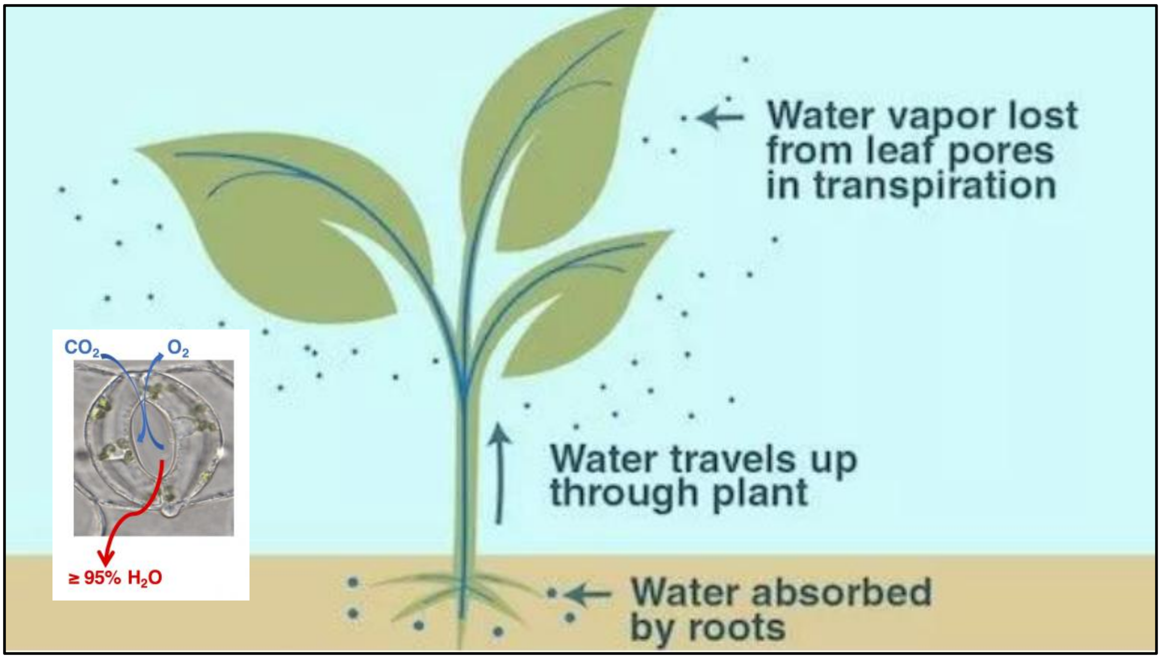
Welcome to the Results Start in the Roots.

Before we start, I need to give credit where credit is due.

There are many within the sound of my voice today including Claude Galipeau, Doreen McMurray, Wayne Campbell, and countless others who have contributed to the understanding and opinions I have today. I thank you.

Special thanks also goes out to Elaine Ingham and her work with the Soil Food Web
Gabe Brown inspiring us to convert Dirt to Soil
The Biological Farmer – Gary F. Zimmer
The Rodale Institute
BioTilth Living Soil Solutions
The Soil Health Institute
Soil Science Society of America
US Department of Agriculture and Natural Resource Conservation Service
Midwest Bio-Systems
True Earth Soil Exploration Farm



So. How does it work?

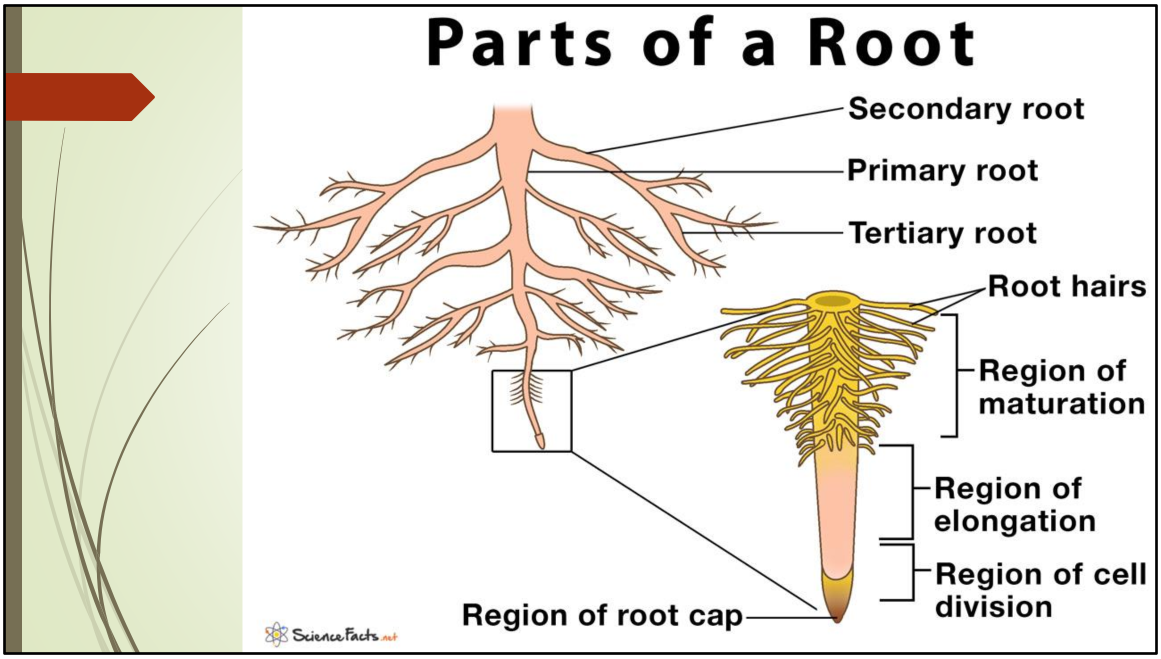
The plant has conductive tissue called xylem and phloem that runs from down in the roots to the extremities of the leaves and branches.

You can think of the xylem and phloem as a big straw like the one you use to slurp down your favorite milkshake.

Stomates, like little regulatory valves on the leaves, open to regulate the biophysical functions of respiration, and transpiration.

When the stomates open, water, and oxygen are released, and carbon dioxide is taken in. This release creates a positive pressure inside the plant called osmotic pressure.

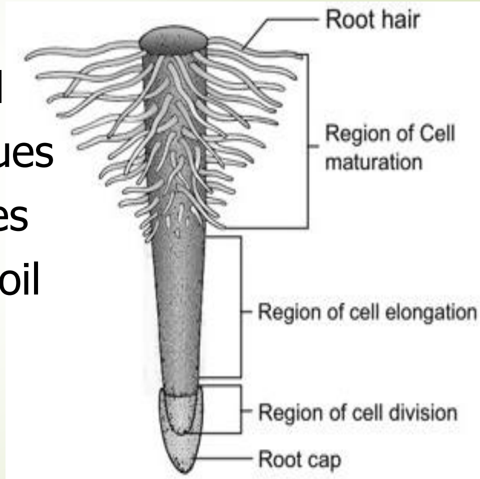
The osmotic pressure creates a suction on the xylem and phloem which draws water and nutrients absorbed by the roots into the plant.



The root system includes primary, secondary and tertiary roots with root hairs that form in developing regions of the root system.

Root Cap

- Intercepts water and minerals from the soil
- Protects growing tissues
- Secretes root exudates
- Communicates with soil microorganisms

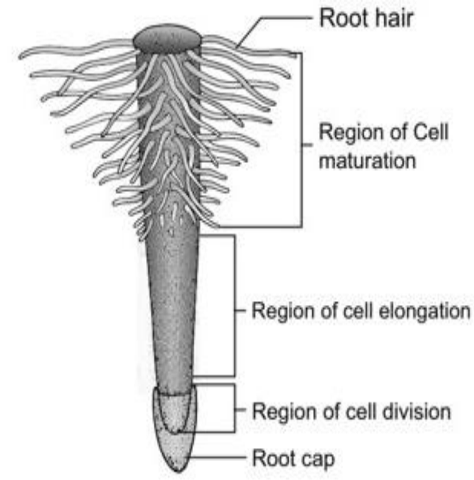


The tip of the root is protected by a multi-cellular structure called the root cap. The cells of the root cap are always in a state of division, constantly renewing and growing in number as the root penetrates through soil.

The root cap intercepts water and minerals from the soil.
Protects the sensitive growing tissues in the root.
Secretes viscous mucilage or exudates that help the root to penetrate the soil and communicate with soil microorganisms

Meristematic Region

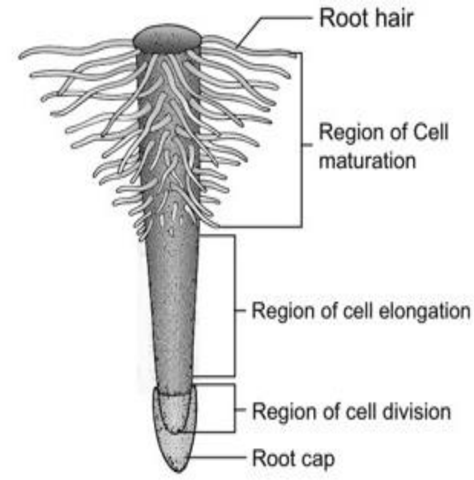
- Root elongation
- Produces new cells
- Region of cell division



The meristematic region is located a few millimeters above the root cap. The cells of the meristematic region are typically small, thin-walled, and contain dense protoplasm.
This is a region of the root where root elongation, cell division, and new cell production occurs.

