

## **Learning Journey: Root Growth**

By absorbing water and nutrients, and depositing exudates into the rhizosphere, roots have a direct impact on crop yields and quality. They are also fundamental to soil health, structure, functionality, and regeneration. Combining what you know about regenerative principles with a knowledge of root growth can help you build resilience in your crops and soils.

This learning journey is a curated collection of educational resources, designed to help you explore root growth. To use this learning journey to its full benefit, please follow along via the steps detailed below.

### All About Plant Roots

#### **A General Discussion About the Foundation of a Plant**

##### Importance of Roots

Roots play a vital role in plant survival by transporting water and nutrients to the above-ground organs and depositing root exudates into the rhizosphere. Their biomass and surface area often surpass those of the visible (above ground) parts of the plant. Since plants cannot move, they have evolved root structures that are specifically adapted to their environments. These roots are highly influenced by external conditions and grow by adding cells to their tips.

##### Roots Detect Stress

Roots are the primary organ of the plant that detects and responds to environmental stresses, such as water availability, nutrient levels, temperature, soil compaction, and even the presence of harmful substances or pathogens, showcasing their critical function in a plant's overall resilience and adaptability.

##### The Role of Plant Roots

Plant roots fulfill three essential roles:

- Anchoring and stabilizing the plant.
- Absorbing water and nutrients (including processes like nutrient solubilization, mycorrhiza colonization, and rhizophagy).
- Storing nutrients, particularly in perennial plants.

## Tap Roots and Fibrous Roots are the Primary Types of Roots Found in Nature

**Tap Roots:** Have a large, central root with smaller lateral roots branching off. They grow deep into the soil and include plants such as chicory and tillage radish.

**Fibrous Roots:** Composed of numerous thin, branching roots that spread widely near the soil's surface to better help the plant absorb water and nutrients. Cereal crops are excellent examples of plants with fibrous roots.

## Root Cell Types

Roots are composed of various cell types, each serving distinct roles to support the plant. Their primary functions include absorbing nutrients and protecting the plant, storing resources and plant regulation, as well as enabling growth and facilitating transport. Let's take a closer look at the cells involved with these plant functions.

### Root Cells: nutrient absorption and protection

#### Epidermal Cells:

- Include root hairs (each root hair is a single cell)
- First line of defense.
- Absorb water, minerals and in the case of rhizophagy, absorb bacteria.
- As root hairs develop, surface area increases, which makes these processes more efficient.

#### Root Cap Cells:

- Protect the delicate root tip as it pushes through the soil.
- Helps the root grow downward by detecting gravity (gravitropism).

### Root Cells: Resource Storage and Regulation

#### Cortex Cells:

- Found between the epidermis (outermost layer of "skin" cells) and endodermis (innermost layer of "skin" cells).
- Store nutrients in the plant (e.g., starch) and help move water and minerals inward.

#### Endodermis Cells:

- Function as gatekeepers.
- Regulate what enters the vascular system, letting in what the plant needs and keeping out unwanted substances.

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## Root Cells: Growth and Transport

### Meristematic Cells:

- Located at the root tip.
- Responsible for root growth.
- These cells divide to make the root longer (primary meristem) and thicker (secondary meristem) over time.

### Pericycle Cells:

- Involved in forming new lateral branching roots, helping the root system expand.

### Vascular Tissue Cells:

- Include xylem and phloem.
- Responsible for transportation within the plant.
- Xylem carries water and dissolved minerals upward.
- Phloem moves sugars around (mainly from the leaves where they are made) to the rest of the plant, thereby nourishing the plant.

## The Role of Roots in Soil Health

### How Roots Contribute to a Healthy Ecosystem

Roots are fundamental to soil health and its functionality. They contribute to soil structure by creating channels and pores as they grow, providing more access for water to infiltrate and microbes to thrive. Their efficiency in absorbing nutrients have a direct impact on crop yields and quality, with effective root systems being able to access deeper soil levels to improve plant function even further. When looking at the effect of roots in soil health the main factors are root mass, soil aggregates, root exudates and soil organic carbon (SOC).

