How Healthy Soils Support Plant Health

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Earth Alive Clean Technologies

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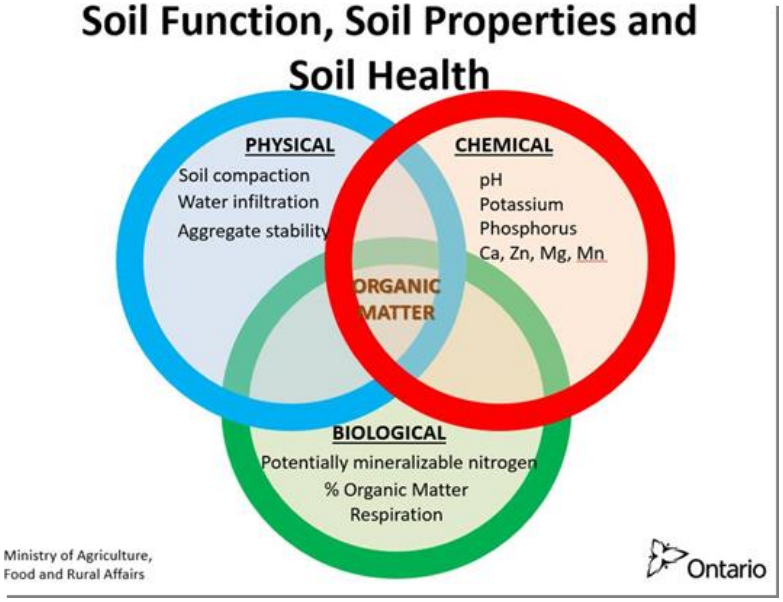
Nature in Balance

Image of Wolf Lake (Temagami ON) by Rob Nelson | http://www.savewolflake.org/ | http://www.robnelson.ca/

- Nature is a self-powered, self-balancing, self-correcting system
- The foundation of this durability is the intimate relationship between green plants and soil
- Life is incredibly durable
- Recovery and Adaptation are limited by only One Factor: Time

- We will explore the Green Ring below, and reveal its importance.
- Dynamic Microbial Communities, and a cascade of Micro and Macro-Fauna Foragers play a key role in soil (and plant) health.
- Healthy Living Soils = Healthy Plants



Ancient Earth – Rock, Oceans, and Tidepools

And in those tidepools, single-celled organisms begin competing for food - and dominance

- After a (1 Billion Year +) Wrestling Match, a winner would emerge from the primordial soup

Image by: Peter Sawyer

The Primordial Leap Forward

It all began - with a Bad Case of Indigestion

- Captured and protected inside an ancient cell, a Clorophyta flourished (and so did it's captor)
- The hitchhiker gave the cell the ability to feed itself – **Bingo!**
- World domination was just around the corner

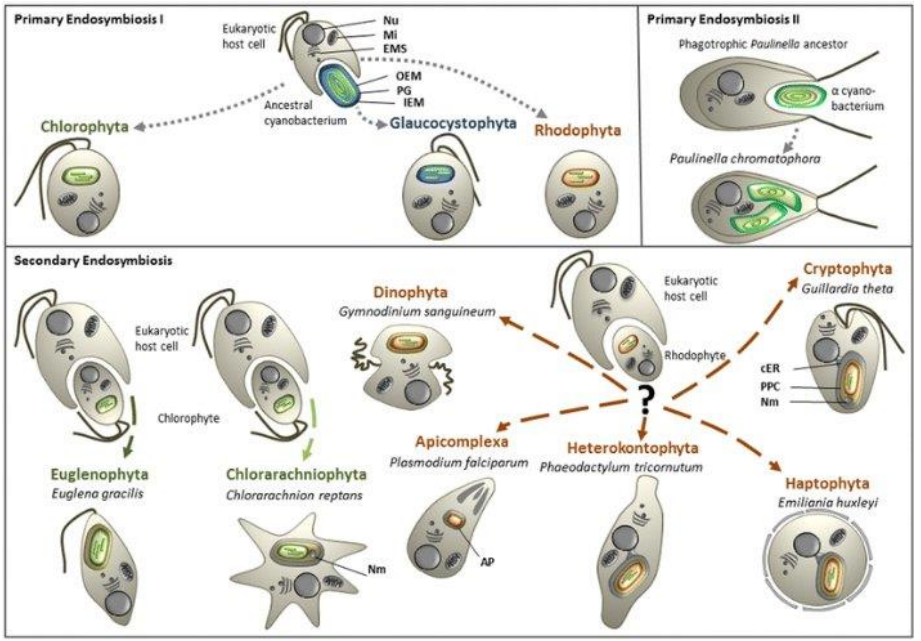


Image by: Gentil, J., Hempel, F., Moog, D. et al. Protoplasma (2017)

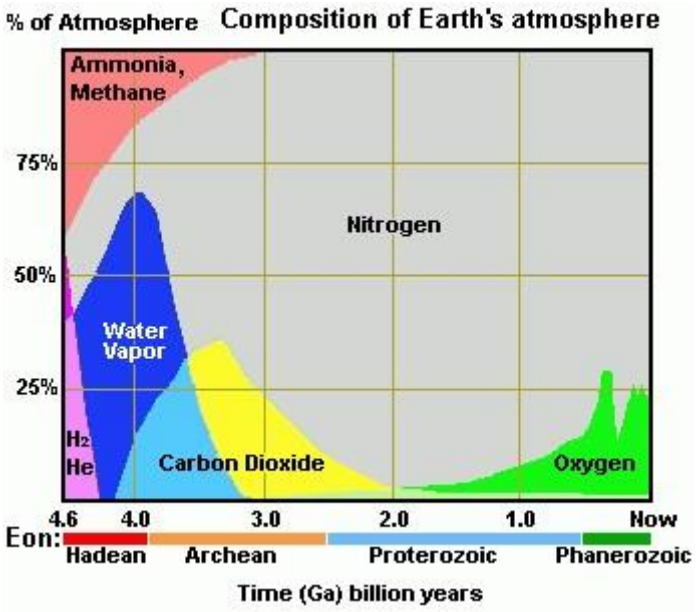
Blue-Green Algae Changes our Earth

The Chlorophyta Hitchhiker inside ancient Cyanobacteria propels this microbe to planet-wide dominance.

- Bad News – its waste product (Oxygen) would ultimately drive it to near-extinction
- Good News - an oxygen-rich atmosphere allowed complex lifeforms (like us) to evolve on Earth

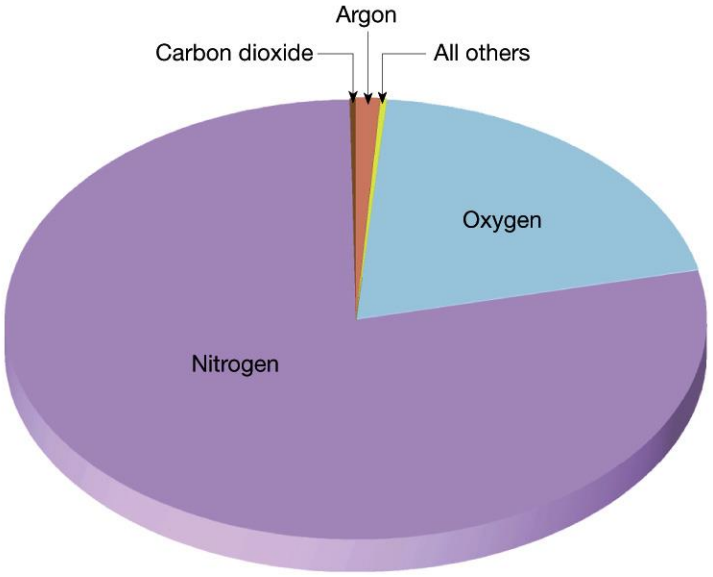
Cyanobacteria Changes Earth's Atmosphere

The Chloroplasts in ancient Cyanobacteria (and today, in other microbes i.e. Diatoms) Drive CO_2 Levels Down and Oxygen Levels Up



Our Ancient Atmosphere

Image Courtesy of scientificpsychic.com



Our Atmosphere Today

Image Courtesy of Lutgens and Tarbuck, *The Atmosphere*

Planet Earth becomes Green

Photosynthesis Changed the World

- The captured Chlorophyta eventually became part of the DNA of its host cell
- Today we call these amazing organelles inside all green plant cells ‘Chloroplasts’
- Green Plants continue to supply Our atmosphere with a very important waste product - Oxygen

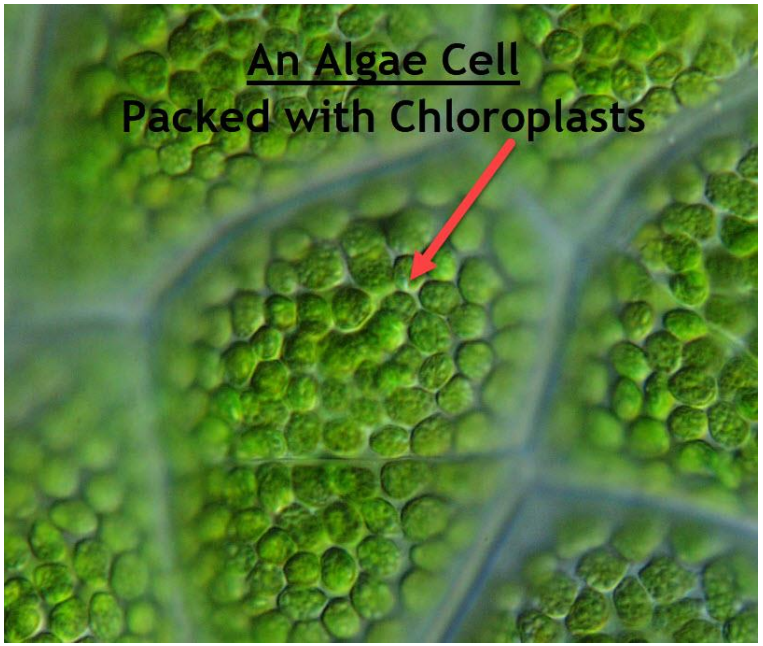


Image by: Gentil, J., Hempel, F., Moog, D. et al. Protoplasma (2017)

Today, ½ the Oxygen we Breathe is Produced by Plants – the rest - by Ocean Diatoms

Diatoms

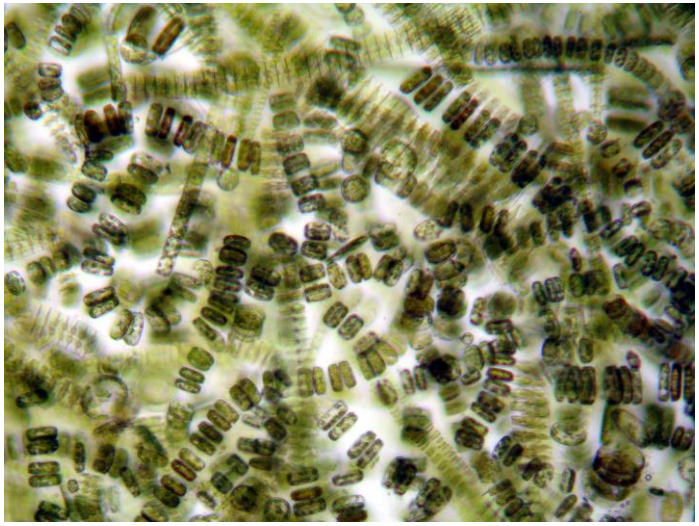


Image credit: B. Caissie

Oxygen bubbles into the air

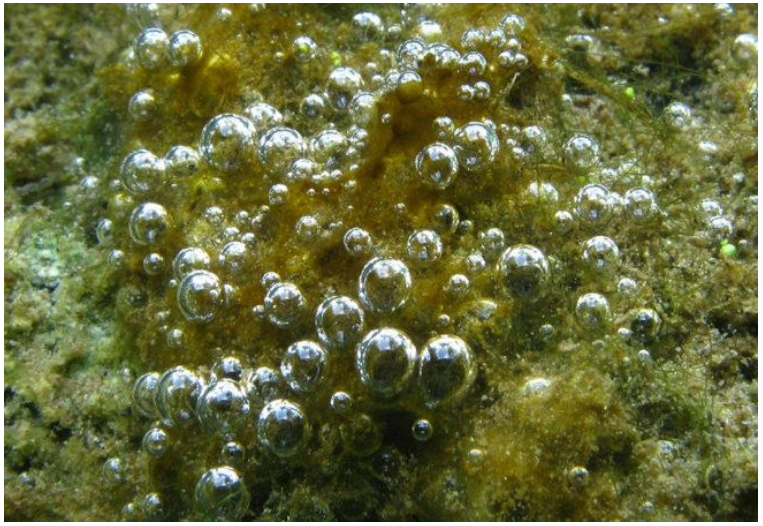
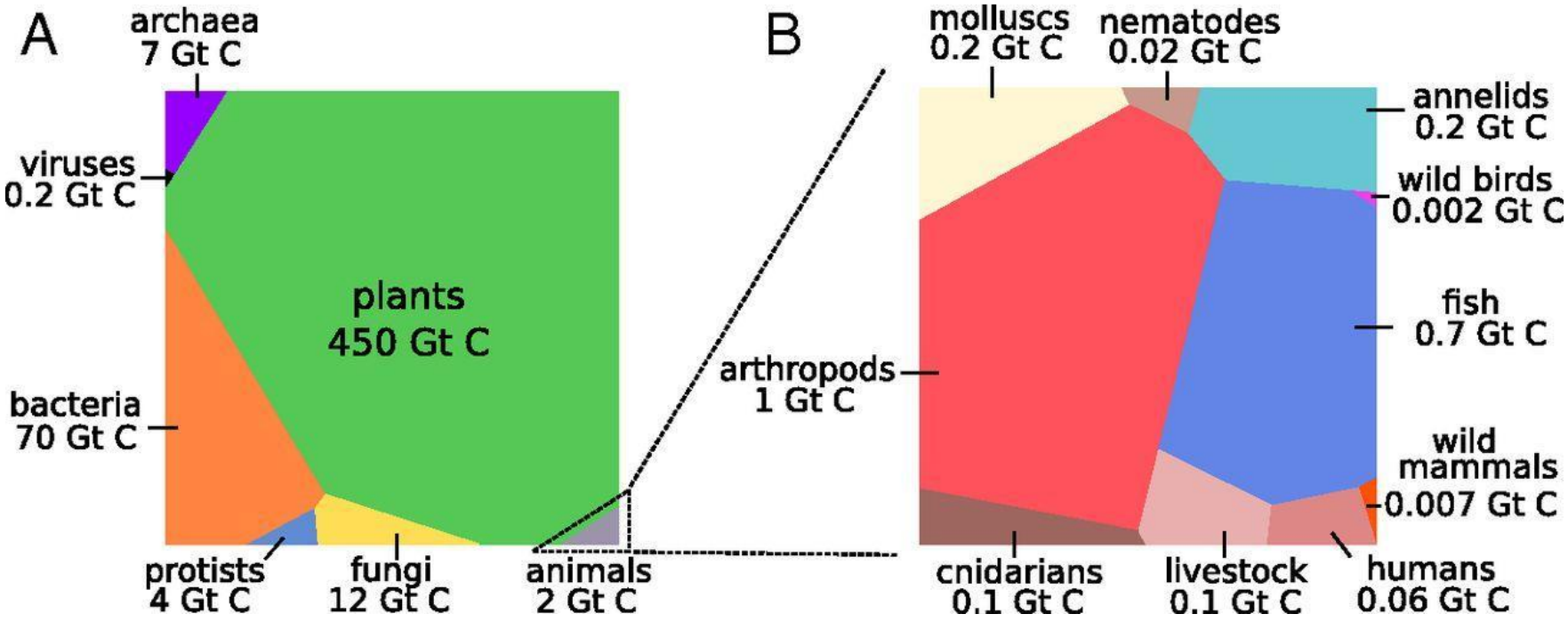


