# The Soil Microbiome and its impact on plant nutrition

## How the microbial life in the soil supports healthy plant growth and greater crop yield

BIOME MAKERS

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# Introduction

Plants are part of a rich ecosystem that comprises numerous and diverse microorganisms that live in the soil. It's long been known that some of these microbes, like certain types of fungi or nitrogen-fixing symbiotic bacteria, play an important role in crop health and yield by improving mineral nutrition. However, it's only been recently that researchers have begun to uncover the full extent of these organisms' impact and the role they could play in replacing synthetic agricultural inputs.

Considering the challenges the agricultural ecosystem faces, this research is of vital importance. As we progress further into the 21st century, it's crucial that we find solutions to produce nutritious food for a growing world population. **Considering this is increasing at a rate of 1.14% per year and set to reach 9.5 billion by 2050**, it is an urgent project. Equally, the current situation is growing demand for biofuels, which need to be cultivated in sufficient quantities without impacting food production.

However, arable soils have been degraded through erosion and exhaustive cultivation for decades. Moreover, substantial amounts of fertilizer nutrients are not taken up by crops, casting doubt over their agricultural and financial worth. Therefore, a central challenge in agriculture is to better understand how soil's resident microbial communities can deliver nutrients to crops more efficiently with minimal losses to the environment, and indeed, a farm's bottom line.

In this guide, we seek to lay out a foundation of **how the soil microbiome affects plant nutrient uptake.** We'll introduce some of the key functions of the different types of soil compounds and how they affect plant nutrition, or 'nutrition pathways', and also briefly explain how microbes can impact these functions. Finally, we outline Biome Maker's innovative functional soil analysis technology and explain how it's useful for monitoring soil microbial nutrient cycling.

# The key plant nutrients and their pathways

Various compounds present in the soil have a significant effect on crop quality and yield. Via the degradation of various organic and inorganic matter, microorganisms play a central role in the biogeochemical release of these soil nutrients. However, before we look at the role of the microbiome in more detail, we will introduce some key plant nutrients and their pathways, namely nitrogen, phosphorus, and potassium.

## Nitrogen pathways

Nitrogen plays a major role in **obtaining the maximum yield from a crop**. This is because it is an essential constituent of chlorophyll, and thus, a vital aspect of plant health. As a result, low nitrogen values in the soil cause slow and stunted plant growth, whereas high levels of nitrogen will lead to a thriving, healthy yield.

High nitrogen levels in the soil are supported by the nitrogen cycle, which is the processing of nitrogen from the atmosphere into the soil, and back out in the atmosphere once more. The degradation of organic nitrogen, nitrogen fixation, and nitrification by microorganisms are essential parts of the nitrogen cycle that introduce derivatives of nitrogen and nitrates into the soil.

For instance, the nitrogen cycle converts nitrogen into multiple chemical forms as it circulates. These processes include ammonification, nitrification, denitrification, and anaerobic ammonia oxidation, all of which are derivatives of nitrogen that plants can absorb through their roots.

## Phosphorus pathways

Phosphorous is another fundamental nutrient required **for healthy plant growth. It enhances the development of roots,** and thus, the more efficient absorption of other nutrients. Meanwhile, its deficiency leads to stunted growth and discolored leaves. This discoloration will usually be dark bluish-green, with leaves and stems eventually becoming almost purplish in color.

Once again, maintenance of phosphorus levels in the soil is supported by microbial activity. Microbial processes include inorganic phosphorus solubilization, where certain types of microorganisms dissolve inorganic phosphorus from minerals and rocks into the soil solution. Equally, during mineralization, the decomposition of organic phosphorus serves to replenish the soil's phosphorus content.

# Potassium pathways

Potassium is a key **regulator of metabolic activities, especially those that produce proteins and sugars**, and regulate crop evapotranspiration, or less technically, water uptake. When the soil is potassium-deficient, plants become weak, flabby, and extremely sensitive to drought. Equally, soil potassium content can impact the assimilation of nitrogen and phosphorus.

