Soil Health & Sustainability

RETHINKING THE MANAGEMENT PARADIGM

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Soil Health
unlock the SECRETS IN THE SOIL
The continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans

Soil Function

unlock the SECRETS IN THE SOIL

The Four Ecosystem Processes

- ***Carbon Cycle*** (Solar Energy to Chemical Energy)
- ***Biocommunity Cycle*** (Soil Food Web, Plants and Animals)
- ***Water Cycle*** (infiltration & availability)
- ***Nutrient Cycle*** (Soluble and Plant Available)

- ***Physical Stability and Support***
- ***Habitat for Biodiversity***

Two Systems for Growing Plants!

unlock the SECRETS IN THE SOIL

Dysfunctional Chemical Paradigm

Functional Ecological Paradigm

Paradigms for Growing Plants

unlock the SECRETS IN THE SOIL

Dysfunctional Chemical Paradigm

Functional Ecological Paradigm

Downward Spiral of Soil Degradation in annual systems

1. Intensive tillage, insufficient added residues, low diversity, no surface cover

2. Soil organic matter decreases, erosion, subsoil compacted

3. Aggregates break down

4. Surface becomes compacted, crust forms

5. Infiltration decreases
Erosion by wind and water increases,
Yield consistency declines

6. MORE ponding & persistent wetness, but LESS soil water storage; less rooting; lower nutrient access efficiency; less diversity of soil organisms, more disease and pests

7. More soil organic matter, nutrients, and top soil lost

8. Crop yields decline

9. Hunger and malnutrition, especially if little access to inputs

Modified from *Building Soils for Better Crops*

We have made our soil “leaky”

Chemical paradigm

↓

Simplified cropping system

↓

Maximize nutrient saturation in space & time

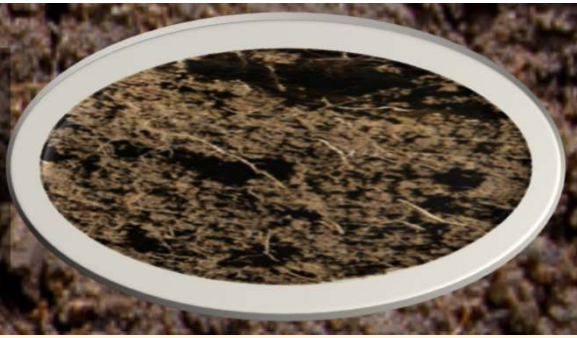
→

A Common *Myth* about inorganic fertilizers: They feed the plant directly

Fertilizer Nitrogen applied lbs/ac 	Corn Grain Yield Bu/ac	Total N in corn plant lbs/ac	Fertilizer derived N in Corn lbs/acre	Soil-derived N in corn, in lbs/ acre	Fertilizer-derived N in corn as percent of total N in corn %	**Fertilizer-derived N** in corn as percent of N applied % 
45	62	77	**25**	54	**33**	56
90	73	131	**50**	81	**38**	55
180	88	141	**78**	63	**55**	43

(Calculated from Reddy and Reddy 1993)
Page 725 13th Edition Nature and Properties of Soil

Regenerative Soil Health Management Systems



9. Better crop yields & quality; lower cost, risk, environmental impact

7. Less energy, inputs and tillage needed, more water stored, better rooting, more nutrient access, greater soil organism diversity, less disease

8. Field conditions more resilient and consistent

5. Infiltration increases, wind and water erosion decrease

6. More SOC, nutrients, and top soil built

3. Aggregates rebuilt

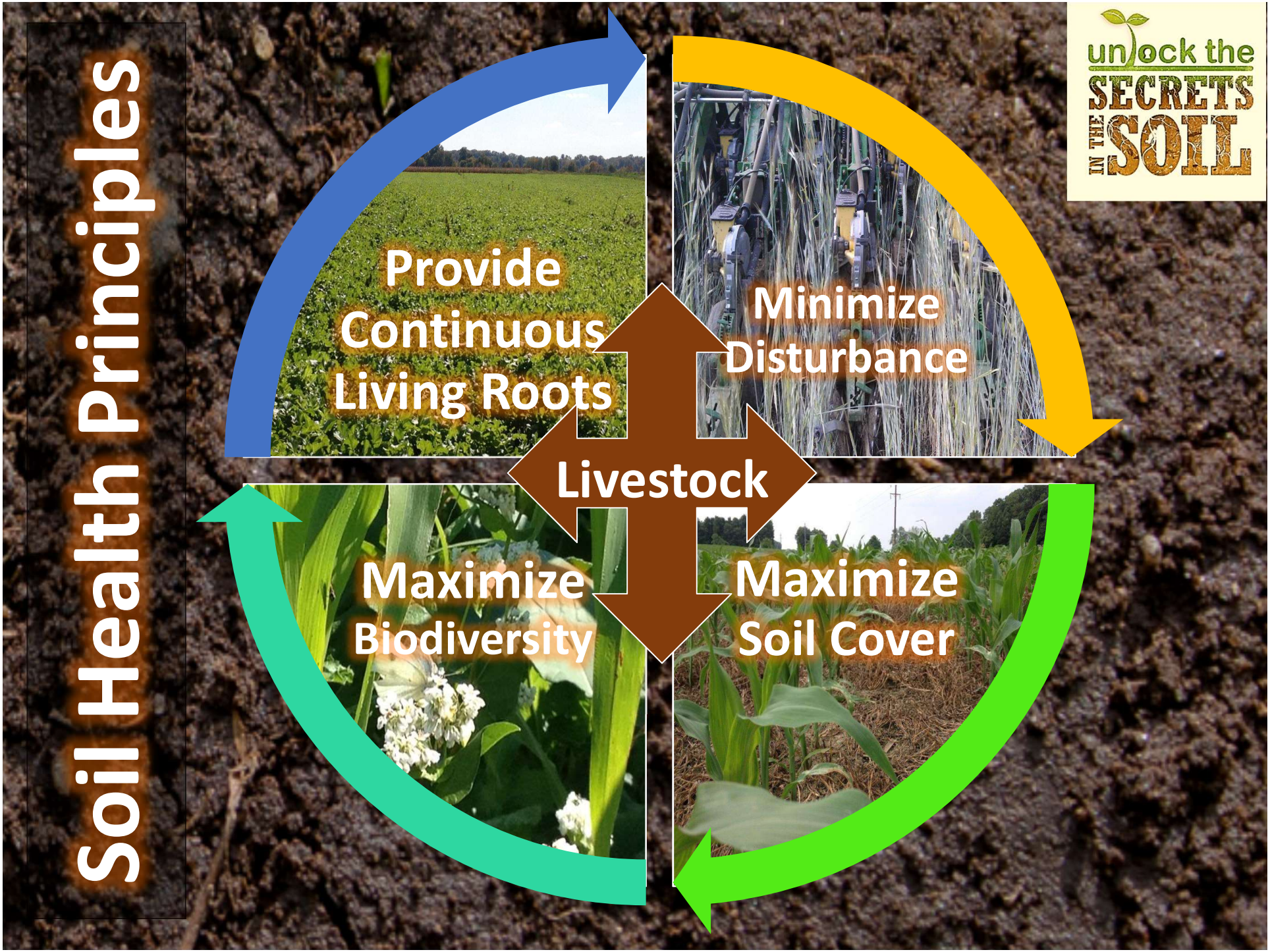
4. AWHC increases

1. Reduced tillage, more rooting, higher diversity, surface cover

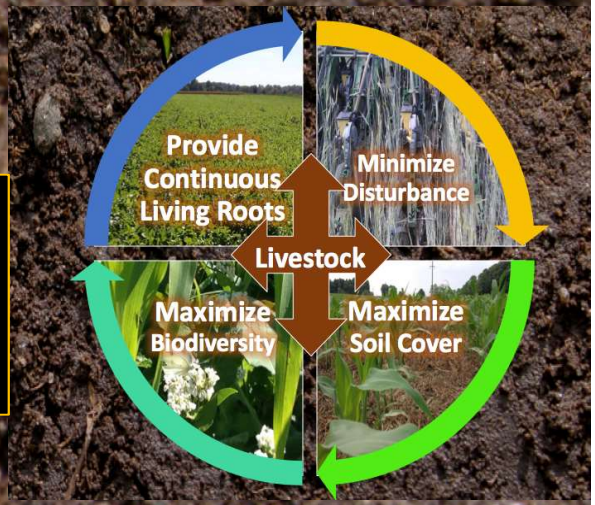
2. SOC increases, rooting reduces compaction

Modified by Moebius-Clune and Cox from *Building Soils for Better Crops*


How do we enhance
Ecosystem Processes?
Soil Health Management Systems
NoTill, Crop Rotation, Cover Crops


Soil Health Principles
Provide Continuous Living Roots
Minimize Disturbance
Maximize Soil Cover
Maximize Biodiversity
Livestock
unlock the SECRETS IN THE SOIL

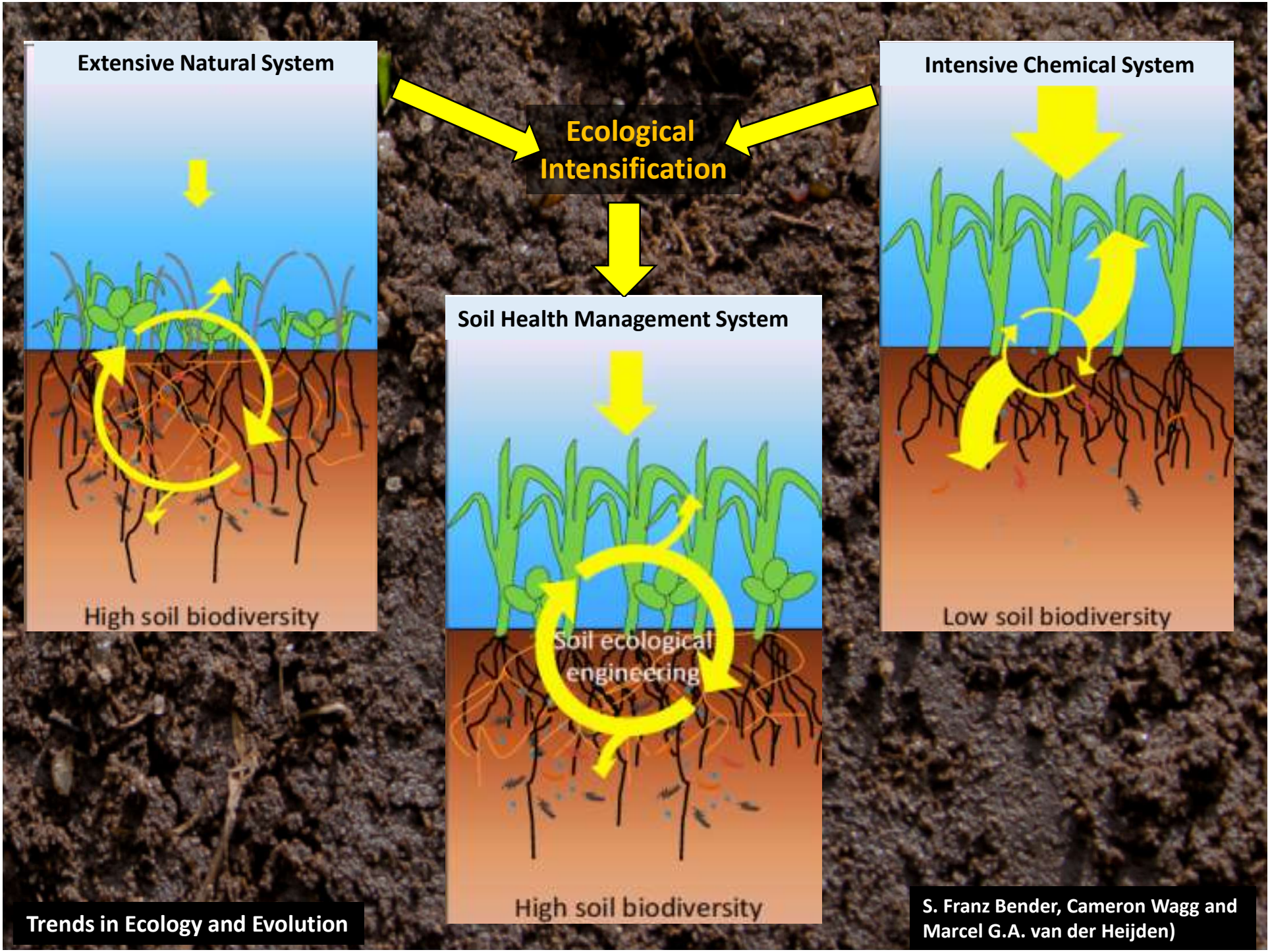
Agricultural Management Practices and Soil Health



Tend to Reduce Soil Health	Tend to Promote Soil Health
Aggressive tillage	No-till or conservation tillage
Annual/seasonal fallow	Cover crops; Relay crops
Mono-cropping	Diverse crop rotations
Annual crops	Perennial crops
Excessive inorganic fertilizer use	Organic fertilizer use (manures)
Excessive crop residue removal	Crop residue retention
Broad spectrum fumigants/pesticides	Integrated pest management
Broad spectrum herbicides	Weed control by mulching, cultivation

Choose practices that feed soil organisms and protect their habitat (soil aggregate)

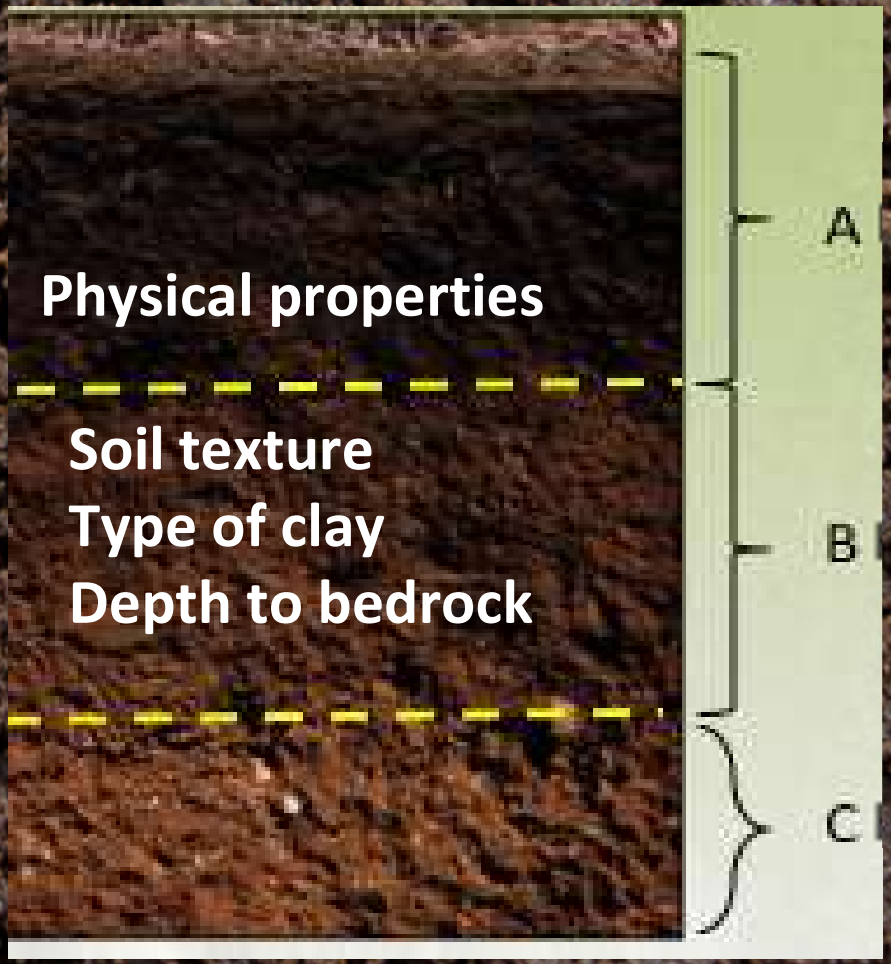
Lehman, R. M., et al. (2015). J. Soil Water Conserv. 70(1): 12a-18a.