Image courtesy of diatoms.org

- Land Plants and Ocean Phytoplankton provide us with our breathable atmosphere today (Diatoms have Chloroplasts too)
- The Health of Land Plants ***and our Oceans*** is linked to Our Health

Which Lifeform Dominates Earth Today?

Photosynthetic Plants: 80% of Earth's Biomass



"Gt C" = "Gigatons of Carbon": The Total Mass is compared

Diagram courtesy of: The Smithsonian Institute

Q: How have Green Plants Dominated Our Planet so Successfully?

A: Like the ancient Cyanobacteria, Plants share One Superpower – and it's a Biggie

The Ultimate Superpower

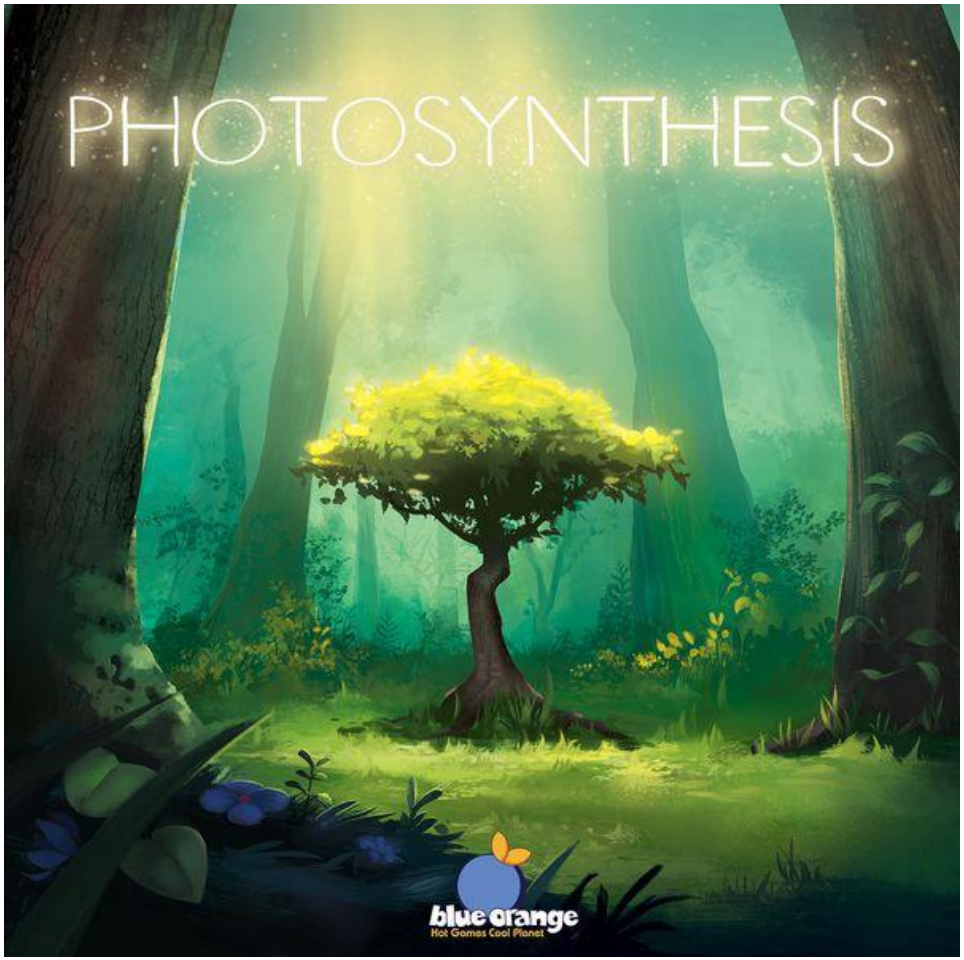
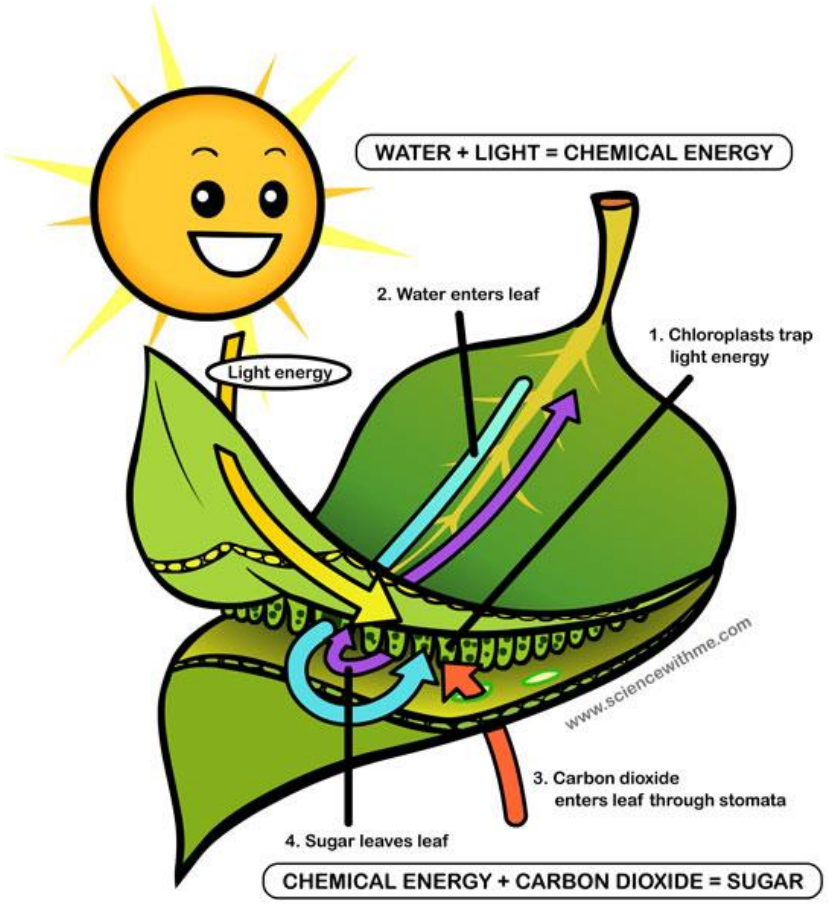


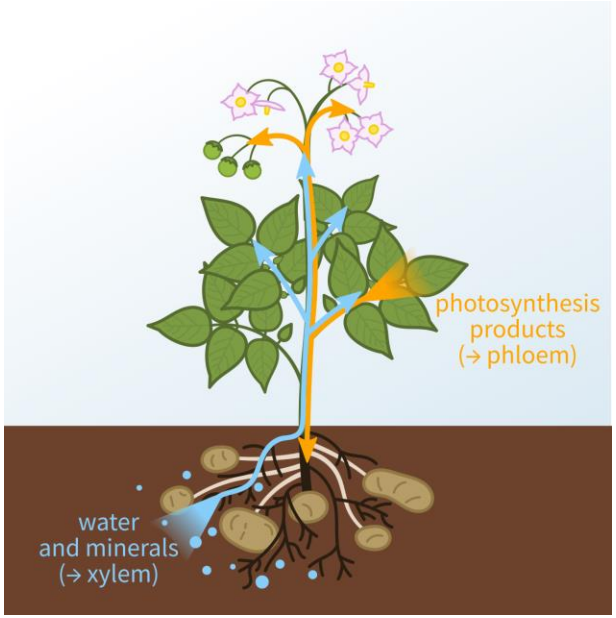
Image Courtesy of: Photosynthesis – the Board Game

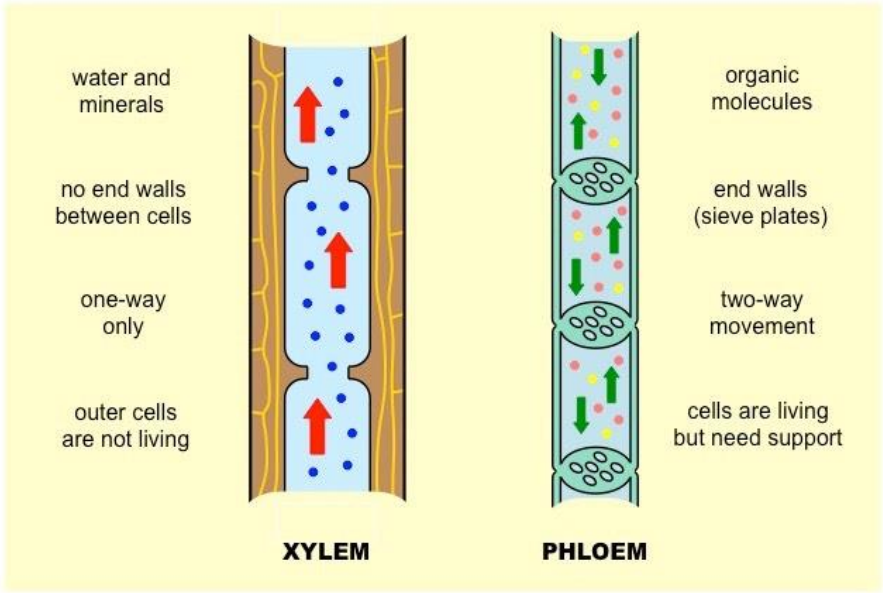
The Power of Green Plants

Photosynthesis: the Engine that Powers All Advanced Life on Earth (Including The Unseen Life In Soils)



The Plumbing of Plants Gives them Control over What Goes Where as Needed

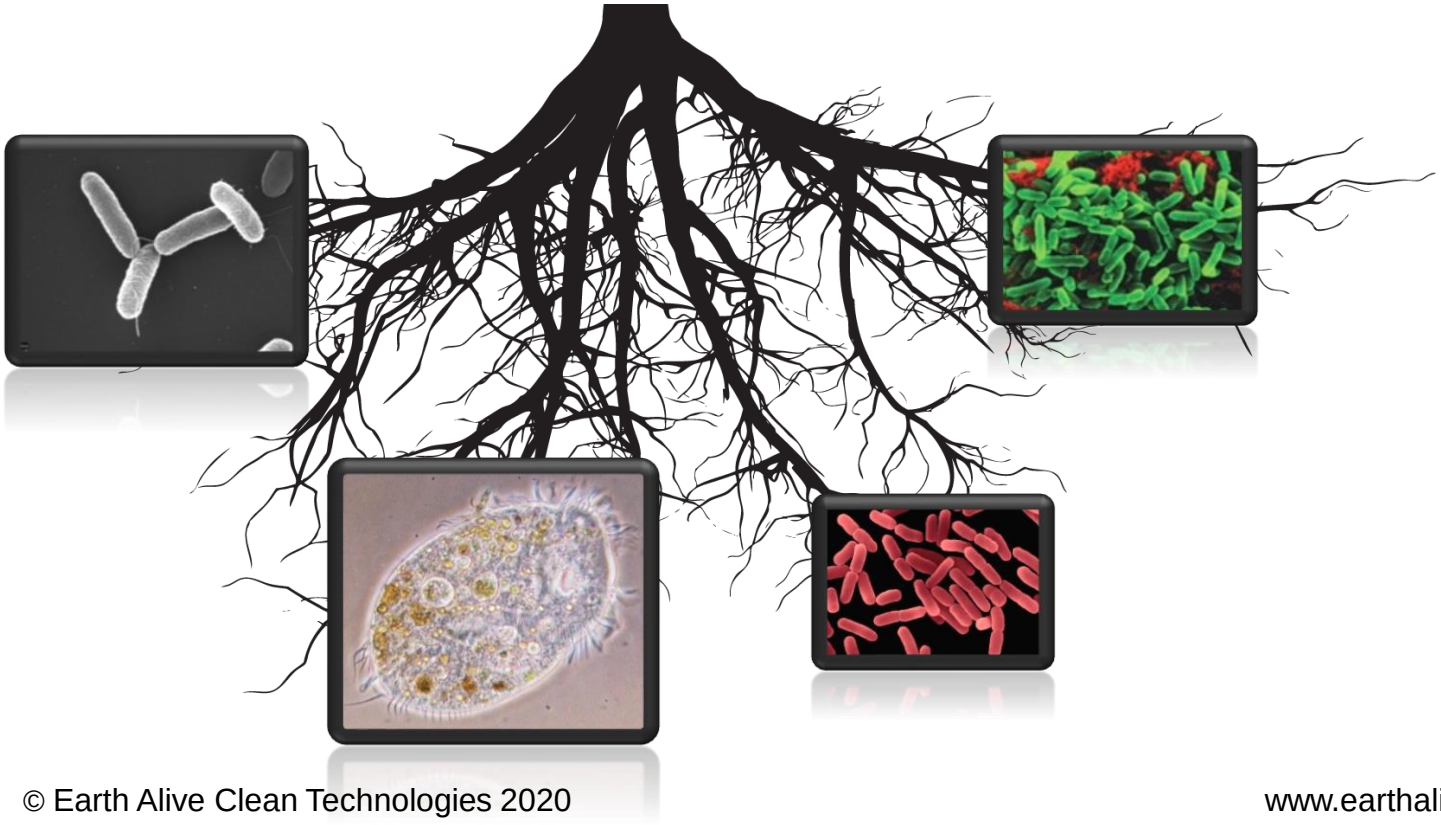




- The Xylem pipeline flows in one direction only: up from the roots. Water and ready-to-use nutrients are delivered to the leaves
- The Phloem is a 2-way transport system: surplus sugars from leaves can flow down into the roots powering the expansion of roots and feeding the microbes that unlock nutrients (and do other work)