Region of Elongation

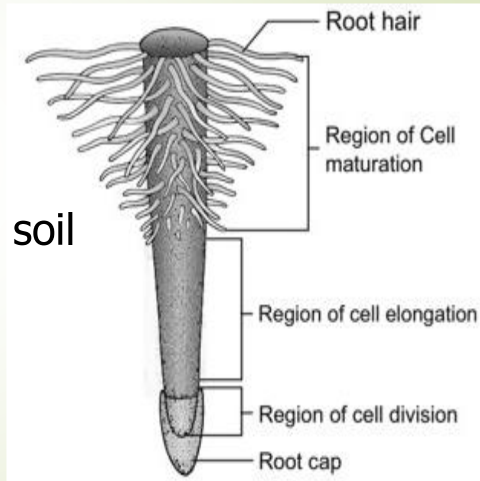
- Absorbs water and minerals
- Increases the length and size of the cells



The region of elongation is next to the meristematic region.
The region of elongation helps with the absorption of water and minerals from the soil.
Cells in this region have hardened, and are now incapable of cell division, but cells do continue to increase in length and size.

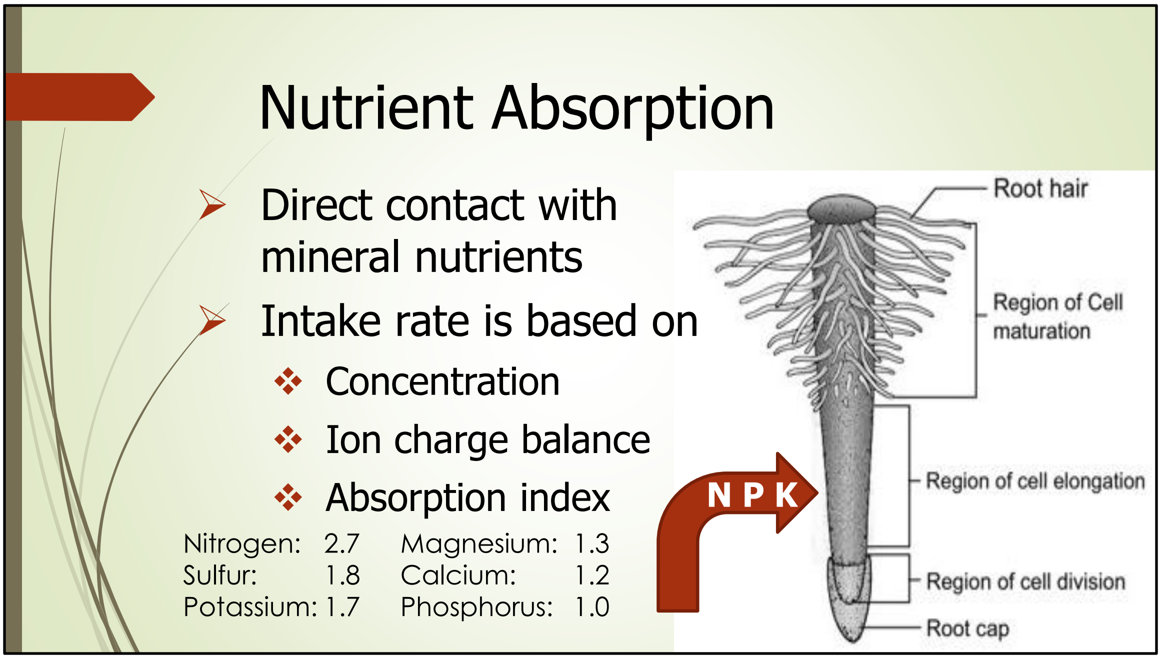
Region of Cell Maturation

- Xylem
- Phloem
- Forms root hairs
- Anchors plants to the soil



After cells have elongated, they mature into specialized tissues such as xylem, phloem, root hairs, endodermis, and cortex.

These special tissues are responsible for absorption, and transport of water and nutrients throughout the plant.
The mature region of the root also anchors the plant to the soil.



Absorption occurs when bare roots come into contact with mineral nutrients in the soil.

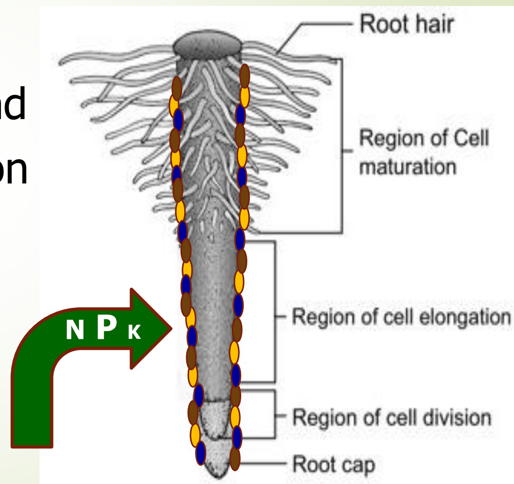
The amount and type of mineral nutrient absorbed at any given time is not necessarily the amount the plant needs.

Absorption of mineral nutrients is enabled by mass flow & diffusion. Which flow is driven by the osmotic pressure in the plant.
The amount and type of mineral nutrient taken in by the plant through absorption depends on the concentration of that specific nutrient in the root zone, ion charge balance, and the nutrient's absorption index. The relative absorption indices for common nutrients are: Nitrogen 2.7, Sulfur 1.8, Potassium, 1.7, Magnesium, 1.3, Calcium 1.2, and Phosphorus 1.0.

Nutrient deficiencies, toxicities, and imbalances can also interfere with balanced absorption rates. One of many examples of this is that elevated sodium in the rootzone can inhibit the uptake of Potassium.

Nutrient Extraction

- Microbial delivery
- Nutrients on demand
- Imbalance protection

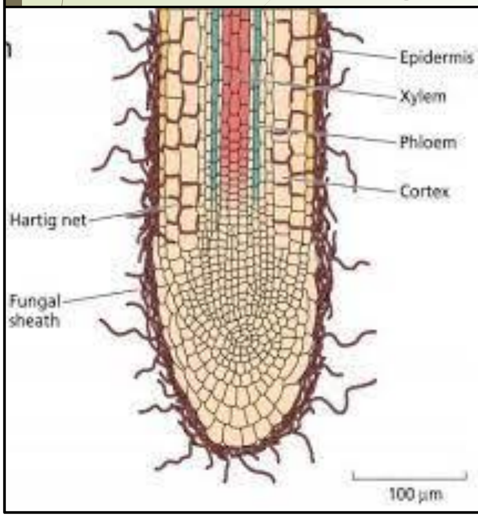


When humus holding an abundant population of diverse aerobic microbes coats the roots, the microbes work symbiotically with the plant's roots to deliver the nutrients the plant needs, when the plant needs them.

The roots send chemical signals through the root exudates to the microbes so they know which nutrients to delver and when.

This enables a healthy nutrient balance in the plant.

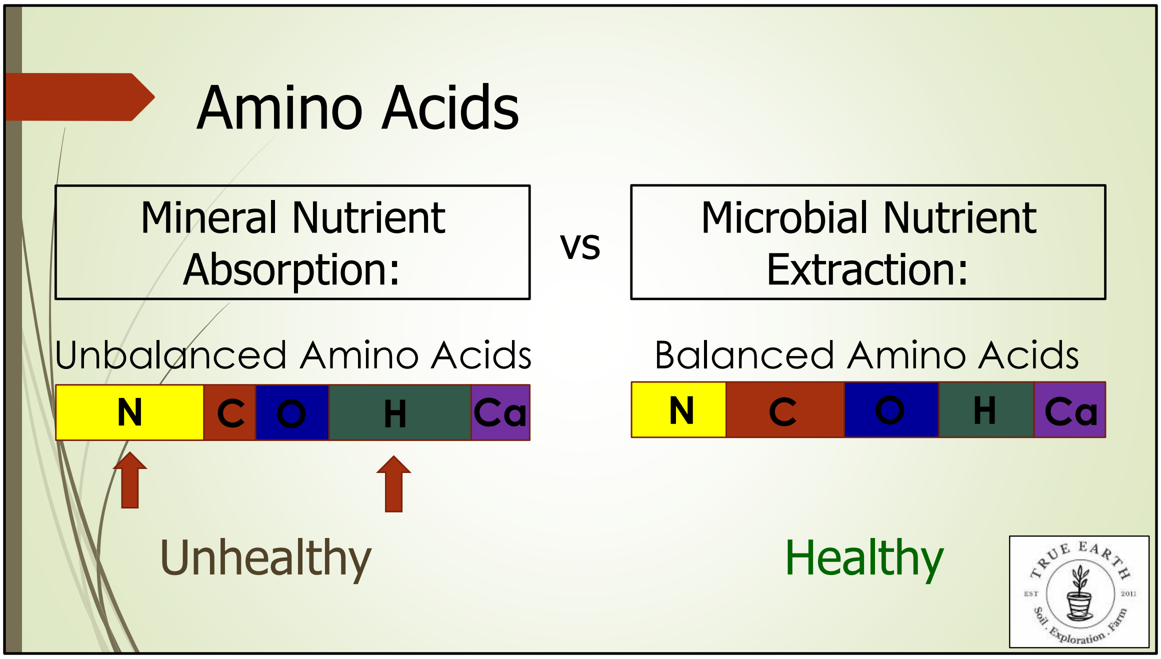
Fungal Sheath



Here is an artist rendition of the root including a fungal sheath.

