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Under Our Feet: Soil Microorganisms as Primary Drivers of Essential Ecological Processes

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Key Points

- Fertile soils teem with microorganisms, which directly contribute to the biological fertility of that soil.
- Biological fertility is under-studied and our scientific knowledge of it is incomplete.
- In addition to fertility, soil microorganisms also play essential roles in the nutrient cycles that are fundamentally important to life on the planet.
- In the past, agricultural practices have failed to promote healthy populations of microorganisms, limiting production yields and threatening sustainability.
- Scientific research is exploring new and exciting possibilities for the restoration and promotion of healthy microbial populations in the soil.

'Soil is essential for the maintenance of biodiversity above and below ground. The wealth of biodiversity below ground is vast and unappreciated: millions of microorganisms live and reproduce in a few grams of topsoil, an ecosystem essential for life on earth…'

From: *Australian Soils and Landscape, An Illustrated Compendium*

Summary

Soil fertility comprises three interrelated components: physical fertility, chemical fertility and biological fertility. Biological fertility, the organisms that live in the soil and interact with the other components, varies greatly depending upon conditions and it is highly complex

and dynamic. It is the least well-understood fertility component. In addition to soil fertility, soil microorganisms play essential roles in the nutrient cycles that are fundamental to life on the planet. Fertile soils teem with soil microbes. There may be hundreds of millions to billions of microbes in a single gram of soil. The most numerous microbes in soil are the bacteria, followed in decreasing numerical order by the actinomycetes, the fungi, soil algae and soil protozoa. A better understanding of soil microbiology is essential if agricultural production is to meet the needs of a growing world population. In many regions, the healthy microbe population is still being threatened, and not promoted, by agricultural practices.

Analysis

Introduction

Soil fertility, or its capacity to enrich natural and agricultural plants, is dependent upon three interacting components: physical fertility, chemical fertility and biological fertility.

Physical fertility refers to the physical properties of the soil, including its structure, texture and water absorption and holding capacity, and root penetration. Chemical fertility involves nutrient levels and the presence of chemical conditions such as acidity, alkalinity and salinity that may be harmful or toxic to the plant. Biological fertility refers to the organisms that live in the soil and interact with the other components. These organisms live on soil, organic matter or other soil organisms and perform a number of vital processes in the soil. Some of them perform critical functions in the nutrient and carbon cycles. Very few soil organisms are pests.

Of the three fertility components, it is the microbiological element, the rich diversity of organisms such as bacteria, viruses, fungi and algae that form interactive microbial communities, that are the most complex and, paradoxically, the least well-understood communities. A near decade-long collaboration between the CSIRO and the Bioplatforms Australia company ranks the understanding of soil microbial communities as important as mapping the galaxies in the universe or the biodiversity of the oceans. It provides an opportunity to discover new species currently unknown to science. Soil microbial communities underpin the productivity of all agricultural enterprises and are primary drivers in ecological processes such as the nutrient and carbon cycling, degradation of contaminants and suppression of soil-borne diseases. They are also intimately involved in a range of beneficial and, at times essential, interrelationships with plants.

Definition

Soil microbiology is the study of organisms in soil, their functions and how they affect soil properties. Soil microorganisms can be classified as bacteria, actinomycetes, fungi, algae, protozoa and viruses. Each of these groups has different characteristics that define the organisms and different functions in the soil it lives in. Importantly, these organisms do not exist in isolation; they interact and these interactions influence soil fertility as much or more than the organism’s individual activities.

Bacteria: Bacteria are organisms that have only one cell and are, therefore, microscopic. There are anywhere from 100 million to one billion bacteria in just a teaspoon of moist, fertile soil. They are decomposers, eating dead plant material and organic waste. By doing this, the bacteria release nutrients that other organisms could not access. The bacteria do this by changing the nutrients from inaccessible to usable forms. The process is essential in the nitrogen cycle.