The solid potassium content is supported by inorganic potassium solubilization, where certain species of microbes dissolve potassium from minerals and rocks into the soil. Both plants and microbes require potassium to function, so in addition, a high concentration of potassium in the soil will stimulate the population of potassium-solubilizing microbes, thus enhancing plant growth and yield.

There are, of course, many other nutrients present in the soil that impact plant health and growth: **sulfur**, for instance, is essential to chlorophyll formation and the metabolism of nitrogen. **Calcium** also contributes to soil fertility by regulating the assimilation of other nutrients; meanwhile, zinc is key for the constitution of many proteins and enzymes, and is essential for hormone production processes. However, for our purposes, we'll focus on these three key nutrients introduced above.

# The microorganisms that affect nutrient pathways

As touched on in our description of the key nutrient pathways, microorganisms are essential for the majority of soil ecosystem functions and the cycling of nutrients. Put simply, **microorganisms are responsible for the degradation** of various matter, which in turn, controls the release of nutrients that promote crop growth. Equally, these organisms interact to either optimize or hinder nutrient cycling.

Through the uptake of different forms of nitrogen, phosphorus, and potassium - among other nutrients - plants are healthier, more resilient, and provide a greater yield. There are certain species of microbe that play particular roles in the cycling of each of these nutrients, which we'll outline in the following section.

## Microbes and nitrogen pathways

The key process that maintains nitrogen levels in the soil is the nitrogen cycle. This is a complex process, so here we'll pick some key steps: the first is **nitrogen fixation**. This is a process through which certain bacteria and archaea metabolize nitrogen gas from the atmosphere and transform it into ammonia, which is turned into ammonium in the soil, becoming available for microbial nitrification into nitrates, or for direct uptake by plants. Examples of symbiotic nitrogen-fixing bacteria include *Rhizobium*, which is associated with plants in the pea family, and various *Azospirillum* species, which are associated with cereal grasses.

In terms of plant nutrition, another key aspect of the nitrogen cycle is **nitrification**. Essentially, this is the oxidation of reduced forms of nitrogen – like ammonia – into nitrates. The first stage of this process is performed by a fairly limited group of autotrophic chemolithotrophic bacteria, which in less technical terms, are bacteria that use the oxidation of inorganic substances as a source of energy in the absence of light. These two types of bacteria fall into the *Betaproteobacteria and Thaumarchaeota* genera. Subsequently, nitrite oxidizers belong to four phylogenetic groups within the *Proteobacteria* family.

However, **nitrogen content in the soil is all about balance**, thus, denitrification is an equally important process as it returns nitrogen to the atmosphere. A broad range of bacteria, archaea and fungi are capable of denitrification, comprising approximately 50% of known evolutionary groups.

## Microbes and phosphorus pathways

Above we touched on organic phosphorus mineralization, which serves to replenish phosphorus in the soil solution. Essentially, this happens as a result of the natural decomposition of plant and animal remains, within which microbes play a significant part. Almost half of the microbes present in soil and plant roots have mineralization potential, via the production of acid phosphatases. In studies, it has been found that mixed cultures of *Phosphorus Solubilizing* Microorganisms (PSMs) *Bacillus, Streptomyces*, and *Pseudomonas* are most effective in mineralizing organic phosphate.

Types of fungi also play a role in aiding phosphorus absorption. For instance, arbuscular mycorrhizal fungi (AMF) – symbiotic fungi that colonize the root cortex – facilitate phosphorus uptake in exchange for carbohydrates from the plant. Although this may sound like the fungus is sapping nutrients, it in fact serves to extend the roots via the branching filaments that make up the mycelium of the fungus. This helps plants access greater quantities of phosphorus, among other nutrients, making them more tolerant to heat, salinity, drought, and extreme temperature stressors.

# Microbes and potassium pathways

In the preceding chapter we briefly explained that most potassium in the soil is locked into minerals and rocks, and thus, isn't readily available to plants. **In fact, a mere 0.1–0.2% of potassium in the soil exists in forms that plants can take up**. As a result, potassium solubilizing microorganisms are crucial to a healthy soil microbiome.