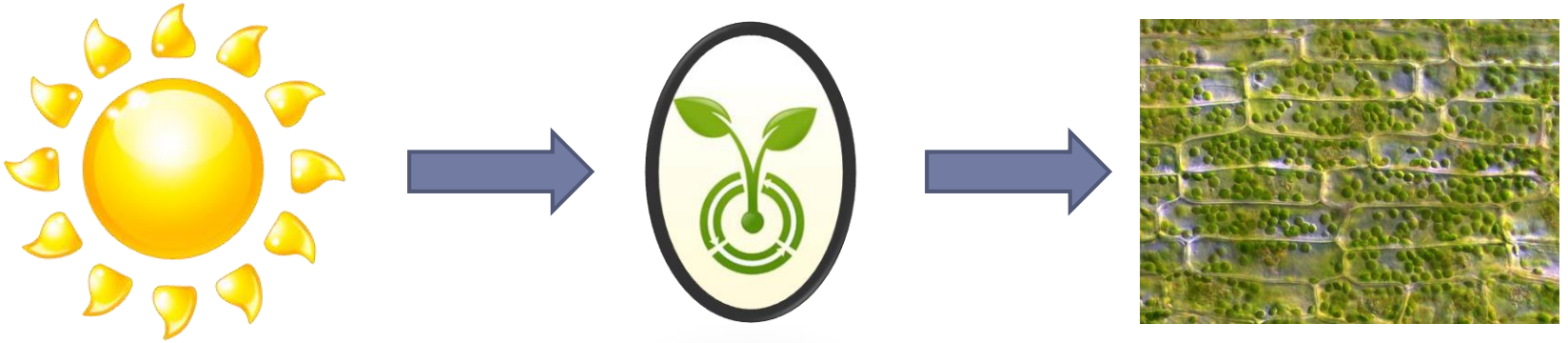
A Plant's Digestive System is Outside its Body

- Just like animals, a plant's 'digestive system' relies on microbes to break down raw food into usable nutrients.
- But unlike animals (which carry their digestive microbes in their gut) plant digestive microbes (bacteria, fungi etc.) are *outside its body* - in the soil.
- Without these microbial digesters in the soil, plants would starve.
- So, plants directly support (feed) billions of soil microbes in exchange for the work that they alone can do



Exudates – The Fuel That Powers Life In Soils

- **Chloroplasts produce 40% More Sugars than a plant needs to grow**



Carbon Compounds Produced Through Photosynthesis (Photosynthates)

60% Used to Grow → **Used by the plant to grow and reproduce**

40% Exuded to form Partnerships → **Traded to beneficial soil microbes in exchange for nutrients, water and other work**

Elodea canadensis image by: Dr. Ales Kladnik

How Do Plants Spend Their Carbohydrate Surplus?

- What soil organisms benefit most directly from the carbohydrate surplus exuded from plant roots?
- What skills do these Microbial Partners have that plants need?

Plants Directly Support Fungi and Bacteria in Soils

- Bacteria and Fungi are even older than plants – they emerged on an Early Earth that was almost uninhabitable
- They survived the near-toxic early earth environment because they developed unique Superpowers of their own…

Bacteria: The Ultimate Survivor

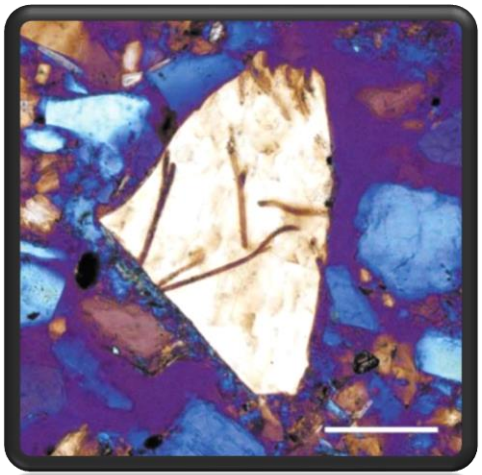
Bacteria Superpowers:

- Rapidly mutate and/or go dormant to survive almost any changes around them
- Thrive and quickly multiply in either and Oxygen-rich (Aerobic), or an Oxygen-starved (Anaerobic) environments
- Digest almost any molecule to dig out its hidden Carbon

Fungi: The Uber Hunter

Fungi Superpowers:

- Fungal Hyphae (Mycelia) grow incredibly fast (100's of times faster than roots)
- The mycelia are only 1 cell thick tubes – they can fit into the narrowest spaces to find water where roots cannot go
- They exude powerful Enzymes (acids) to extract nutrients from sources plant roots cannot access – especially nutrients locked inside minerals – in other words, **Fungi can Eat Rocks**



Essential to Soil Health: 1. Green Plants

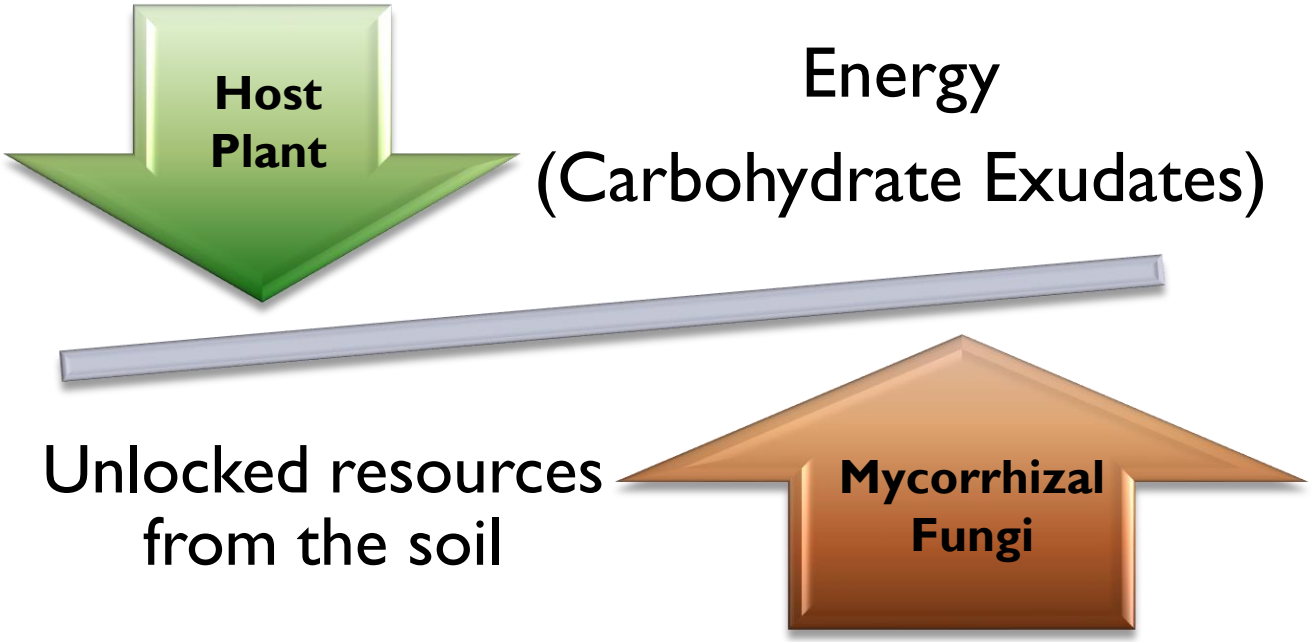
1. Photosynthetic Plants (a Green Plant Community)
2. Fungi (Symbiotic Root Partnerships and Recyclers)
3. A Mix of Soil Biota (Bacteria, Protozoa, Beneficial Foragers)
4. Plant and Other Organic Residues (for Nutrient Cycling)
5. Soil Parent Material (a Mineral Nutrient Supply Reservoir)

Essential to Soil Health: 2. Fungi

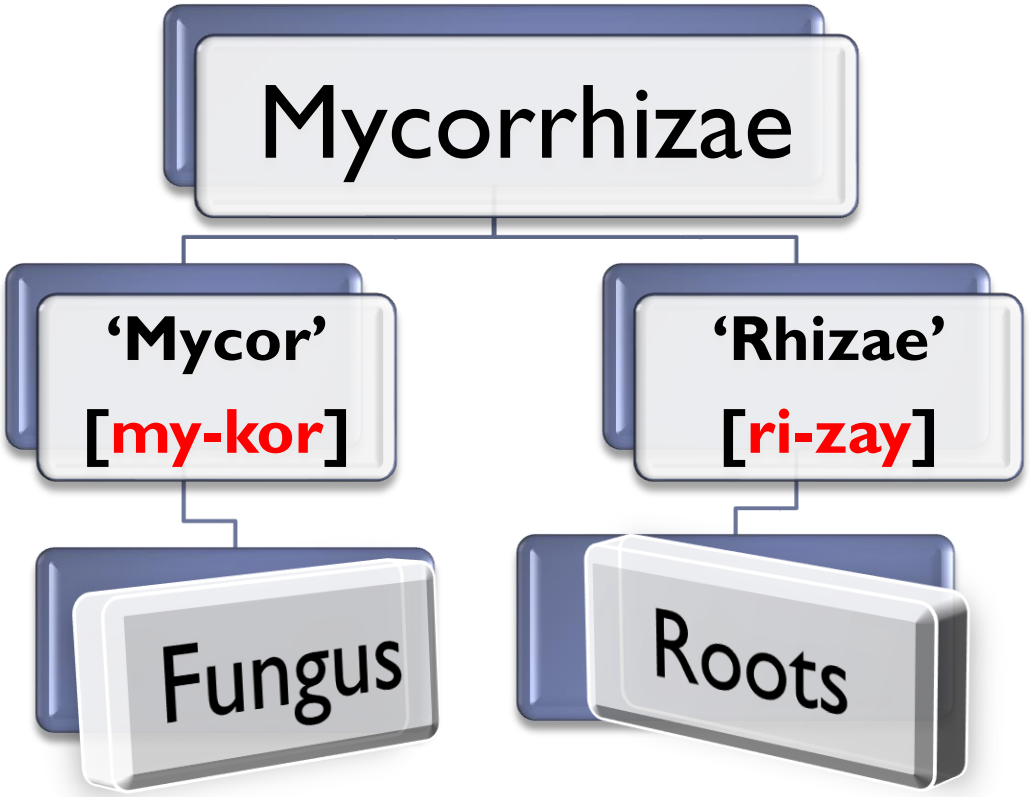
1. Photosynthetic Plants (a Green Plant Community)
2. Fungi (Symbiotic Root Partners and Recyclers)
3. A Mix of Soil Biota (Bacteria, Protozoa, Beneficial Foragers)
4. Plant and Other Organic Residues (for Nutrient Cycling)
5. Soil Parent Material (a Mineral Nutrient Supply Reservoir)

The Natural Trading Partnership

- **20%** of all Photosynthates are given to **Mycorrhizal Fungi** (via various carbohydrate exudates)