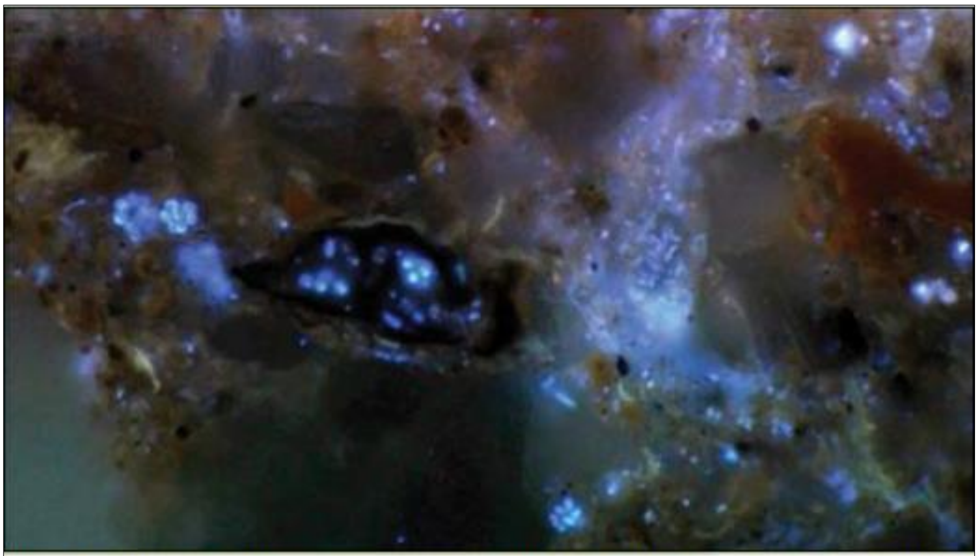

Figure 1: Colonies of soil bacteria (shown in light blue). Each bacterium is approximately one micron in size.
Source: Karl Ritz (soilquality.org.au)

Actinomycetes: Actinomycetes are soil microorganisms similar to both bacteria and fungi, and have characteristics linking them to both groups. They are often believed to be the missing evolutionary link between bacteria and fungi, but they have many more characteristics in common with bacteria than they do fungi. Actinomycetes give soil its characteristic smell. They have also been the source of a number of significant therapeutic medicines.

Fungi: Fungi are unusual organisms, in that they are not plants or animals. They group themselves into fibrous strings called hyphae. The hyphae then form groups called mycelium which are less than 0.8mm wide but can get as long as several metres. They are helpful, but could also be harmful, to soil organisms. Fungi are helpful because they have the ability to break down nutrients that other organisms cannot. They then release them into the soil, and other organisms get to use them. Fungi can attach themselves to plant roots. Most plants grow much better when this happens. This is a beneficial relationship called mycorrhizal. The fungi help the plant by giving it needed nutrients and the fungi get carbohydrates from the plant, the same food that plants give to humans. On the other hand, fungi can get food by being parasites and attaching themselves to plants or other organisms for selfish reasons.

Some of the functions performed in soil by fungi are:

- ***Decomposers*** – saprophytic fungi – convert dead organic material into fungal biomass, carbon dioxide (CO_2), and small molecules, such as organic acids.

- ***Mutualists*** – the mycorrhizal fungi – colonise plant roots. In exchange for carbon from the plant, mycorrhizal fungi help to make phosphorus soluble and bring soil nutrients (phosphorus, nitrogen, micronutrients and, perhaps, water) to the plant. One major group of mycorrhizae, the *ectomycorrhizae*, grow on the surface layers of the roots and are commonly associated with trees. The second major group of mycorrhizae are the *endomycorrhizae* that grow within the root cells and which are commonly associated with grasses, row crops, vegetables and shrubs.

- ***Parasites***: The third group of fungi, *pathogens* or *parasites*, causes reduced production or death when they colonise roots and other organisms.