Can you see a fungal sheath with the naked eye?

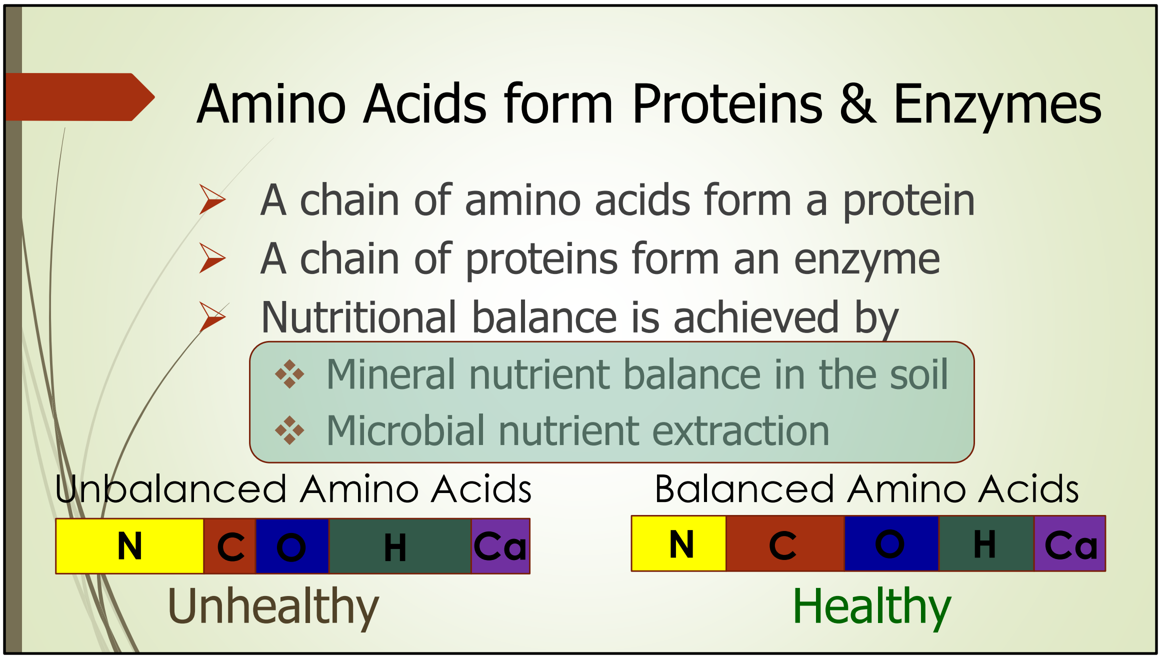
This is a photo previously sent to me by Wayne Campbell showing excellent fungal sheaths on the roots of these plants.



Amino Acids, formed by the plant using nutrients from the soil, are the basic building block for plant health. Lets take a closer look at the influence of mineral nutrient absorption vs microbial nutrient extraction on the production of amino acids in the plant: Mineral nutrient absorption is driven by mass flow, and diffusion. Therefore, amounts and types of nutrients taken into the plant by absorption are based on the concentration and properties of the mineral nutrients around the roots.

Unmetered nutrient absorption by itself, can cause plant amino acids to become imbalanced. For example, excessive or disproportionate amounts of ammonia nitrogen taken up by the plant can cause unbalanced amino acids that are loaded with water & nitrogen limiting the needed amounts of carbon and calcium. One symptom of imbalanced amino acids in the plant is lodging in small grains or green snap in corn.

Microbial nutrient extraction that is guided by the plant by releasing root exudates that stimulate the behavior of microbes. The microbes assist the root in taking in the correct quantity and variety of nutrients. The microbes protect the root from imbalances in nutrient concentrations in the soil rendering production of proportionately balanced amino acids and a more healthy plant.



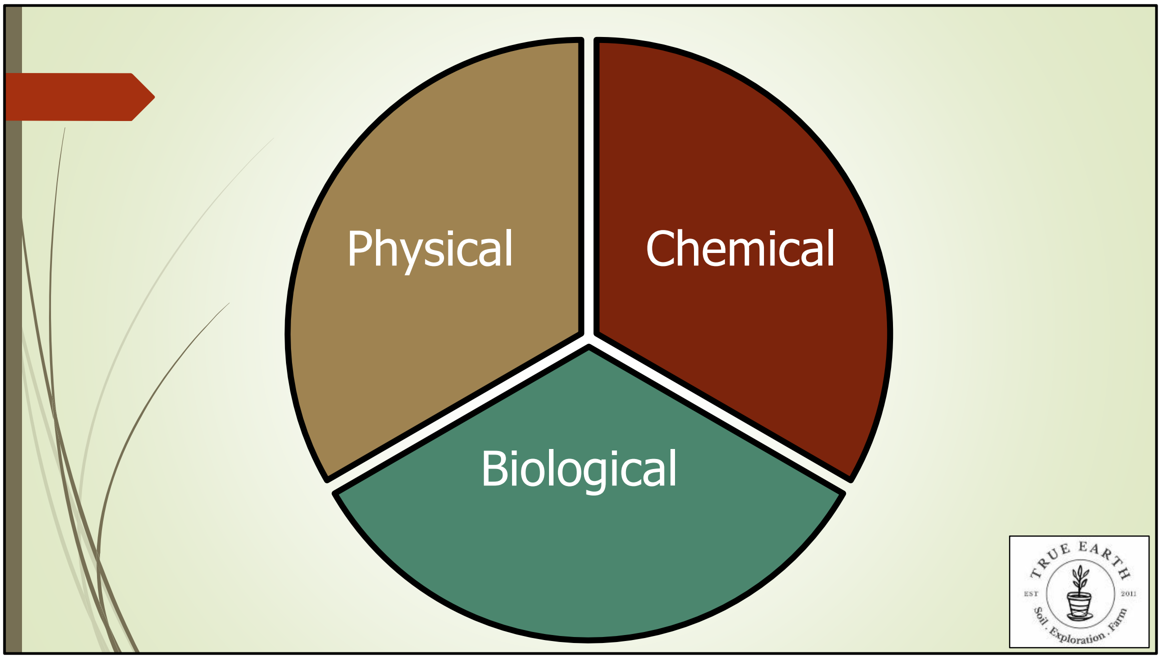
Amino acids are the basic building blocks of plant health.
A chain of amino acids form a protein. It takes more than 30 amino acid blocks for form the simplest protein.

Several proteins linked together make an Enzyme.

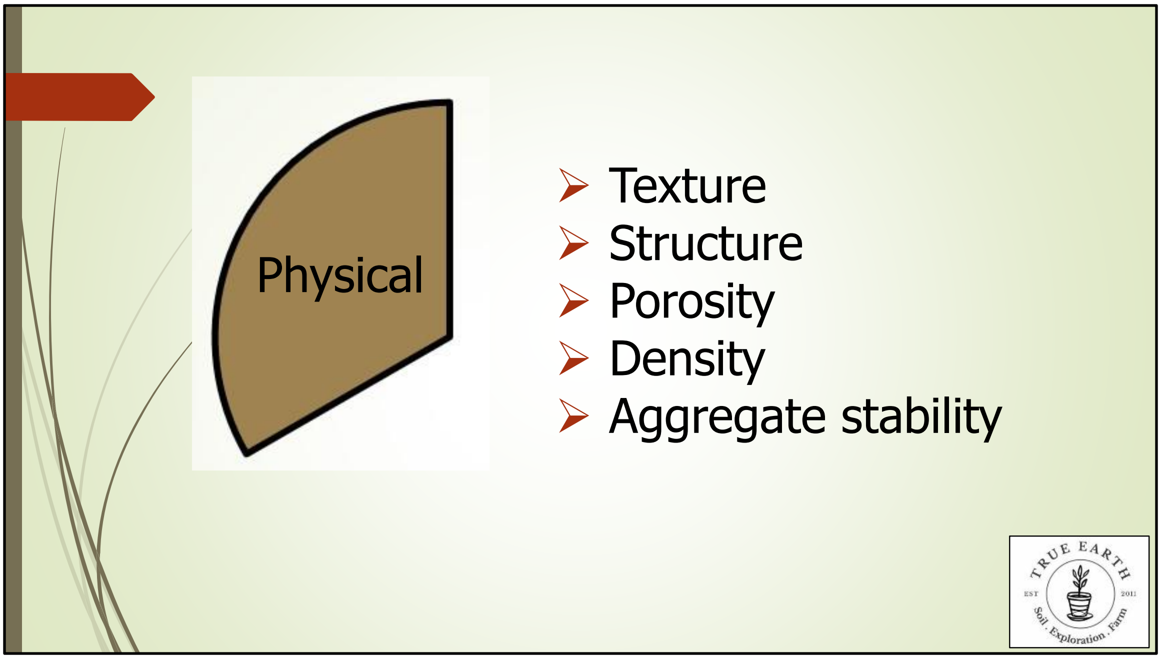
Nutritional balance is achieved by soil balance and the microbial nutrient extraction.

Are the proteins and enzymes being developed in your plants healthy or unhealthy?