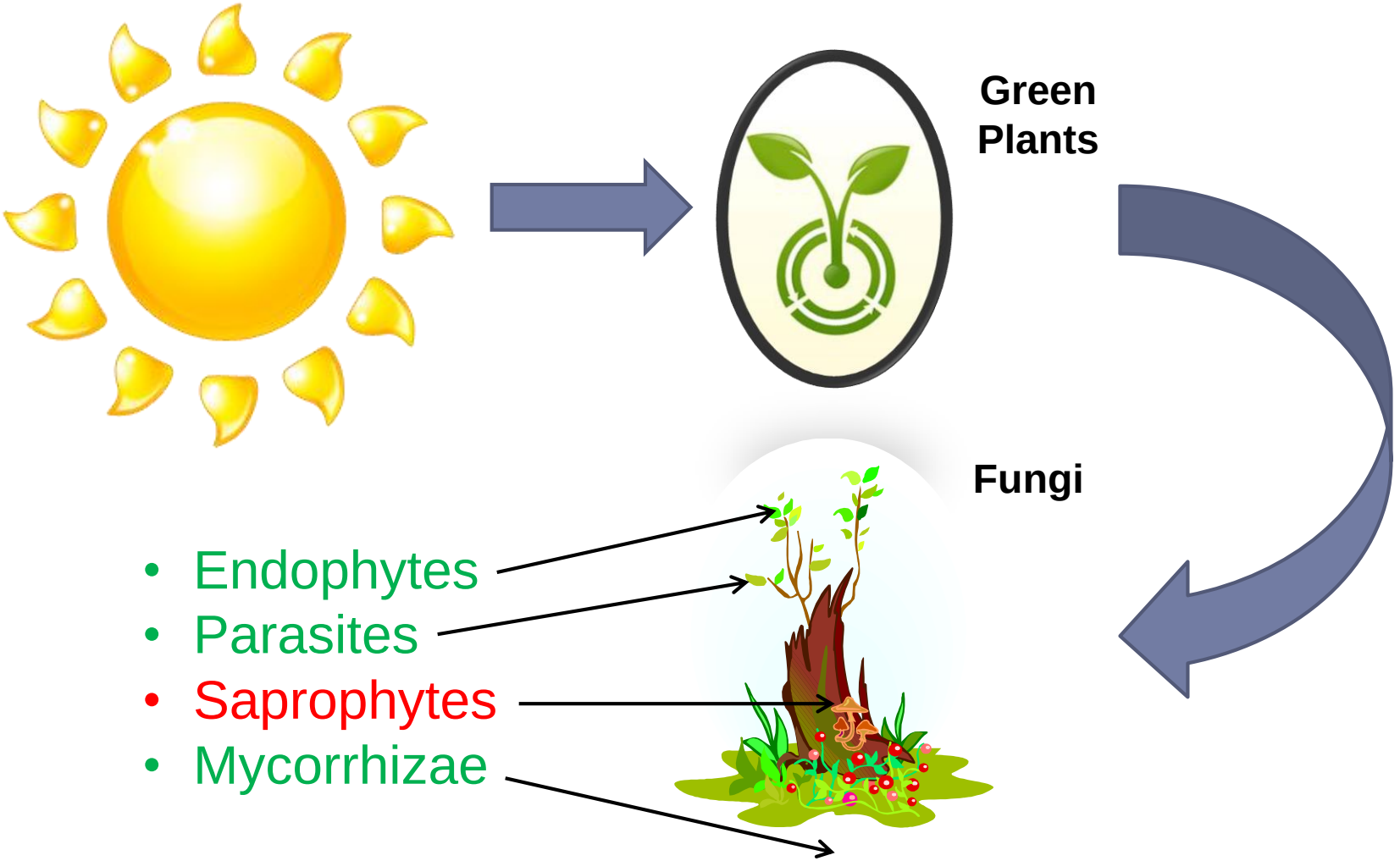
How do you say that?



- **In undisturbed nature, 95% of plants form a unique partnership with ancient fungi. Mycorrhizae help plants find water and nutrients in soil (and more).**

Energy (Carbon) Acquisition by Fungi

- Fungi acquire carbon energy from either Living or Dead hosts



A *Very Old* New Thing!

- **Mycorrhizal Fungi** have been part of the natural world ever since the first plants appeared on land

A Long-Tested Partnership

- Nature is constantly perfecting, repairing, adapting and rebuilding. Through countless ages, a direct partnership between plants and mycorrhizal fungi has persisted.

Arbuscular Mycorrhizal Fungi [AM] – then, and now

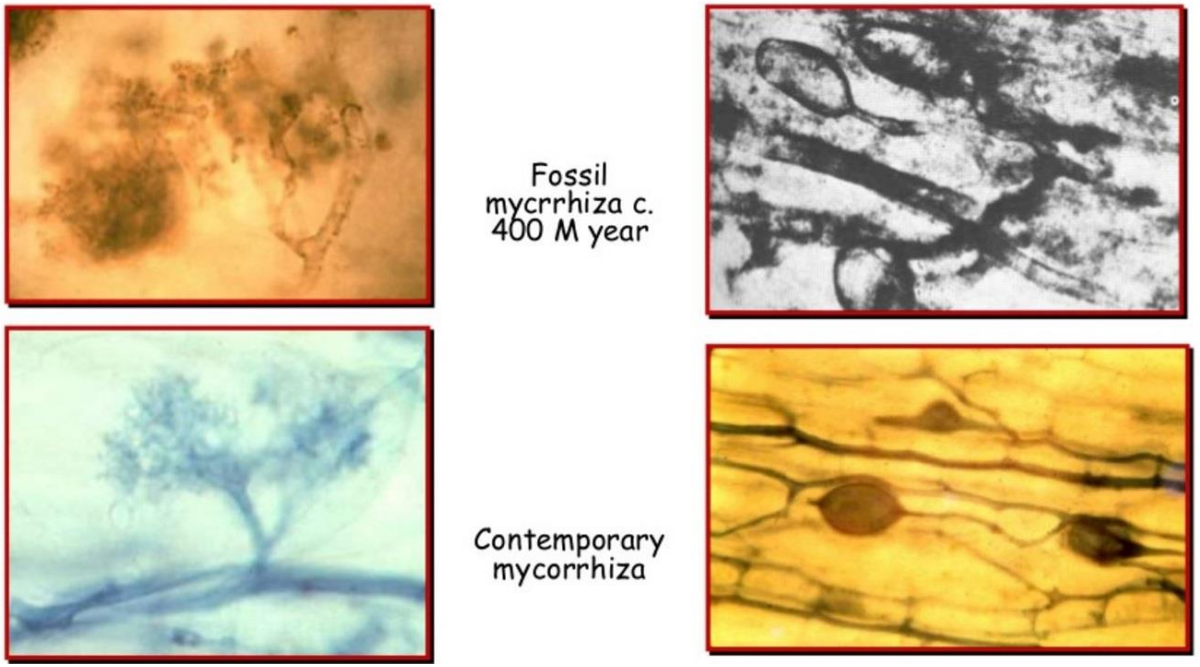
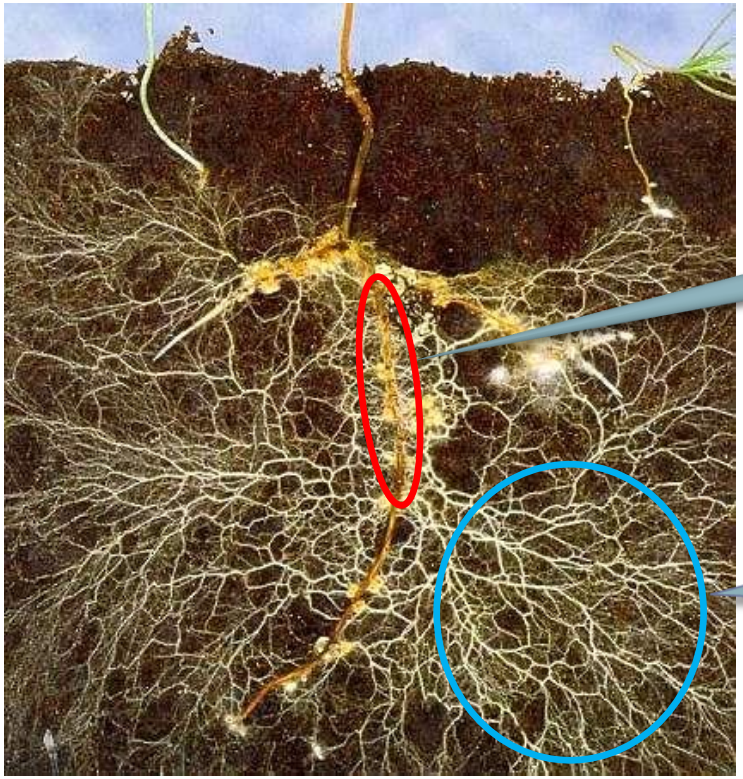


Image by Alberto Bago et al | c/o http://www.slideshare.net/

Let's Look Closer…

- Only **1** to **3** % of soil volume is roots
- Mycorrhizal hyphae can increase this density to **20%**



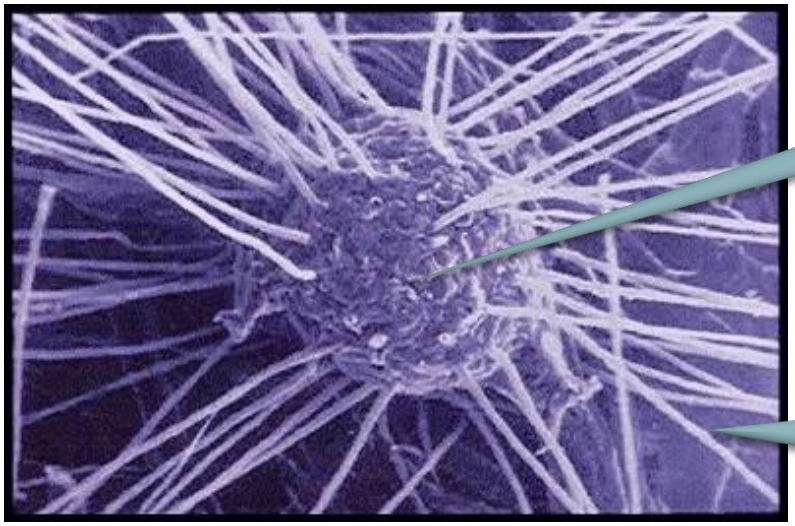
Host Root

Mycorrhizal Web (Hyphae)

Pinus sylvestris & Suillus [ECM]
Image c/o S.E. Smith / D.J. Read

Looking Even Closer…

Now that's small!



A Root Hair Tip

Mycorrhizal hyphae

- The only absorptive surface that a root has is the root tip

The Nutrient Depletion Zone is Expanded 100 to 1000 Times Over by Mycorrhizae

- Mycorrhizal mycelium increase the absorptive surface of roots by adding the Mycorrhizosphere to the Rhizosphere

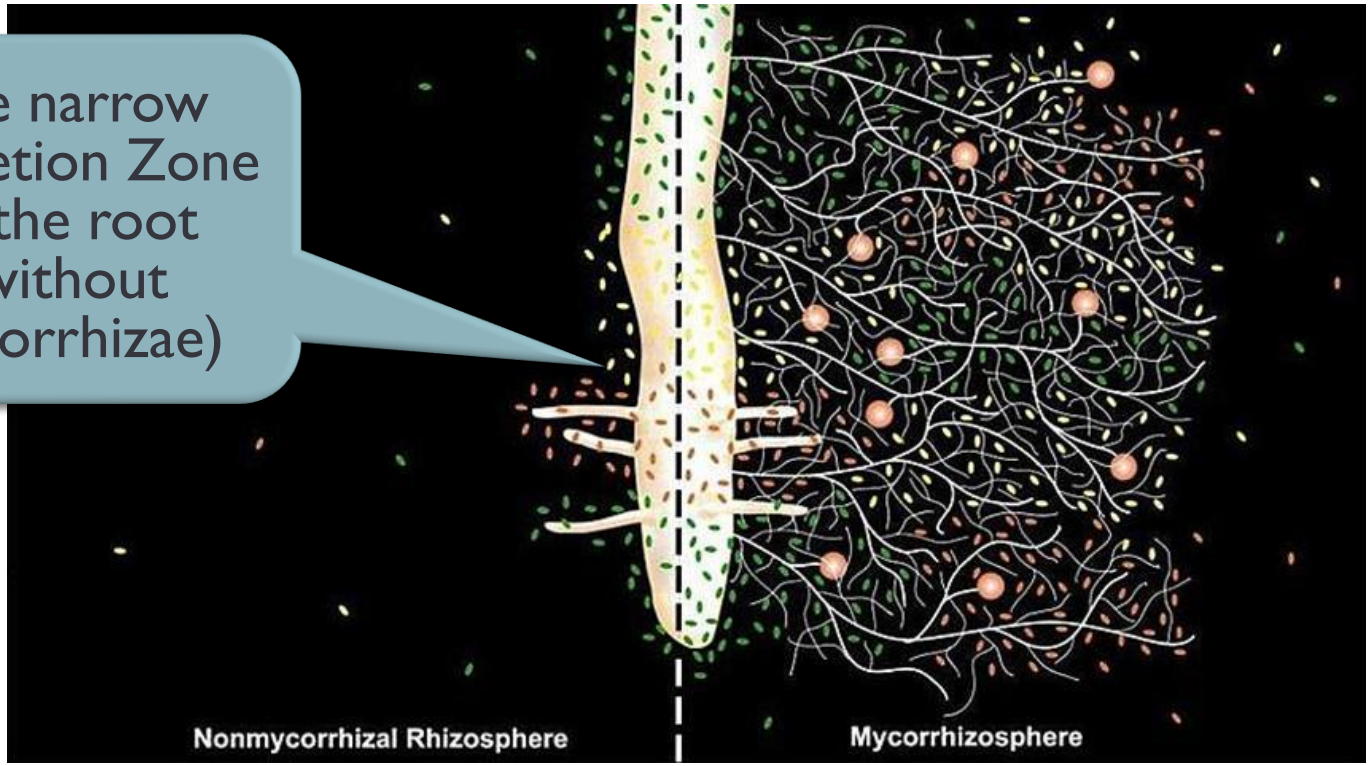
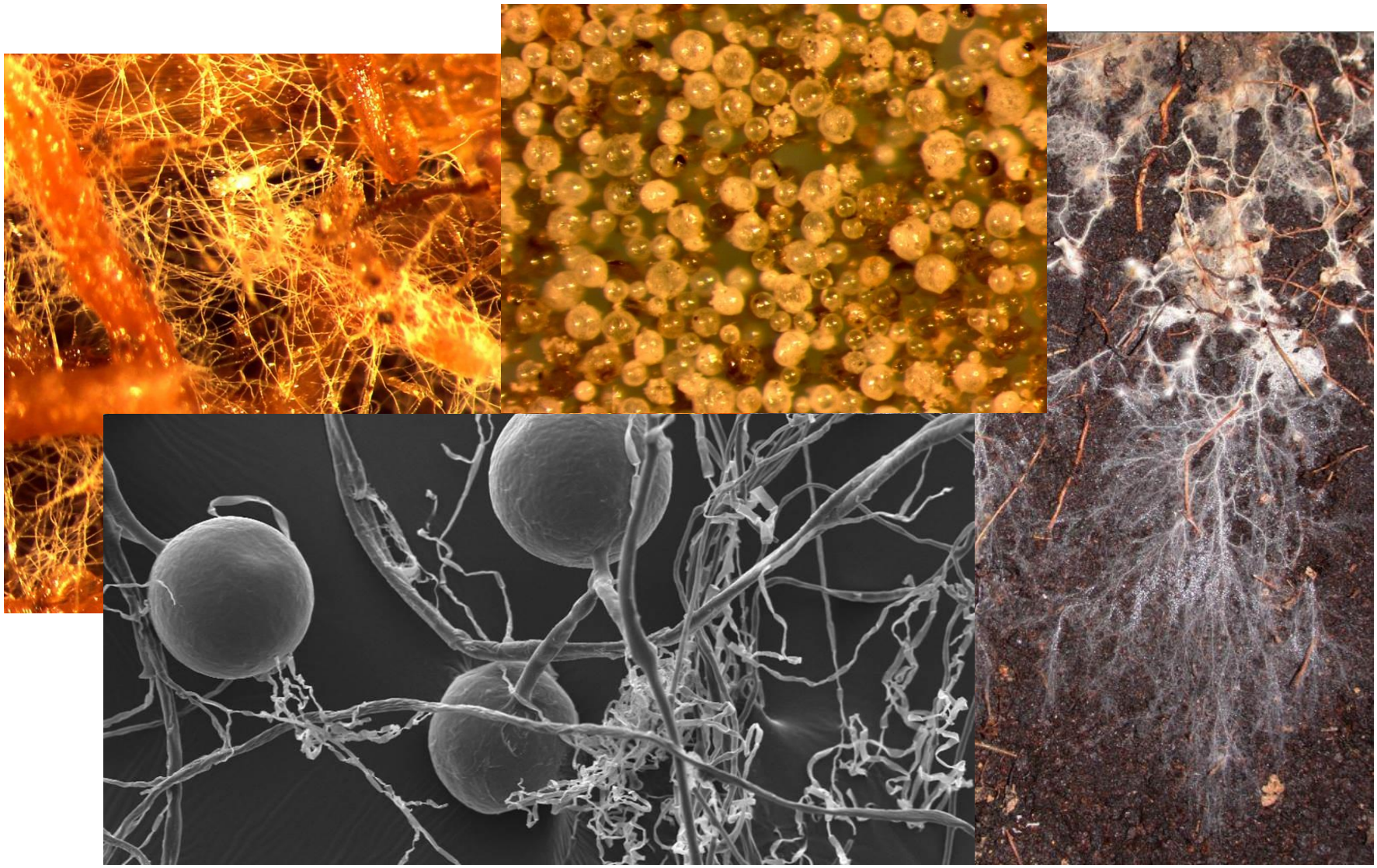


