Learning Journey: Rhizophagy

How Do Plants Access Nutrients?

Passive Absorption:
Nutrients can be passively absorbed into the roots from dissolved minerals in soil water. This process can take place through osmosis, capillary action, diffusion or aquaporins.

Mycorrhizal Connections:
Nutrients can be obtained via mycorrhizal associations. A symbiotic relationship is created where the plant feeds the fungi with root exudates and the fungi provide the nutrients back to the plant.

The Rhizophagy Cycle:
Nutrients gained through the rhizophagy cycle (oxidatively extracted from soil microbes within root cells).

What Is Rhizophagy?

An Introduction to Rhizophagy
Rhizophagy is an emerging understanding of the primary way that plants obtain nutrients through a symbiotic relationship with soil microbes. The plant roots are literally eating the insides/juices of microbes to extract nutrients from their bodies, then spitting out the microbes back into the soil. This process was first discovered by researchers in Australia in 2010 and was later picked up by Dr. James White.

What Does “Rhizophagy” Mean?
Rhizophagy is derived from Greek, with “rhizo-” meaning “root” and “-phagy” meaning “eating”. It is a plant mechanism for the mutualistic transfer of nutrients from symbiotic microbes (bacteria, fungi) to host plant roots. This process is called the Rhizophagy Cycle.

The Rhizophagy Cycle
There are five main steps involved in the rhizophagy cycle, and they are:

- Microbes Enter Root Cells
- Nutrient Extraction and Absorption
- Protoplasts Exit and Stimulate Root Growth
- Microbes Regenerate in Soil
- Cycle Repeats

Step One: Microbes Enter Root Cells
Microbes enter root cells carrying nutrients from the soil and are absorbed into root cells where cell walls are soft.

Step Two: Nutrient Extraction and Absorption
Nutrients are extracted from microbes by reactive oxygen species (superoxide) which strip off the cell wall of the microbe releasing the nutrients into the plant cells. The microbe is left with a plasma membrane and the internal contents of its cell which is called a protoplast cell.

Step Three: Protoplasts Exit and Stimulate Root Growth
Microbes in protoplast form exit the tips of the root hairs, exhausted of nutrients. During this process they stimulate elongation of root hairs. This increases the surface area of the root and enhances nutrient uptake, microbial interaction and carbon flow.

Step Four: Microbes Regenerate in the Soil
Protoplast microbes regenerate their cell walls by taking up nutrients in the rhizosphere (soil at roots). This process is further supported by plant root exudates in the form of sugars, mucilage and other compounds to help synthesize new cell wall materials.

Step Five: Cycle Repeats
With the microbes being released back into the soil to ingest more nutrients, they can potentially be “eaten” once again by the plant.

Understanding the Rhizosphere

What Is the Rhizosphere?
The rhizosphere is a narrow zone surrounding the plant roots where plants interface with soil and the microbes that inhabit it. This zone can extend from 2 mm (cereal crop) and up to 80mm (trees) away from the root surface. Within this zone, biological activity becomes increasingly dynamic as you approach the root, with the highest activity concentrated at the root tips.

What Is a Microbiome?
The rhizosphere hosts a complex microbiome—a community of microorganisms, including bacteria, fungi, and other microbes all drawn to and interacting with the plant roots. The microbiome plays a crucial role in nutrient cycling, disease suppression, and overall plant health.

Plants Can Manipulate the Rhizosphere pH
Plants can raise or lower the pH around the roots using several different chemical mechanisms. This is important because the availability of certain nutrients to a plant depends on the local pH and the form in which the nutrient exists in the soil. Modifying soil pH can help the plant acquire nutrients it that they would not otherwise have access to.

How Do Plants Lower pH?

- The release of hydrogen ions (H^+) from the plant roots.The released hydrogen ions acidify the surrounding soil, which lowers soil pH.
- Cation exchange (K^+, Ca^{2+}, Mg^{2+}).When a plant uptakes cations, the plant will release hydrogen ions (H^+) into the rhizosphere to maintain an internal charge balance. This process results in acidification or the lowering of pH.
- Root respiration (release of CO_2).The production of root exudates in the form of organic acids, such as citric or malic acid.

How Do Plants Increase pH?

The uptake of nitrate anions by the plant roots (NO_3^-).

- Plants will often release hydroxide ions (OH^-) to maintain their internal chemical balance which will increase the pH in the rhizosphere.
- Release of bicarbonate ions (HCO_3^-).
- The production of root exudates in the form of organic alkali exudates (glutamine and asparagine).