### Soil Aggregates

Soil aggregates are clusters of soil particles that are bound together by organic matter, microbial activity, and root exudates. When these aggregates form around the root from root exudates and microbial activity, it gives the root a brown color and is referred to as a rhizo-sheath. This can be observed by searching for high biological activity at the roots.

## Root Mass

Root mass plays an important role in soil health, feeding and housing the microbial community and increasing carbon in the soil. It has been found that smaller roots provide a greater surface area for rhizo-deposition (root exudates and carbon), while root density affects both the input of carbon and soil aggregate stability. Researchers found that grassland and pasture management systems nearly doubled the root mass when compared to row cropping.

When looking at management practices, vast improvements to soil health can be found by increasing root mass and especially fine root mass.

## Root Exudates

Root exudates are important for soil organic carbon formation and for the shaping and regulating of the microbial community. Plants can deposit different types of exudates into the soil to perform various functions, such as feeding microbes, disease suppression and sequestering carbon. Furthermore, the relationship between root exudates and microbes create cascading effects upon nutrient cycling and the breaking down of organic matter.

Through management practices such as the application of bio inoculants, we can enhance the microbial community, creating more diversity and better soil health.

## Soil Organic Carbon

Soil organic carbon is created by microbial activity, such as fungi decomposing organic matter or dead/decomposing roots. Researchers have found that as much as 10-60% of the total net fixed carbon produced by the plant is released as rhizo-deposited carbon into the soil via the roots.

## Conclusion

It is clear that roots play a pivotal role in soil health. When you consider plant root systems and their symbiotic relationship with the soil microbial community, you can enact management practices that can further enhance root function and ultimately the performance and yield of your crops.

## Annual vs. Perennial Roots

Annuals and perennials have evolved different root strategies due to their life cycles, with annuals typically establishing fibrous roots and perennials often establishing tap roots.

### Annuals

The life cycle of an annual is within a single year, so annuals generally tend to have shallower and less complex roots. This plant evolution allows them to grow and uptake nutrients rapidly. Due to their short lifespan, they prioritize efficiency and speed over longevity and storage.

### Perennials

Perennials live over multiple years, so their root systems are typically deeper and more extensive, allowing them to access water and nutrients from deeper levels. They often include root structures such as tap roots and/or rhizomes (horizontal plant stems that allow reproduction) which allows them to store energy and nutrients, providing resources for regrowth in subsequent years.

## The Relationship Between Climate and Root Systems

Climate change is having an ever-increasing impact on crop production, from increases in heatwaves, to fewer days of frost and less rainfall that comes in heavy bursts. This presentation delves into the effects of heat stress and flooding on plant root systems.

### The Effects of Heat Stress

Roots require an optimal temperature range for proper growth and function which tends to be lower than the above ground parts. As the heat of the roots becomes higher than the plant likes, hormonal and metabolic changes are triggered as the plant tries to overcome the stress.

### Plant Compounds Affected by Heat Stress

The following compounds are currently the most commonly identified primary contributors affected by this response:

Salicylic Acid - Improves heat tolerance and mitigates damage in some crops.

Ethylene - Reduces oxidative damage and supports maintenance of chlorophyll content.

**Abscisic Acid** - Controls tolerance to abiotic stress by increasing photochemical efficiency and membrane stability.

**Cytokinin** - A key regulator of the root system architecture. Decreased levels of this hormone lead to an enlarged root system, thereby increasing heat tolerance but decreasing surface area for nutrient cycling and microbial activity.

**Carbohydrates** - Carbohydrate concentrations (i.e., glucose, fructose, galactose and sucrose/xylose) are typically lower after roots experience high temperatures.

### Temperature Sensing and Signaling in Roots

Warmer temperatures alter stability of membranes, cytoskeleton components, proteins and nucleic acids. Increased temperatures will also affect a plant's metabolism which impacts carbohydrate structures, amino acid balance, lipid metabolism and the activation of heat and oxidative pathways to prevent disruption of root growth. Heat also affects hormone levels which trigger transduction pathways that prepare the plant to overcome the stress. Extreme heat at the roots is often accompanied by abiotic and biotic stresses such as drought, salinity, nutrient deficiencies and pathogenic infections.