Extensive Natural System
High soil biodiversity
Ecological Intensification
Intensive Chemical System
Low soil biodiversity
Soil Health Management System
Soil ecological engineering
High soil biodiversity
Trends in Ecology and Evolution
S. Franz Bender, Cameron Wagg and Marcel G.A. van der Heijden)

Properties of Soil Health

unlock the SECRETS IN THE SOIL

Inherent Properties:



Physical properties

Soil texture
Type of clay
Depth to bedrock

Dynamic Properties:

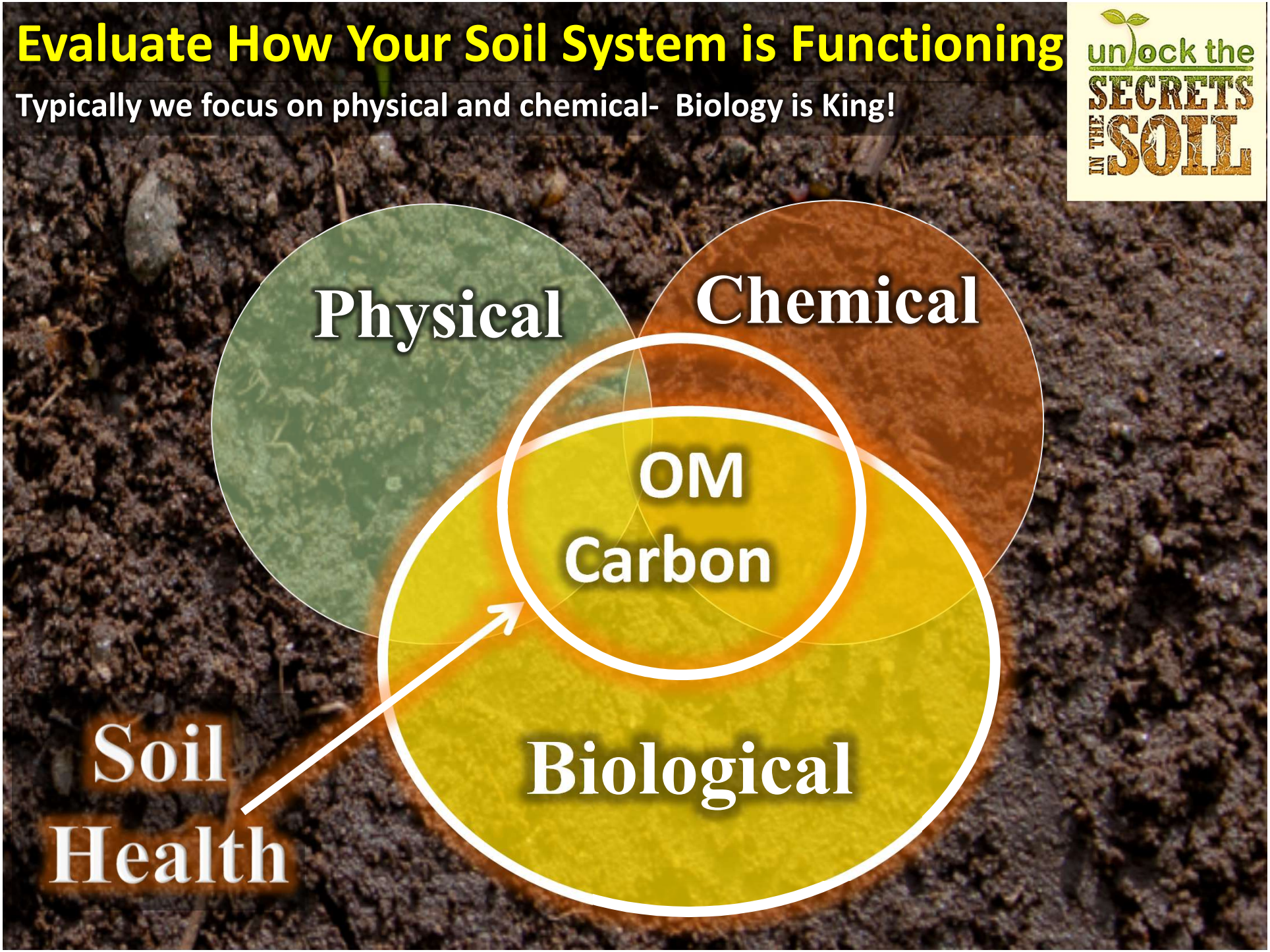
Management dependent properties

Organic matter content
Biological activity
Aggregate stability
Infiltration
Soil fertility
Soil reaction (pH)

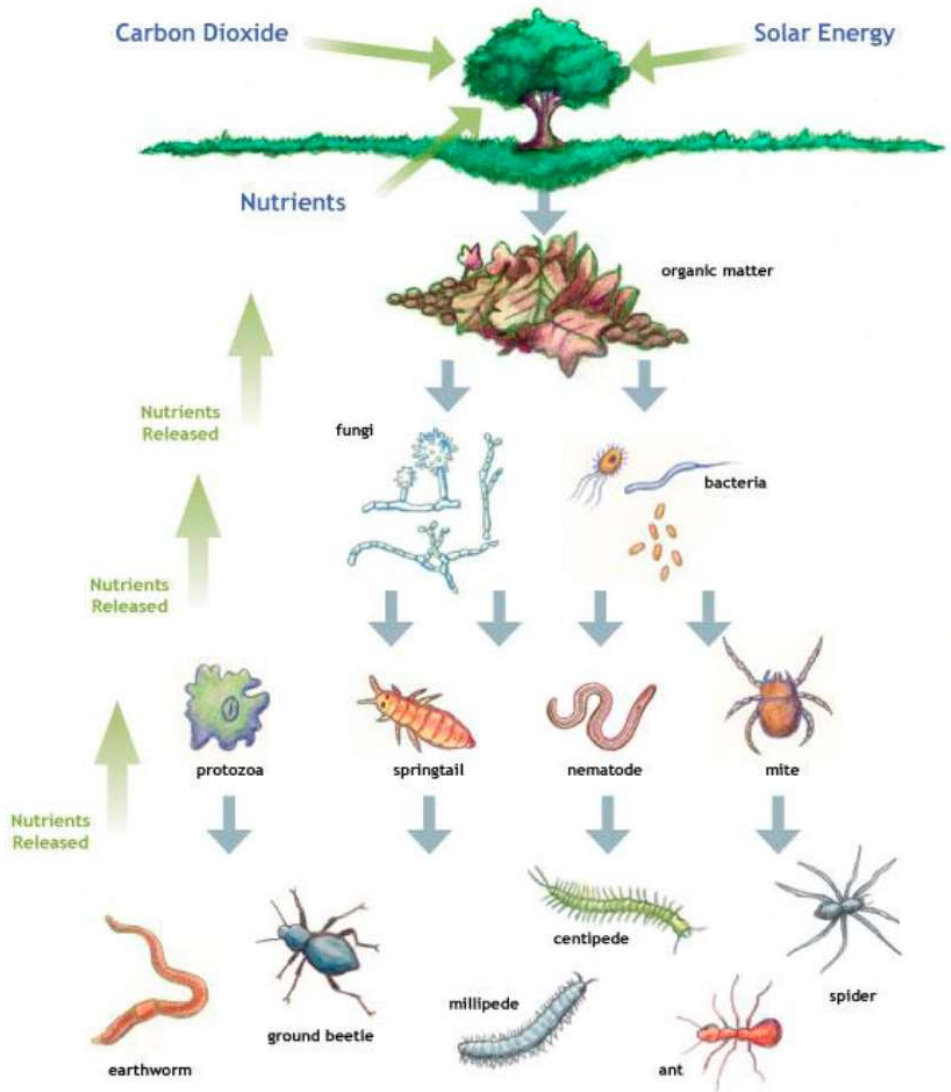
Evaluate How Your Soil System is Functioning

Typically we focus on physical and chemical- Biology is King!

unlock the SECRETS IN THE SOIL



Eye Of The Needle



Functions of a Healthy Soil Food Web

Organic matter decomposition

Carbon sequestration

Soil structure, soil porosity

Water infiltration

Pest control

Nutrient storage

Nutrient release

Breaking down toxic compounds

http://landscapeforlife.org/soil/support-the-soil-food-web/

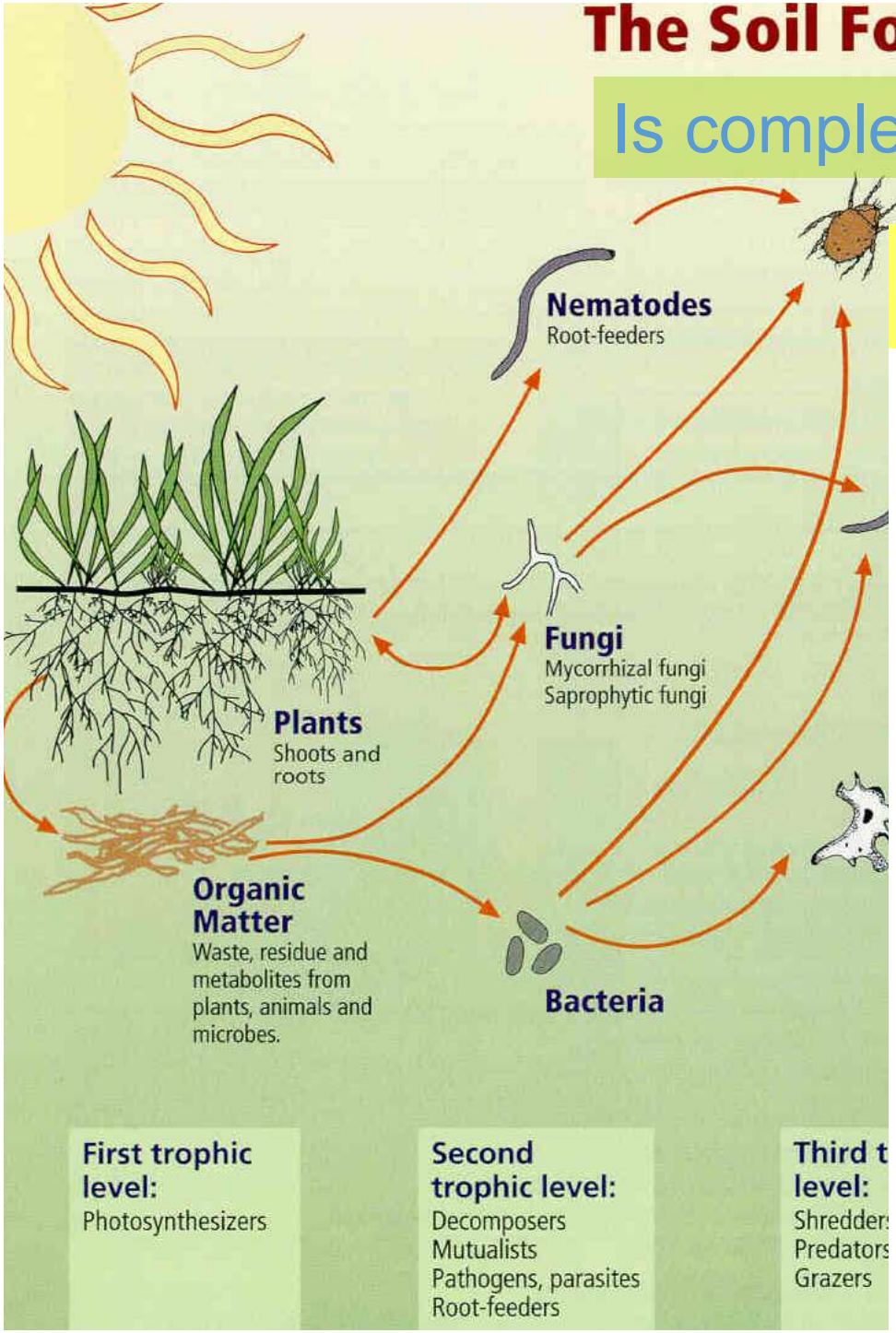
Soil is a Living Factory

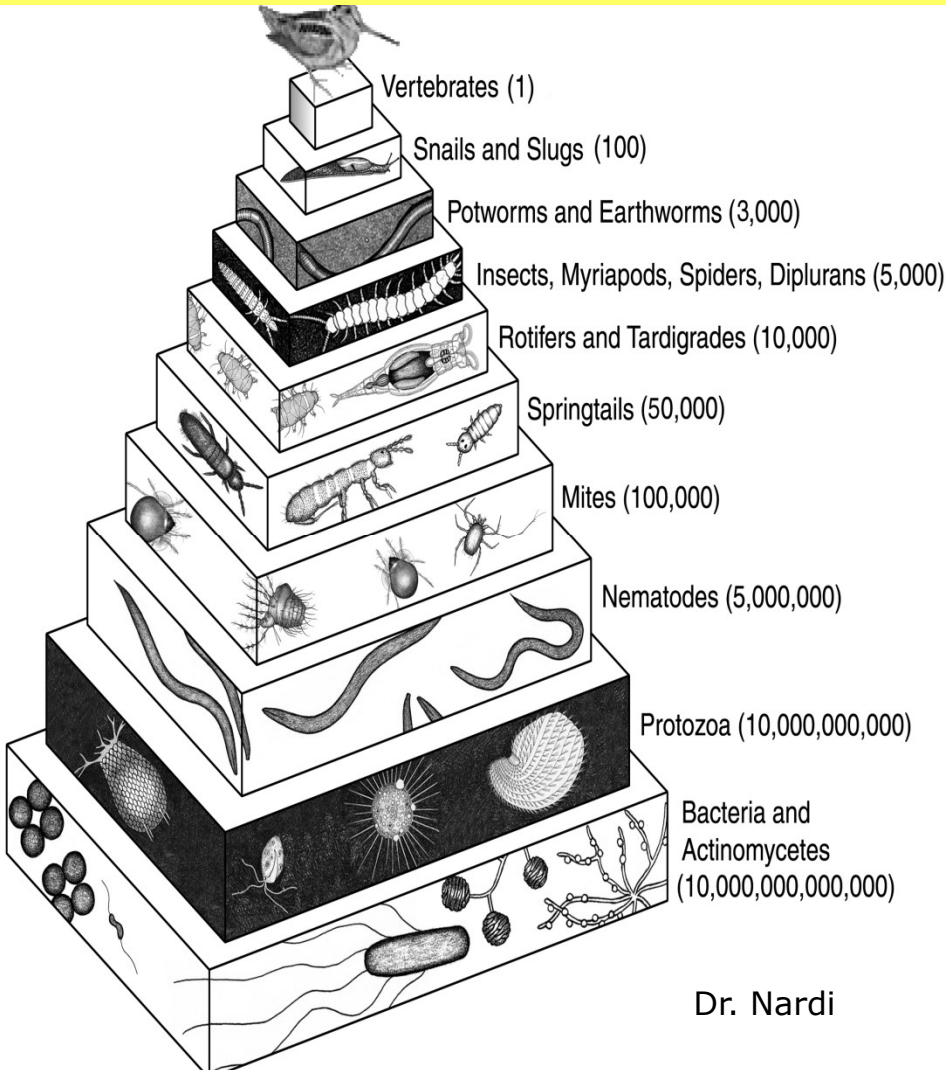
- Macroscopic and microscopic organisms
  - Food
  - Water
  - Shelter
  - Habitat
  - Powered by sunlight
- Management activities improve or degrade soil health
  - Tillage
  - Fertilizer
  - Pesticides
  - Grazing
  - Plant Diversity