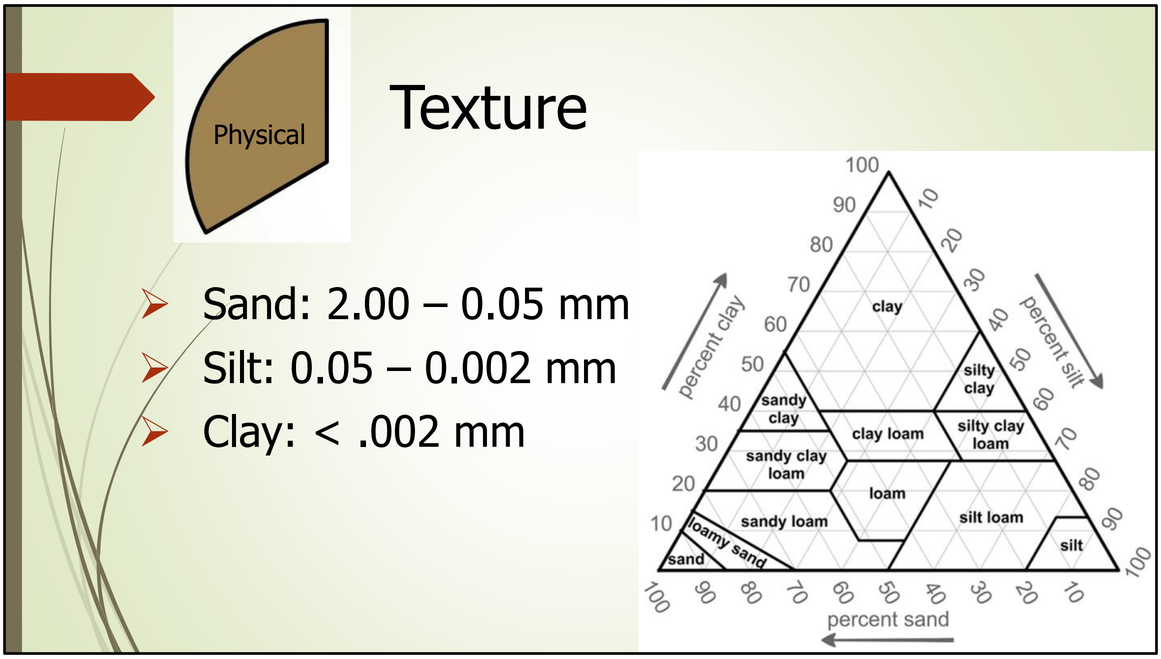
What do we need to focus on to improve that?



Balanced soil health will take into account the Physical, Chemical, and Biological aspects of the soil.



The physical attributes of the soil include texture, structure, porosity, density, and aggregate stability. These properties affect processes such as water infiltration, water holding capacity, and water availability. Nutrient cycling, nutrient holding capacity, and nutrient availability. As well as biological activity.



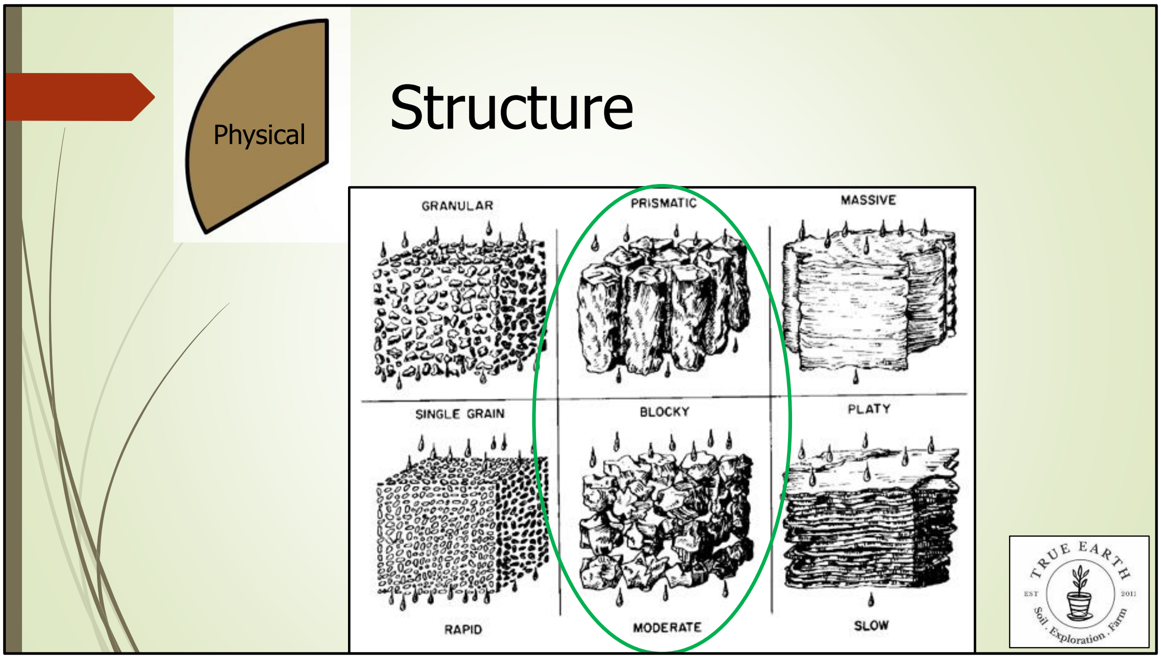
Soil texture is the distribution of soil particles.

Sand particles are: 2.00 – 0.05 mm
Silt particles are: 0.05 – 0.002 mm
Clay particles are: < .002 mm

To give you a point of reference, assume that a sand particle is the size of a city block. In comparison, a silt particle would be the size of a king size mattress. And a clay particle would be the size of an index card.

The percentage of each of these particle sizes in the soil determines the soil type according to this soil textural triangle.

The specific proportions of each particle size affect physical attributes of the soil such as pore space, water infiltration rates, water holding capacity and water availability. Cation exchange capacity, nutrient holding capacity, and nutrient availability.

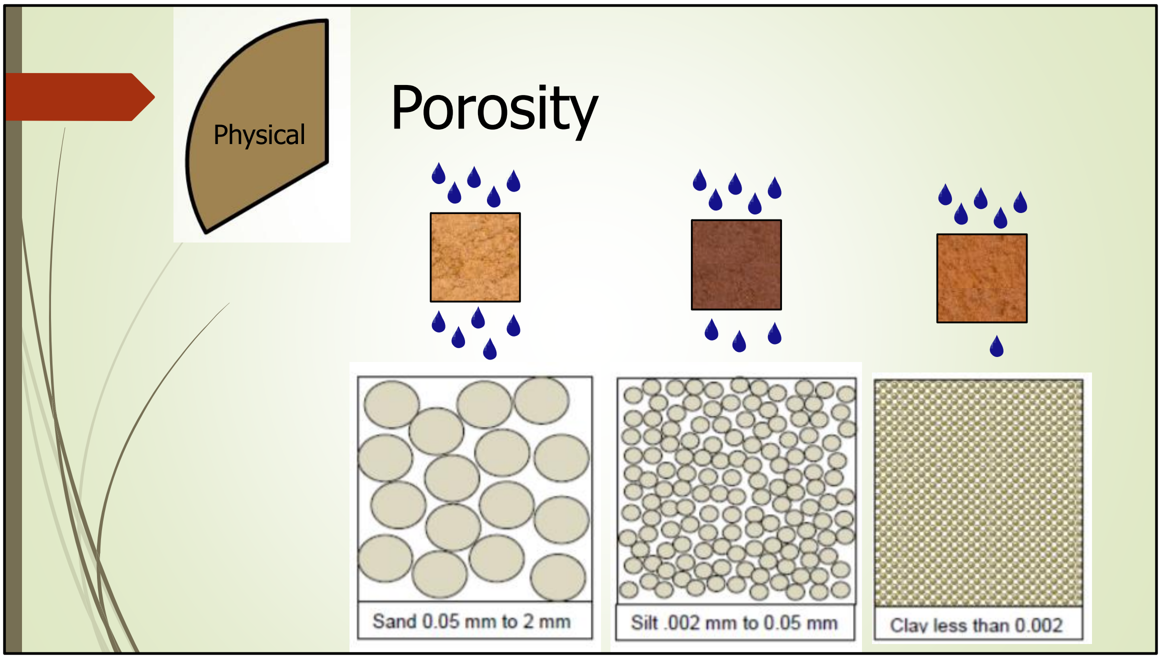


Let’s talk a little bit about soil structure.

This chart represents the common types of soil structure and their influence on water holding capacity, root penetration, and oxygen in the rootzone.

- Organic virgin soils generally have prismatic or blocky structure. This structure is the perfect balance of water holding capacity, water infiltration, root penetration and oxygen in the rootzone.
- After some tillage, the natural structure is broken down into granular or single grain structure. This condition enables water to infiltrate rapidly through the soil. Increasing the potential for leaching of nutrients past the rootzone and reducing water availability to plants.
- Finally, after excessive tillage and equipment traffic, soil structure is destroyed completely and we end up with massive or platy structure. These conditions are noted by ponding water as infiltration is very slow. Plant root development is restricted, nutrient capacity is diminished, and oxygen in the rootzone is significantly reduced which adversely affects the microbiome.

What is needed to accelerate the formation of soil structure? Physically break up compaction, add organic matter and life to the soil.



Sandy soils have larger pores, drains quickly after rain or irrigation, and dries out quickly.
Silty soils have medium pores drains fairly well, holds more moisture than sandy soils, easily compacted.
Clay soils have small pores, and drains slowly.