Image c/o Paul Kuttner 2015 / www.culturalorganizing.org

The Root's Fungal Workforce



A Plant Chooses Its Mycorrhizal Partners

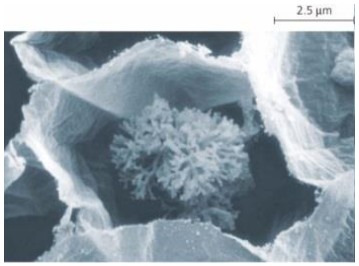
95% of landscape plants associate with 2 classes of mycorrhizae:

Endomycorrhiza [AM]

Ectomycorrhizae

Endo vs. Ectomycorrhizae

An Arbuscule [AM]



Endomycorrhizae [AM] enter a root cell of the host plant and build a tree-like Arbuscule ***inside cortical cells*** where nutrients, carbohydrates, and water are exchanged.

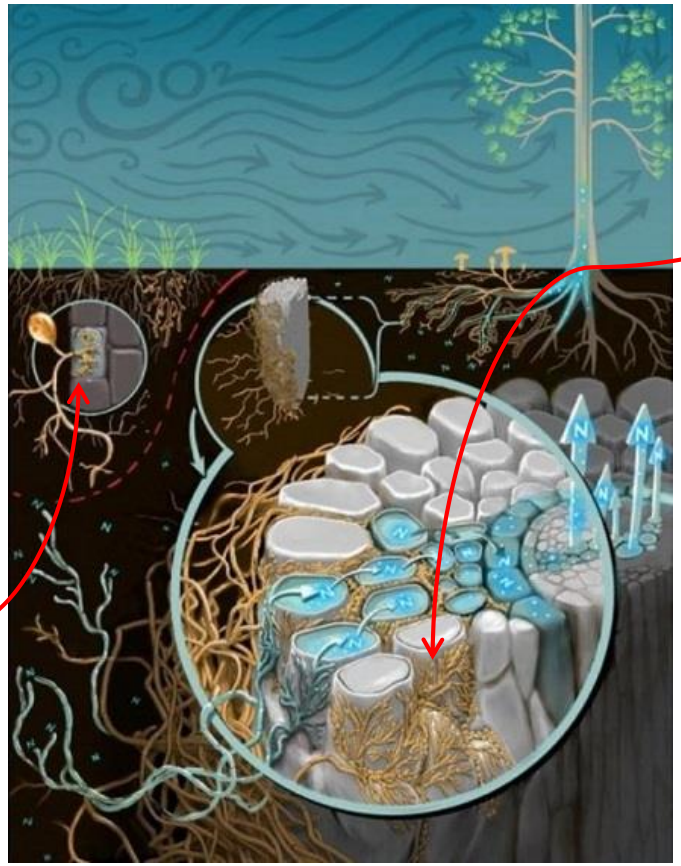
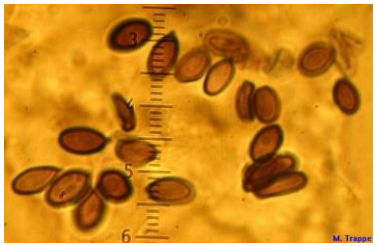


Image by: Victor O. Leshyk

Ectomycorrhizae [ECM] build a dense fibrous latticework of Hyphae called a 'Hartig Net' ***between and on the outside*** of the host plant's root cells where assets are exchanged through the cell wall membrane

ECM Spores



Landscape Plants choose between these Mycorrhizal Types

ENDO [AM]

- Herbaceous Perennials
- Ferns, Grasses,
- Woody Shrubs (Including Juniper, Cedar, Yew)
- Many Deciduous Trees (Maple, Prunus, Malus, Pyrus…)
- Annuals, Vegetables, Grains

ECTO

- All Conifers (Spruce, Pine, Fir, Hemlock, Larch…)
- Hardwood Trees (Birch, Beech, Oak, Ostrya, Poplar…)
- Nut Trees (Hickory, Hazel...)

The Oldest Trees East of the Mississippi rely on mycorrhizae for both water and nutrients

- "The Snake" (Thuja occidentalis) Date of Birth: 795 AD

This ancient Eastern White Cedar is growing in a 5mm crack in the face of the Niagara Escarpment near Lion's Head Ontario.

As of 2020, The Snake is 1,226 years old

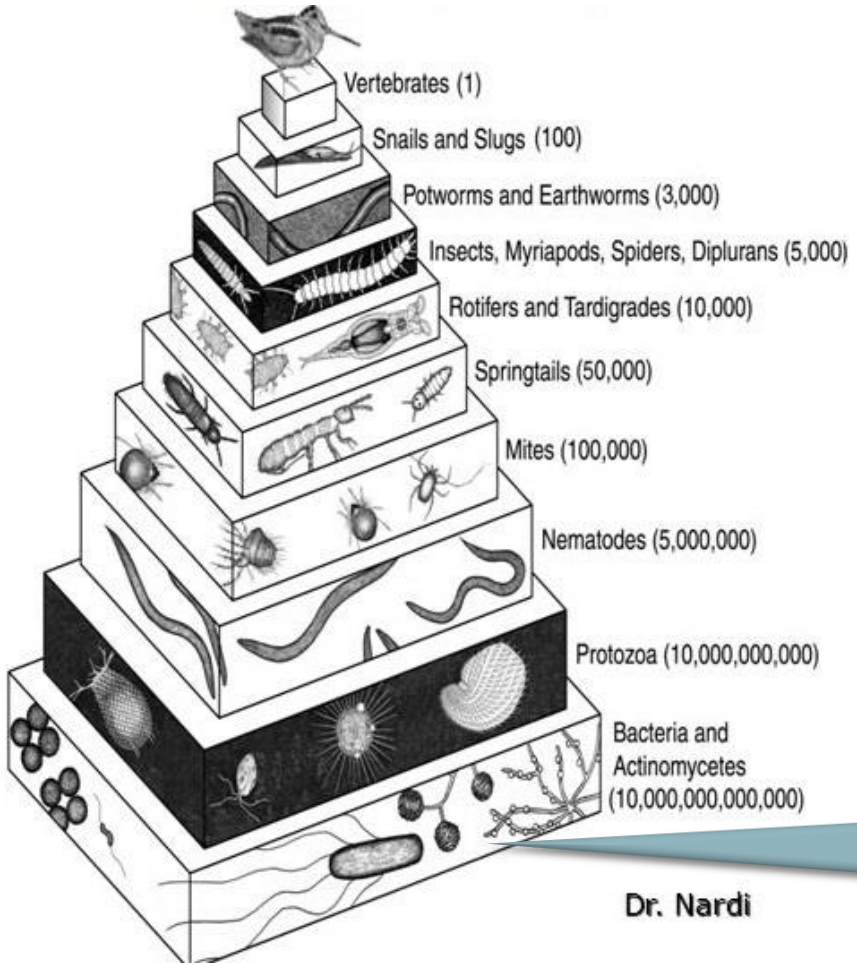
Image by: Peter E. Kelly | from "The Last Stand" P.E. Kelly & Douglas Larson | Natural Heritage Books 2007

Essential to Soil Health: 3. A Consumer Culture

1. Photosynthetic Plants (a Green Plant Community)
2. Fungi (Symbiotic Root Partnerships and Re-cyclers)
3. **A Mix of Soil Biota (Bacteria, Protozoa, Beneficial Foragers)**
4. Plant and Other Organic Residues (for Nutrient Cycling)
5. Soil Parent Material (a Mineral Nutrient Supply Reservoir)

Soil Microbes and Progressively Larger Foragers

- Healthy soil is teaming with a mixed community of countless billions of individual organisms – both single-celled and complex

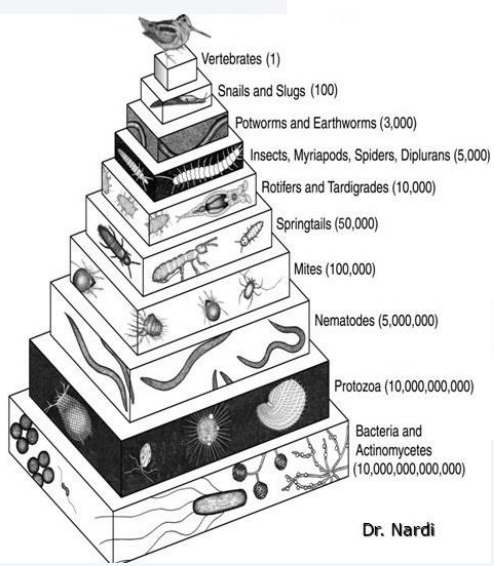


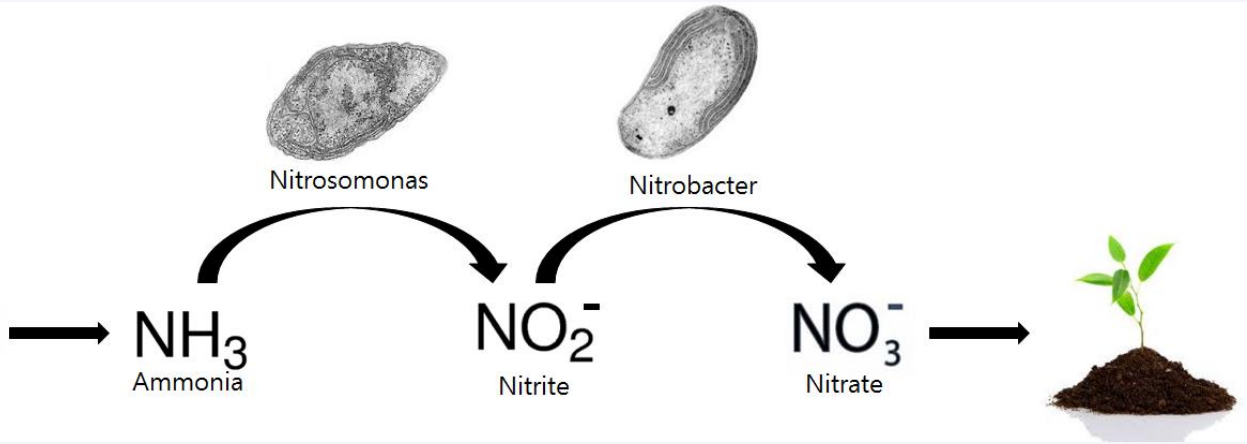
The 9 Trophic Levels of Life in Healthy, Undisturbed Soils

The bottom of the pyramid supports all soil life

Nothing in a Healthy Soil Environment is ever wasted – <u>Especially Waste</u>

The zillions of creatures foraging (and perishing) in in healthy soils produce copious amounts of Ammonia (NH_3)





Bacteria convert this abundant Nitrogen resource into Nitrate (NO_3)

Bacteria Perform Essential Services for Plants

- Plants spend their surplus carbohydrates to feed selected bacterial colonies that perform “Digestive Tasks” that they cannot do
- These Bacteria are identified as: plant growth-promoting bacteria (PGPB)