### Endoplasmic Reticulum Stress

Heat stress creates an accumulation of unfolded proteins that are potentially toxic, and this process is known as endoplasmic reticulum stress. The endoplasmic reticulum (ER) is responsible for protein and lipid synthesis, folding, and transport, and plants react to this ER stress by forming heat shock proteins and brassinosteroids. These compounds help the plant improve membrane stability and aid in the creation of antioxidant enzymes.

### Temperature Effects on Plant Roots

High soil temperatures will alter root structure and limit root growth, reducing root: shoot ratio due to the plant prioritizing shoot growth to increase transpiration. Increased soil temperatures typically reduce the surface area between root and soil due to root enlargement (to mitigate lower photosynthesis and increased transpiration) and reduction of root mass, thereby decreasing nutrient and water uptake.

## How Roots Cope with Heat Stress

Researchers have found that plants may increase the length of root hairs as a coping strategy to help with nutrient and water uptake via rhizophagy. During extreme heat, the root's membranes will become rigid, thereby heavily decreasing the root's ability for water uptake. This is the plant's defense mechanism to protect root cells from dying.

## The Effects of Flooding

Not only does flooding hurt plant roots, the re-oxygenation following flooding does as well. The following slides discuss how flooding impacts root systems on various levels.

### What Happens When Roots Become Flooded?

Plants will downregulate photosynthesis in favour of survival, leading to overall poorer health of the plant.

Gas diffusion of soil is reduced, preventing oxygen from entering the soil and CO<sub>2</sub> from getting out. Microbes will compete with roots for oxygen. Once oxygen is gone, the roots and microbes will die due to anaerobic conditions.

The plant will do everything it can to maintain aerobic metabolism in the root, such as forming aerenchyma (air-filled cell tissues that transport oxygen from the shoots to the roots) and/or shift metabolism to ferment carbohydrates to produce ATP (adenosine triphosphate) for plant energy.

Starch reserves in the root will be rapidly used up. Energy supply, membrane integrity and ion transport become impaired, resulting in nutrient deficiency in the root and shoot. Plants will downregulate photosynthesis in favor of survival leading to overall poorer health of the plant.

### Reactive Oxygen Species (ROS)

Reactive Oxygen Species (ROS) are produced in hypoxic (low oxygen) environments and are a result of oxidative metabolism imbalance. ROS can cause oxidative damage and degrade cell membranes, proteins and lipids. When roots become flooded with water, the lack of oxygen triggers the production of ROS and can lead to lipid peroxidation, which causes membrane damage, enzyme inactivation and eventually cell death. This all leads to a weaker plant that will have reduced productivity.

## Plant Defense Mechanisms Against Root Flooding

A plant will activate antioxidant defense systems and increase accumulation of potential osmolytes (small organic molecules that protect cells from stress) to fight against root flooding.

- Superoxide dismutase (SOD), catalase (CAT), glutathione reductase (GR) all work together to scavenge flooding-induced ROS, helping the plant to survive. These compounds already exist in plants and increase during a flooding event.
- Glutathione (GSH), ascorbic acid, carotenoids and tocopherols work to protect membranes and photosynthetic apparatus by scavenging ROS.
- Proline, sugars, soluble proteins and free amino acids will accumulate to counter toxic effects of flooding.

## Conclusion

Weather and climatic events can have devastating effects upon crops. By understanding plant root responses to these effects, you can be better situated to create management practices to mitigate these dangers and create resiliency in your cropping systems.

## Linking the Role of Plant Roots to the Principles of Regenerative Agriculture

### Introduction

By applying your knowledge of roots alongside regenerative principles, you can build resilience in your soil so that your crops are better equipped to deal with climatic conditions. Roots have a powerful role to play in soil regeneration and in this section, we will look at the ways that diversity, livestock integration and armouring the soil facilitate the process of regenerating soil health.

