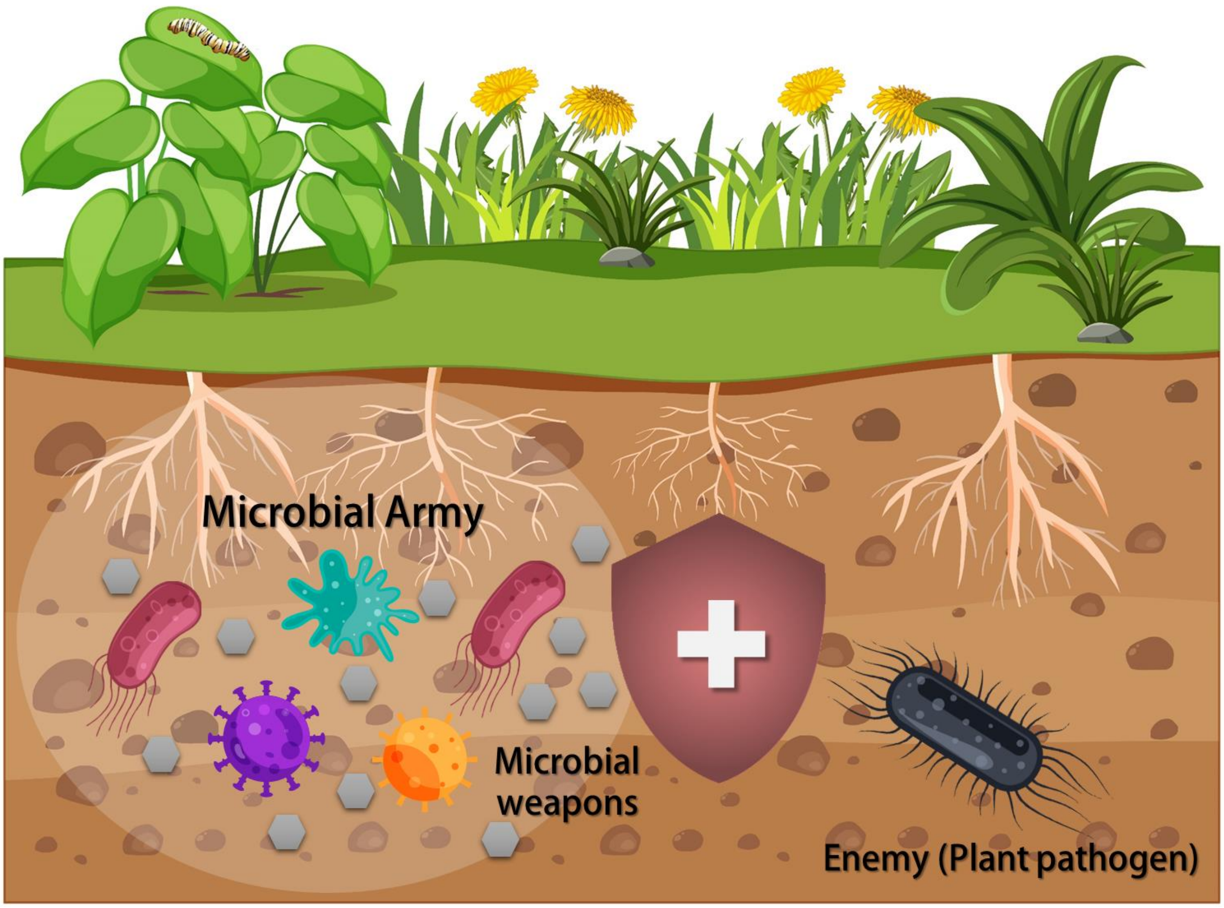
Disease suppressive soils: a battlefield beneath our feet

Mummy: How can plants protect themselves if they can't run away from danger?