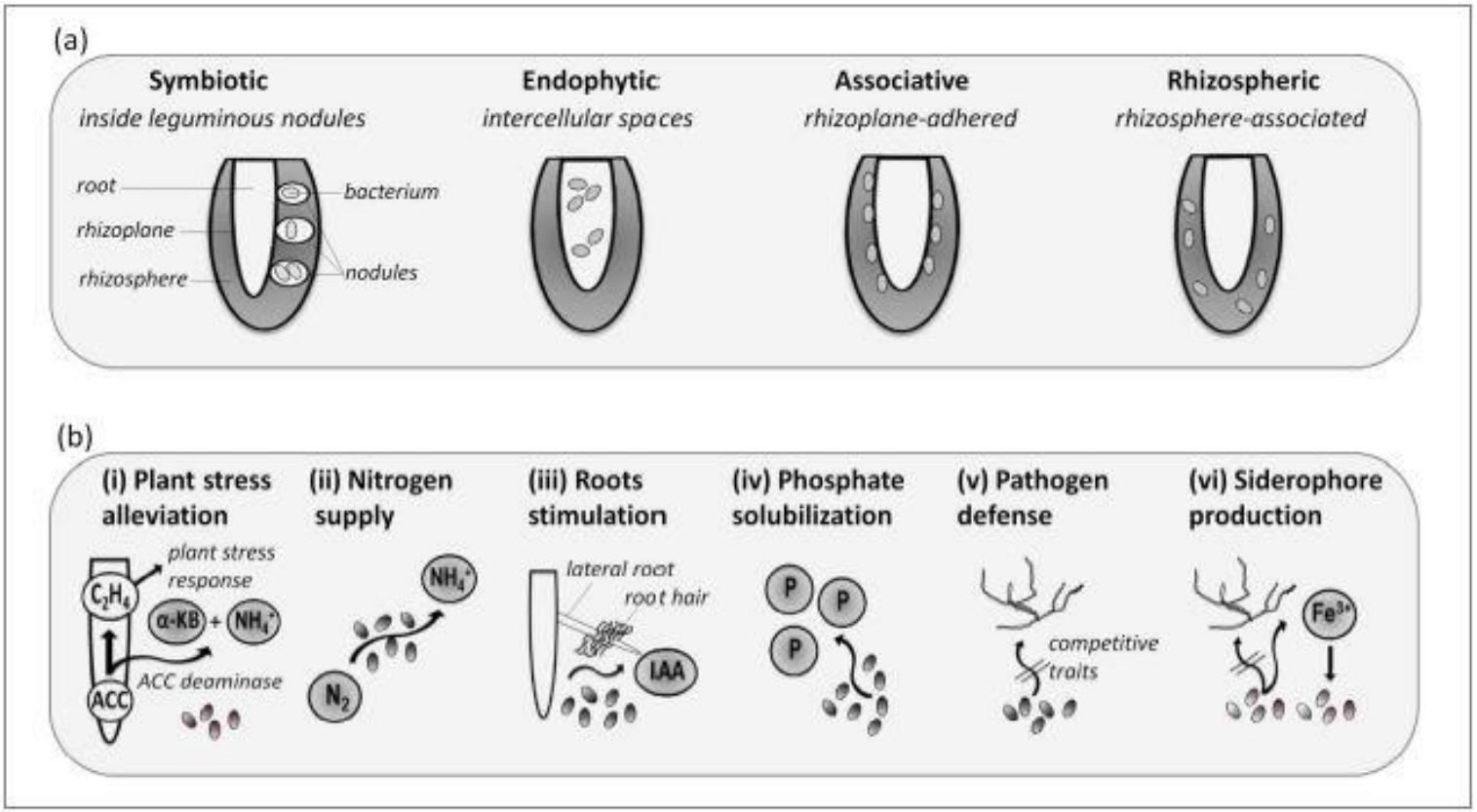
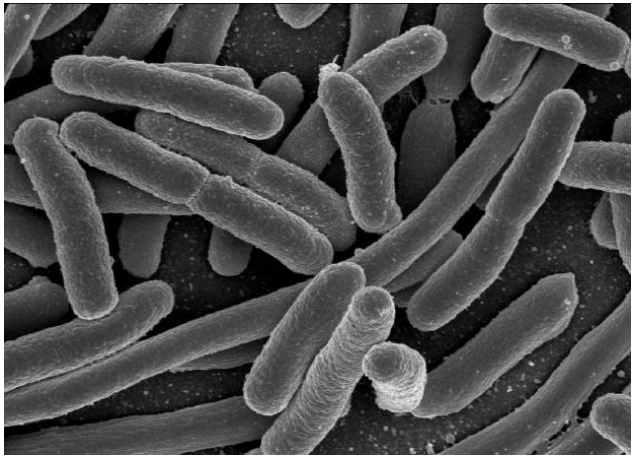


Image courtesy of: Adriana Ambrosini et al

Bacterial Colonies Exploit any source of Carbon

In the presence of scant water (just a Biofilm), within the right temperature range, PGPB colonies will rapidly multiply



Guaranteed Microorganisms	Minimum Count
Bacillus subtilis	2.48×10^8 cfu/g
Bacillus amyloliquefaciens	5.00×10^6 cfu/g
Pseudomonas monteilii	1.00×10^6 cfu/g

CFU = Colony Forming Unit

Soil Microbes and Progressively Larger Foragers

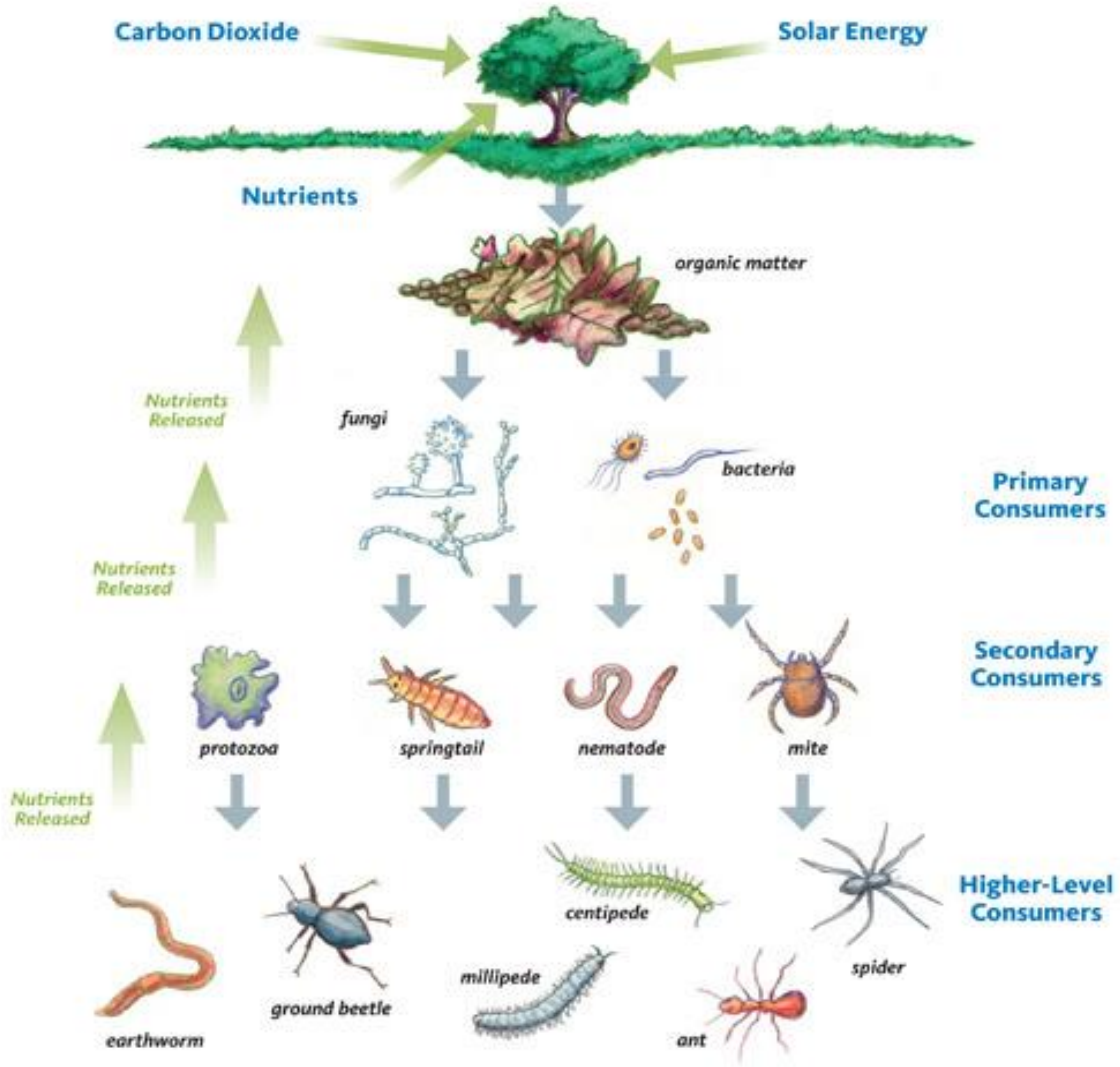


Image courtesy of: Landscapes For Life

It's all about
Who Eats What
(or whom)
and the Nutrient
Residues of all
that Activity

The Soil Food Web & its Pipeline

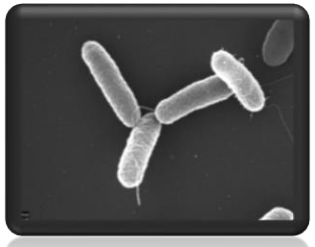
- Plant Roots exude surplus carbohydrates - Mycorrhizal networks are built
- Nitrogen digested by foragers is then converted into Plant Available Nitrate by bacterial colonies. Nitrate is also captured from Free Nitrogen Fixing bacteria – all flow to the roots through mycorrhizal hyphae (the living nutrient delivery pipeline)

The Mycorrhizal Mycelial Network

Aerobic Foraging Bacteria (abundant in healthy soils)

Free Nitrogen Fixing Bacteria

Protozoa
(Exude Ammonia)



Nitrifying Bacteria

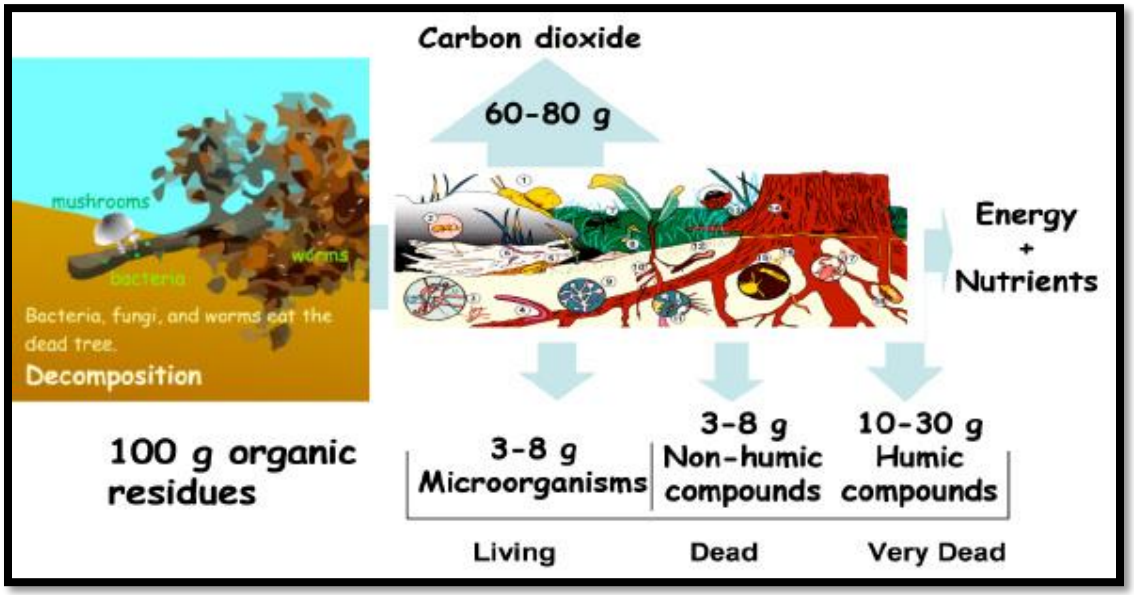
PA Nitrate flows to the roots through the Mycelia

Essential to Soil Health: 4. Soil Organic Matter

1. Photosynthetic Plants (a Green Plant Community)
2. Fungi (Symbiotic Root Partnerships and Re-cyclers)
3. A Mix of Soil Biota (Bacteria, Protozoa, Beneficial Foragers)
4. Plant and Other Organic Residues (Nutrient Cycling Results)
5. Soil Parent Material (a Mineral Nutrient Supply Reservoir)

Soil Organic Matter [SOM]

- SOM: living microorganisms, fresh (recently dead) organic residues, plant roots, microbes, insects and animals, and very tough (long dead) organic compounds that resist microbial decomposition (humic compounds). These are the CEC 'Batteries' in soil that hold Nutrient Cations until needed by plants
- In healthy soils, billions of microbes digest and dismantle SOM, then root tips and mycorrhizal fungi transport the converted nutrients into plant roots



CEC = Cation Exchange Capacity

Diagram courtesy of OSU Fact Sheet SAG-16

Essential to Soil Health: 4. Mineral Reserves

1. Photosynthetic Plants (a Green Plant Community)
2. Fungi (Symbiotic Root Partnerships and Re-cyclers)
3. A Mix of Soil Biota (Bacteria, Protozoa, Beneficial Foragers)
4. Plant and Other Organic Residues (for Nutrient Cycling)
5. Soil Parent Material (the Mineral Nutrient Supply Reservoir)

How do these ancient Red Pines get the nutrients that they need from the unyielding Granite of the Canadian Shield?