These microorganisms are both bacteria and fungi; potassium solubilizing bacteria include *Firmicutes* (B. mucilaginosus, B. edaphicus, etc.), *Proteobacteria* (*Pseudomonas sp., or Klebsiella sp.*), and *Actinobacteria (Arthrobacter sp.*). Potassium solubilizing fungi are from the *Ascomycota phylum* family, with species including *Aspergillus fumigatus*, *A. niger*, and *Torulaspora globosa*.

All these microbes and fungi excrete organic acids that lower pH, stimulating the solubilization of potassium from inorganic matter. Furthermore, recent studies suggest that microorganisms can mediate potassium transfer to plants by symbiotic interactions, inducing plant genes that improve potassium nutrition.

# Potential negative effects of microorganisms in the soil

As highlighted above, microorganisms play a vital role in ensuring the effective uptake of nutrients by crops. However, this isn't to say that every microorganism in the soil microbiome is good. Needless to say, there are pathogenic microorganisms that can cause disease, become resistant to pesticides, and reduce soil quality.

These pathogens are often difficult to control once widespread, and thus, it's essential to manage them early on. Pathogenic microorganisms include fungi, oomycetes, bacteria, and viruses, among others.

Examples of soil-borne pathogenic microorganisms include *Phytophthora, Fusarium, Verticillium, Pythium*, and *Rhizoctonia*. Perhaps the most well-known among commercial farmers is Fusarium, which is responsible for seedling damping-off in many crops, dry rot in potatoes, bare patch disease in turfgrass, and Panama disease in banana. Equally, *Phytophthora* is the scourge of the horticultural and ornamental plant industry, where over 100 species of the pathogenic oomycete can completely destroy crops. It was a species of this pathogen that caused the Irish Potato Famine in the 19th century.

Considering their prevalence, monitoring the soil for the presence of such microbes is essential to good crop management. Of course, early detection to ensure diagnosis occurs prior to outbreak is critical, as it enables more effective and targeted treatments and mitigation measures.