### Principle of Diversity

Plant diversity is a cornerstone principle that can be integrated into your management via intercropping, cover crops, and crop rotation. These practices all have cascading effects upon soil health. As plant diversity is increased, new roots (and root types) and their association with symbiotic microbes diversifies, and consequently more plant resilience and disease protection can be achieved.

## Intercropping and Cover Cropping Systems

Intercropping systems in particular can encourage the flow of nutrients at different levels because of the different root systems involved, and this is especially true when plant functional groups are utilized. By practicing crop rotation and cover cropping, future nutrients needed in the system can be anticipated and planned for accordingly, such as incorporating legumes in your rotation for nitrogen-fixing. Cover crops in a shoulder season can also be utilized for both future nutrient needs and increasing biological activity by keeping a living root in the ground.

## How Is Diversity Linked to Root Growth?

Overall, it has been found that plant diversity improves the overall root volume and soil organic matter of the plants involved. By having a diversity of roots, you can create a soil sponge that will help save and regulate water during droughts, as well as have a faster rate of water infiltration during floods without losing structure.

## Linking the Principle of Livestock Integration and Root Growth

In a recent study by Moore et al., researchers studied the effects of soil health on grazed cover crops and found that grazing had beneficial effects on root mass. They also found that both carbon and nitrogen pools in the soil increased, leading to greater nutrient cycling. It is also worth noting that the excrement left from the grazing cattle also enhances the biological life in the soil, further boosting soil health.

## Linking Root Growth to the Principle of Armouring the Soil

Roots are sensitive to heat, and this creates cascading effects on all plant processes. One of the most effective management practices for conserving root health is armouring the soil. This can be achieved through practices such as roller crimping, maintaining a well-covered canopy, and leaving plant litter on the ground. Bare soil can be five to twenty degrees hotter than the ambient temperature, so it is critical to reduce heat stress in the soil by armouring it in order to maintain plant root health.

## Conclusion

Roots play an important role, both in regenerative principles and management practices. By honing this knowledge, you can gain a more holistic view that opens possibilities for utilizing cascading effects to your benefit.

Moore, E.B., Mriganka, D., Nunes, M.R., Saha, D., Jin, V., Li, L., Johnson, J.M.F., Karlen, D.L., McDaniel M.D. Connections between roots and soil health across agriculture management practices. *Plant Soil*. (2025). Retrieved from: <https://doi.org/10.1007/s11104-025-07367-w>

## The Effects of Compaction on Plant Roots

### **And the Plants That Can Help Mitigate Compaction**

#### Addressing Compaction

When integrating regenerative principles into growing strategies, it is possible to be quickly faced with the prospect of reducing tillage in the fields. This is because compaction can occur as a result of heavy tillage. This is good motivation to seek a better understanding of the processes involved in creating compaction as well as strategies to overcome high tillage processes. In this section, take a look at the root response to compaction and learn about some plants that can be integrated to help with this serious issue.

#### The Impacts of Compaction

Compaction can happen in both topsoil and subsoils, as well as at the surface of the soil. Because farm equipment is getting heavier, there is an increased risk of chronic subsoil compaction. As soil becomes more compacted, roots require more strength to push deeper into the soil profile. Roots tend to become thicker and develop longer root hairs, and this helps with resource acquisition and root tip penetration in compacted soil.

#### The Product of Ethylene

Roots sense soil compaction via the buildup of ethylene in the rhizosphere. Ethylene is produced by the roots and engages in normal gas exchanging with the atmosphere. However, ethylene accumulation at the root tips triggers abscisic acid and auxin as downstream signals to regulate root adaptive responses in compacted soil. Ethylene promotes lignification (formation of rigid and woody structures) of outer cortical cells, providing mechanical stability for penetration in compacted soil. Ethylene also helps regulate the navigation strategies of root tips when encountering mechanical obstacles.

#### The Effect of Compaction on Water Infiltration

Compaction can reduce water infiltration capacity and water storage capacity while increasing water runoff events. In runoff events, gas exchange with the atmosphere becomes limited. If oxygen consumption is higher than supply, it can lead to anaerobic conditions in the soil, which can lead to a reduction of soil organisms, including earthworms. Soil compaction sets off negative cascading effects (i.e., reduced soil quality, soil respiration, water and nutrient availability, potential increase of phytotoxins, etc.).