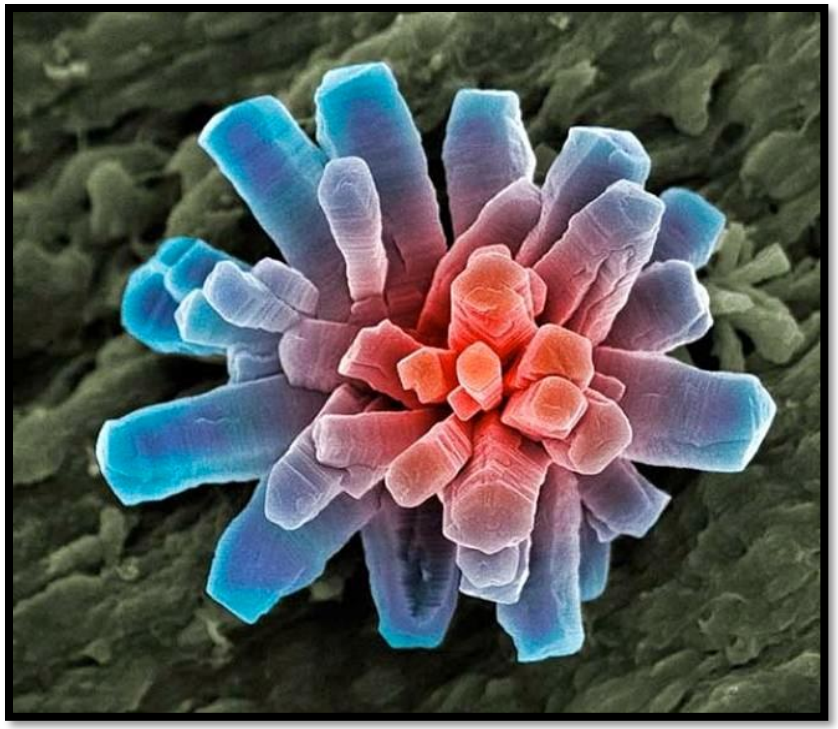
Image of Wolf Lake (Temagami ON) by Rob Nelson | http://www.savewolflake.org/ | http://www.robnelson.ca/

- Nutrients from mineral sources are obtained by plant roots through close associations with soil microbes and mycorrhizal fungi – these essential organisms solubilize minerals.

A Very Close Look at Phosphate

- Mycorrhizae use enzymes (acids) to release tightly-bound nutrient anions

A calcium phosphate crystal 'bound' to a typical clay matrix

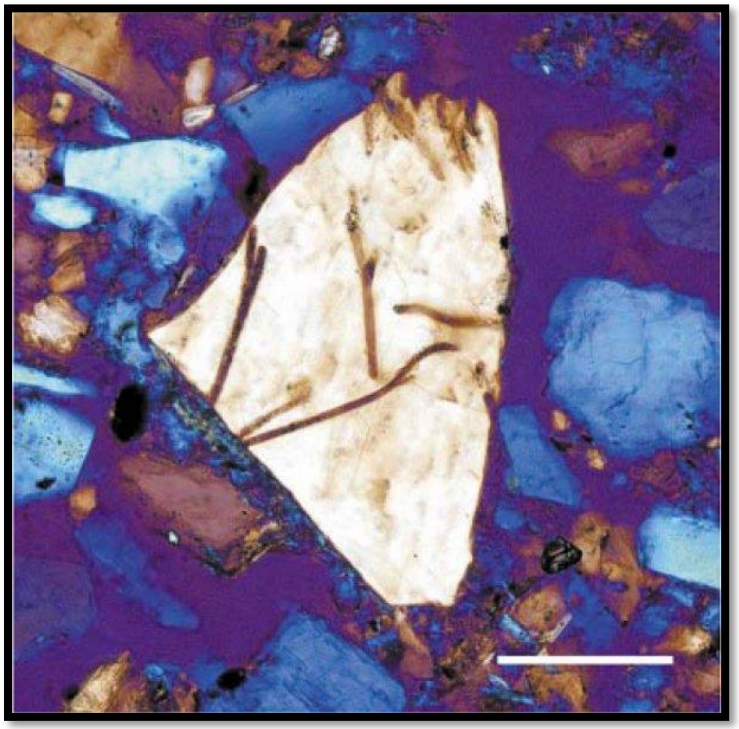


- Mycorrhizal hyphae inundate the parent material of soil and release bound nutrients
- Phosphatase enzymes exuded by mycorrhizal hyphae convert mineral phosphate to a Reactive (Plant Available) form and deliver it to the roots

Mineral Mining in Action

- Mycorrhizal hyphae mining for minerals

A flake of feldspar showing grooves where hyphae 'bored' holes



- Phosphorus, potassium, calcium, magnesium, boron, manganese, zinc, iron, molybdenum, copper…
- Enzymes and acids exuded by mycorrhizal hyphae release and capture mineral macro and micronutrients needed by their plant hosts

Image by: Landeveert 2001
from Scientific American - by Jennifer Fraser

Breaking Nature's Balance: The Factors that Disturb Urban Soils

3 Major Factors Disrupt Natural Soil Life:

1. Industrial Contamination (Toxins)
2. Construction and Cultivation
3. “Lazy Root Syndrome”

Heavy Duty Damage

The fact that this kind of human activity harms the ecosystem is not hard to imagine. But it doesn't take industrial-scale damage to harm soil ecology.

What Gets Broken when we build?

Topsoil is Stripped, Piled and Compressed

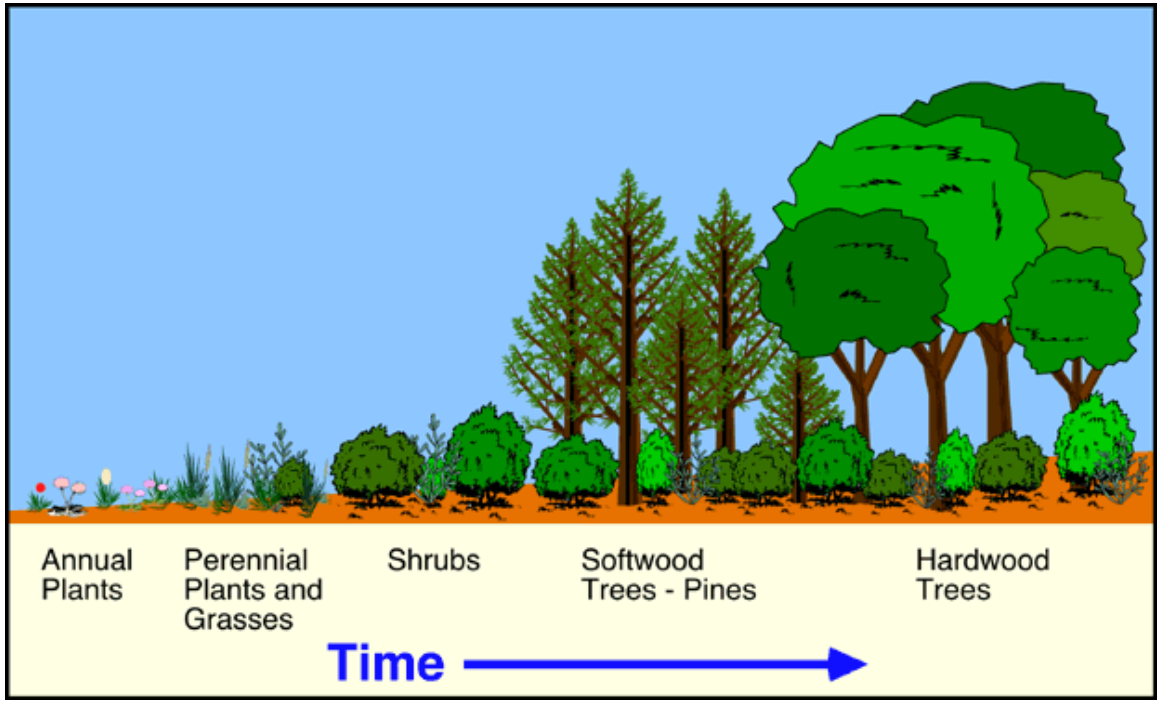
- Subsoil is raised by construction
- Heavy equipment compacts it all
- Desiccated organics drift in the wind

Dust rises and the new streets look like a Western Ghost Town

- Eventually a thin layer of the crushed topsoil is spread over the compacted land
- Sod is rolled out and people move in

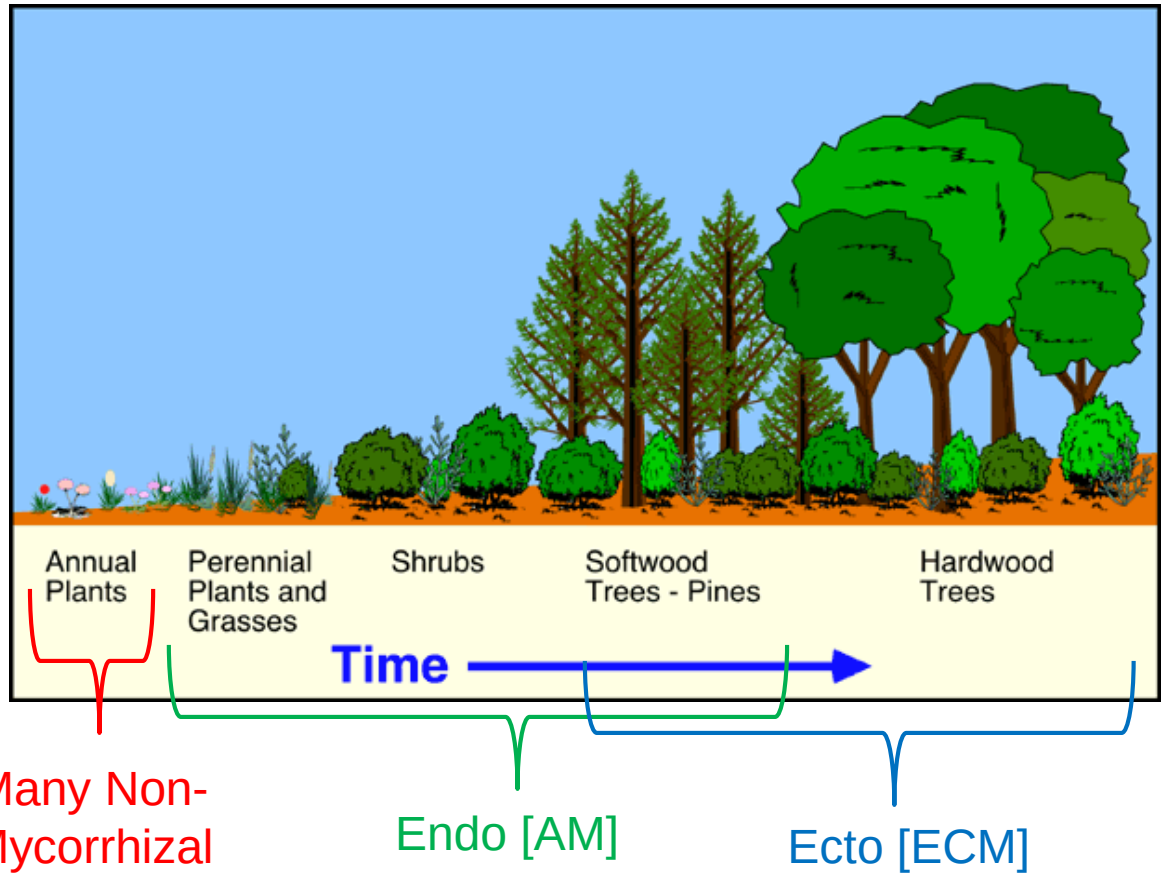
Disturbed Soils are what Landscapers work with

- The soil on new construction sites are either sterile or bacterial, triggering aggressive infiltration of early-succession plants (weeds)
- But - we plant mid and climax-succession plants into these highly disturbed urban soils – no wonder they struggle to establish roots



Mid & Climax Succession Plants struggle in Disturbed Soils

- Plants installed into the disturbed soils on landscape sites need mycorrhizal partnerships and nutrient producing microbial communities to function optimally
- **Assist plant adaption in disturbed soils.** Apply: Mycorrhizae matched to the plant host (AM/Ecto) + Bacterial Inoculates proven to provide nutrients



Synthetics Switch-Off Natural Soil Life

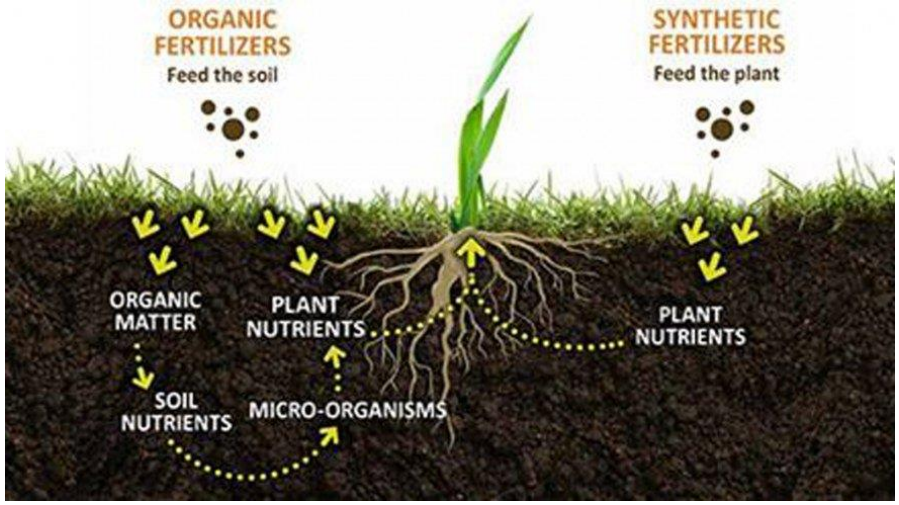
- Plant roots do not metabolize synthetic nutrients efficiently
- Leachates are a major environmental problem
- And - Plants abandon (stop feeding) their mycorrhizal/microbial partnerships. This is called "Lazy Root Syndrome".
- Soils become lifeless, shallow, compacted and unstable

Synthetic Fertilizers Work – But…

- Synthetic Fertilizers Feed the Plant via salt-based chemistry
- Whereas, Organic Fertilizers & Bio-Fertilizers Feed the Soil