Physical

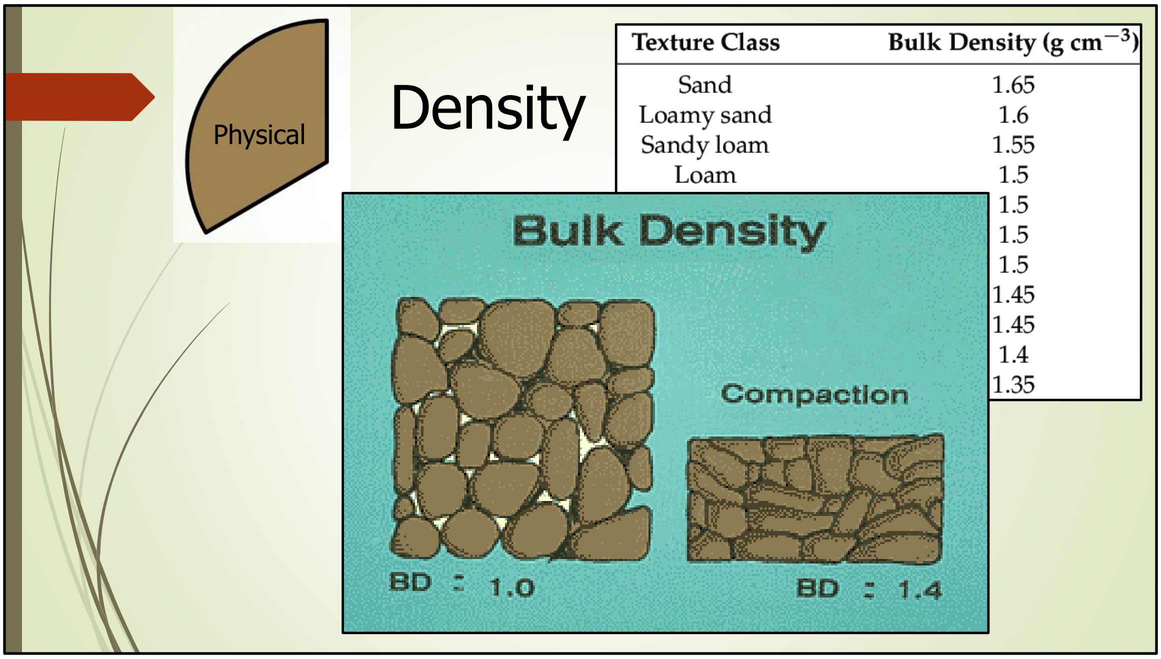
Porosity

Soil type	Basic infiltration (mm/hr)
Sand	< 30
Sandy loam	20 – 30
Loam	10 – 20
Clay loam	5–10
Clay	1–5

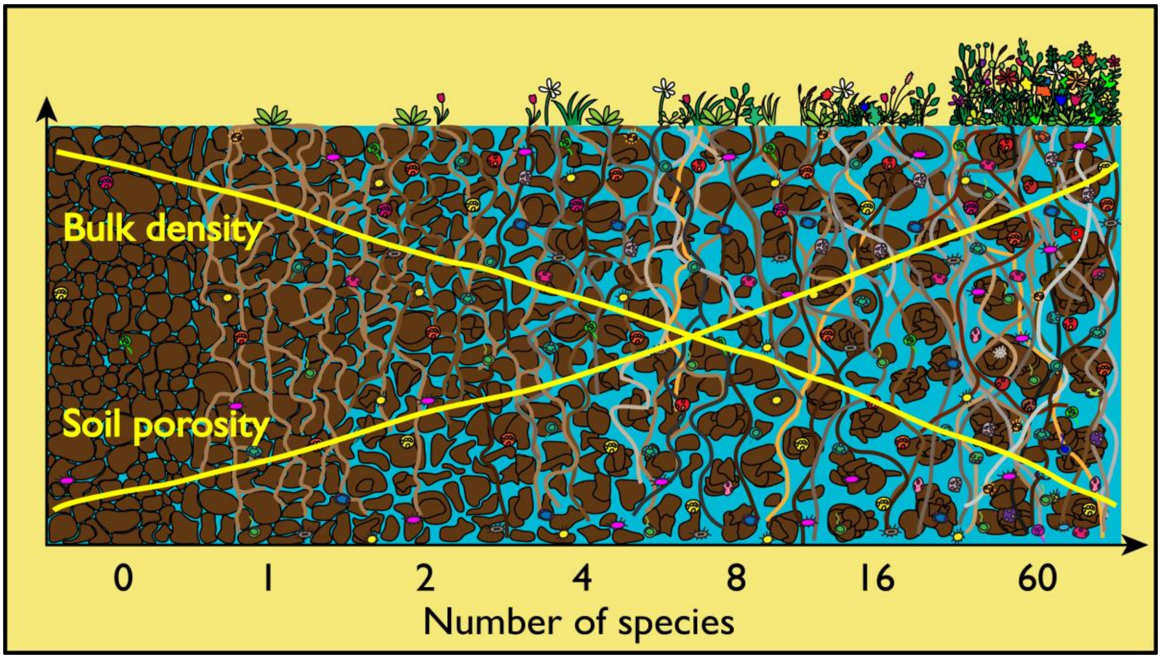
Source: Anon, (2009b

Textural class	*Water holding capacity, inches/foot of soil*
Coarse sand	0.25 - 0.75
Fine sand	0.75 - 1.00
Loamy sand	1.10 - 1.20
Sandy loam	1.25 - 1.40
Fine sandy loam	1.50 - 2.00
Silt loam	2.00 - 2.50
Silty clay loam	1.80 - 2.00
Silty clay	1.50- 1.70
Clay	1.20 - 1.50

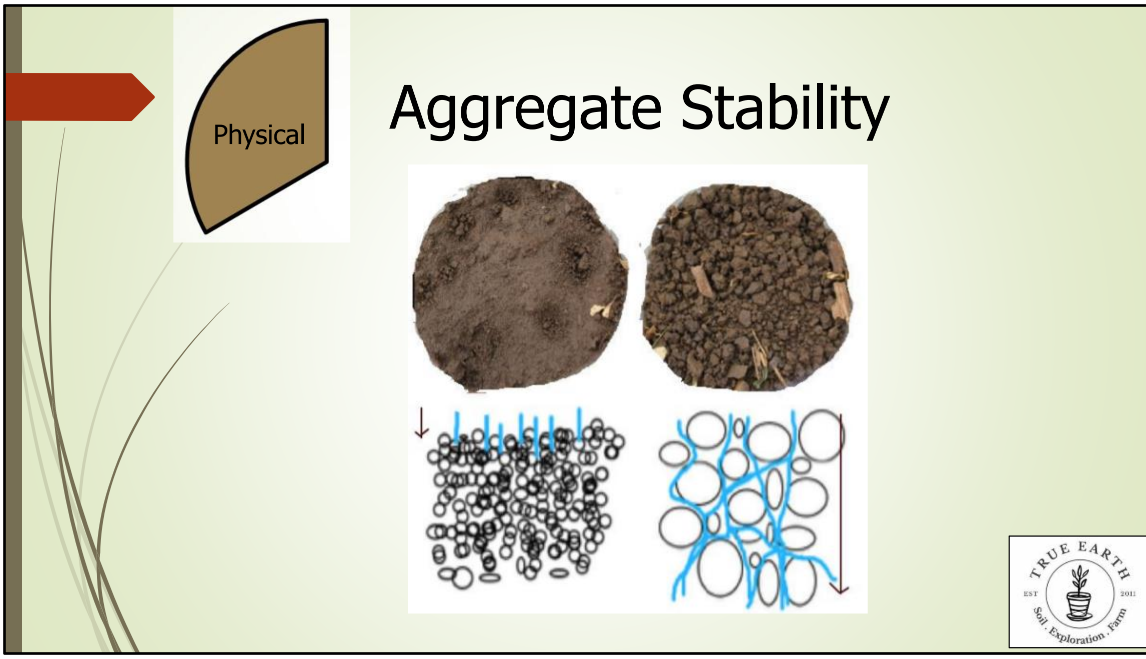
Texture and related porosity affects the water infiltration rates and water holding capacity of soils.



Bulk density is the mass of dry soil per unit volume.
The soil on the left has macropores that result in a bulk density of 1.0. When compacted to a bulk density of 1.4, the pore space is reduced significantly, limiting permeability, drainage, root penetration, and biological activity.