## Root Sensing of Compaction

Roots are extremely sensitive to compaction. In certain scenarios, compaction can induce severe root growth reduction, suppression of branching, root hair elongation, crown root number enhancement, and thickening of roots. When roots try to penetrate a compaction zone, there is a buildup of the gaseous hormone ethylene. This is due to reduced gas exchange in the soil which triggers a buildup of ethylene in the rhizosphere. This buildup can activate the endogenous ethylene signaling pathway at the root tip. Restricted ethylene diffusion -- not mechanical forces -- are the primary signal.

## Root Response to High Concentrations of Ethylene in Rhizosphere

Auxin accumulates in the root epidermal cells which inhibits root growth. Abscisic acid (ABA) serves as an essential regulator in response to soil compaction, and it increases root diameter. Recent research suggests that multiseriate cortical sclerenchyma (MCS) is a set of highly-lignified outer cortical cells that enhance mechanical support for root penetration of compacted soil by increasing tensile strength and root tip resilience. MCS has been found in heritage varieties of maize, wheat and barley and is considered a vital downstream output of ethylene.

## Circumnutation

Circumnutation is the helical movement of the root tip and is a proposed action of the root tip to navigate obstacles. Ethylene, auxin and cytokinin are thought to be primarily responsible for this. Circumnutation enables bypassing of hard obstacles and is especially evident with young plants, like seedlings.

## Strategically Reducing Compaction

Soil compaction can be mitigated through strategic plant choices and management practices that enhance soil structure, increase organic matter, and promote biological activity. Plants can be added to cash crops via under-seeding, intercropping and polycropping systems. Cover cropping is also an effective way of incorporating plants that can reduce hardpan while adding organic matter and increasing microbial activity.

## Plants that Help Reduce Compaction

**Deep roots:** These plants can help with compaction as they are well-suited to dig deep into the soil with their tap roots. They include daikon radish, tillage radish, alfalfa and chicory.

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**Fibrous roots:** These plants, like ryegrass and sudan grass, have dense roots that can help stabilize the soil while providing organic matter.

**Brassicas:** Some brassicas, such as forage turnip that has a taproot, and mustard that has deep roots, also help with compaction.

### Using Functional Groups to Reduce Compaction

Using functional groups in combination with one another is an important way to obtain maximum benefit when dealing with compaction. It allows for a synergistic relationship with the plants involved while improving soil function. With the knowledge shared in the previous slide, the hope is that you may be inspired to find other plants to include in your seed mixes that work in your context.

### Conclusion

Roots are a critical function of a plant's resiliency and ability to adapt to the environment. We have learned how roots respond to environmental stresses like heat waves, flooding and compacted soil. Throughout this document, it has also become apparent that soil organic matter and soil biology have a symbiotic relationship with roots. By obtaining a more complete picture of plant function, we can modify management practices to better tackle our changing landscapes.

## Root Health Assessment Checklist for Producers

### Introduction

This guide is designed to assist producers in the field with assessing root health, the rhizosphere, and legume nodulation. It provides key observations and evaluation techniques to help monitor soil and plant health.

### Considerations

- **Timing:** Examine roots when plants are at their peak, just before flowering, to observe the most robust root growth.
- **Soil Condition:** Conduct the examination when the soil is moist to make root extraction easier.
- **Root Type:** Determine whether the plant has a tap root or fibrous roots, and consider where these roots are most likely located within the soil profile.

### Steps for Root Health Assessment

#### Digging and Excavation:

- Use a shovel to dig deep enough to extract a sizable section of the root system.

#### Examine Roots:

- Assess root abundance, branching, and depth.
- Take note of:
  - The width of the tap root.
  - The number of roots extending below the excavation point.
  - Any horizontal growth or sharp angles, which may indicate potential soil barriers or compaction.