The Soil Food Web

Is complex

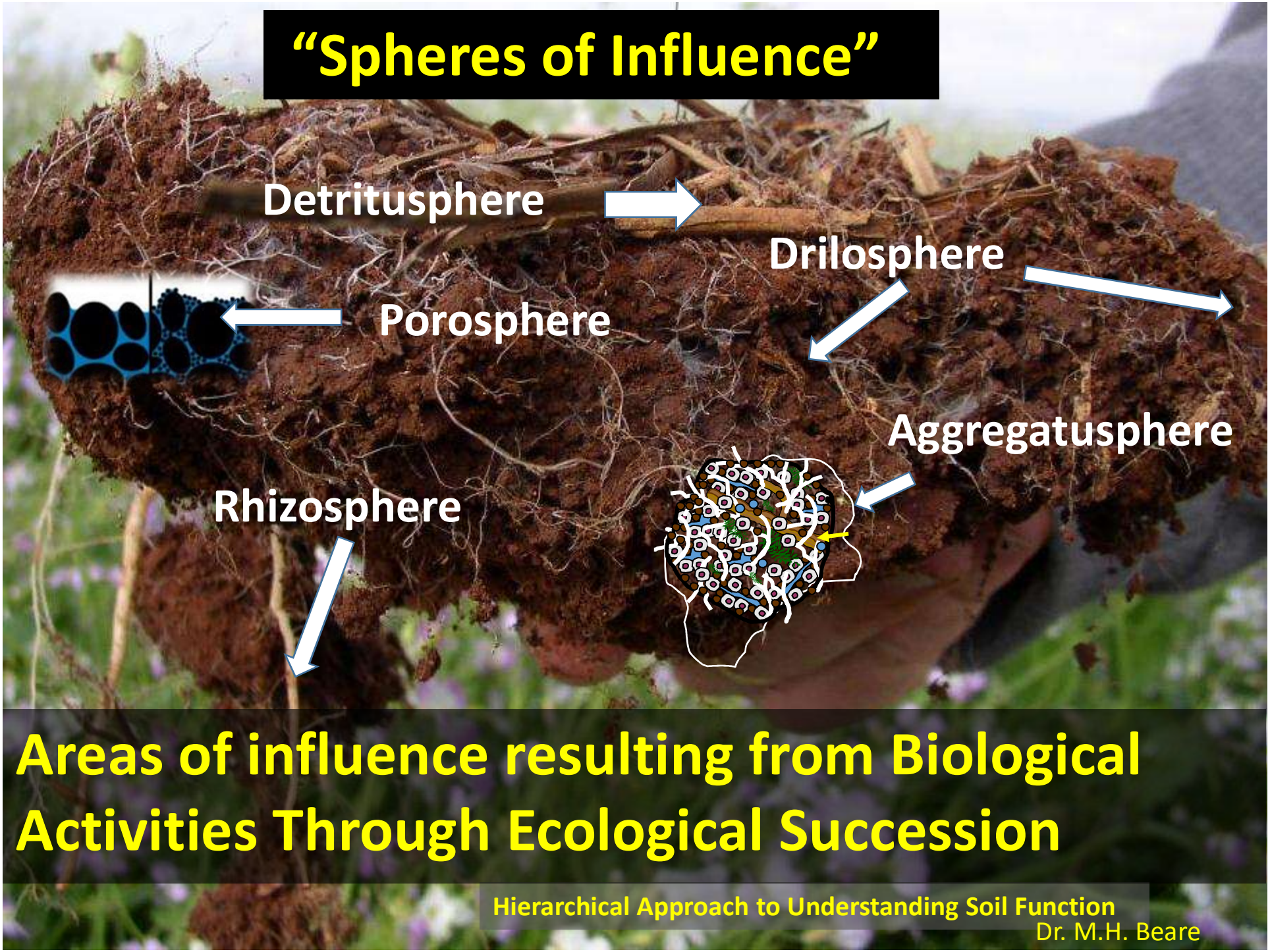
Every trophic level must function for the soil food web to function!





Dr. Nardi

"Spheres of Influence"



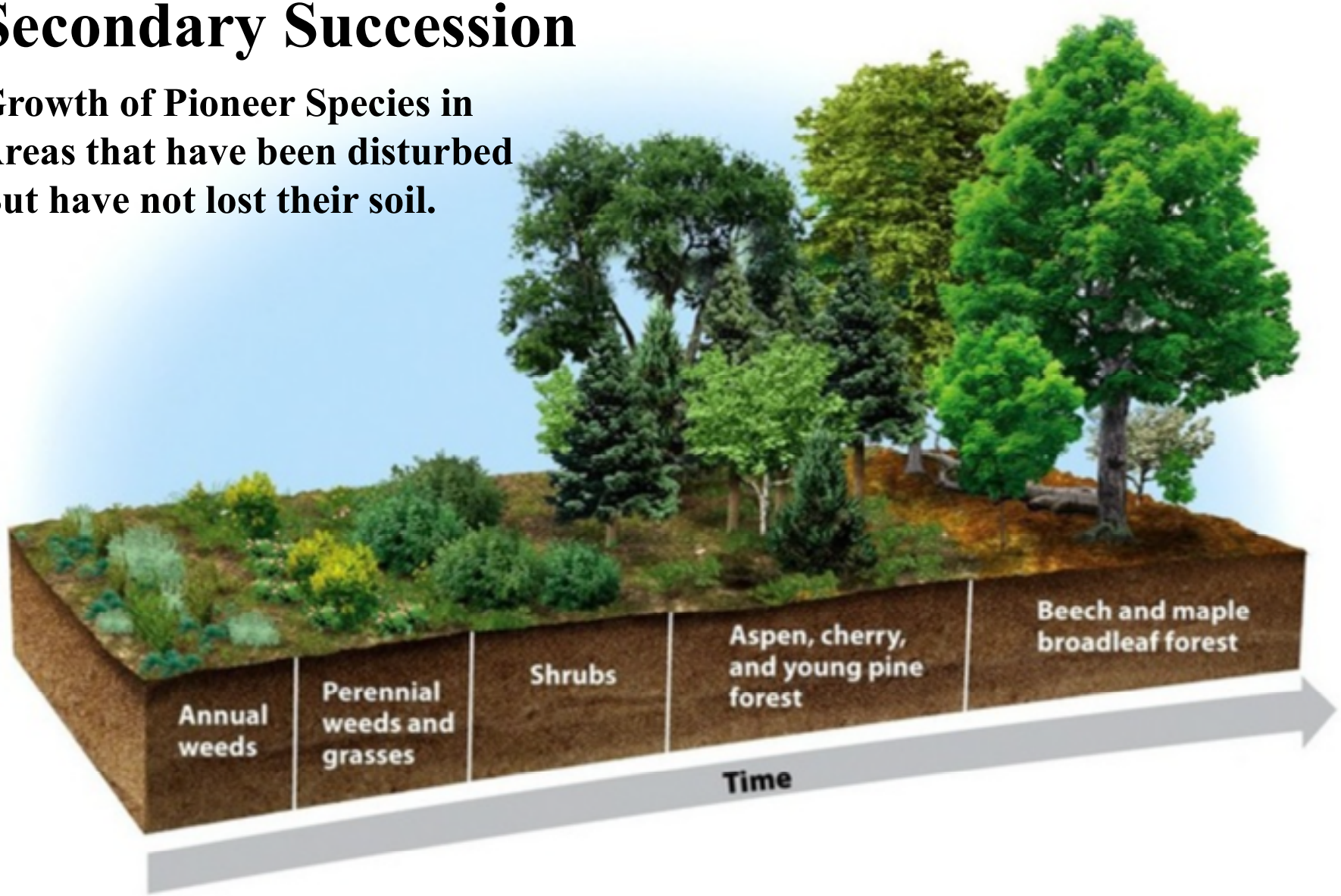
Areas of influence resulting from Biological Activities Through Ecological Succession

Hierarchical Approach to Understanding Soil Function

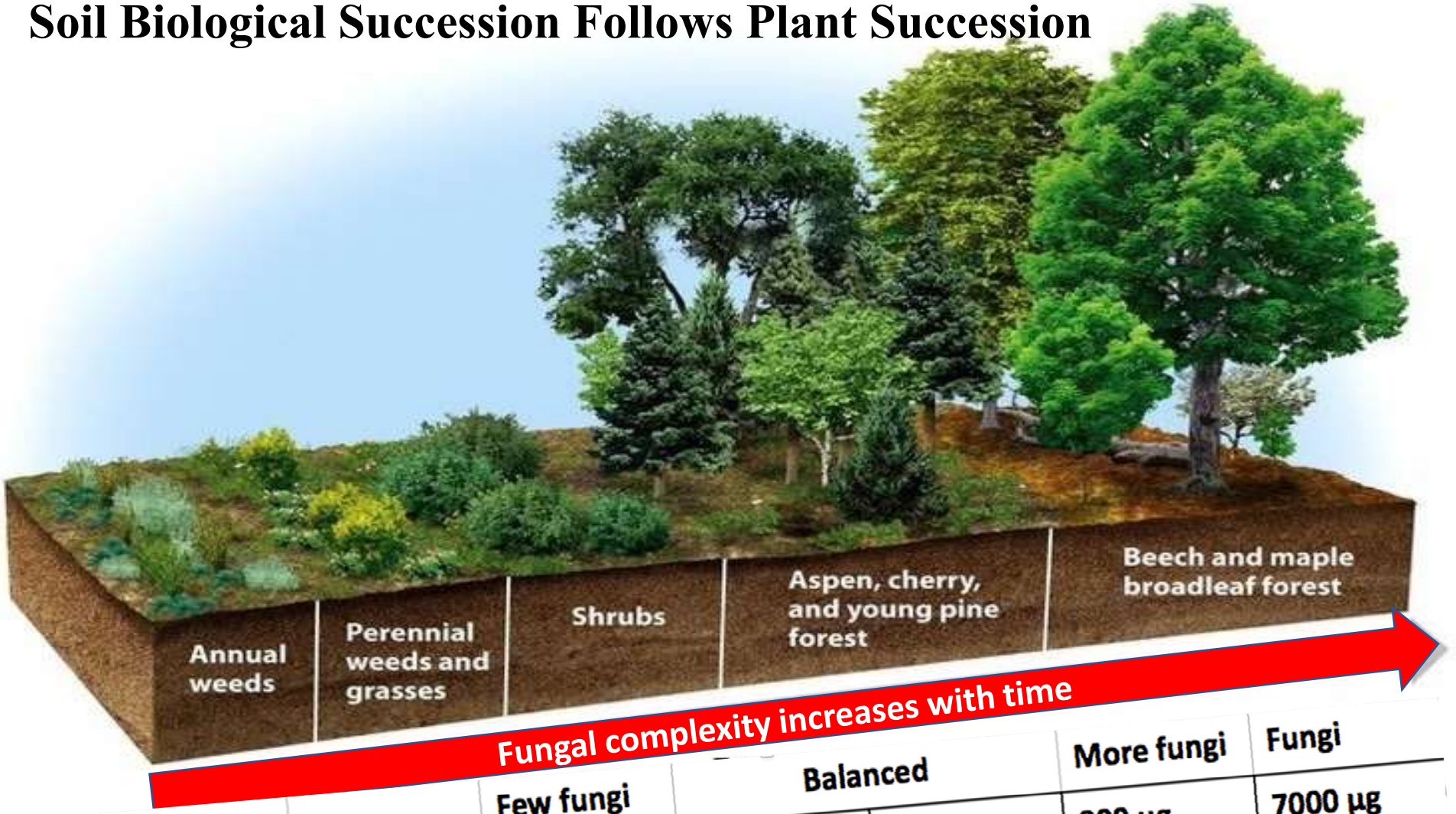
Dr. M.H. Beare

Secondary Succession

Growth of Pioneer Species in
Areas that have been disturbed
But have not lost their soil.



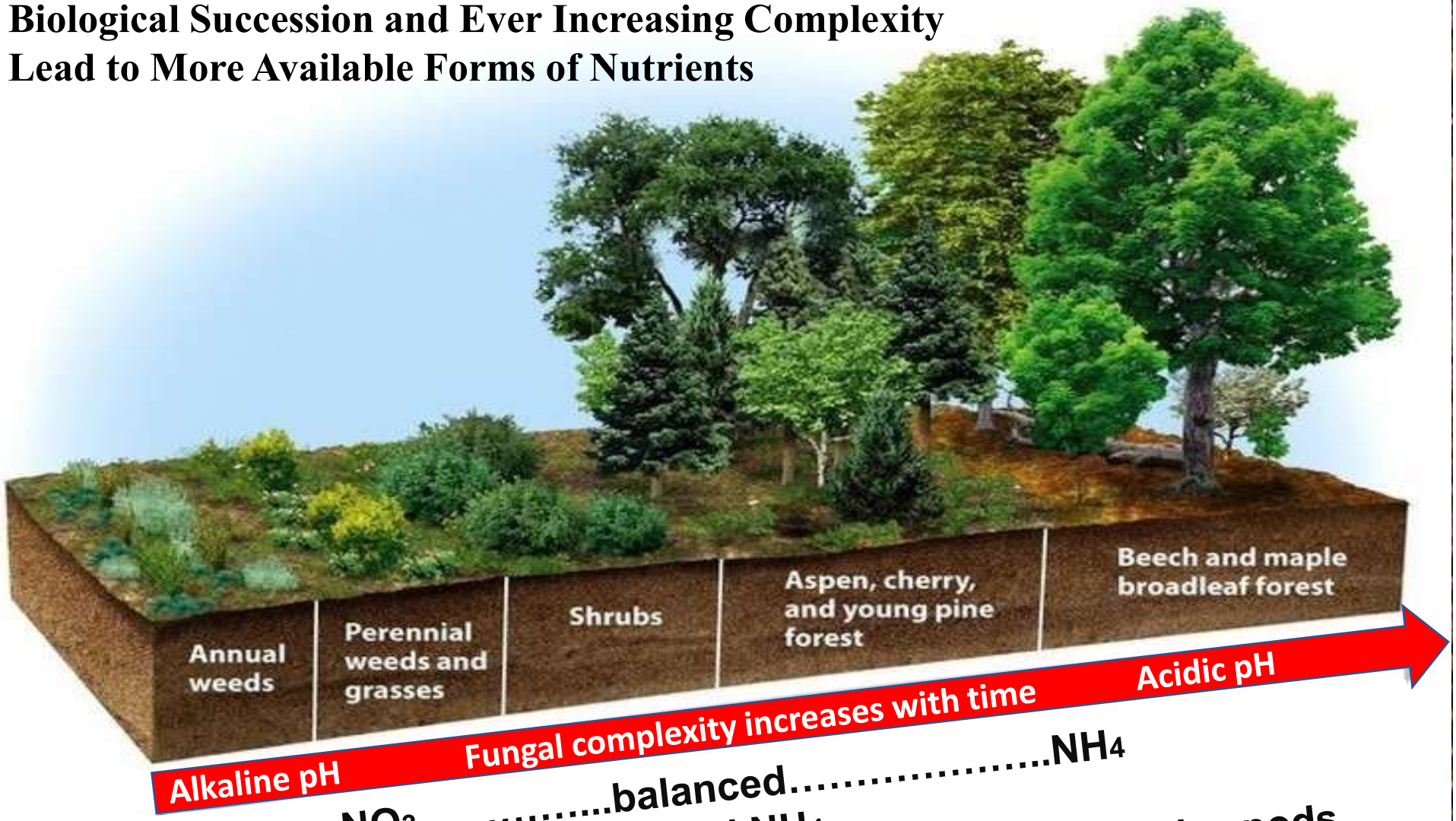
Soil Biological Succession Follows Plant Succession



Bacteria		Few fungi	Balanced	More fungi	Fungi
Fungi	0 µg	10 µg	250 µg	600 µg	800 µg	7000 µg
Bacteria	10 µg	100 µg	500 µg	600 µg	500 µg	700 µg

Dr. Elaine Ingham

Biological Succession and Ever Increasing Complexity Lead to More Available Forms of Nutrients