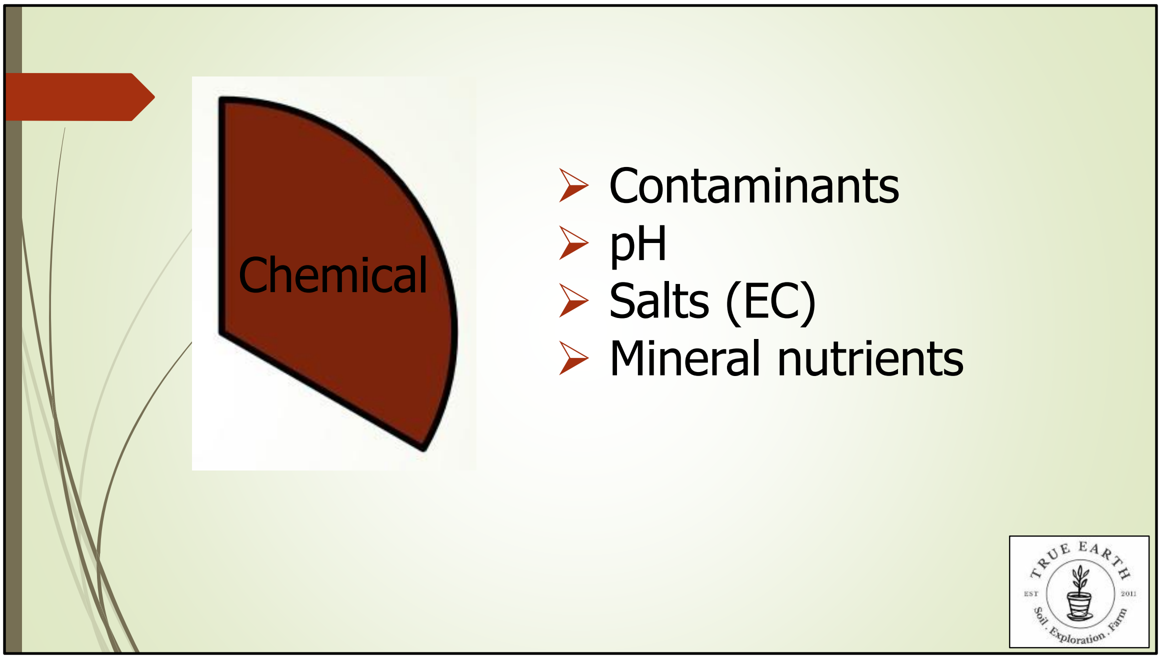


Soil porosity and bulk density are inversely proportional. As bulk density decreases, soil porosity increases along with the ability to support biological life.



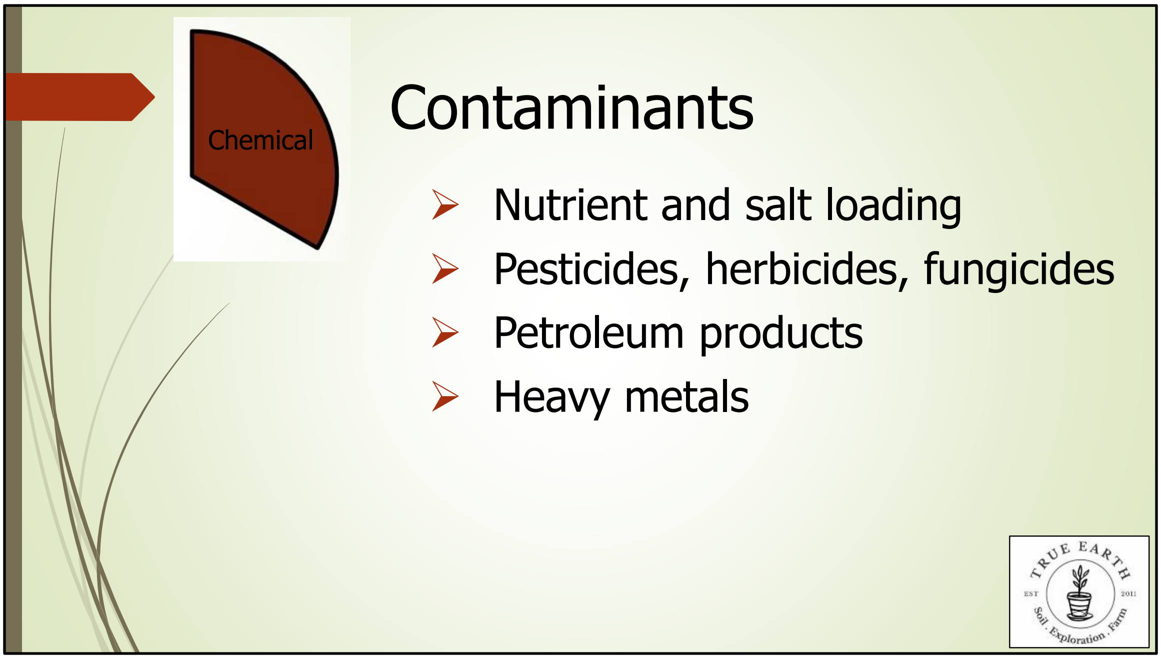
Aggregate stability is crucial for soil health. Soils with good aggregate stability are less susceptible to erosion and have improved infiltration. Aggregate stability increases with organic matter content in the soil and can be improved through a combination of management practices such as reduced tillage, adding organic matter amendments, and increasing the amount of crop residues and organic matter retained in the soil.

Avoid extensive tillage and reduce physical disturbances to prevent the destruction of soil aggregates. By keeping soil covered with surface residues, erosive impacts can be minimized as well.



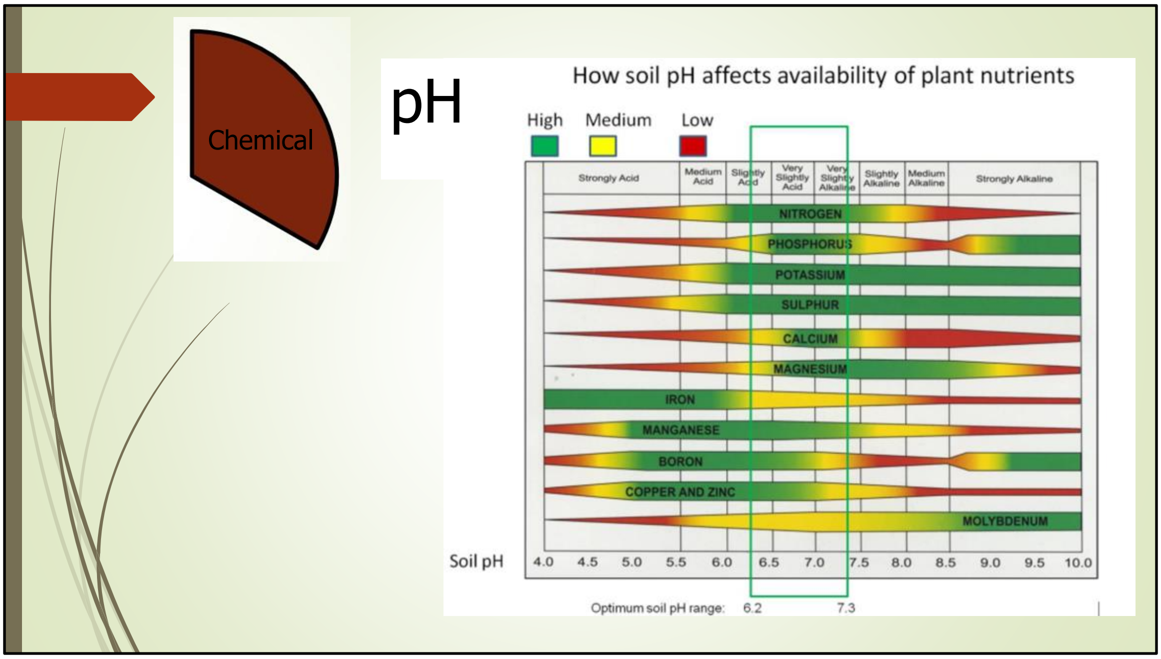
Chemical attributes of the soil include pH, salts, mineral nutrients, heavy metals & other contaminants.

These properties affect processes such as water infiltration, water holding capacity, and water availability. Nutrient cycling, nutrient holding capacity, and nutrient availability. As well as biological activity.



The main soil contaminants to be concerned with include nutrient and salt loading.
Pesticides, herbicides, and fungicides
Petroleum products
Heavy metals

What do you do if you have a contamination issue?
Proactive measures of remediation should be taken.



The availability of mineral nutrients is strongly influenced by pH. Optimum pH for crop production is 6.2 – 7.3

Chemical

Salts (EC)

Table 1. Classes of salinity and EC (1 dS/m = 1 mmhos/cm; adapted from NRCS Soil Survey Handbook)

EC (dS/m)	Salinity Class
0 < 2	Non-saline
2 < 4	Very slightly saline
4 < 8	Slightly saline
8 < 16	Moderately saline
≥ 16	Strongly saline

Soil classification	EC*	pH	SAR
Normal soil	<4	<8.5	<13
Saline soil	>4	<8.5	<13
Sodic soil	<4	8.5-10	>13
Saline-sodic soil	>4	≥8.5	>13

*EC, Electrical conductivity; SAR, sodium adsorption ration; pH, level of alkalinity/acidity. Source: Scherer (1996).

Soil classification based on electrical conductivity (EC), pH and sodium adsorption ratio.

Regarding Salts,

If your EC is less than 4 and pH is less than 8.5, you are good to go.
If your EC is less than 4 and your pH is > 8.5, you have a sodic soil. This means that sodium is taking over the exchange sites in the soil profile.
What do you do? Confirm the source, add calcium.
If your EC is greater than 4, and pH is less than 8.5, you have a saline soil. What do you do? Confirm the source of the problem, leach salts with clean irrigation water.
If you EC is greater than 4, and pH is > 8.5, you have a saline-sodic soil. What do you do? Confirm the source of the problem, add calcium to exchange sodium off CEC sites, and leach with clean irrigation water.