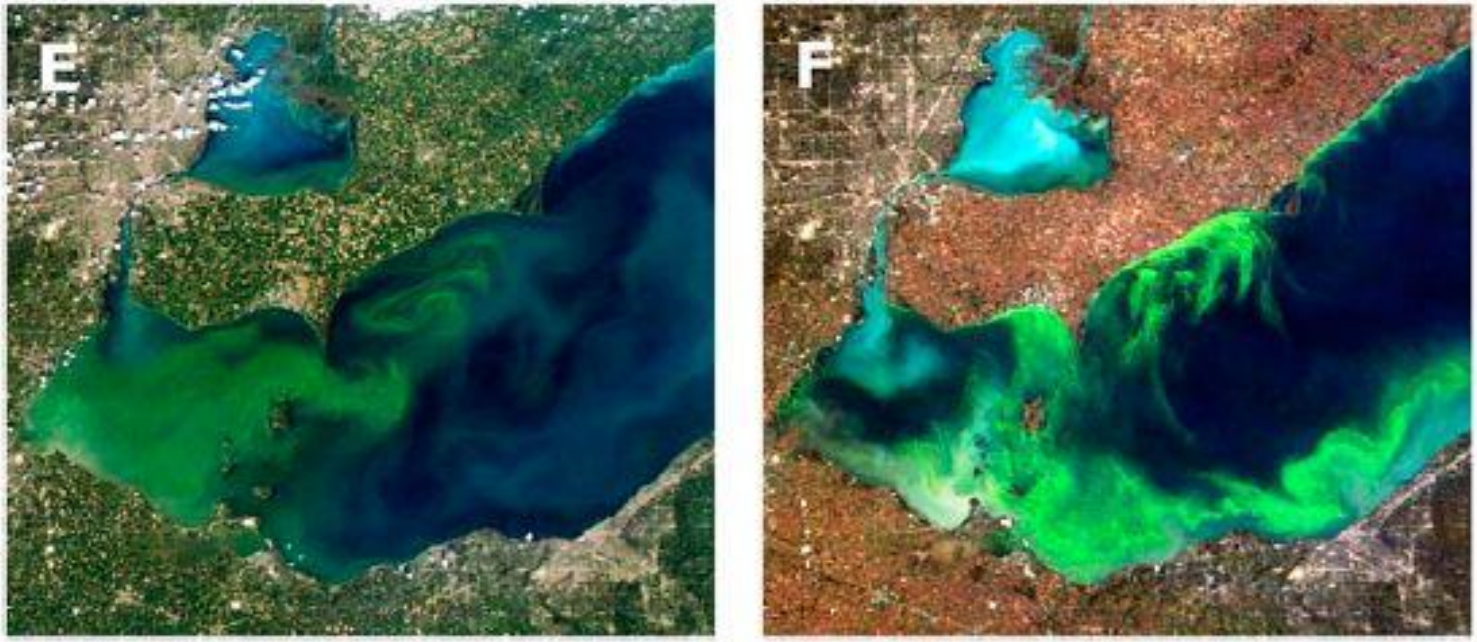
So, when we use Synthetic Fertilizers:

1. The microbial life in soil is starved-out and their benefits are lost
2. Plants have not evolved to directly access nutrients – they are only about 20-25% efficient at this task. As a result, 75-80 % of applied synthetic fertilizers escape as highly-reactive leachates



Where do synthetic phosphates end up after leaching from fields and landscape soils?

- The Lake Erie toxic algae bloom as seen from space in Fall 2011
- According to the IJC, this annual algal bloom is created by a sustained runoff of Dissolved Reactive Phosphorus [DRP] from the watershed



Images from: International Joint Commission (2014). Report: A Balanced Diet for Lake Erie…

Plants Roots do not Metabolize Dissolved Reactive Phosphate Efficiently

- Only 20% of applied synthetic phosphate is absorbed by plant roots – **80%** escapes into the environment – the consequences are far reaching
- Plant roots 'bathed' in synthetic nutrients develop "Lazy Root Syndrome"
- Plants stop supporting mycorrhizal fungi and the soil biome – and become dependent on continued synthetic fertilizer applications.

Image from: International Joint Commission (2014) Report: A Balanced Diet for Lake Erie

We Can Restore the Benefits of Soil Microbial Life on Landscape Sites

- **An organically maintained landscape site.** Mycorrhizal Networks and Microorganisms below grade supporting a diverse plant (and soil life) community
- No leaching of valuable plant nutrients into groundwater and streams
- Survival rate on this Zone 5a site in Caledon (2015-2016): **100%**

Image courtesy of Reevisions Designs and Doug McClure Land Services (2015)

Re-establishing Natural Soil Ecology on Urban Landscape Sites

Image of Wolf Lake (Temagami ON) by Rob Nelson | http://www.savewolflake.org/ | http://www.robnelson.ca/

- We can learn from the way natural soils function
- We can re-establish/restore natural soil structures and biology on urban landscape sites
- The environmental and economic benefits are real

Does Restoring the Mycorrhizal Population Help When Planting?

How do we know that Inoculation with Compatible Mycorrhizal Fungi works?

- 4 years of testing by the University of Guelph
- The latest technology was used

Replicate – then – do it again!

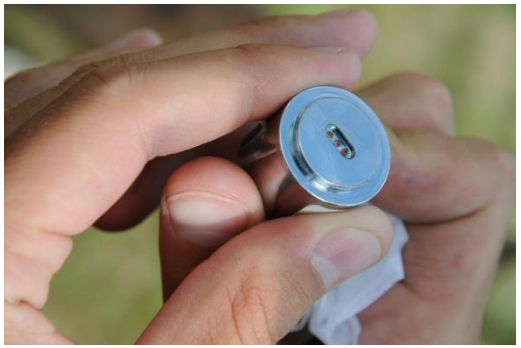
- Stem Psychrometers simultaneously reporting the stress levels of 32 trees
- Half were drenched with Root Rescue Transplanter – half were just watered
- Stress level data was collected every 30 minutes, 7 days a week

Research Supports Biological Plant Care

UNIVERSITY of GUELPH

- Stem Psychrometers are attached to the trunk of a tree by scraping away a small amount of bark – exposing the Xylem layer – the pipeline from the roots.

Expose the Sapwood



Check the Sensor

Attach the Sensor

Seal the Connection

Attach the Datalogger

Insulate the Sensor

Graphing Water Status (Stress) - 24/7

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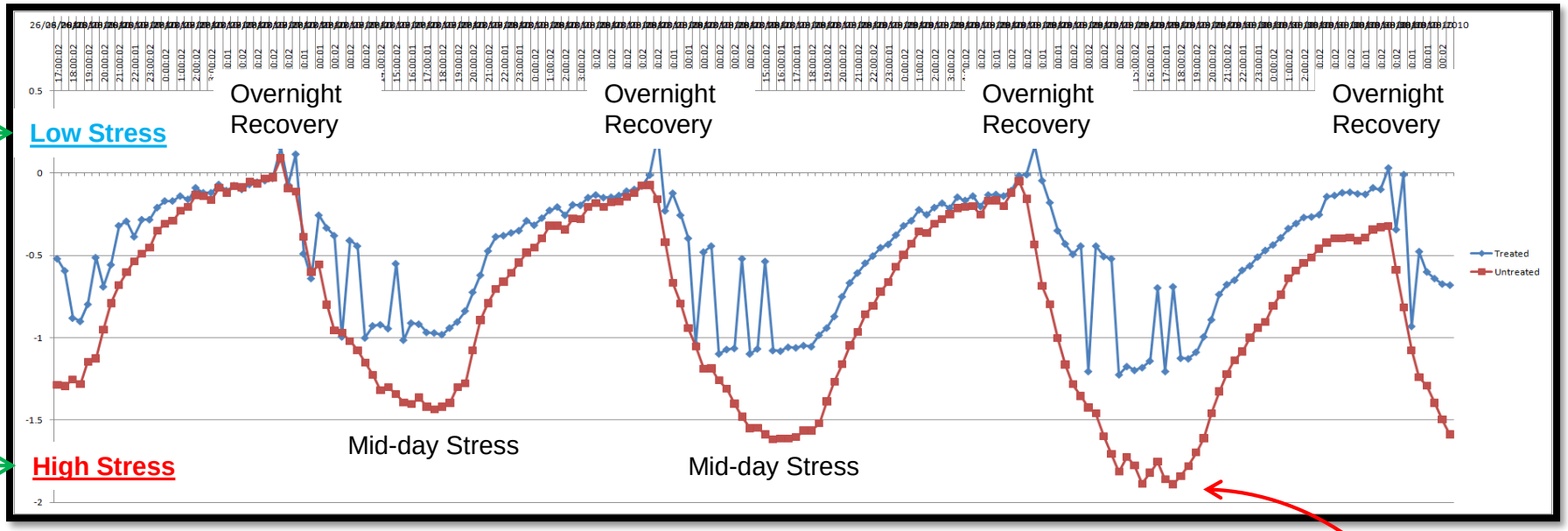
The data sample in this graph presents the average water status of 6 treated vs 6 non-treated Dawn Redwood

Four Days Without Rain – a Pattern Emerges



- The Daily Rhythm of Stress and Recovery
- Blue trees: inoculated with a consortia of compatible mycorrhizae
- Red trees: simply watered
- The Dangerous Dip

When the Going Gets Tough the Mycorrhizal Advantage Kicks In

- Chanticleer Pear
- Stress takes its toll

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- U of G Research published in 'Acta Horticulturae' in 2015
- Publication available for download at: http://www.rootrescue.com/site/university-of-guelph-data

Growing Plants with Biology

DO:

- Inoculate all new plantings with a Compatible Mycorrhizae
- Use Mulching Mowers. Grass clippings have a high C:N ratio
- Convince your clients that a lawn with 25% clover in it is "A Beautiful Thing"
- Boost healthy soil microbial soil communities with Beneficial Bacteria Inoculates, Compost Tea, and high-quality Compost
- Get a Leaf Shredder. The finer that leaves and twigs are broken down, the quicker they can be composted

DONT:

- Use synthetic fertilizers with a P_2O_5 percentage higher than 8% (if you must use synthetic fertilizer, only use slow-release forms - better still - use Organic Fertilizers)

How Caring for Soil Life Improves Your Bottom Line

- Natures has developed an incredibly efficient microbial community that supports landscape plants
- Engaging and supporting this natural network is like switching on an unpaid, self-sustaining workforce
- Once the microbial workforce has 'Punched-In", nutrient and other inputs can be reduced
- Plants establish deep root systems - soils retain more storm water - reducing irrigation requirements and storm runoff
- Healthy soil/plant communities also reduce the occurrence and severity of plant disease and insect attack

The ROI

The Early Payback comes from Reduced Plant Failure Rates on Landscape Sites

- Replacing failed plant material kills profits - and makes no friends.
- Organic Inputs may cost more – but are used less frequently, have a sustained effect, and a perceived higher market value
- All sectors of the economy linked to 'Organics' are growing in market share.
- Today's homeowner is highly motivated to choose products and services based on concerns for the health and safety of their family and the environment.
- Your company's 'Organic Profile' will win you market share

Growing Plants with Biology (rather than Chemistry)

Why make the change?

Unlock the Power in Microbial Soil Life

Are we not “The Green Industry”?

We need to become Stewards of The Soil – Nature can, and will, take care of plants.

Key Points:

- Respect the dynamics of soil life.
- Move toward Sustainability – and beyond - to Restoration
- We have new tools in the toolbox
- Synthetics-based plant care ignores or disrupts the sustained power that a healthy soil microbiome provides to plant communities – and to all of us
- Support plants with Biology not Chemistry - inputs and failures decline as self-sufficiency increases
- Synthetics damage the wider ecosystem – we have alternatives
- Nature has perfected a self-correcting, sustainable engine for growing plants. Ignore it, or employ it – it’s your choice

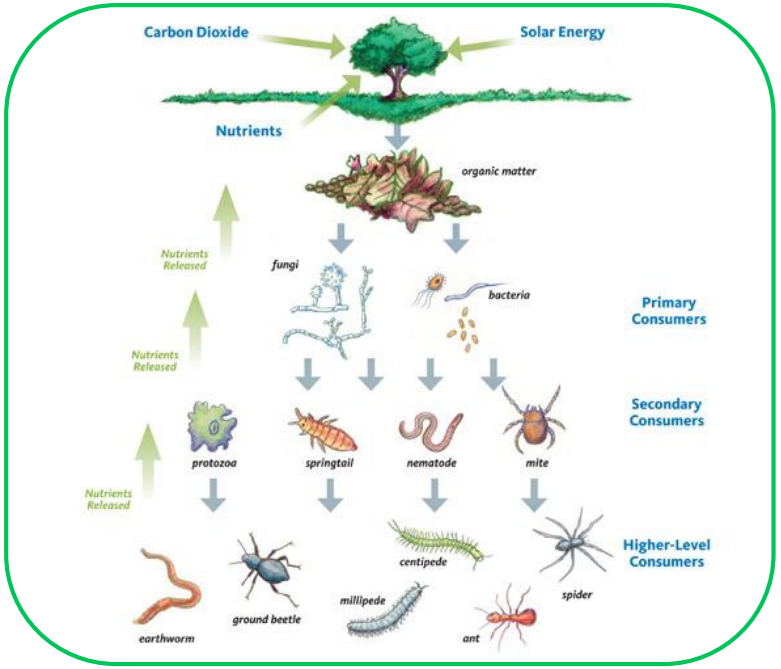
The 2 Options we have:

A Nitrogen Fixing 'Plant'

Powered by:

- Burning and converting billions of cubic meters of non-renewable natural gas to make Urea
- A massive hydrocarbon-fueled infrastructure

A Nitrogen Fixing 'Plant'



Powered by:

- A dynamic living soil community
- Organic fertilizers and composts
- And – The Sun
- Note: Also fixes Phosphorus, Potassium, Carbon, Zinc, Boron….

Tulip Tree
Field Trial – Summer 2009
(Photo taken Oct. 2015)

Thank You!

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