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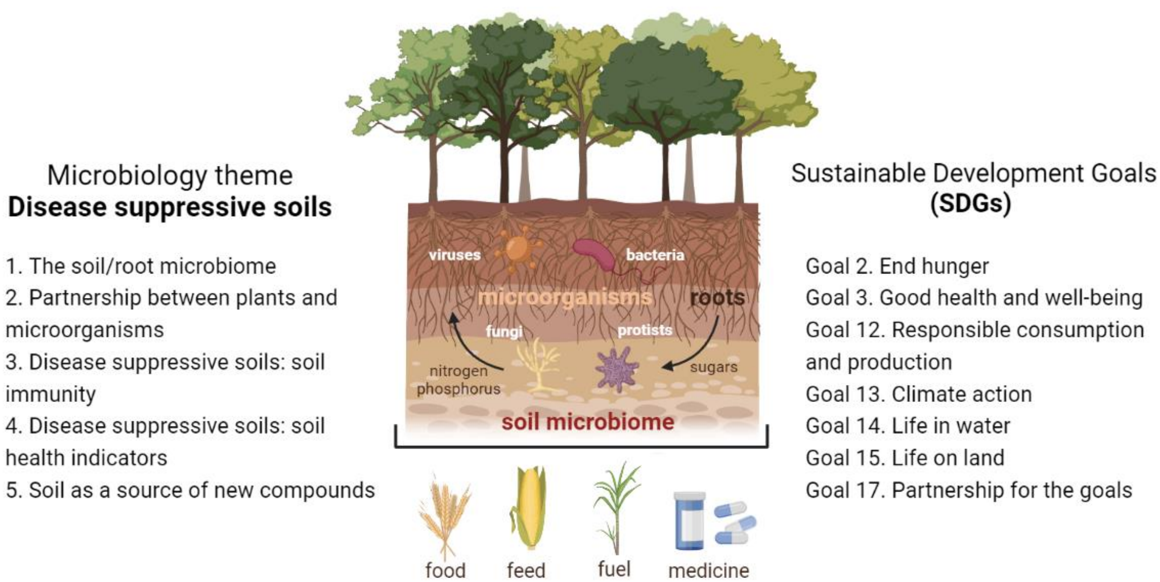
Viviane Cordovez

Department of Microbial Ecology, Netherlands Institute of Ecology (NIOO-KNAW), The Netherlands

Disease suppressive soils

Storyline

Plants have different strategies to escape from dangers imposed by natural enemies (for example, insects and pathogens). In addition to their own physical and chemical defenses, they can also count on a 'microbial army' to protect them against herbivory (plant-eating predators) and diseases. Disease suppressive soils are an example of successful partnership between plants and microorganisms. In these soils, plants develop very little or no disease symptoms, despite the presence of plant pathogens. The suppression of plant diseases is often triggered by the activity of microorganisms (bacteria and fungi) living in the soil and plant roots, which hinder the growth of pathogens via the production of inhibitory compounds, for example antibiotics ('microbial weapons'). Disease suppressive soils have been identified and studied worldwide and offer a valuable source of beneficial microorganisms. These microorganisms can be used in agriculture for controlling plant diseases and enhancing crop yield. This practice has great potential for improving agricultural productivity in a sustainable manner, addressing several Sustainable Development Goals (SDGs).



Overview of the topics presented in this Microbiology Theme and its associated SDGs.
Designed with Biorender.

The Microbiology and Societal Context

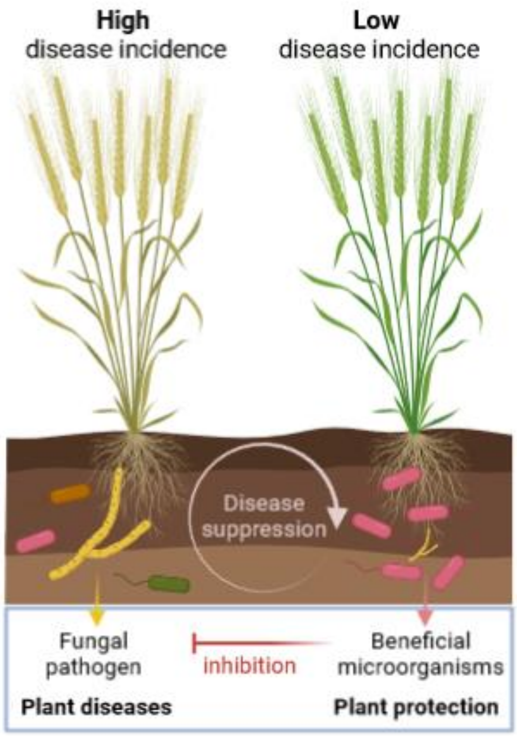
Plant diseases caused by pathogens living in soil lead to significant economic losses worldwide. Naturally-occurring disease suppressive soils have been described for a number of plant pathogens. The disease suppression capacity may function as an indicator for a healthy soil ecosystem. Understanding the diversity and natural functions of soils microorganisms is an important step for combating plant diseases in a sustainable manner. Decreasing crop losses due to plant diseases will be key to increase yield in the face of the increasing world population.