Chemical

Salts (EC)

Table 2. Influence of soil EC on microbial process in soils amended with NaCl or nitrate (adapted from Smith and Doran, 1996)

Microbial process	Salt added	EC Range (dS/m)	Relative Decrease (%)	Threshold EC (1:1)
Respiration	NaCl	0.7 - 2.8	17 - 47	0.7
Decomposition	NaCl + alfalfa	0.7 - 2.9	2 - 25	0.7
Nitrification	soil + alfalfa	0.7 - 2.9	10 - 37	0.7
Denitrification	NO_3-N	1 - 1.8	32 - 88	1

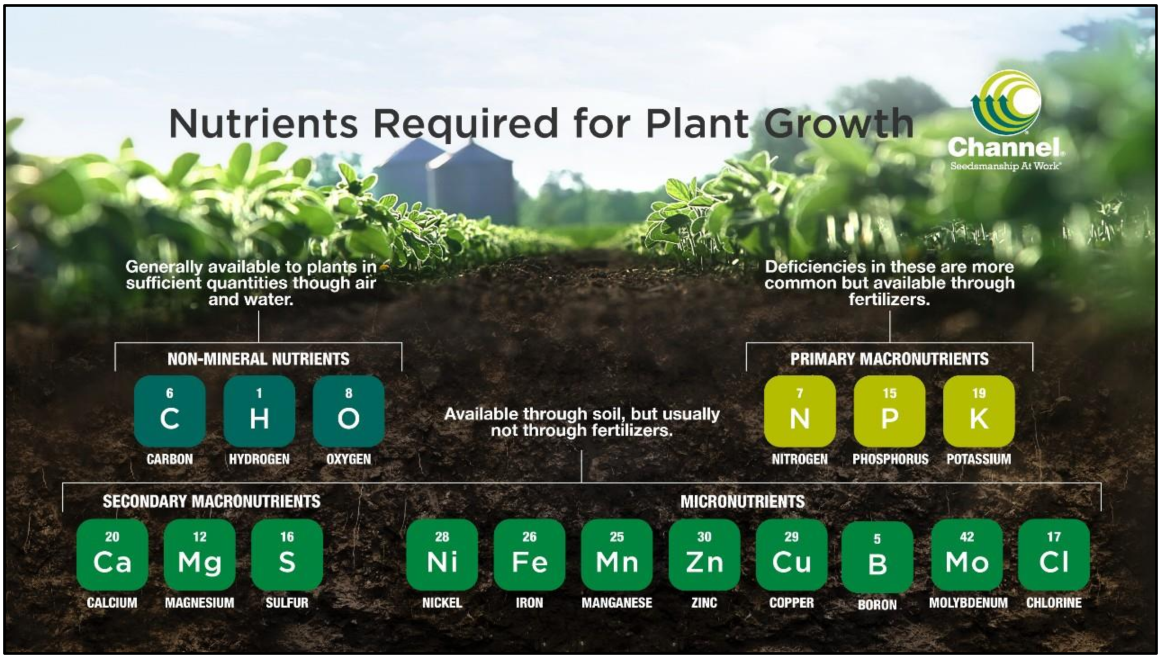
Table 3. Salt tolerance of crops and yield decrease beyond EC threshold (adapted from Smith and Doran, 1996)

Crop species	Threshold EC 1:1 (dS/m)*	Percent yield decrease per unit EC beyond threshold EC
Alfalfa	1.1 - 1.4	7.3
Barley	4.5 - 5.7	5.0
Cotton	4.3 - 5.5	5.2
Peanut	1.4 - 1.8	29
Potato	1.0 - 1.2	12
Rice	1.7 - 2.1	12
Soybean	2.8 - 3.6	20
Tomato	1.4 - 1.8	9.9
Wheat	3.9 - 5.0	7.1

* *Electrical conductivity of a 1:1 soil/water mixture relative to that of a saturated paste extract*

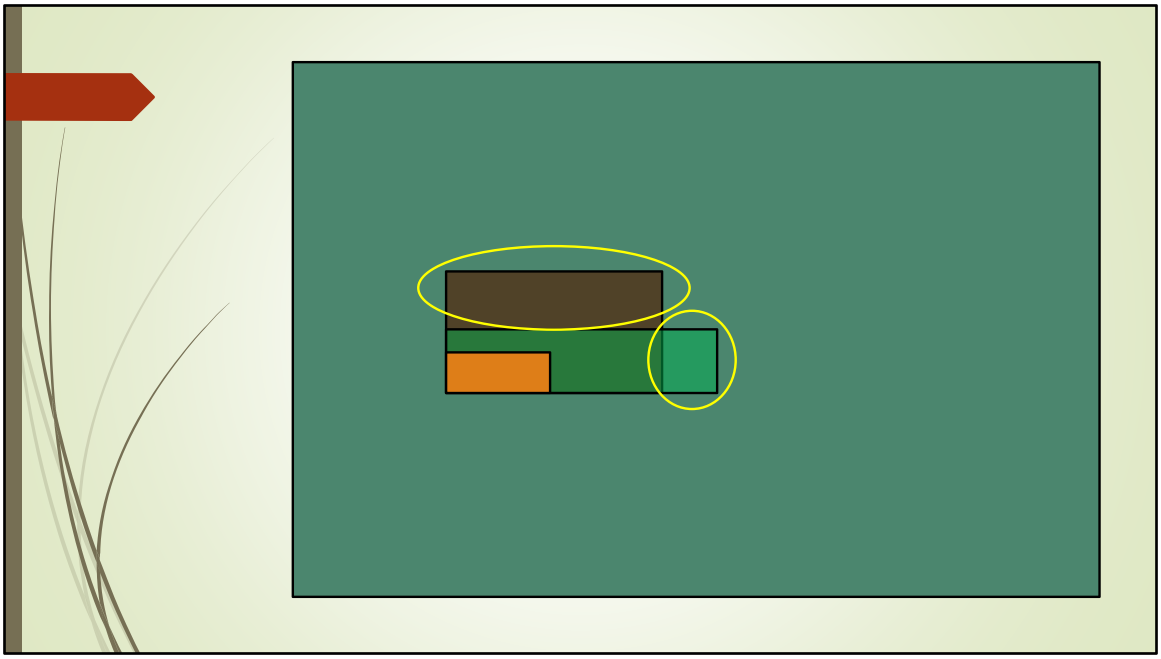
Long before salt loading is classified as a saline, sodic, or saline sodic soil, salts can begin to affect crop yield. Potatoes for example, are not nearly as tolerant of elevated salts as wheat is.

Microbial processes in soils are also limited by elevated salt levels in the soil.



There are 17 elements required for plant growth. Carbon, hydrogen, and oxygen are generally available to plants in sufficient quantities through air and water. Deficiencies in nitrogen, phosphorus, and potassium are more common, but can be supplied through fertilizers. The remaining secondary macronutrients and micronutrients are available through the soil, but usually not through fertilizers.

Think about what role does soil life play in the availability of soil nutrients?

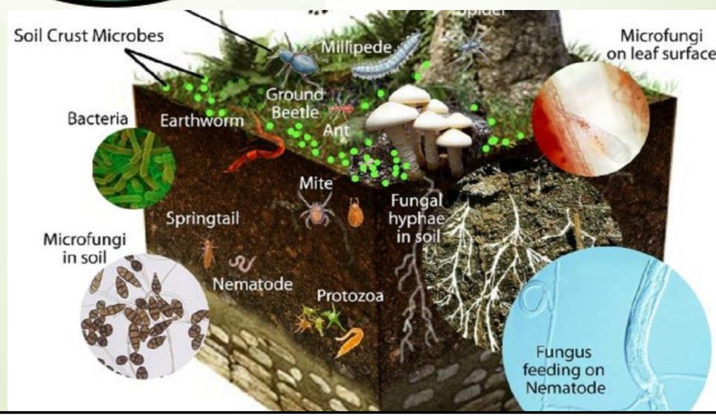


This dark green rectangle represents the total amount of nutrients held in the soil.
The orange rectangle represents the portion of those nutrients that are soluble in soil solution and readily available to the plant.
The Brown rectangle represents the nutrients that are exchangeable – easily pulled off soil surfaces and can be made plant available when in contact with root exudates.
The lighter green rectangle represents the amount of nutrients needed to produce a crop.

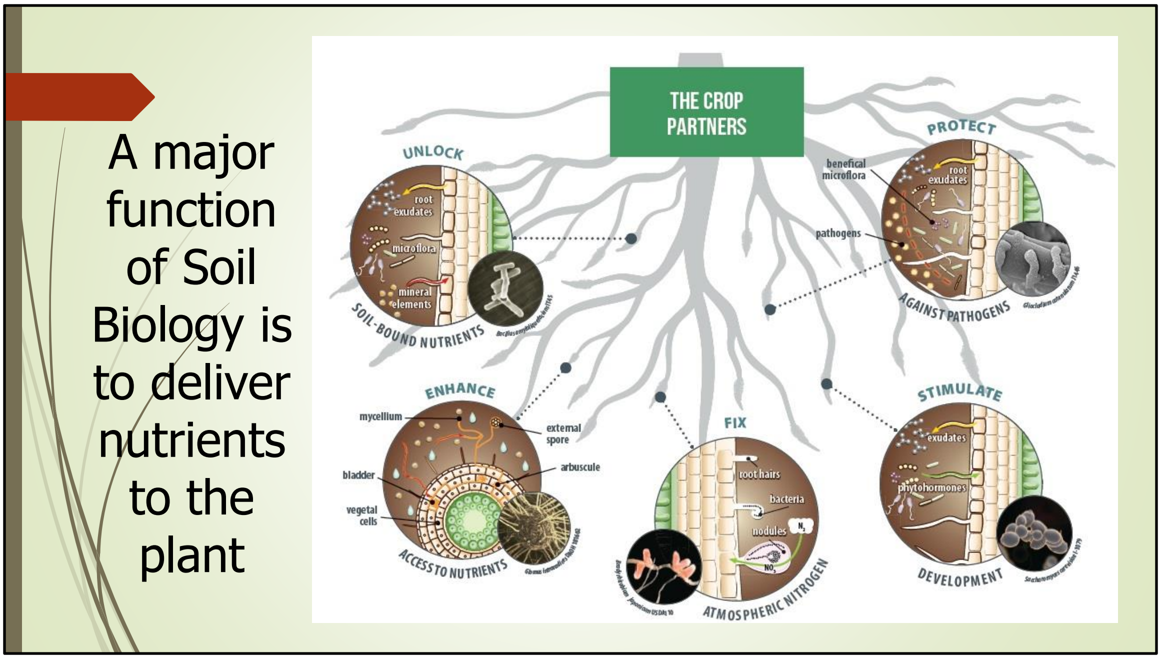
The fact that the brown rectangle is taller than the green rectangle is an indication that the availability of some nutrients is higher than what the plant will actually need.
The fact that the green rectangle is longer than the brown rectangle is an indication that the availability of some nutrients is less than what the plant will need.
What do we do? Add fertilizer? When our long range plan is to simply add synthetic fertilizer, we are not looking at the whole picture.
Remember that the dark green rectangle represents the total amount of nutrients held in the soil. Hence there is enough if we can simply engage the biological nutrient cycling needed to release it to the plant.