.....NO_3.....balanced.....NH_4

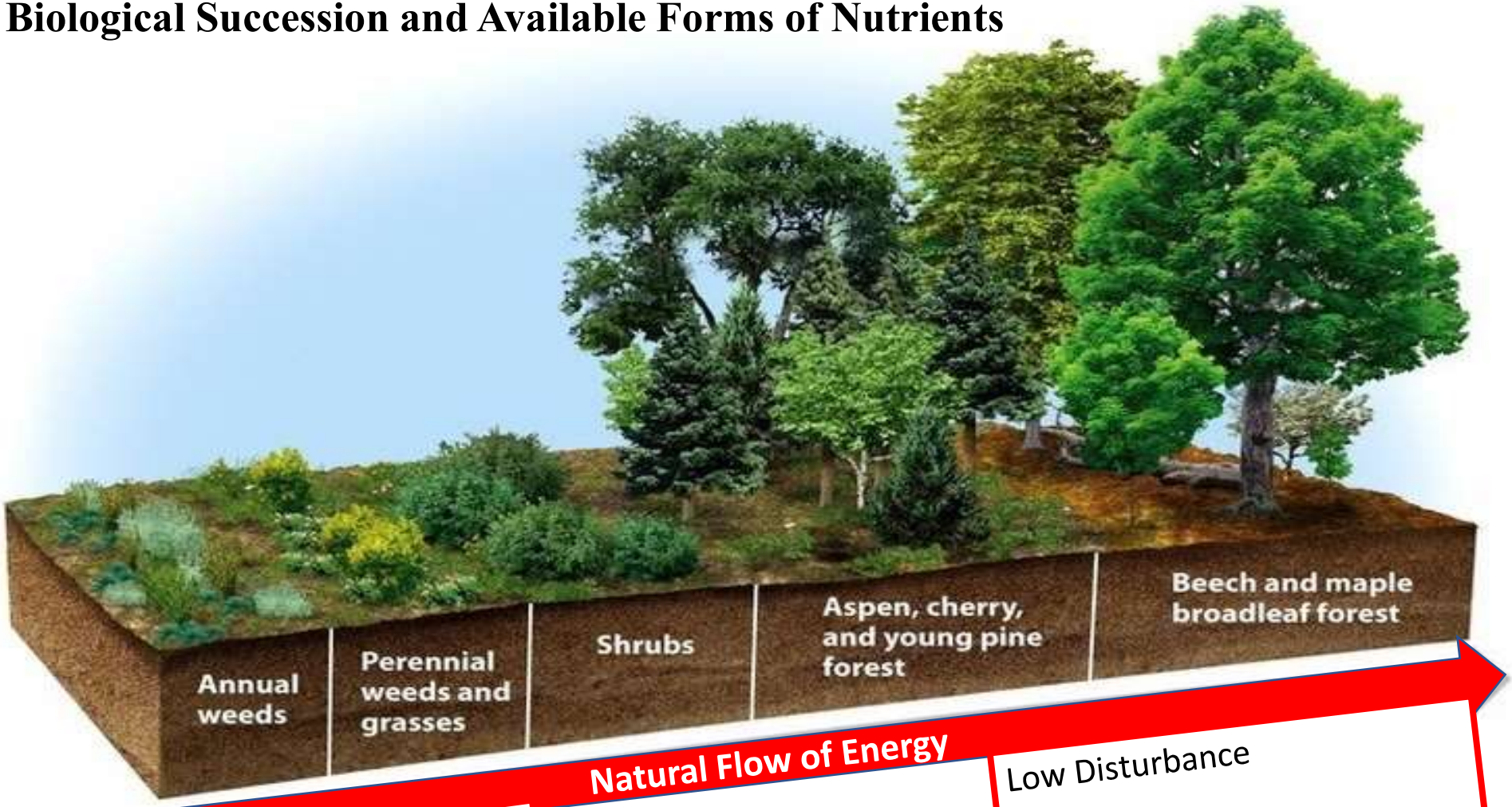
NO_3 and NH_4

Protozoa.....B-f.....F-f.....Predatory..... Microarthropods

Nematodes

Dr. Elaine Ingham

Biological Succession and Available Forms of Nutrients

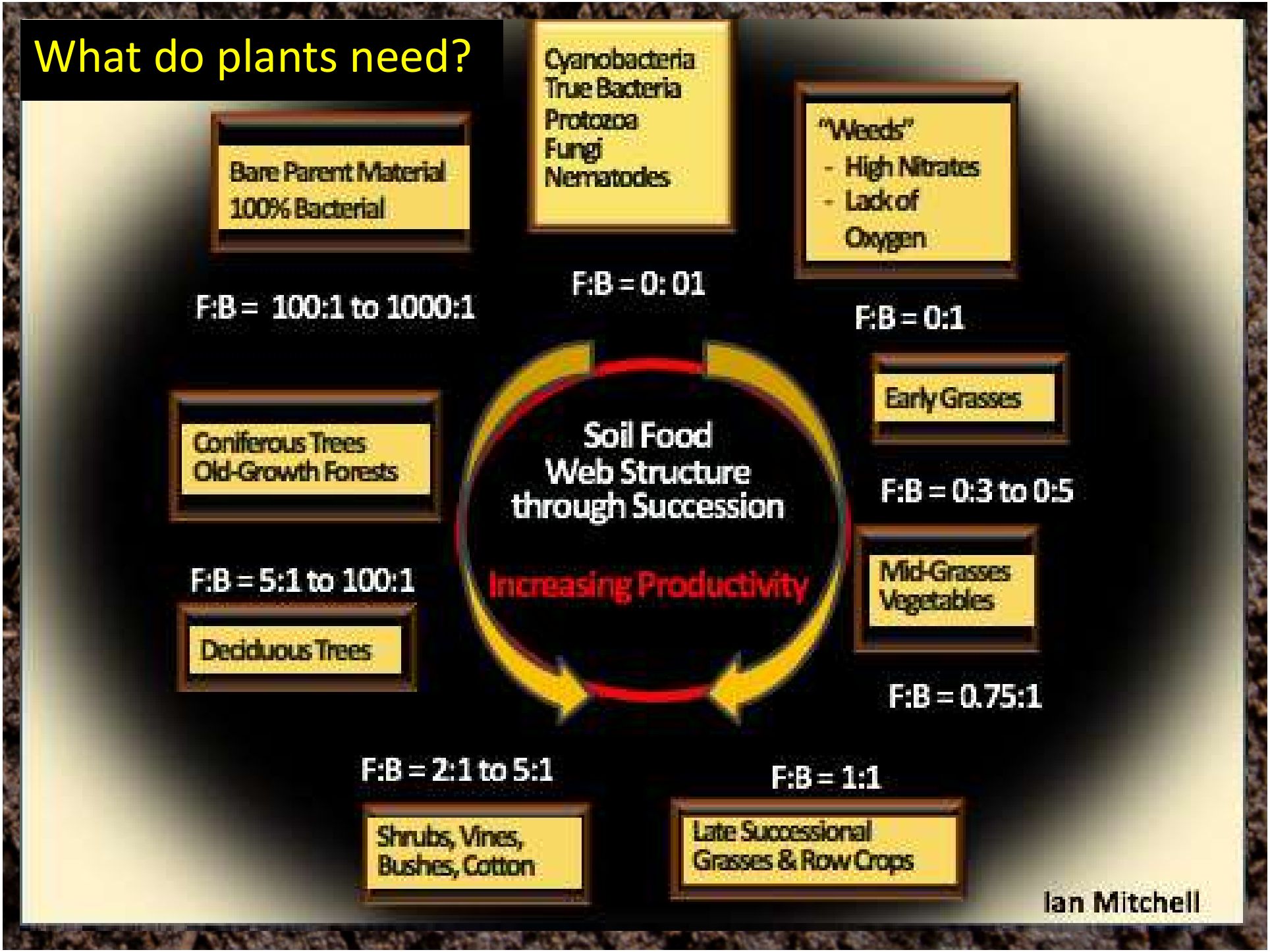


Natural Flow of Energy

High Disturbance
Low Diversity
High Human inputs
Disrupted Eco services

"Dynamic Equilibrium State"

Low Disturbance
High Diversity
Low Human Inputs
Highly Functioning Eco services


What do plants need?
Cyanobacteria
True Bacteria
Protozoa
Fungi
Nematodes
Bare Parent Material
100% Bacterial
"Weeds"
- High Nitrates
- Lack of Oxygen
F:B = 0: 01
F:B = 100:1 to 1000:1
F:B = 0:1
Early Grasses
Coniferous Trees
Old-Growth Forests
Soil Food
Web Structure
through Succession
Increasing Productivity
F:B = 0:3 to 0:5
Mid-Grasses
Vegetables
F:B = 5:1 to 100:1
Deciduous Trees
F:B = 0.75:1
F:B = 2:1 to 5:1
Shrubs, Vines,
Bushes, Cotton
F:B = 1:1
Late Successional
Grasses & Row Crops
Ian Mitchell

Impacts of Disturbances

Bare parent material
100% bacterial

Foodweb development:
Cyanobacteria
True bacteria
Protozoa
Nematodes
Microarthropods
F:B = 0.01

"Weeds"
-high NO3
-lack of O2
F:B = 0.1

Early annuals

F:B = 0.3

Mid-grasses, vegetables (mid-successional)

F:B = 0.3

Pasture, row crops

F:B = 1:1

Shrubs, vines, bushes

F:B = 2:1 to 5:1

Deciduous trees
F:B =
5:1 to 100:1

Conifer, old-growth forests
F:B =
100:1 to 1000:1

Disturbances push systems "backwards," but how far? Depends on intensity & frequency

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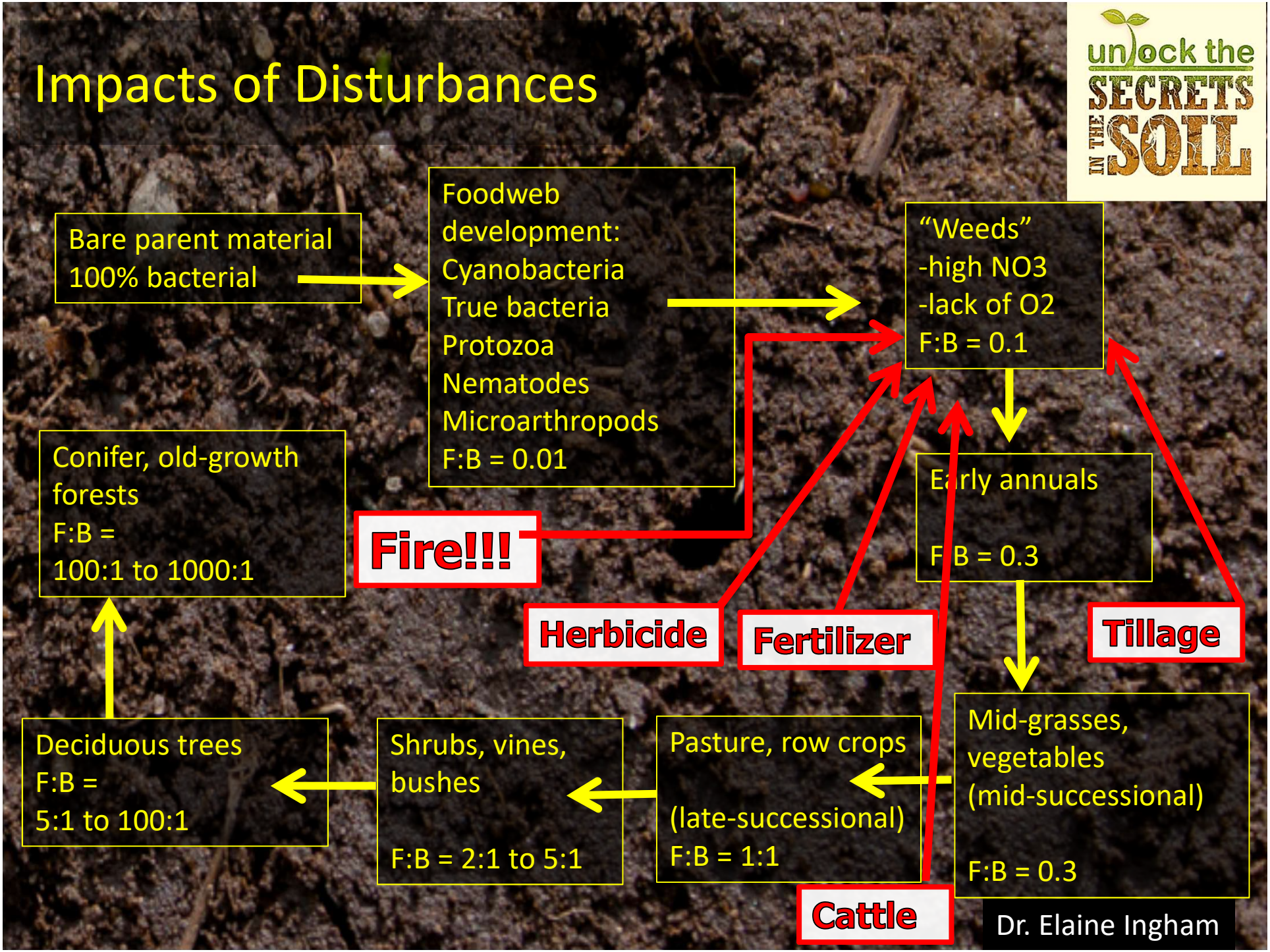
Impacts of Disturbances



What do you see? Healthy or Not?

Plant Succession









Bacterial Dominance

Bacteria/Fungi Balance

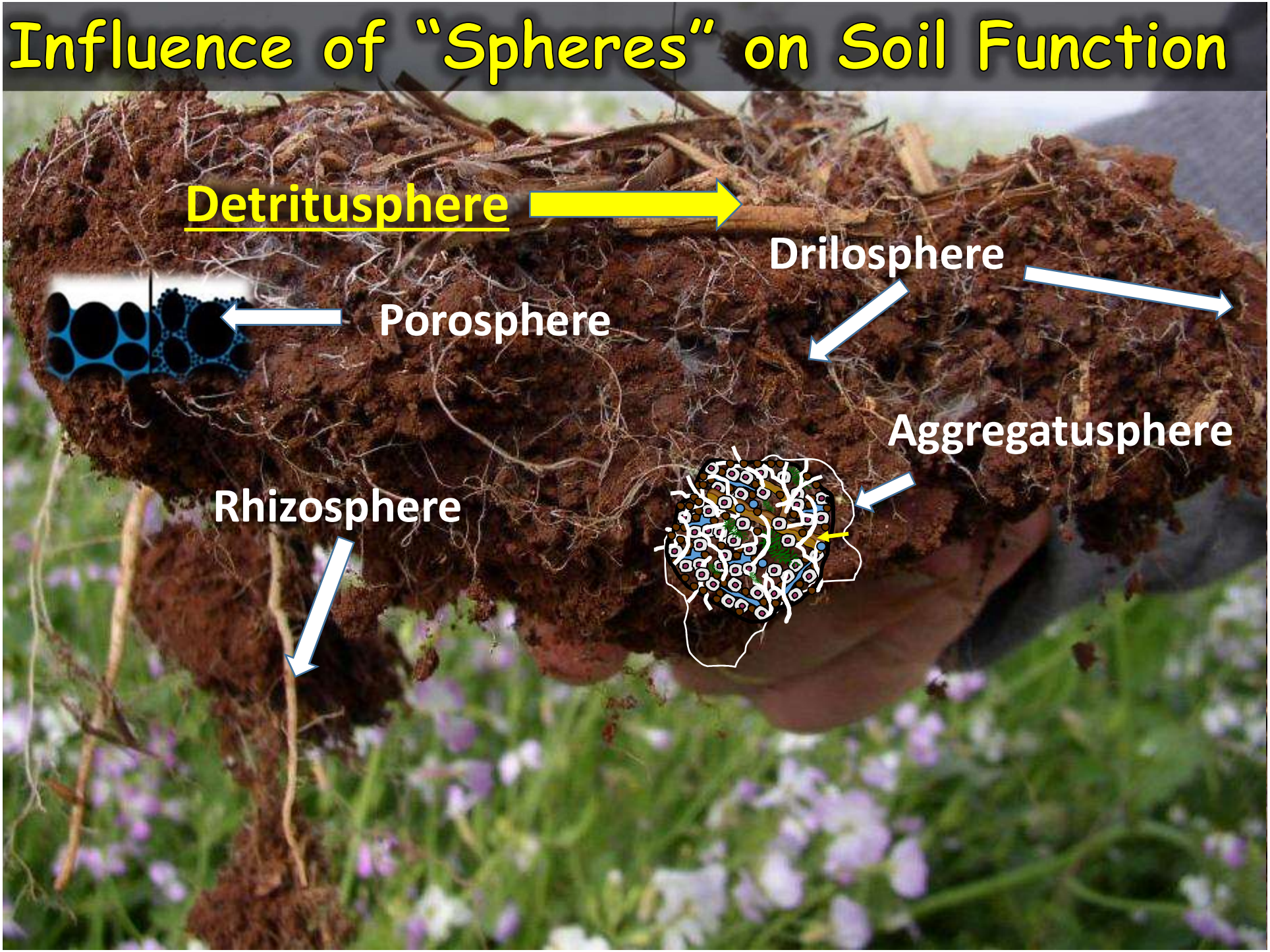
Fungal Dominance

This soil is naked, hungry, thirsty and running a fever!