Disease suppressive soils: the Microbiology

1. **The soil/root microbiome.** Soil is often thought as lifeless dirt, but in fact soil harbors a rich microbial life, hosting a quarter of the world's biodiversity. One tea spoon of soil contains millions of microorganisms, including fungi, bacteria, viruses, and protists. The microbiome is the community of microorganisms (fungi, bacteria, viruses, and protists) living in the soil (soil microbiome), roots (rhizosphere microbiome) and leaves/flowers/fruits (phyllosphere microbiome). Some soil microorganisms can be dangerous and can cause diseases in humans, animals and plants. On the other hand, many of these microorganisms are beneficial and provide other organisms with essential functions. Some examples are decomposition of organic matter, nutrient cycling, production of antibiotics, removal of soil contaminants, and disease suppression. The presence of these microorganisms is important for soil and plant health and, consequently, for food, feed, fiber and medicine production.

2. **Partnership between plants and microorganisms.** Just like any other organism, plants do not function alone. Most plants are rooted to the ground, and for this reason, they cannot run away and have to cope with several hostile conditions, for example, low nutrient availability, soil contaminants and/or pathogen attack. In addition to their own physical and chemical defense mechanisms, plant growth and health strongly relies on the interactions with their microbiome. Plants shape their root microbiome by actively recruiting beneficial microorganisms from the surrounding soil via the production of sugars and other compounds released by their roots. These microorganisms not only supply plants with nutrients (e.g. nitrogen and phosphorus), but also offer a natural defense layer against pathogens.

3. **Disease suppressive soils: soil immunity.** Disease suppressive soils have been described for different plant diseases caused by soil fungi, bacteria and nematodes, as well as for parasitic weeds. General disease suppression develops through the collective activities (e.g. competition for nutrients and space) of soil microorganisms and can be boosted by the addition of organic matter. This type of suppression can be compared to the innate immune response in animals, which constitutes their first line of defense. In contrast, specific disease suppression is mediated by a select group of microorganisms with specialized activities, similar to the adaptive immune response in animals, which requires time and specialized cells to suppress the pathogen. Specific disease suppression is usually developed after a severe disease outbreak in soils which have been used for continuous cultivation of susceptible (vulnerable) crops. Plants under pathogen attack release compounds (root exudates) into the soil, which attract specific microorganisms that can fight plant pathogens.



Plants growing in disease suppressive soils (right) display very low or no disease symptoms, despite the presence of a pathogen and a susceptible plant. Plants under pathogen attack (e.g. fungal infection in the roots) call for help by releasing compounds through their roots which attract beneficial microorganisms. These microorganisms inhibit pathogen growth by competing for space and nutrients, producing antibiotics and toxins, as well as stimulating plant defenses. (Designed with Biorender).

4. **Disease suppressive soils: soil health indicators.** Soil health is connected to the ability of the microbial community to suppress plant pathogens. Therefore, the capacity of soils to suppress disease may function as an indicator of the health of soil ecosystems. Studying the activity and diversity of the soil/root microbiome can help monitoring the soil status and the efficacy of soil management in agriculture.