Biological

- Life in the soil



Biology is the study of life. Therefore, the biological attributes of the soil are made up of all living things in the soil.

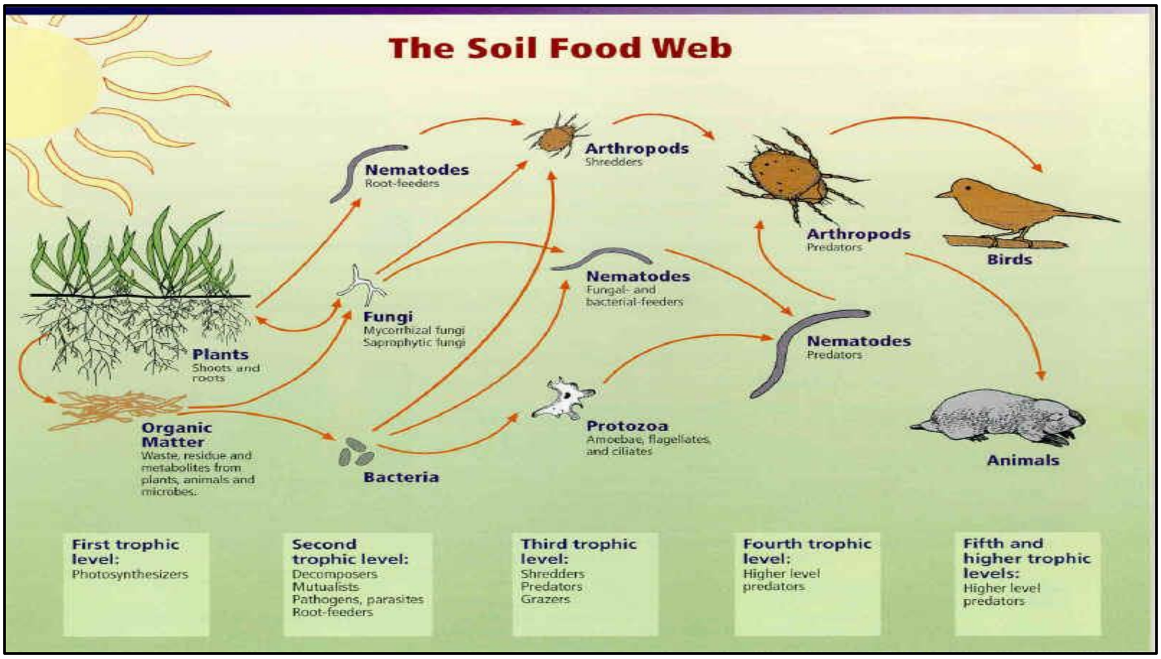


One of the major functions of soil biology is to deliver nutrients to the plant.

There are numerous classifications of micro organisms in the soil. Some of which I will mention here, and others I am certain I have overlooked. Each classification has a myriad of species & sub species. There are about 30,000 species of bacteria, 144,000 species of fungi, more than 50,000 species of protozoa, and more than 5 million species of arthropods. There are more than 10,000 tons of microbes in the top 3 inches of 1 acre of soil.

They unlock soil bound nutrients, enhance nutrient availability, fix atmospheric carbon, nitrogen and other volatile nutrients, stimulate development of balanced amino acids, and protect against pathogens.

Where do these beneficial creatures come from? For the most part, they were just born there.



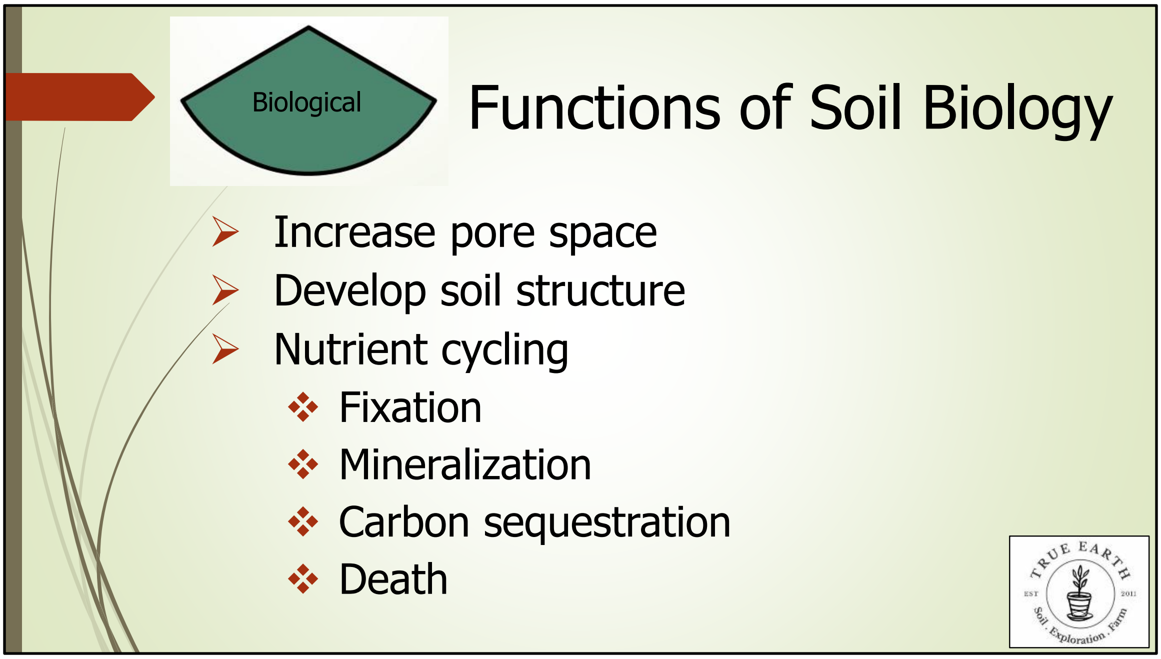
One of the many circles of life involves a soil food web. The first trophic level is photo synthesizers. That's right - without plants, the cycle stops. That is why it is critically important to use diverse cover crops and keep living roots in the soil at all times.

The second trophic level includes decomposers and mutualists like symbiotic bacteria and fungi, pathogens, parasites, and root feeders like anaerobic bacteria, and root eating nematodes. Decomposers – good, mutualists – good, but pathogens, parasites, and root feeders, bad! So if we stop here, it could be problematic for the crop.

The third trophic level includes shredders, predators, and grazers like nematodes, protozoa, and small arthropods that feed on organic matter and level two organisms. These guys eat the pathogens, parasites, and root feeders and poop out nutrients for the plant.

The fourth and fifth trophic levels are higher level predators like worms, insects, arthropods, borrowing animals, and birds.

Each of these creatures is a critical part of the biological balance in the soil.



Large and small, biological life in the soil is responsible for increasing pore space, developing soil structure, and nutrient cycling through fixation, mineralization, carbon sequestration, and death.

Biological

Functions of Soil Biology

- Decompose toxins
- Breakdown of soil organic matter
- Retain nutrients
- Plant nutrient extraction
- Regulation of nutrient uptake
- Suppress pathogens & disease

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Soil biology is also responsible for the break down and decomposition of organic matter, plant nutrient extraction, regulation of nutrient uptake, and suppressing pathogens & disease through competition, inhibition, and consumption.

Pathway to a Healthy Microbiome

- Site assessments
- Mitigation of production limiting factors
- Subsoiling
- Organic amendments
- Cover crops & companion crops
- Integrated pest management
- Integration of Livestock

The pathway to a Healthy Microbiome begins with a site assessment and mitigation of production limiting factors.
Subsoiling to break up compaction and the application of organic amendments, cover crops and companion crops for biodiversity.
Follow it all up with integrated pest management and integration of livestock.

Naturally balanced, healthy soils are the key to resilient, high producing crops. Please feel free to give us a call or send an email with any questions you may have. We look forward to working with you and we are confident that together, we can gain a better understanding of your soil health and make the appropriate adjustments to improve the productivity of your farm.

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