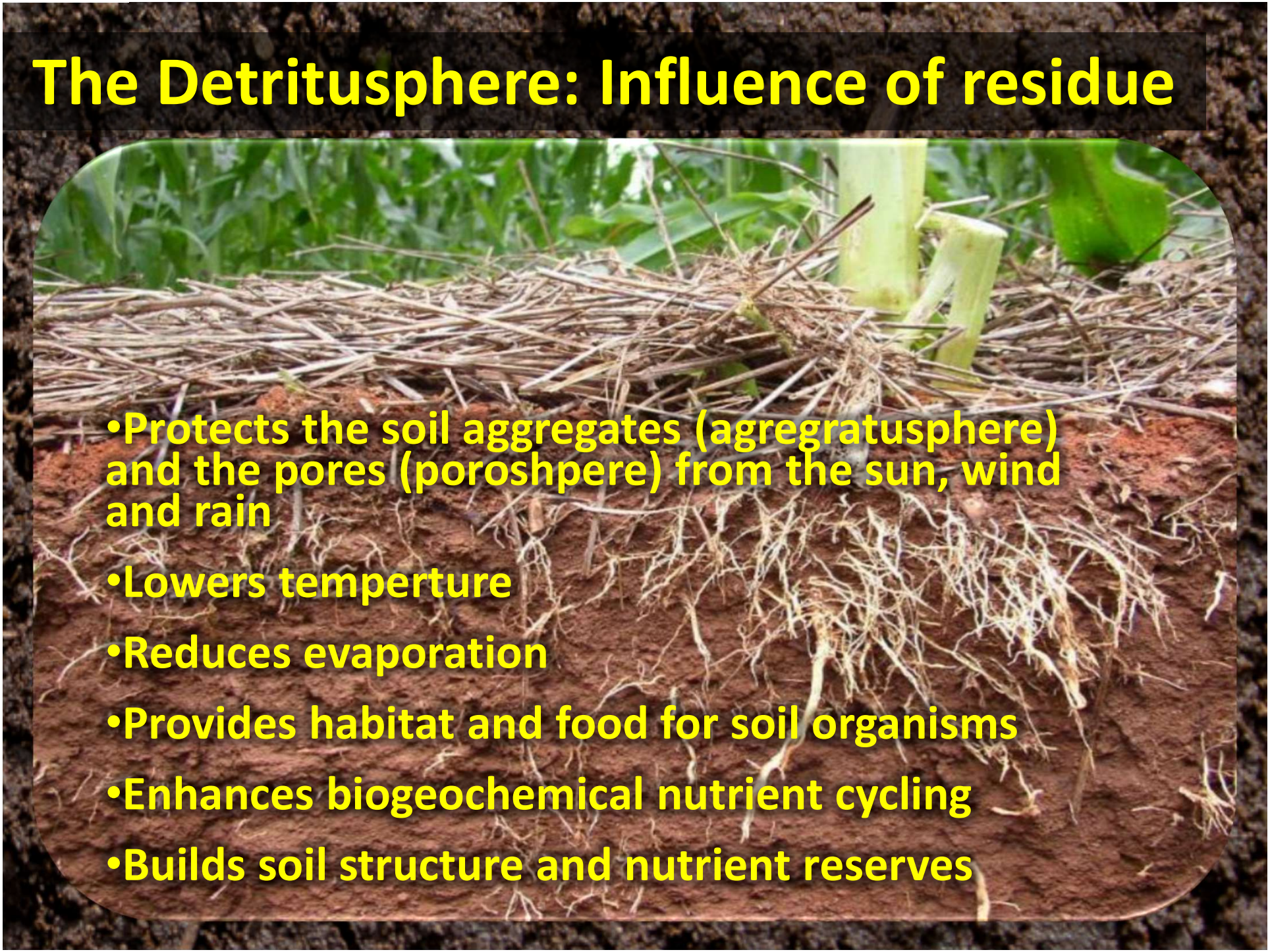
Ray Archuleta 2007

Impacts of Tillage

Influence of "Spheres" on Soil Function



The Detritusphere: Influence of residue



- Protects the soil aggregates (agregratusphere) and the pores (poroshpere) from the sun, wind and rain
- Lowers temperture
- Reduces evaporation
- Provides habitat and food for soil organisms
- Enhances biogeochemical nutrient cycling
- Builds soil structure and nutrient reserves

Types of Arthropods

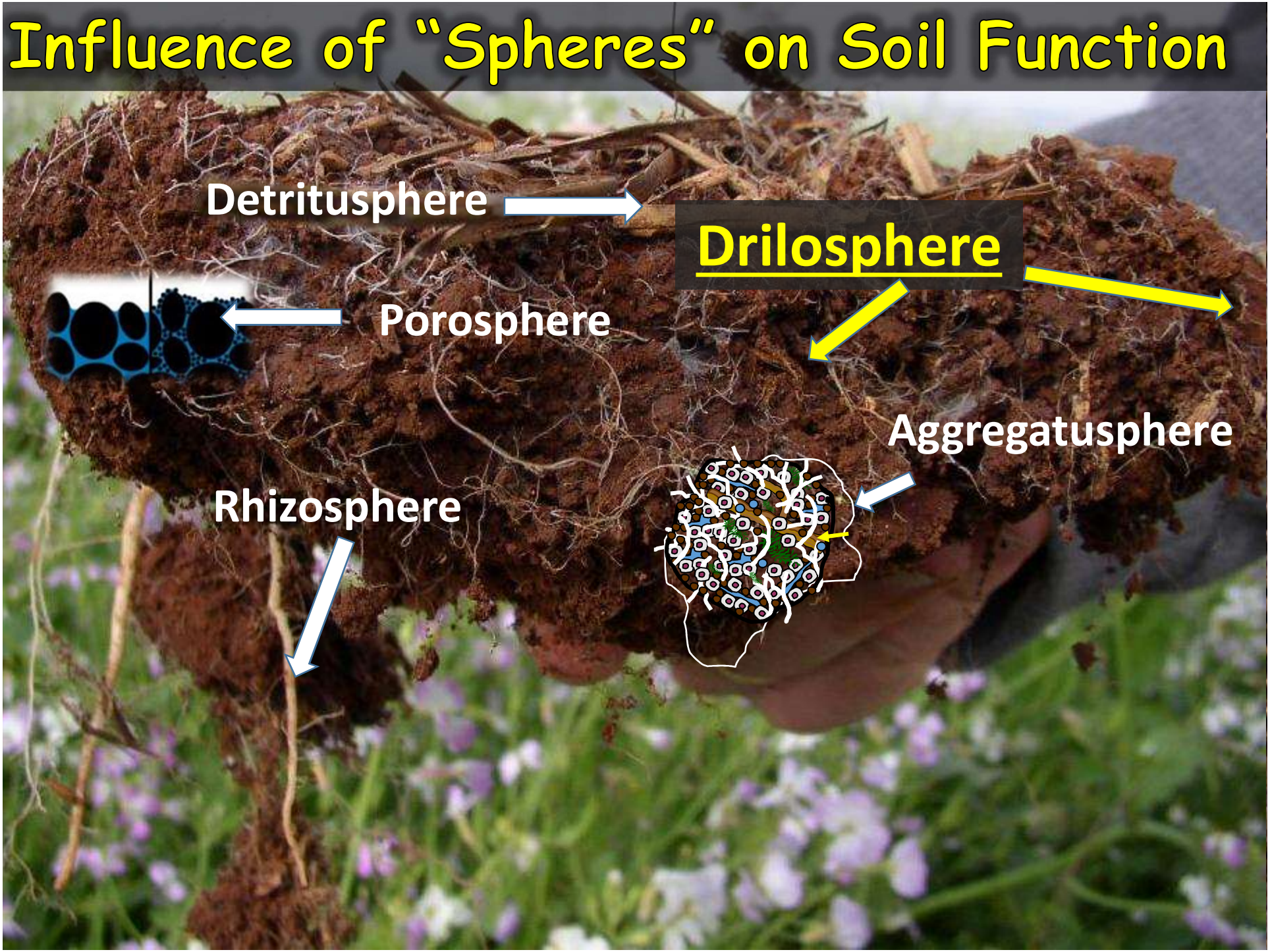
Shredders

Predators

Herbivores

Fungal-feeders

Influence of "Spheres" on Soil Function



Nature's Tillage Machine and Residue Managers

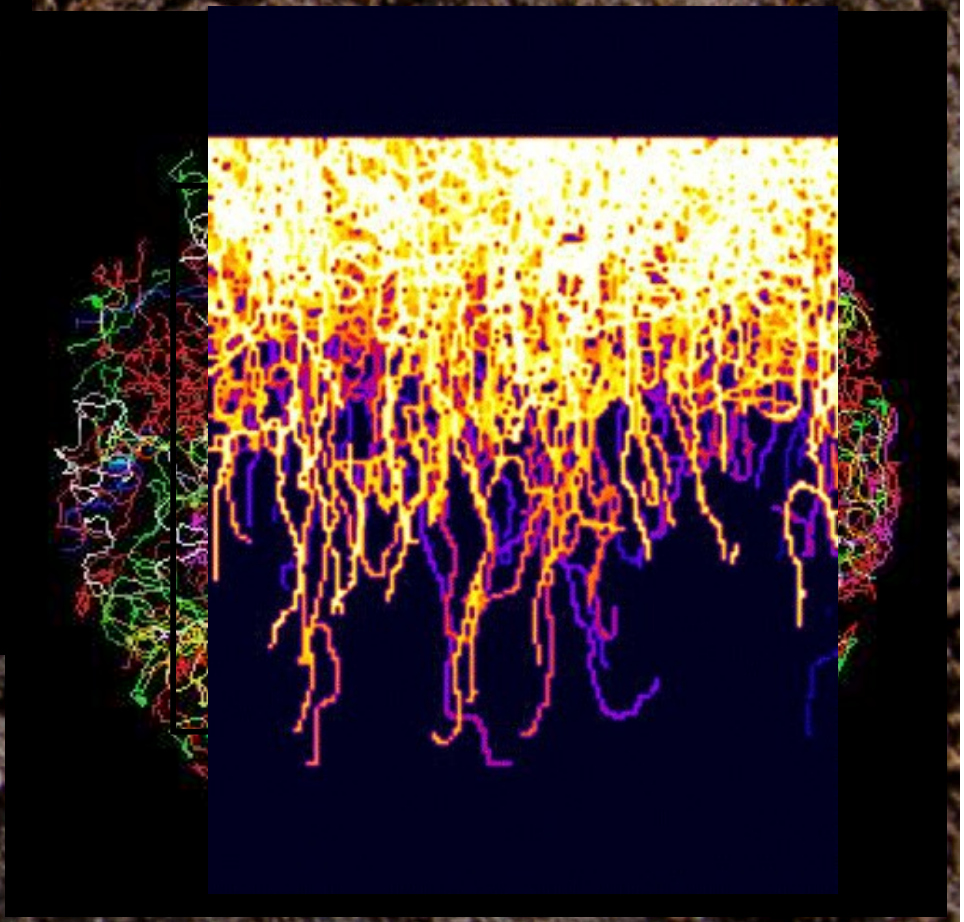
(Odette Menard)

Earthworms increase the availability of nutrients

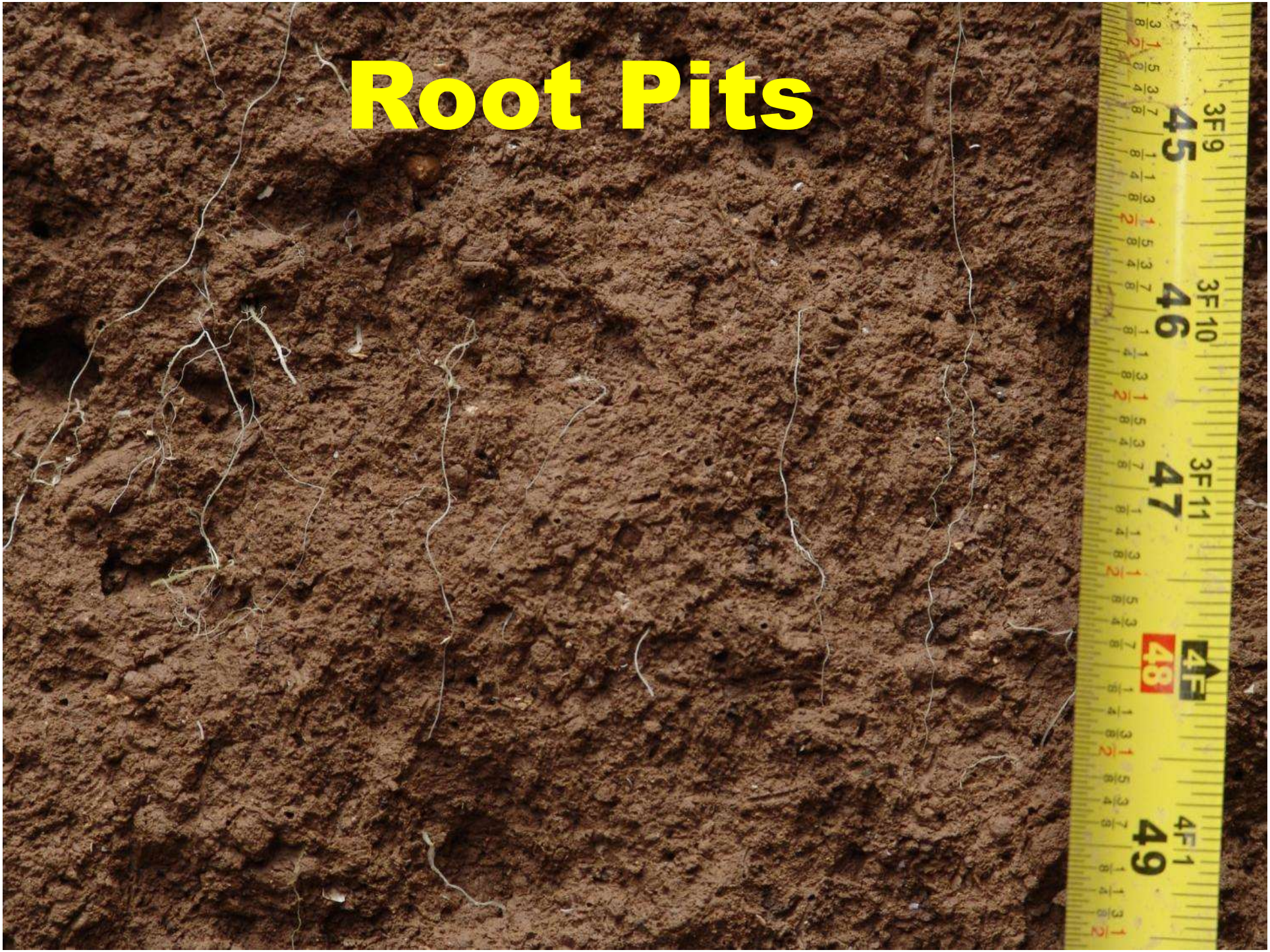
unlock the SECRETS IN THE SOIL

Earthworm casts contain:
11% of the humus
7X the Nitrogen
11X the Phosphorus
9X the Potash
More Available Water