Plants Alter the Oxidation-Reduction Potential (Eh)

Plants can alter the redox value (Eh) through the process of oxidation and reduction at the roots, and it is also an important factor in a plant's ability to absorb nutrients. By influencing the soil's redox conditions, plants can actively create an environment favorable for their nutrient uptake and root health.

Plants can induce oxidation in the rhizosphere by releasing oxygen and organic compounds as root exudates (indirectly by feeding microbes that oxidize), and through the creation of oxidase enzymes. Plants can induce reduction in the rhizosphere through root respiration (oxygen consumption at roots), organic compounds (donation of electrons to soil or microbes), and the creation of peroxidase enzymes.

Plants Affect Nutrient Cycling Through Rhizosphere Microbiome

In a natural system, plants work symbiotically with microbes to obtain nutrients. They do so by secreting specific root exudates that signal to microbes to deliver specific nutrients or other products that the plant can't obtain for itself. This includes nitrogen (plants cannot get N from the air and often rely on nitrogen-fixing bacteria), phosphorus (difficult for plants to access on their own), carbon (Pseudomonas break down organic matter) and other nutrients. Some examples of attracting free living microbes in the soil are rhizobium bacteria for nitrogen fixation and mycorrhiza fungi for phosphorus uptake.

Observing Rhizospheres

There is huge value in grabbing a shovel and going out into the field to find out what is happening with plant roots. The following are a few things to look for when examining the plants roots:

- Is there a rhizosheath?
- Compare the soil around the root to the soil with no root, especially perennials. Do you observe any differences?

- Are there mycorrhiza?
- Can you find *Rhizobia*?
- Are there root hairs?

Through observations, we can gain valuable insights. Over time, these insights can help direct our management practices.

For Further Information

- The rhizosphere microbiome: Plant–microbial interactions for resource acquisition (Article)
- Unveiling the significance of rhizosphere: Implications for plant growth, stress response, and sustainable agriculture (Article)
- Regenerative Farming Network Ep. 3 - Exploring the Root Rhizosphere (Video)
- Uncovering the secret world of the rhizosphere microbiome, the plant's 2nd genome (Video)

Three Benefits of the Rhizophagy Cycle

Plants Absorb Nutrients from Microbes
The plant actively controls the internalization of the microbes into its root cells, it maximizes nutrient extraction, and then ejects the protoplast cells.

Increased Oxidative Stress Tolerance in Plants
Increased reactive oxygen activity in root cells stimulate the plant to create antioxidants which protect against cell damage, support overall health, and promote growth and development.

Soil Fungal Pathogens Have Reduced Virulence
This happens because the plant's root exudates and the reactive oxygen produced during the rhizophagy cycle can inhibit the growth and activity of these pathogens.

The Roles of Micro-Life in the Soil

The Soil Food Web
As we come to understand more about how natural systems support healthy plants, we inevitably look at the interactions of life in the soil, known as the soil food web. This is an ever-evolving field of study that continues to grow. In our exploration of the relationship between plants and soil life, we will look at life directly and indirectly connected to the plant and its roots, such as microflora (microscopic plants, bacteria and fungi) and the life that feeds on the same microflora, such as microfauna (microscopic animals including nematodes and protozoa).

First, Let's Take a Look at Microflora.
Microflora are the microscopic organisms associated with a plant's environment or tissues, such as bacteria, fungi, algae and archaea that live on or in plant surfaces (roots, leaves and stems) or in the surrounding soil (like the rhizosphere). Microflora play a critical role in regenerative processes, like building soil structure, retaining water and nutrient cycling and availability.

Microflora: Bacteria
These single-celled organisms play an important role in nutrient cycling, decomposition and plant growth. There are different genera of bacteria responsible for different processes:

- Nitrogen-fixing bacteria convert atmospheric nitrogen into a plant-useable form (e.g., *Rhizobia*,
- *Azospirillum*, *Azotobacter*)
- Phosphorus-solubilizing bacteria (e.g., *Pseudomonas*, *Bacillus*)
- Decomposition and soil health bacteria (e.g., *Actinomycetes*)

Microflora: Fungi
Fungi often form symbiotic relationships with plants. Their collaboration with the plant can:

- Enhance nutrient and water uptake (e.g., arbuscular mycorrhizal fungi)
- Improve phosphorus availability (e.g., *Penicillium bilaiae*)
- Improve phosphorus availability with improved shoot growth (e.g., *Aspergillus niger*)
- Bio-control with bio-stimulant (e.g., *Trichoderma asperellum*)

Microflora: Algae
Algae are photosynthetic organisms that can:

- Fix nitrogen (e.g., *Anabaena* in rice fields)
- Add carbon to soil through decomposition (e.g., *Chlorophyta*, *Xanthophyta*, *Bacillariophyta*)
- Release phosphorus through decomposition (e.g., *Bacillariophyta*)
- Algae are commonly found in topsoil or wet conditions.