# How functional soil analyses helps nutrient management

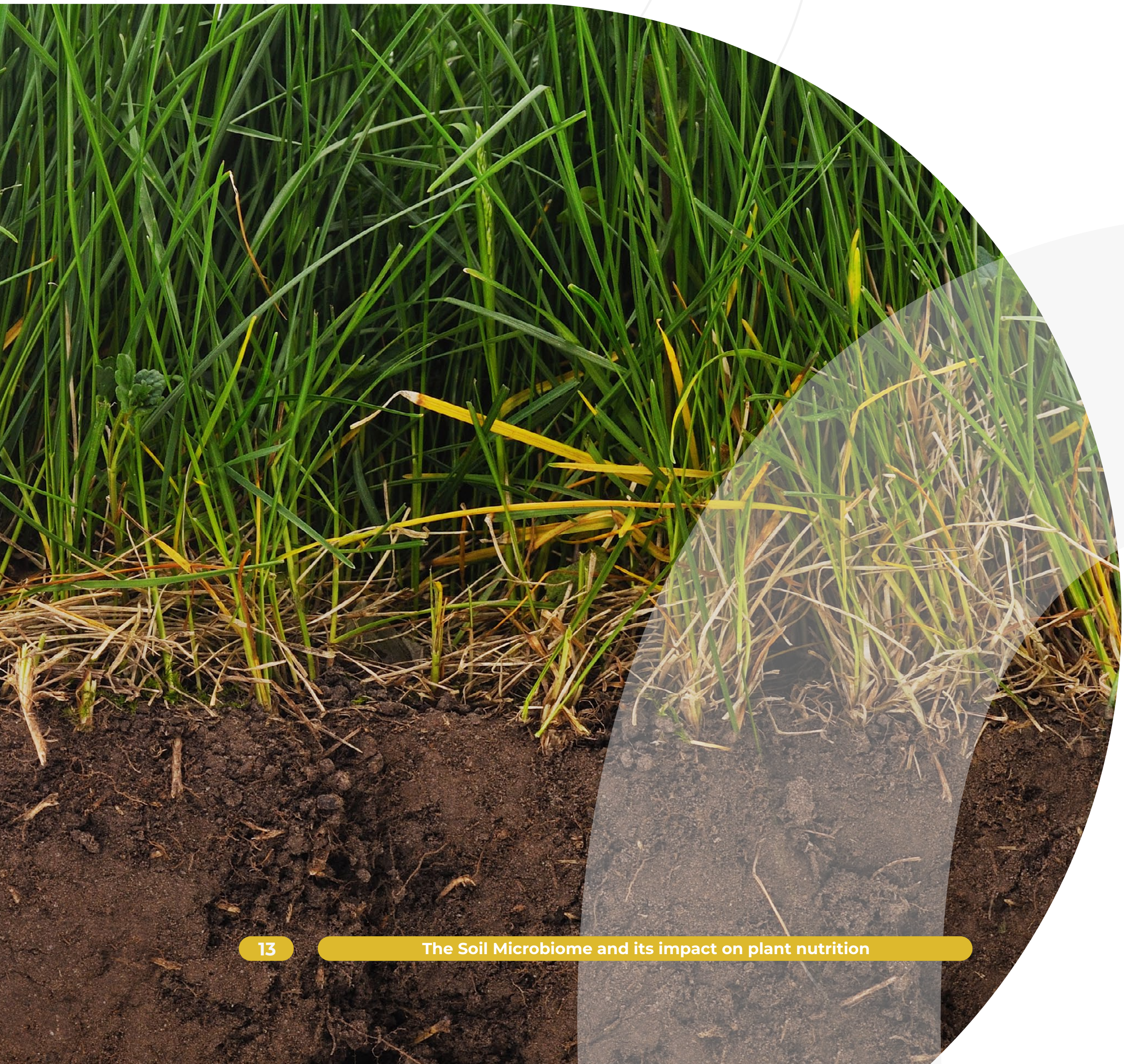
As is clear, the ability to monitor nutrient levels in the soil is essential to managing plant health and crop yield. But what if we could go a step further, and analyze the presence of the bacteria, fungi, and archaea in the soil that facilitate enhanced nutrient levels and uptake? Equally, this information is immensely helpful for monitoring the presence of pathogens, allowing crop farmers to take action before yields are negatively affected.

In the past, large scale soil analysis has been too unwieldy a project to be viable for most commercial farms. However, **Biome Makers has revolutionized the process** to create functional analyses of soil samples to create a detailed picture of the soil's microbial biology. By using amplicon sequencing and bioinformatics we can characterize the soil microbiome and obtain information about:

- Soil microbiome **biodiversity**
- Role of each microorganism in **plant health**.
- Microbial potential for nutrient **cycling**.
- Specific **effect of biofertilizers** on the soil microbiome.
- **Duration** of inoculated species in the soil.
- Microbial **composition and quantification** of biological products.

Generally, Biome Makers recommends **one sample per acre** as a composite soil sample of at least three soil cores. Via amplicon sequencing and cross-referencing with their bioinformatic cloud, Biome Makers can generate a species list, alongside information about the soil microbiome's metacommunity and its interactions. Additionally, Biome Makers reports also contain a resistance index, based on ecological information that illustrates the resistance of the microbial network to physical and chemical disruptions.

With these clearly visualized reports, **everyone can obtain a clear picture of the biodiversity, health, and nutrient cycling potential of their soil**. With this knowledge, farmers can take naturally-driven, sustainable action to maintain their soils healthy, functional, and productive. Considering the challenges that lie ahead for the agricultural ecosystem, this fine-tuned, scientific approach is vital. By facilitating a more sustainable approach to farming, we can produce more nutritious food in greater quantities, and with that, a better life.



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Biome Makers is a Smart Microbial Discovery startup based in Sacramento. We connect soil biology into decision-making processes in agriculture to benefit farmers and reverse the degradation of arable soils, encouraging carbon sequestration in soil. Through our leading soil tech platform, BeCrop, we measure the biological quality of the soil and deliver agronomic insights to optimize farm operations.