Earthworms Are Soil Engineers



Bastardie, Capowiez *et al.* Biol Fertil Soils (2002) 36:161–169

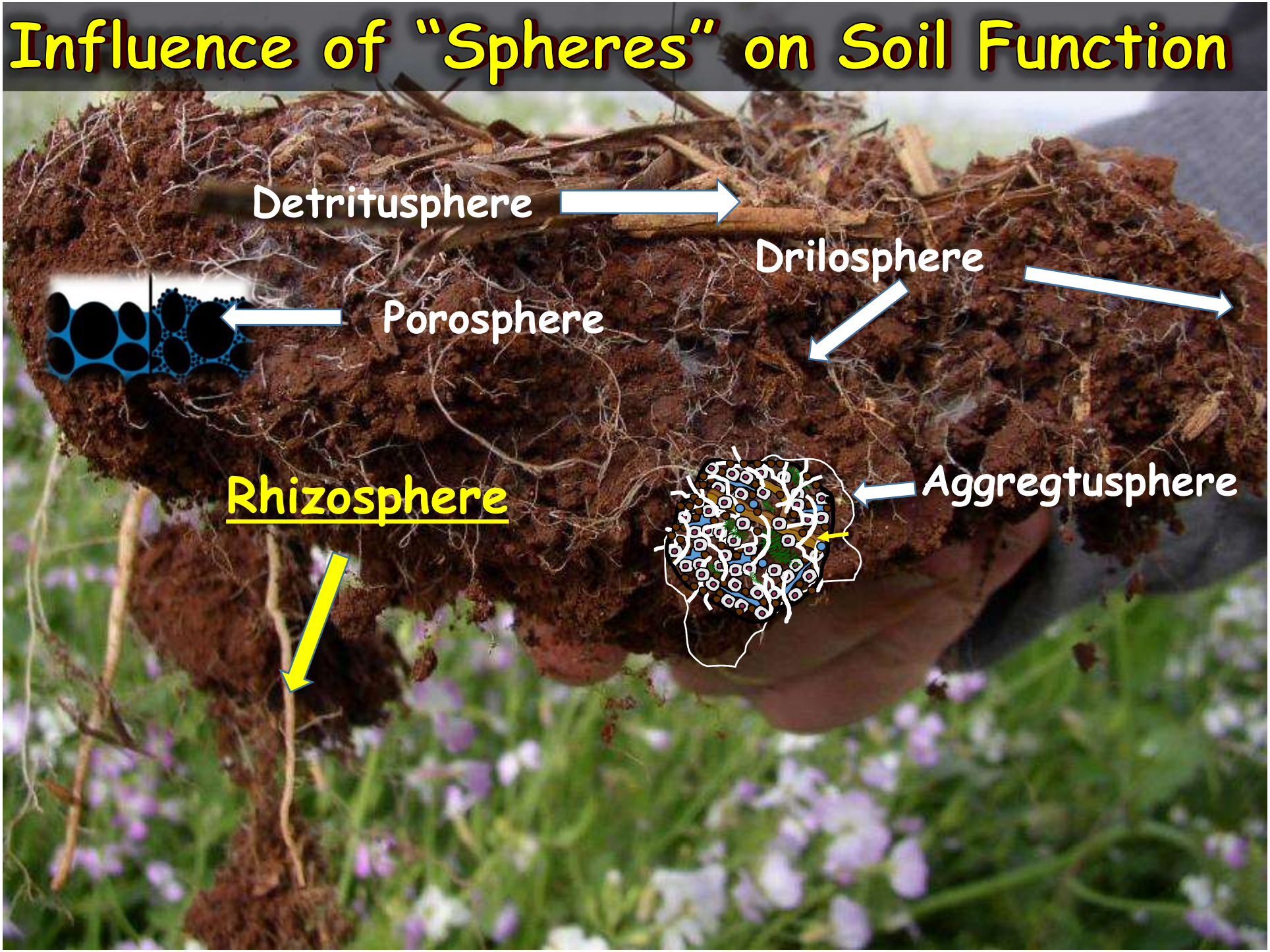

Root Pits


unlock the
SECRETS
IN THE
SOIL
"Red Bull" for
Earthworms
Dr. Jill Clapperton
Dave Brandt - Ohio

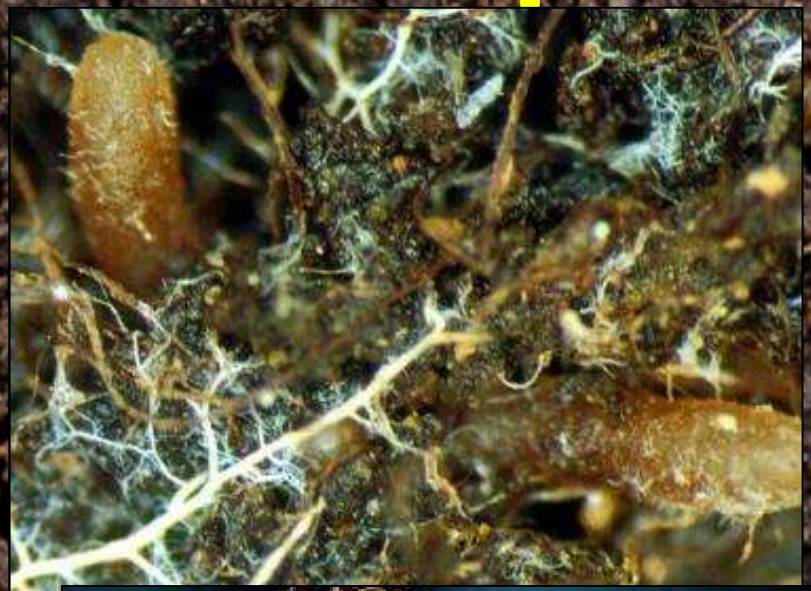
Earthworm Castings

unlock the SECRETS IN THE SOIL

Influence of "Spheres" on Soil Function

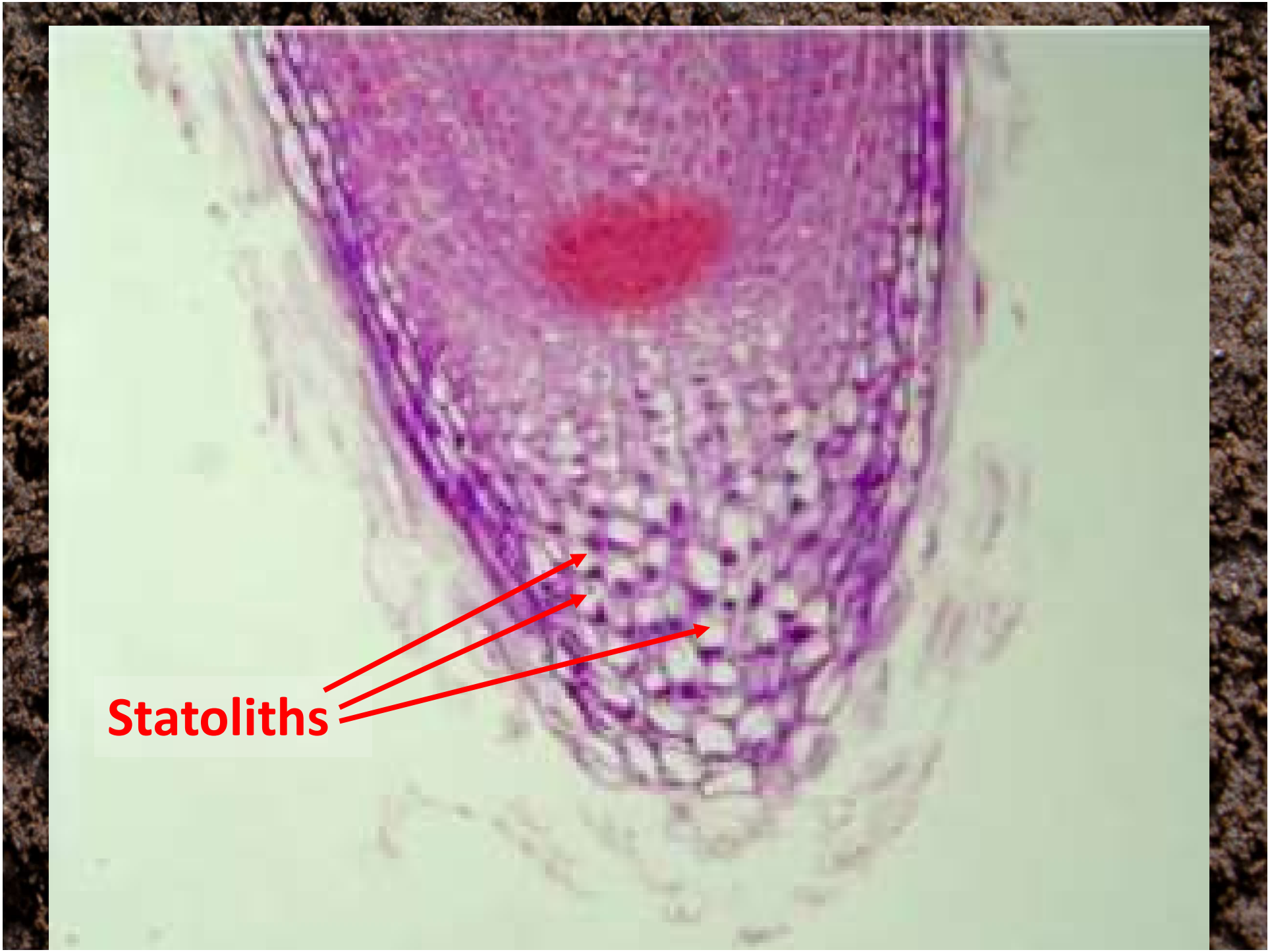


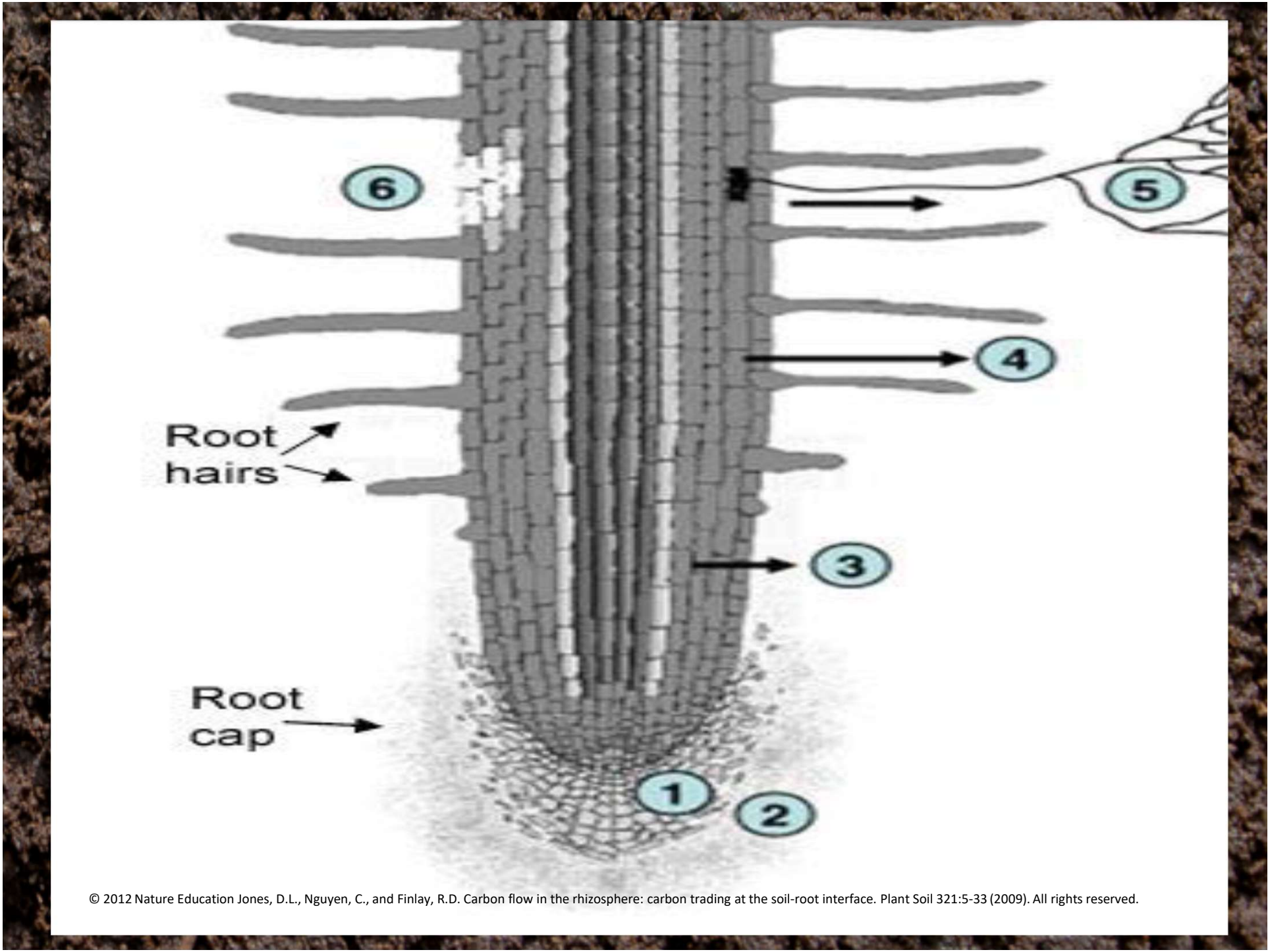
Rhizosphere

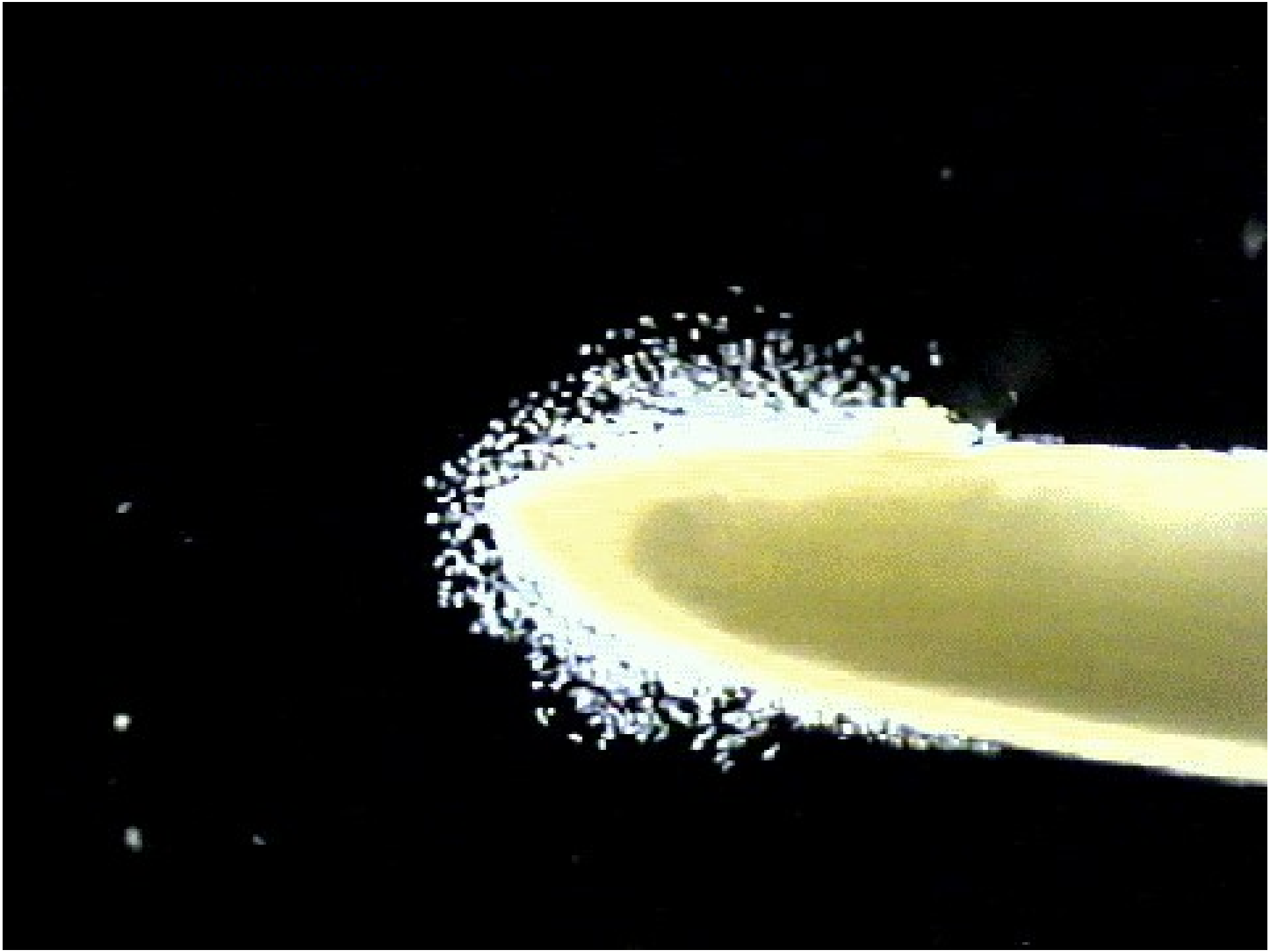


"The ***Rhizosphere*** is the zone surrounding the roots of plants in which complex relations exist among the plant, the soil microorganisms and the soil itself."