### Record Observations

Use the root observation checklist to assess root health:

- **Poor:** Roots are restricted, sparse, or lack abundant growth.
- **Fair:** Roots are somewhat restricted, with some fine roots visible, but growth is moderate.
- **Good:** Roots are abundant, well-branched, and appear unrestricted, indicating healthy growth.



Poor



Fair



Good

## Rhizosphere Health Assessment Guide

### What Is the Rhizosphere?

The rhizosphere is the area of soil surrounding plant roots, where plant roots and soil microbes interact. It plays a critical role in plant health and nutrient uptake. A key indicator of rhizosphere health is the presence of rhizosheaths, which is a layer of soil particles that cling to the roots, created by beneficial microbes.

### Steps for Rhizosphere Health Assessment

1. Breaking away soil
  - a. After excavating the roots, gently break away the soil around them.
  - b. Lightly shake the roots to remove any loose soil from the root system.
2. Look for rhizosheaths
  - a. Check if there is any soil adhering to the roots. This can indicate the presence of rhizosheaths.
  - b. The presence of rhizosheaths indicates active microbial life and healthy soil-root interactions. Microbes make the glues that hold the sheaths together. No microbes = no glues = no sheaths.

### Scoring Rhizosphere Health

Use the following scale to assess the health of the rhizosphere based on the presence and coverage of rhizosheaths on plant roots:

- Poor: no soil covering around the roots; roots are white, clean, and lacking rhizosheaths.
- Fair: some roots are coated with soil, either partially or fully; rhizosheaths are present but not abundant.
- Good: most or all roots are fully coated with soil, indicating healthy rhizosheaths.



Poor



Fair



Good

## Legume Nodulation Assessment Guide

### Nitrogen Fixation in Legumes

Legumes have a unique ability to partner with nitrogen-fixing bacteria, which form nodules on the roots. These bacteria can fix nitrogen from the air, converting it into ammonia, a key nutrient for plant growth.

### Steps for Legume Nodulation Assessment

1. Excavate the Roots
  - a. Gently break or wash away soil surrounding the roots of the legumes to expose the root system.
2. Examine for Nodules
  - a. Look for swollen, rounded lumps on the roots. These are the nodules where the nitrogen-fixing bacteria reside.
3. Cut and Inspect Nodules
  - a. Cut open the largest nodules and observe the color inside.
  - b. Red or pink color indicates active nitrogen fixation, meaning the bacteria are effectively converting nitrogen from the air into ammonia.

### Scoring Nodulation Health

Use the following scale to assess the nodulation and nitrogen-fixing activity:

- Poor: no nodules or very few, small nodules located high on the roots.
- Fair: small nodules present high on the roots.
- Good: well-distributed, healthy nodules across the root profile, with pink or red coloration inside.



Poor



Fair



Good

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## Learn More About Root Growth with These Related Resources

- [Importance of individual root traits to understand crop root system in agronomic and environmental contexts \(Article\)](#)
- [Root Growth \(Book Chapter\)](#)
- [Molecular and Environmental Regulation of Root Development \(Article\)](#)
- [The hidden half comes into the spotlight: Peeking inside the black box of root developmental phases \(Article\)](#)
- [Bottom-up perspective – The role of roots and rhizosphere in climate change adaptation and mitigation in agroecosystems \(Article\)](#)
- [Root Growth Adaptation to Climate Change in Crops \(Article\)](#)
- [Plant Adaptation to Flooding Stress under Changing Climate Conditions: Ongoing Breakthroughs and Future Challenges \(Article\)](#)
- [Beyond the surface: delving into plant signaling during flooding stress \(Article\)](#)
- [A helping hand when drowning: The versatile role of ethylene in root flooding resilience \(Article\)](#)
- [Connections between roots and soil health across agriculture management practices \(Article\)](#)
- [The Role of Plant Roots in Nutrient Uptake and Soil Health \(Article\)](#)
- [Soil microbiome: An intrinsic driver for climate smart agriculture \(Article\)](#)
- [Soil compaction sensing mechanisms and root responses \(Article\)](#)
- [Uncovering root compaction response mechanisms: new insights and opportunities \(Article\)](#)

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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.

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