5. **Soil as a source of new compounds.** Most of the antibiotics used today to treat human infections are based on compounds produced in nature by soil bacteria and fungi. These compounds provide the producing microorganisms with an advantage by inhibiting other microorganisms inhabiting the same niche and that compete for nutrients and space. We benefit from this mechanism since disease suppressive soils can offer us valuable compounds to inhibit not only plant pathogens but also human pathogens. The discovery of new antibiotics is of extreme importance and is crucial in the face of the crisis of antibiotic-resistant pathogens, a worldwide public health problem.

Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 2. End hunger.** Soils are estimated to contribute to over 95% of our food production. Food quality and quantity is directly linked to soil health. In order to ensure food security for an increasing world population, it is of high importance to raise awareness of the role of soils, its microbial life and their impact on disease suppression. Disease suppressive soils offer great potential to address future food security goals by controlling plant diseases caused by soil pathogens and in turn, reducing crop losses and improving crop yield.

- **Goal 3. Good health and well-being.** Life is not possible without soils. Soils allow the growth of plants which provide us with food, feed and fuel as well as oxygen. In addition, microorganisms living in soils and on plant roots have significant impact on plant growth and health, and in turn, in food production. These microorganisms are also a source of antibiotics. By 2050, it is estimated that as many as ten million people per year could die of infections caused by antibiotic resistant bacteria. Thus, a global search for new effective antibiotics is crucial. Natural ecosystems, such as disease suppressive soils, are a great source of potential new antibiotics.
- **Goal 12. Responsible consumption and production.** Soil is a finite resource that takes hundreds to thousands of years to form. Soil biodiversity largely contributes to soil health and resilience. Soil is currently facing a number of challenges, including erosion, desertification, pollution and loss of nutrients, organic matter and biodiversity. Agricultural management practices can significantly alter the soil environment and often impact the abundance and activities of antagonistic microorganisms, which are crucial players in soil disease suppression.
- **Goal 13. Climate action.** Climate change is expected to have adverse effects on agriculture, such as an increase in infections by plant pathogens and pests. This leads to a significant decrease in food production and a threat to global food security. More specifically, as temperatures increase, a risk of infection from 80 fungal and fungal-like pathogens will increase in cooler climates. These emerging plant pathogens will become a major threat to crop production and food security; new plant disease management strategies, such as soil disease suppression, can contribute to mitigate the effects of climate change.
- **Goal 14. Life in water.** Fertilizer (nitrogen, phosphorus) and pesticide use in agriculture leads to contamination of rivers, lakes and oceans through runoff and soil erosion. Excess fertilizers promote the overgrowth of algae (algae blooms) which can lead to low oxygen levels in the water (hypoxia) as well as the production of toxins, impacting the aquatic life. Microorganisms in disease suppressive soils can be exploited for sustainable maintenance of plant and soil health; thus fewer and lower chemical inputs are needed to reach the desired crop yield.
- **Goal 15. Life on land.** Humans have altered a large portion of the Earth's land surface. Current agricultural practices, with extensive use of agrochemicals and pesticides, are threatening the quality of our soils. Intensive agricultural practices have changed land use, strongly impacting the soil microbiome and, consequently, disease suppression. Natural systems generally display more disease suppression capacity than agricultural systems. This is likely due to the deterioration of soil health during intensive farming, which in turn decreases soil biodiversity and the antagonistic microorganisms involved in soil disease suppression. More sustainable soil management practices will be key to preventing and controlling plant diseases while preserving the soil quality. Currently, several biostimulant, biofertilizer and biocontrol products are available on the market which improve crop yield, tolerance to (a)biotic stresses, water uptake and control of pests and diseases.
- **Goal 17. Partnership for the goals.** The interactions between plants, microorganisms and environmental factors (soil pH, temperature, nutrient status, etc) are complex. Disease-

suppressive soils have great potential for controlling soil-borne diseases while decreasing the use of pesticides. A number of approaches have been proposed to stimulate the growth of beneficial microorganisms with antagonistic activities against plant pathogens. Yet, the practical application of soil disease suppression requires further understanding of the microbiological basis. The identification of the different microbial roles as well as the factors impacting the microbial abundance and activities will be key. For that, it is also important to promote collaborations between scientists in the field of microbiology, plant pathology, soil science, agronomy and plant breeding. Ultimately, this knowledge will give insights into how to steer microbial communities for disease suppression. Another important step also includes the translation of this knowledge to farmers and governmental institutions.