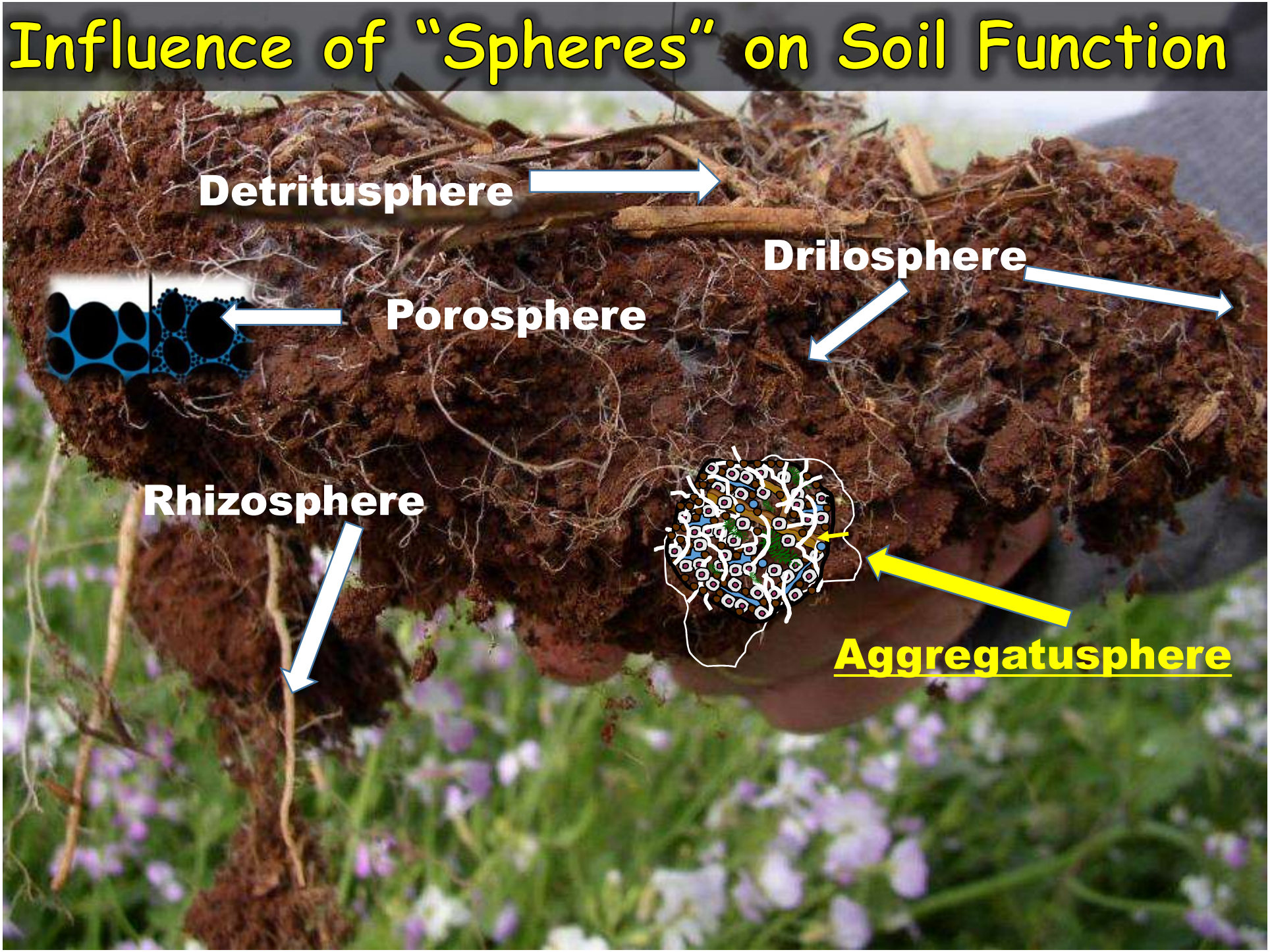
Living Roots Release Exudates


Statoliths





Influence of "Spheres" on Soil Function

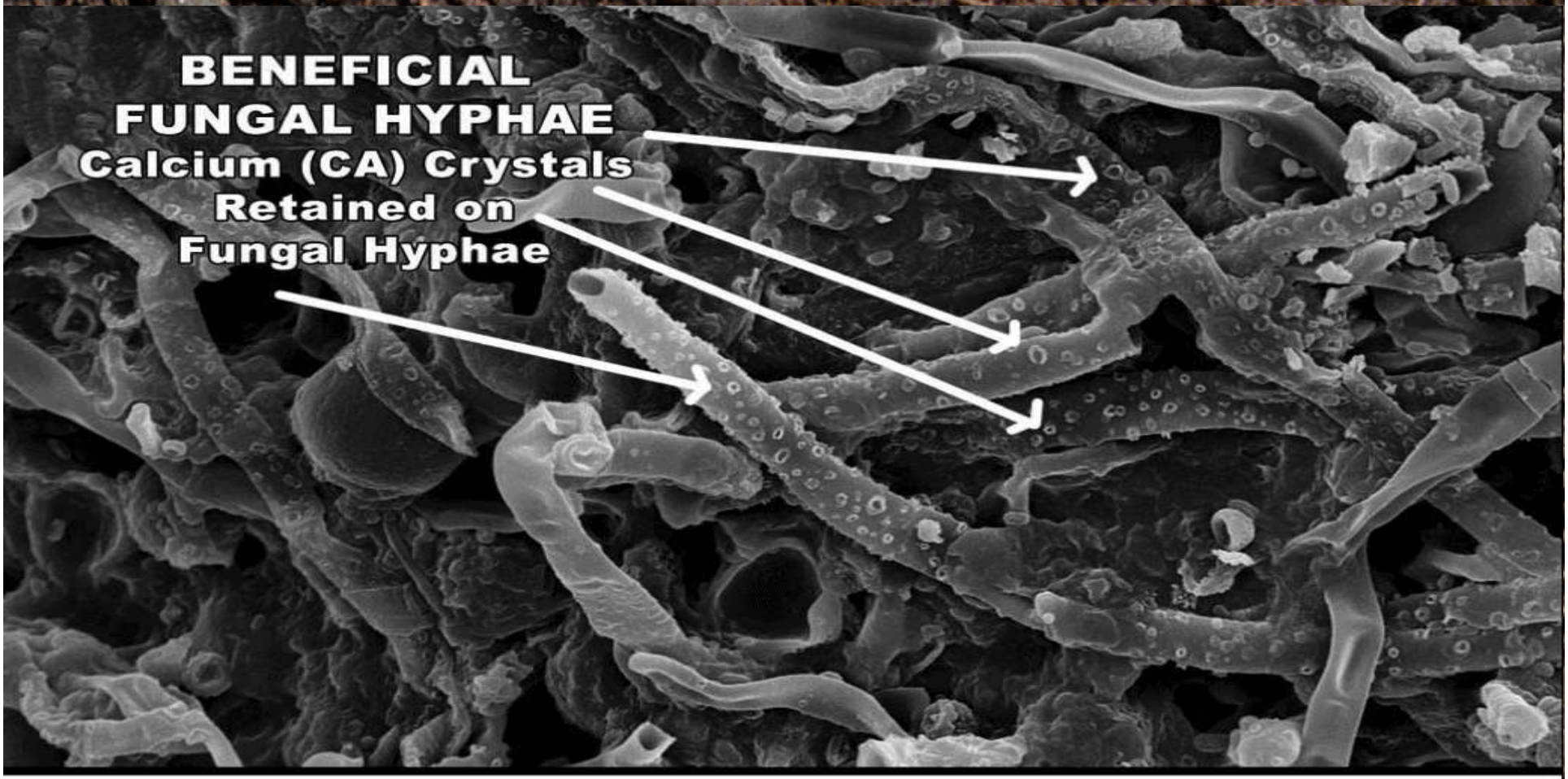


Soil Aggregation Begins

Brady & Weil, The Nature and Properties of Soils, Chapter 4, pg. 140, Figure 4.20.

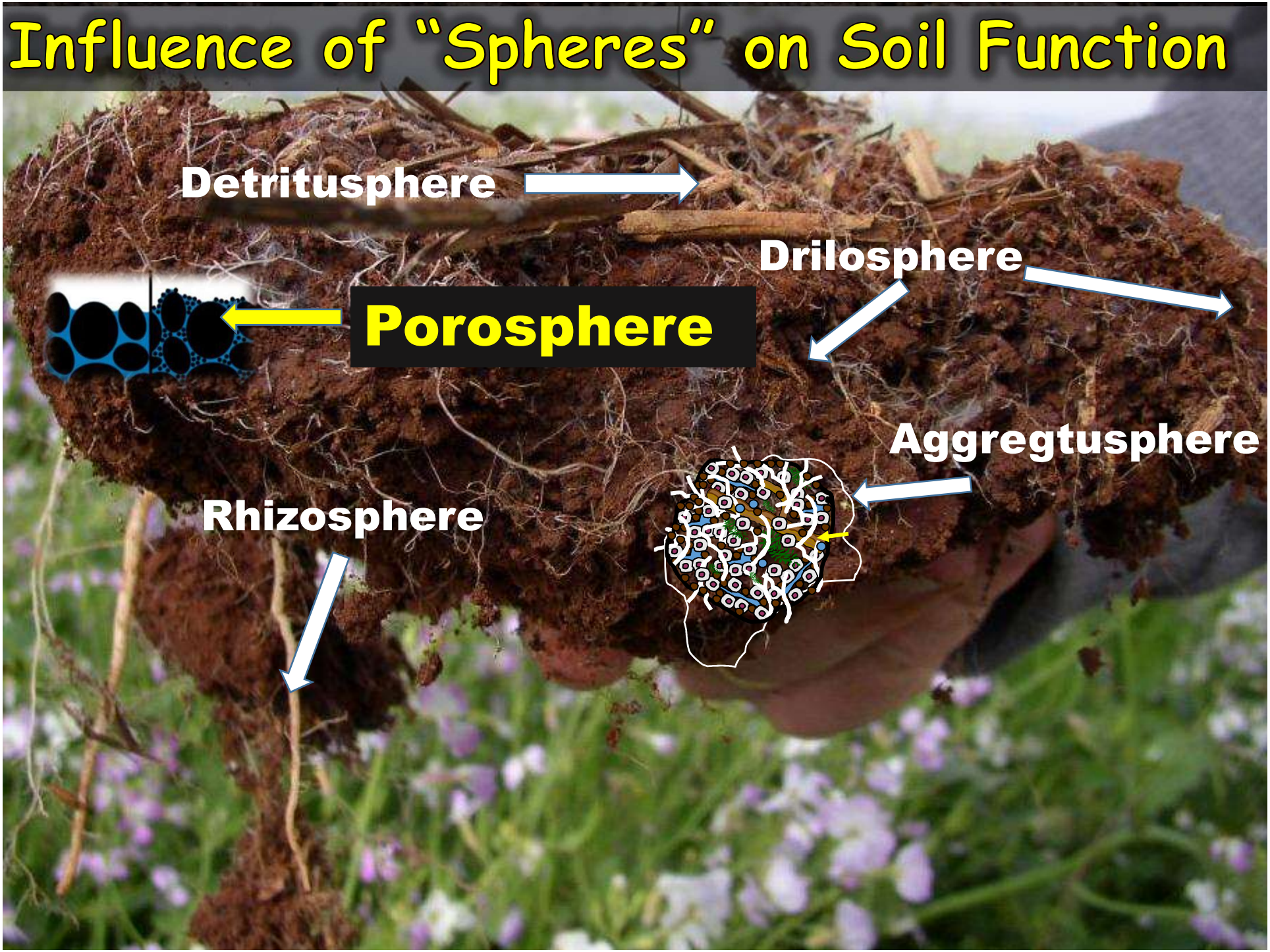
Fungi Retain Nutrients

unlock the SECRETS IN THE SOIL



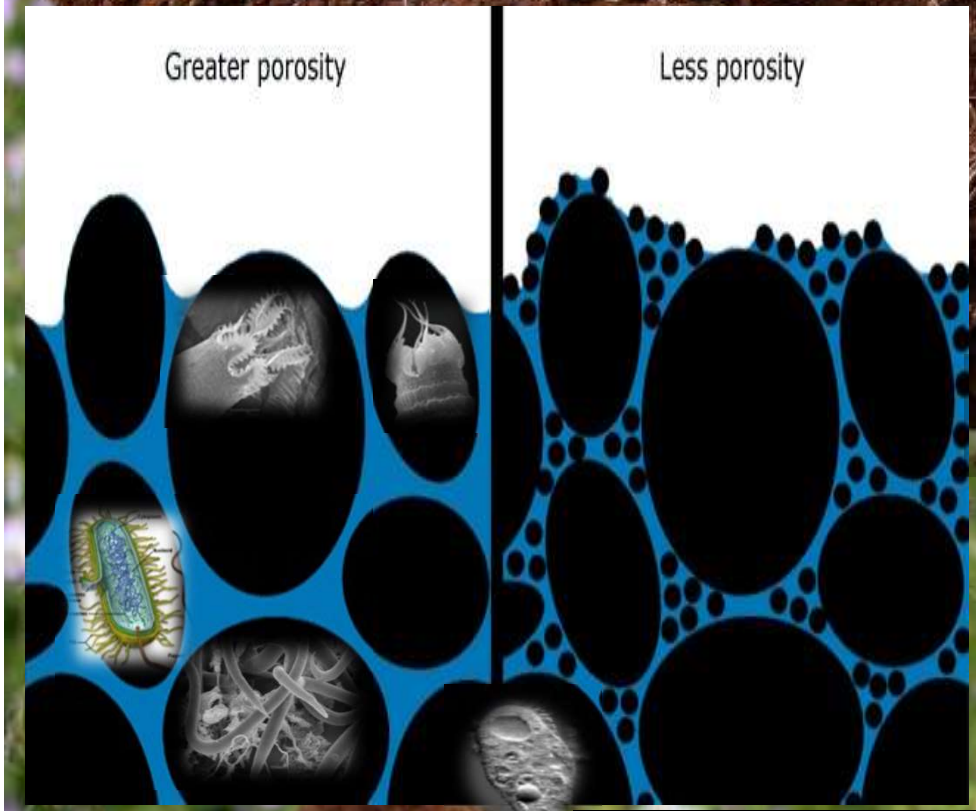
CALCIUM ON FUNGI

Influence of "Spheres" on Soil Function



Porosphere: Arrangement of Solids and Voids

Lungs and Circulatory System of the Soil



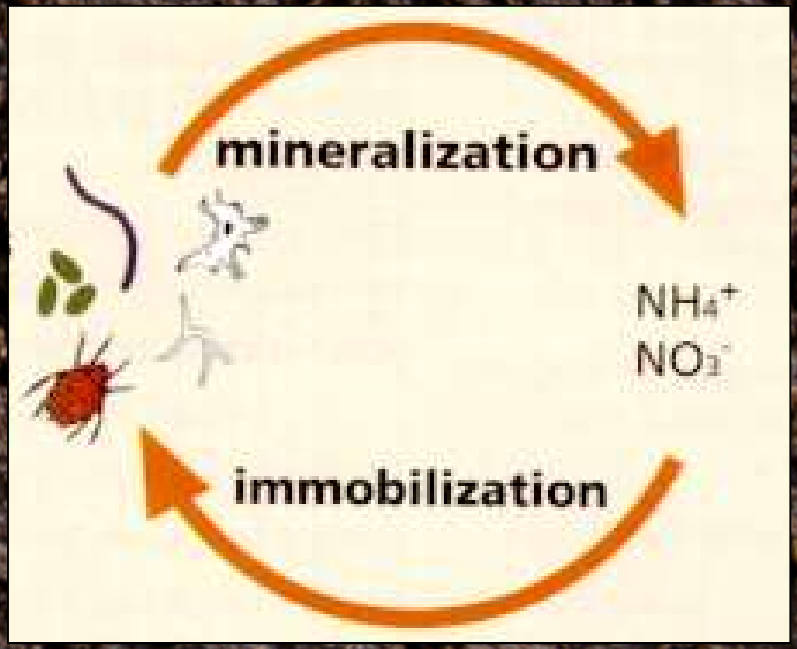
Aquatic Habitat

M.H. Beare, D.C. Coleman, D.A. Crossley Jr., P.F. Hendrix and E.P. Odum (1995)

Mineralization and Immobilization

unlock the SECRETS IN THE SOIL

Organisms consume other organisms and excrete inorganic wastes.