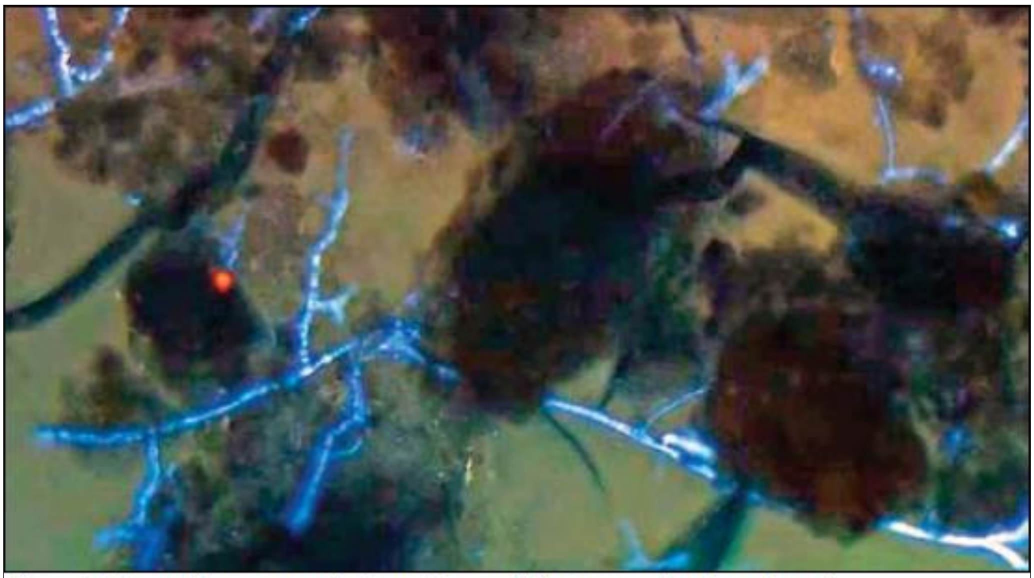

Figure 2: Fungal filaments, or hyphae, (shown in blue) extending through soil.
Source: Karl Ritz (soilquality.org.au)

Algae: Algae are present in most of the soils where moisture and sunlight are available. Their number in the soil usually ranges from 100 to 10,000 per gram of soil. They are capable of photosynthesis, whereby they and obtain carbon dioxide from atmosphere and energy from sunlight and synthesise their own food.

The major roles and functions of algae in soil are:

- Playing an important role in the maintenance of soil fertility, especially in tropical soils.

- Adding organic matter to soil when they die and thus increasing the amount of organic carbon in soil.

- Acting as a cementing agent by binding soil particles and thereby reducing and preventing soil erosion.

- Helping to increase the water retention capacity of soil for longer time periods.
- Liberating large quantities of oxygen in the soil environment through the process of photosynthesis and, thus, facilitating submerged aeration.
- Helping to check the loss of nitrates through leaching and drainage, especially in un-cropped soils.
- Helping in the weathering of rocks and the building up of soil structure.

Protozoa: These are colourless, single-celled animal-like organisms. They are larger than bacteria, varying from a few microns to a few millimetres. Their population in arable soil ranges from 10,000 to 100,000 per gram of soil and they are abundant in surface soil. They can withstand adverse soil conditions, as they are characterised by a protected, dormant stage in their life cycle.

The major functions, roles and features of protozoa are:

- Most protozoans derive their nutrition from feeding or ingesting soil bacteria and, thus, they play an important role in maintaining microbial/bacterial equilibrium in the soil.
- Some protozoa have been recently used as biological control agents against organisms that cause harmful diseases in plants.
- Several soil protozoa cause diseases in human beings that are carried through water and other vectors. Amoebic dysentery is an example.

Viruses: Soil viruses are of great importance, as they may influence the ecology of soil biological communities through both an ability to transfer genes from host to host and as a potential cause of microbial mortality. Consequently, viruses are major players in global cycles, influencing the turnover and concentration of nutrients and gases.

Despite this importance, the subject of soil virology is understudied. To explore the role of the viruses in plant health and soil quality, studies are being conducted into virus diversity and abundance in different geographic areas (ecosystems). It has been found that viruses are highly abundant in all of the areas studied so far, even in circumstances where bacterial populations differ significantly in the same environments.