Potential Implications for Decisions

1. ***Individual***
   - **a.** Support organic farmers by purchasing (local) organic products
   - **b.** Reduce, reuse, and recycle clothes and textiles

2. ***Community and national policies***
   - **a.** Educate kids and parents about making healthy food choices and understanding the value of our environment/soils
   - **b.** Increase citizen awareness of soil health by promoting training and building capacities for soil-related science initiatives
   - **c.** Promote educational programs for teaching school kids the importance of soil in their daily life
   - **d.** Consider the harmful impact from the overuse of pesticides and other chemical inputs on human and animal health
   - **e.** Support agricultural producers implementing soil health practices
   - **f.** Provide financial, technical, and educational support for increasing efforts to promote soil health

Pupil Participation

1. ***Class discussion of the importance of disease suppressive soils for food security***

2. ***Pupil stakeholder awareness***
   - a. What is the impact of our actions on the health of soils and their 'microbial inhabitants' for human and animal health.
   - b. What are the links between unhealthy soils and key societal concerns (*e.g.* climate change, human health, ocean health, food safety, pollution, etc.)?
   - **c.** How can farmers minimize or eliminate the use of chemical fertilizers and pesticides? by applying compost and natural pest control products
   - d. Would you consider volunteering to serve in a conservation/restoration program?
   - e.

3. ***Exercises.***
    a. Explore the soil microbial life (see activities below)
    b. Evaluate the importance of soils (see activities below)
    c. Evaluate the impact of your actions on soil health. What can you do to help protect the planet's soils? *(prevent soil degradation and pollution, practice sustainable soil management, prevent soil pollution, combat climate change, shrink your carbon footprint, stop food waste, spread the word about the importance of soils)*

The Evidence Base, Further Reading and Teaching Aids

Quiz
How much do you know about soils? Fifteen questions to celebrate the 2015 International Year of Soils.
https://www.fao.org/soils-2015/news/news-detail/en/c/317128/
Activities
https://www.fao.org/soils-2015/resources/educational/en/
https://www.fao.org/3/i4771e/i4771e.pdf
Media
Why soil is one of the most amazing things on Earth | BBC Ideas
https://www.youtube.com/watch?v=OiLITHMVcRw
Soil is a living organism
https://www.youtube.com/watch?v=8ugaL6wsXME (EN)
https://www.youtube.com/watch?v=gJOiEbdFURE (ES)
The Living Soil: How Unseen Microbes Affect the Food We Eat
https://www.youtube.com/watch?v=-dhdUoK7s2s

Glossary

Pathogens: microorganisms that cause diseases
Herbivory: act of eating plants only
Ecosystem: group of all living organisms (e.g. animals, plants, bacteria, fungi) interacting with each other and also with their environment (e.g. water, soils, climate)
Biodiversity: variety of organisms in a habitat/ecosystem (biological diversity)
Protists: microscopic organisms that are not animals, plants or fungi
Organic matter: living and once-living material (e.g., plant residues, manure) in various stages of decomposition
Nutrient cycling: process in which nutrients are transferred from the environment (e.g. soils) to living organisms (bacteria, fungi) and back to the environment
Nematodes: group of worms, including free living organisms (feeding on soil bacteria and fungi) and parasites (of humans and animals)
Erosion: washing or blowing away (by water, wind, human action) of the top layer of soil
Desertification: process by which a piece of land becomes dry and turn into a desert
Biostimulant: substance or microorganism applied to plants for improving nutrition efficiency, abiotic stress tolerance and/or crop quality

Biofertilizer: substance containing microorganisms which increases soil fertility and promotes plant growth
Biocontrol: method for controlling pests (insects, mites, weeds) and plant pathogens using other (micro)organisms
Abiotic stresses: problems caused by deficiencies or excesses in environmental factors (e.g. water, salt, light, temperature, and nutrients)