, sales, etc), while the application of the product could support the creation of jobs related to the agriculture, forestry or ornamental industry. It is important to highlight that agricultural or forest lands previously abandoned due to tree illness or low productivity, could be rejuvenated, creating new job opportunities.
- **Goal 13**: **Take urgent action to combat climate change and its impact**. Trees, as major players in planetary photosynthesis, play a major role in carbon capture and burial, so are key elements in global warming and climate change. The use of biofertilizers or microorganisms to prevent tree diseases reduces the use of chemical fertilizers, pesticides, etc, which aids in mitigating the greenhouse gas emissions that take place during their production, and in the releasing of contaminants and harmful compounds to the field. In addition, a healthy root system has a positive impact on the aerial part (leaves, trunk) of the trees, which promotes higher photosynthetic activity and therefore higher CO_2 fixation levels and O_2 emissions to the atmosphere.
- **Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.** The exploitation of trees and their products (wood, resin, fruits, etc) can challenge achievement of this SDG. If an infected tree has not been properly diagnosed and it is used, the infection can be spread to other trees (for example, by using contaminated forest tools such as saws etc), which may trigger important environmental and economical losses. In contrast, the use of microbiome-based fertilizers and products based on disease-preventing microorganisms can help promote healthier forests and combat desertification. As forests act as homes for many other plants, animals and microorganisms, their conservation and health improvement has a strong positive impact on the maintenance of global biodiversity.

Pupil participation

1. ***Class discussion about the importance of the trees and their organs (specially roots) worldwide. Discuss also the relevance of tree-microorganisms interactions.***

2. ***Pupil stakeholder awareness***
    a. Why should we care about the health status of the rhizosphere?
    b. By ensuring a healthy tree rhizosphere, which SDG do you think that can not be achieved?
    c. Can you think about something you might do to ensure a healthy rhizosphere or to protect our forests?
    d. Concerning the use of microbial biofertilizers to improve the tree health:
        i. From which ecosytems should we isolate microoganisms to be inoculated?
        ii. Could we find human pathogens in the rhizosphere of forest trees? And in the rhizosphere of crop trees that have been treated with cow or sheep manure?
3. ***Exercises***
    a. Imagine your favorite tree (forest, ornamental or crop tree, for instance, pines) and
        i. discover its distribution area worldwide. Which are the places where this species is mainly found?
        ii. What would be the consequences of losing this species (due to an infection, massive cut-downs, etc). You can start from a local point of view (for example, the orchard of your grandmother) to a global scale (all the orchards worldwide).
        iii. Would our feed supply be affected?
        iv. Would animals like bees or goats have enough food?
        v. Would human well-being be negatively affected? Consider all the tree-derived products that you can use or consume: wood to build houses, beans of the cocoa tree needed to obtain chocolate, etc.

The Evidence Base, Further Reading and Teaching Aids

Protection of Soil Biodiversity
https://kids.frontiersin.org/articles/10.3389/frym.2022.677917

***The rhizosphere microbiome*:**
Mendes, R., Garbeva, P. & Raaijmakers, J.M. 2013. The rhizosphere microbiome: significance of plant beneficial, plant pathogenic, and human pathogenic microorganisms. FEMS Microbiol Rev 37: 634-663. https://doi.org/10.1111/1574-6976.12028

Mercado-Blanco, J., Abrantes, I., Barra Caracciolo A., Bevivino, A., Ciancio, A., Grenni, P., Hrynkiewicz, K., Kredics, L., & Proença, D. 2018. Belowground Microbiota and the Health of Tree crops. Front Microbiol 9: 1006. https://doi.org/10.3389/fmicb.2018.01006

The soil fungi:
https://kids.frontiersin.org/articles/10.3389/frym.2022.652660

Glossary

Cell wall: a structure that is located in the external part of the some cells, which separates one cell from another. This structure also provides protection from pathogens and the surrounding environment, and physical support to the cells. Cell walls can be found in different organisms like plants, fungi, bacteria, algae, etc, although their composition varies depending on the organism.

Enzyme: proteins that act as machines, since they can execute many different reactions than happen inside (even outside) the cells. They help the biological reactions to take place faster or easier. There are many different types of enzymes depending on their structure or function, and they can be found in all living organisms. For example, one of them is involved in the transformation of the meat you eat into small pieces in your intestine so you can absorb the nutrients from the meat.

Microbiota or Microbiome: group of different microorganisms that live in a specific ecosystem. The microbiome can be composed of bacteria, fungi, yeasts, viruses, protozoa, algae, etc, depending on the ecosystem they inhabit.

Mycorrhizal fungi: fungi that form mutualistic relationships with the roots of plants. They cannot live without interacting with a plant since they are not able to take nutrients and energy from the environment, so plants have to provide them, and they provide plants other nutrients need by the plant host. Almost 80% of all plant species wordwide interact with mycorrhizal fungi. Two types of mycorrhizal fungi have been described: endomycorrhizal (penetrating the host's cells) and ectomycorrhizal (they do not penetrate plant cell wall).

Nematode: microscopic roundworms that live inhabit soils, water, and animal and human tissues. Some especies of soil nematodes are beneficial for plants, while other are harmful (parasites) and feed on roots, causing severe impact on many food crops such as carrots or parsnips.

Nodule: beneficial tumors developed in the roots of some plant species. They are formed as a result of a symbiotic relation between some plants and some types of bacteria. Inside the nodules, bacteria are able to fix N_2 from the environment and provide N to the plant, while plants provide nutrients and energy to the bacteria.

Phytohormone: plant hormone. Organic molecules produced by plants and certain microorganisms which are involved in essential plant processes, such root development, stem elongation, flowering, fruit production etc.

Rhizosphere: soil closely attached to and under the influence of plant roots. It is rich in plant-derived compounds released by the roots (root exudates, composed of sugar, aminoacids, organic acids, etc), and in microorganisms.

Root rot disease: a common plant root disease that is caused by different microbial pathogens such as fungi and by an excess of water. Although symptoms start in the roots, they can spread aboveground and plants can even die. Common symptoms are: continually wet soil even in you have not watered the plant, mushy roots, soil that smells rotten, slow growth of the plant, wilt and yellowing leaves.

Symbiotic relation (symbiosis): mutualistic relation between different organisms, in which both of them obtain benefits.

Yeasts: yeast are unicelular fungi that live in many different environments, such as soils, human bodies, water ecosystems, among others. They are commonly used in different industries to obtain fermented products such as bread, beer, wine and other alcoholic drinks, biofuel, even medicines. There are certain species than cause disease in human, animals and plants.