Soils probably harbour many novel viral species that, together, may represent a large reservoir of genetic diversity. Some researchers believe that investigating this largely unexplored diversity of soil viruses has the potential to transform our understanding of the role of viruses in global ecosystem processes and the evolution of microbial life itself.

Nematodes: Not microorganisms (strictly speaking), nematode worms are typically 50 microns in diameter and one millimetre in length. Species responsible for plant diseases have received much attention, but far less is known about the majority of the nematode community, which play beneficial roles in soil. An incredible variety of nematodes have been found to function at several levels of the soil food web. Some feed on the plants and algae (the first level), others are grazers that feed on bacteria and fungi (second level), and some feed on other nematodes (higher levels).

Free-living nematodes can be divided into four broad groups based on their diet. Bacterial-feeders consume bacteria. Fungal-feeders feed by puncturing the cell walls of fungi and sucking out the internal contents. Predatory nematodes eat all types of nematodes and protozoa. They eat smaller organisms whole or attach themselves to the cuticle of larger nematodes, scraping away until the prey's internal body parts can be extracted.

Like protozoa, nematodes are important in mineralising, or releasing, nutrients in plant-available forms. When nematodes eat bacteria or fungi, ammonium is released because bacteria and fungi contain much more nitrogen than the nematodes require.

Nematodes may also be useful indicators of soil quality because of their tremendous diversity and their participation in many functions at different levels of the soil food web.

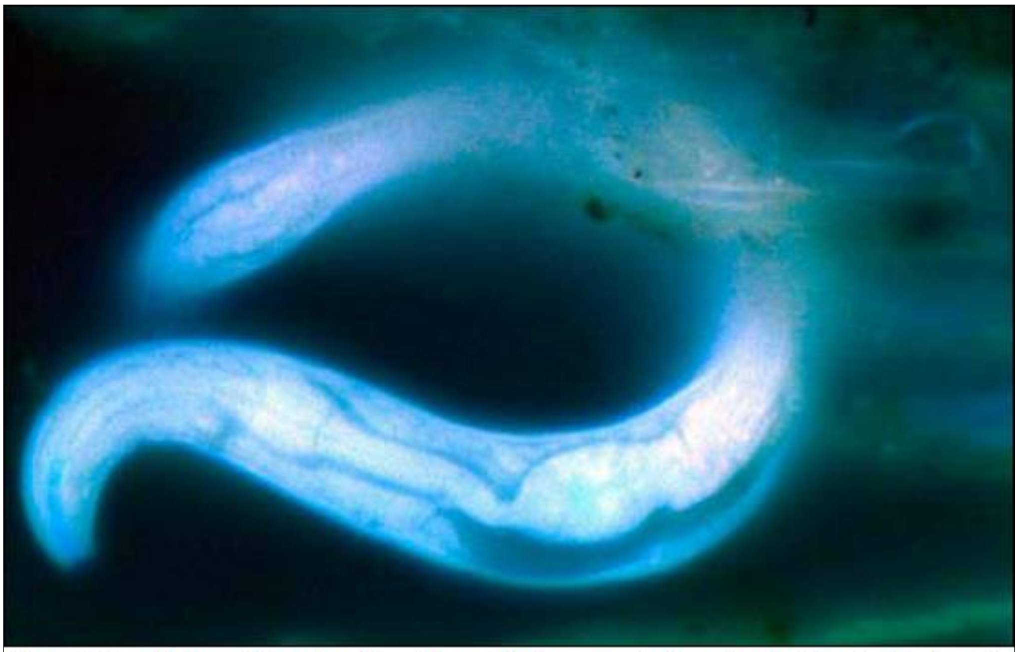

Figure 3: A soil nematode worm. Harmful species have received much attention, but far less is known about the majority of the nematode community, which play beneficial roles in soil.
Source: Karl Ritz (soilquality.org.au)

Role and Functions

Collectively, soil microorganisms play an essential role in decomposing organic matter, cycling nutrients and fertilising the soil. Without the cycling of elements, the continuation of life on Earth would be impossible, since essential nutrients would rapidly be taken up by organisms and locked in a form that cannot be used by others. The reactions involved in elemental cycling are often chemical in nature, but biochemical reactions, those facilitated by organisms, also play an important part in the cycling of elements. Soil microbes are of prime importance in this process.