Microflora: Archaea
These microorganisms are often found in extreme environments but can also be found in soil. They can:

- Convert ammonia to nitrite (e.g., *Thaumarchaeota*)
- Fix atmospheric nitrogen to ammonia (e.g., *Euryarchaeota*)
- Archaea are often found in high salinity and/or low oxygen soils.

Now, Let's Take a Look at Microfauna
Microfauna are microscopic animal life that interact with plants or inhabit their immediate environment, such as soil and plant surfaces. They include protozoa, nematodes, microarthropods, enchytraeids, and rotifers. They generally feed on organic matter and microflora.

Microfauna: Protozoa
These single-celled organisms include ciliates, flagellates and amoebae. Ciliates typically feed on bacteria, algae and other protozoans, flagellates feed on bacteria, and amoebae feed on bacteria, fungi and algae. When protozoa feed, they release excess nitrogen and phosphorus into the soil by means of their excrement (often referred to as the "poop cycle").

Microfauna: Nematodes
A large grouping of multicellular creatures that are often referred to as roundworms. They include:

- Beneficial (organism-eating)

- Potentially detrimental (root-eating, parasitic)
- Omnivorous species

They are generally found in soil water films and contribute to litter decomposition and nutrient cycling.

Microfauna: Microarthropods
This is a term used to encompass a diverse group of creatures that play a variety of roles in the soil but all have characteristically hard exoskeletons (e.g., insects, arachnids etc.). These creatures employ various feeding strategies, consuming a variety of materials including:

- Root exudates
- Organic matter
- Fecal material
- Bacteria
- Fungi
- Nematodes
- Other microarthropods

These feeding processes can help make more nutrients available to the plants (i.e., the “poop cycle”) and reduce pest pressure.

Microfauna: Enchytraeidae
Sometimes known as pot worms, these very small worms are visible with the naked eye and -- at first glance – can be mistaken for minute, translucent “baby” earthworms. They are commonly found in cool soils with high organic matter. Though not much is known about this group, current research suggests they feed on nematodes and organic matter, adding value to the nutrient cycles in the soil.

Microfauna: Rotifers
These are multicellular creatures that feed on bacteria, fungi, algae and organic material. They live in water films on surface soils and plant litter, contributing to the nutrient cycle by breaking down organic matter. It is believed that these creatures help to maintain microbial balance in the soil.

In Conclusion
Although this is not an exhaustive list of the massive world of micro-life in the soils, we hope this introduction gets you thinking about the soil food web and the extensive ecosystem that exists below ground. Familiarizing ourselves with soil organisms enables us to look at what is going on with the food webs in our fields to determine what may be missing. If we lack fungi or bacteria, then we are unlikely to find any of the organisms that depend on fungi or bacteria for food. We can use this information to inform our management practices and improve the health of our soils.

For Further Learning
Check out these links to continue your learning on the soil food web:

- Soil Biota: In-Depth Overview of Microbes and Fauna (Article)
- Micro and Macro (Organisms) and Their Contributions to Soil Fertility (Article)

- Soil Organisms, Functions and Their Role in Soil Fertility (Article)
- Soil Fauna: Occurrence, Biodiversity, and Roles in Ecosystem Function (Book Chapter)
- Important soil microbiota's effects on plants and soils: a comprehensive 30-year systematic literature review (Article)
- Soil Microarthropods and Soil Health: Intersection of Decomposition and Pest Suppression in Agroecosystems (Article)
- Soil Microorganisms: Their Role in Enhancing Crop Nutrition and Health (Article)

Learn More With These Related Links

- Farm Ecosystem Web (Educational Guide)
- The rhizosphere microbiome: Plant–microbial interactions for resource acquisition (Article)
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Find Out More. Give Us Your Feedback. Get Involved.

Thank you for participating in this Learning Journey on Canadian Organic Growers' Regenerative Organic Hub. We hope you were inspired and found practical information and tools that will support you on your regenerative organic journey.

We invite you to click below and use our contact form to ask us any questions you may have, or comment on your Hub experience. This form is also the place to let us know if you would like to get involved with COG, including as part of our next cohort of Regenerative Organic Oats (ROO) program participants.