Soil microbes are also important for the development of healthy soil structure. Soil microbes produce lots of gummy substances (polysaccharides and mucilage, for example) that help to cement soil aggregates. This cement makes aggregates less likely to crumble when exposed to water. Fungal filaments also stabilise soil structure because these threadlike structures branch out throughout the soil, literally surrounding particles and aggregates like a hairnet. The fungi can be thought of as the "threads" of the soil fabric. It must be stressed that microbes generally exert little influence on changing the actual physical structure of the soil; that is performed by larger organisms.

Soil microorganisms are both components and producers of soil organic carbon, a substance that locks carbon into the soil for long periods. Abundant soil organic carbon improves soil fertility and water-retaining capacity. There is a growing body of research that supports the hypothesis that soil microorganisms, and fungi in particular, can be harnessed to draw carbon out of the atmosphere and sequester it in the soil. Soil microorganisms may provide a significant means of reducing atmospheric greenhouse gasses and help to limit the impact of greenhouse gas-induced climate change.

Conditions

We can see that healthy soils contain enormous numbers of microbes and substantial quantities of microbial biomass. This translates into an enormous potential for microbial activity when soil conditions (available carbon sources, moisture, aeration, temperature, acidity/alkalinity and available inorganic nutrients, such as nitrogen), are favourable. The potential for activity must be stressed because, under normal situations, the microbial population as a whole does not receive a constant supply of readily-available substrates to sustain prolonged high rates of growth.

Almost all soil organisms (except some bacteria) need the same things that we need to live: food, water and oxygen. They eat a carbon-based food source, which provides all their nutrients, including nitrogen and phosphorus. They require a moist habitat, with access to oxygen in the air spaces in soil. These reasons explain why 75 per cent of soil organisms are found in the top five centimetres of soil. It also explains, however, why many of our agricultural soil microorganism populations are depleted. Unfortunately, some of the agricultural practices that were standard in Australia up until the 1980s, such as excessive land clearance, the burning of stubble, inappropriate fertiliser use and over-tillage, have degraded soils and produced conditions such as salinity, acidification, soil structural decline and desertification.

Remediation

While in many areas, our agricultural soils are still considered to be under threat, in recent decades, changes to the farming practices detailed above are helping to create healthier soils. Until recently, this was considered the only way to improve biological fertility. Creating the right conditions and microbes will come and, alternatively, if the conditions are not correct, efforts to introduce beneficial microbes are doomed to fail. Recently, however, scientific research has achieved significant success in the inoculation of soils and seeds with beneficial bacterial and, in particular, mycorrhizal fungi to improve yields and to promote healthier soils. While still in an early stage of development, field trials have been positive and may, in the future, lead to a wide range of benefits based upon improved soil biological fertility.

Conclusion

In the past, soil microbiological science has focussed upon the harmful or pathogenic threat posed by a small number of soil-dwelling microorganisms. This is has skewed our understanding away from the vast majority of soil microorganisms that pose no threat to human health or to agricultural production and that perform essential roles in mechanisms that are fundamentally important to the sustainability of human civilisation and life on the planet generally. This emphasis, however, is changing. In a relatively recent initiative, scientists from Bioplatforms Australia, the Director of National Parks, the Western Australian Department of Environment and Conservation, the Department of Primary Industries in Victoria, several universities and research and development corporations and the CSIRO, are undertaking a project to map Australia's soil biodiversity. This initiative embraces the challenge of acknowledging and understanding the rich diversity of organisms, such as bacteria, viruses, fungi and algae, which form microbial communities in the soil.

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