Organic nutrients are stored in soil organisms and organic matter.

Inorganic nutrients are usable by plants, and are mobile in soil.

Organisms take up and retain nutrients as they grow.

Essential Nutrients

unlock the SECRETS IN THE SOIL

Non-Mineral Nutrients
- Carbon (C)
- Hydrogen (H)
- Oxygen (O)

Primary Nutrients
- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)

Secondary Nutrients
- Calcium (Ca)
- Magnesium (Mg)
- Sulfur (S)

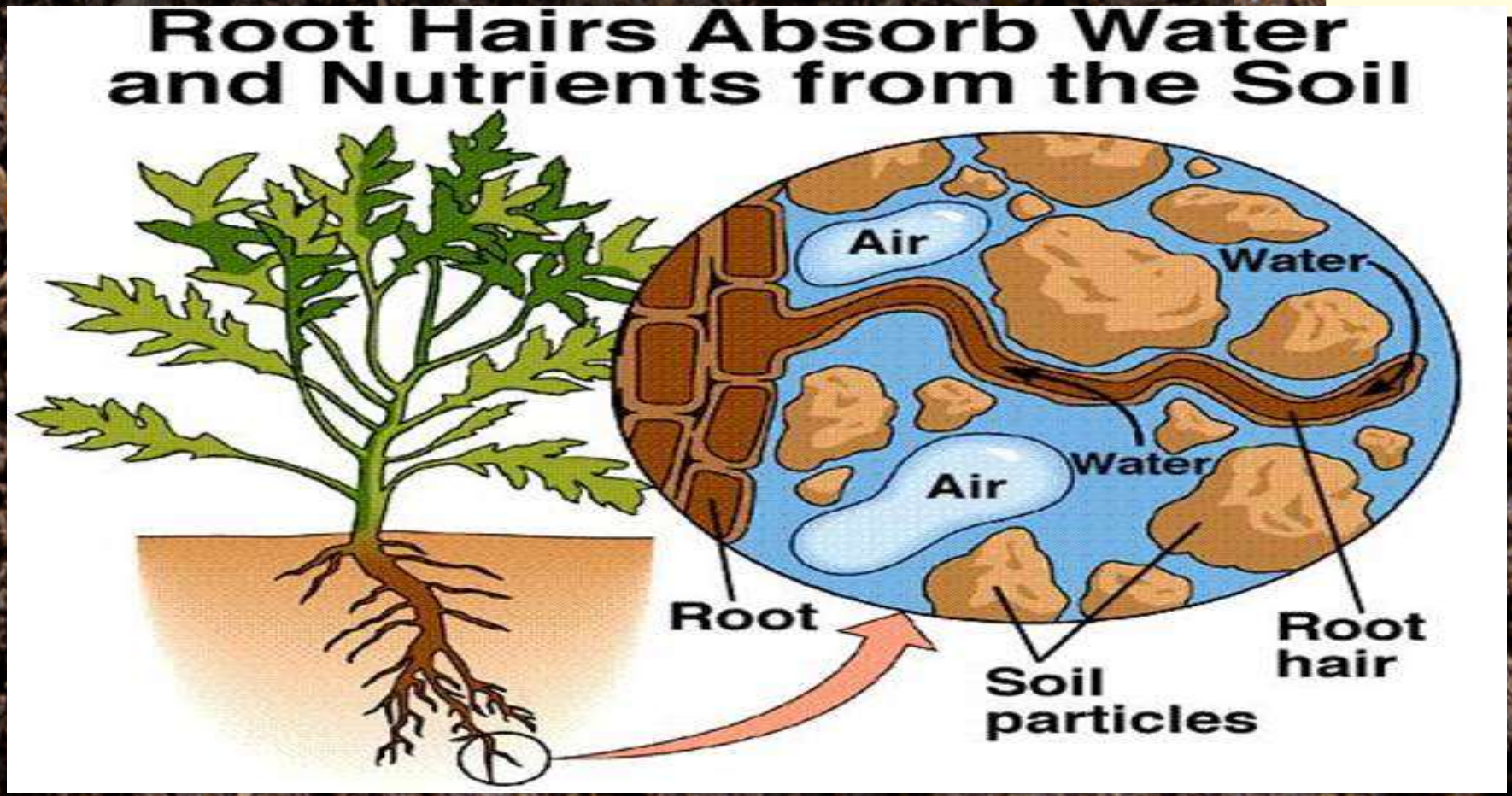
Essential Micronutrients
- Boron (B)
- Chloride (Cl)
- Copper (Cu)
- Iron (Fe)
- Manganese (Mn)
- Molybdenum (Mo)
- Sodium (Na)
- Nickel (Ni)
- Zinc (Zn)

Trace Minerals – Over 100 Types

Rhizosphere Activity

unlock the SECRETS IN THE SOIL

Plants take up Nutrients in Forms of IONS!

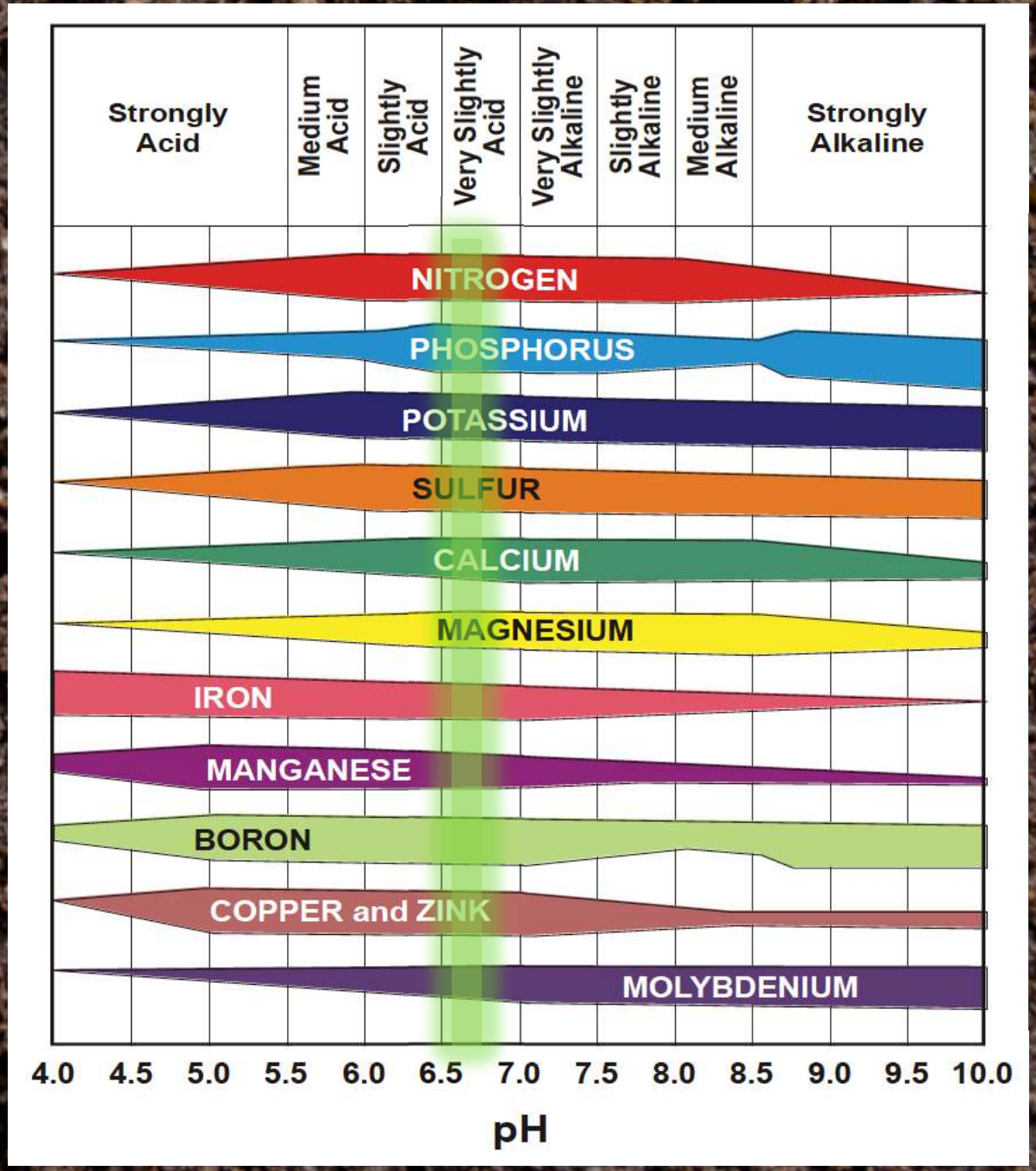


What are Ions?

An Ion is a positively or negatively charged compound.

Water Availability And Nitrogen Forms

unlock the SECRETS IN THE SOIL



unlock the SECRETS IN THE SOIL

Without biology, you are stuck with pH as the sole arbiter of what is available to plant roots. Add microbes, then plant nutrition is no longer ruled by pH alone. Microbes can use enzymes to solubilize plant nutrients.

Plant Uptake of Chelated Nutrients

unlock the SECRETS IN THE SOIL

The word chelate derives from the Greek word "chel", meaning a crab's claw, and refers to the pincer-like manner in which one mineral is bound by another.

With Biology, Chelation can happen as part of an organism's digestive process. Add microbes, and plant nutrition is no longer ruled by pH alone and chelated nutrients are no longer salts.

Mycorrhizae assist with Organic Nitrogen Uptake

unlock the SECRETS IN THE SOIL

Amino Acids inside mycorrhizal hyphae

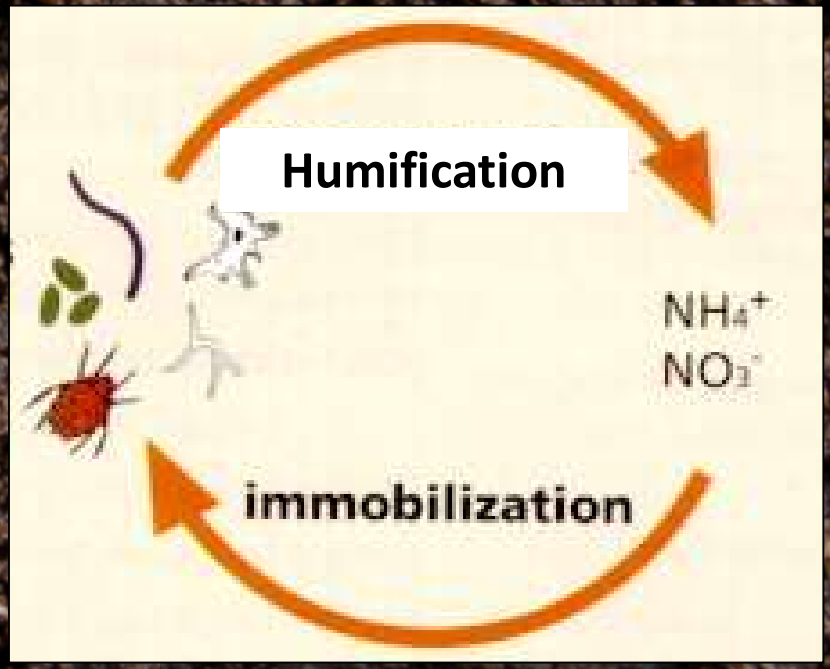
Amino Acids have entered the root from mycorrhizal hyphae

Fungal Digestion is Humification

unlock the SECRETS IN THE SOIL

Organisms consume other organisms and excrete inorganic wastes.

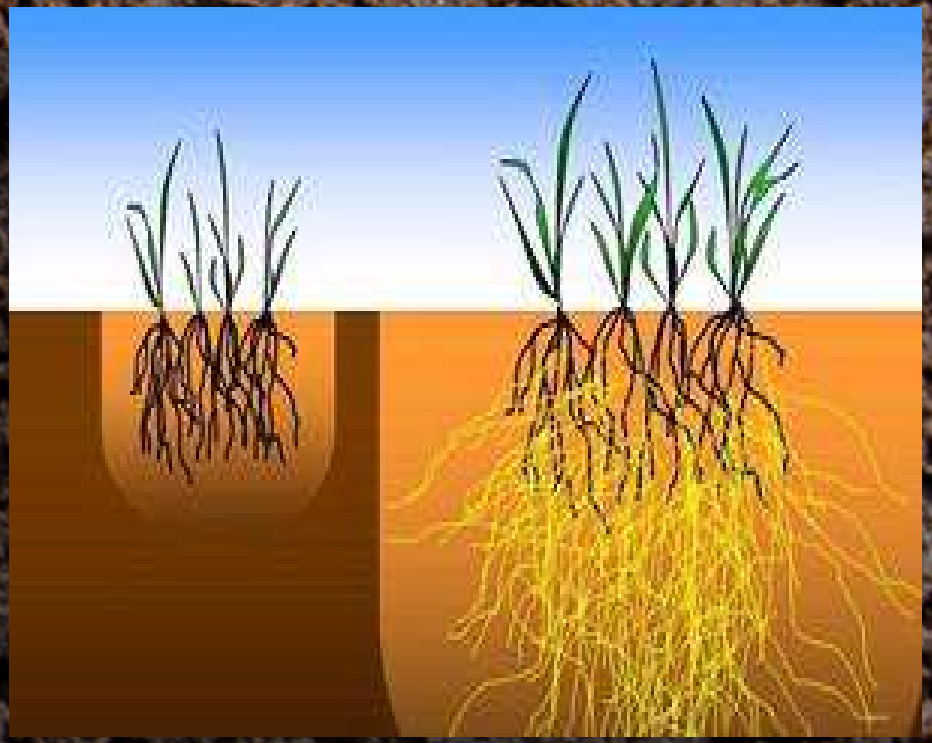
Organic nutrients are stored in soil organisms and organic matter.



Inorganic nutrients are usable by plants, and are mobile in soil.

Organisms take up and retain nutrients as they grow.

Mycorrhizae & Humification Process

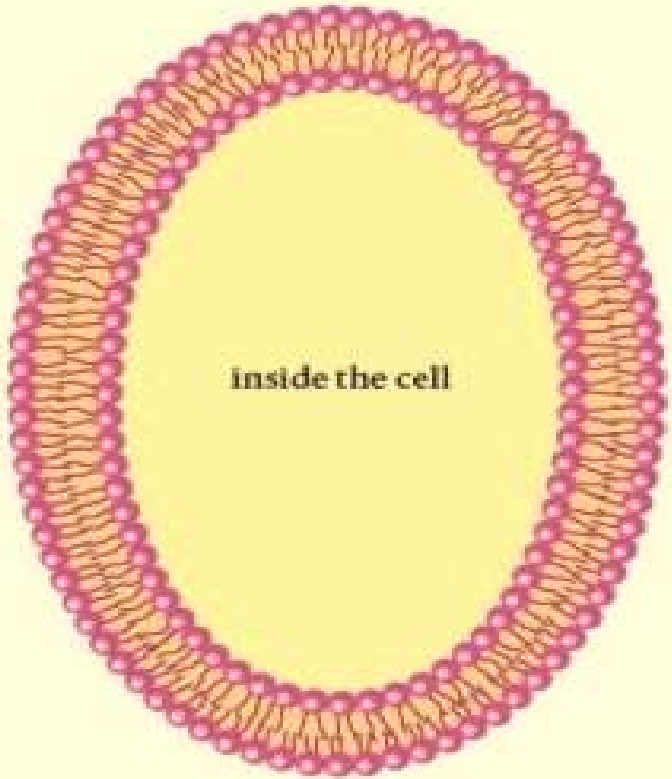


- Photosynthesis
- Sucrose to Hexose
- Hexose to Lipids
- Cycled and Translocated into the extraradical network outside the root.

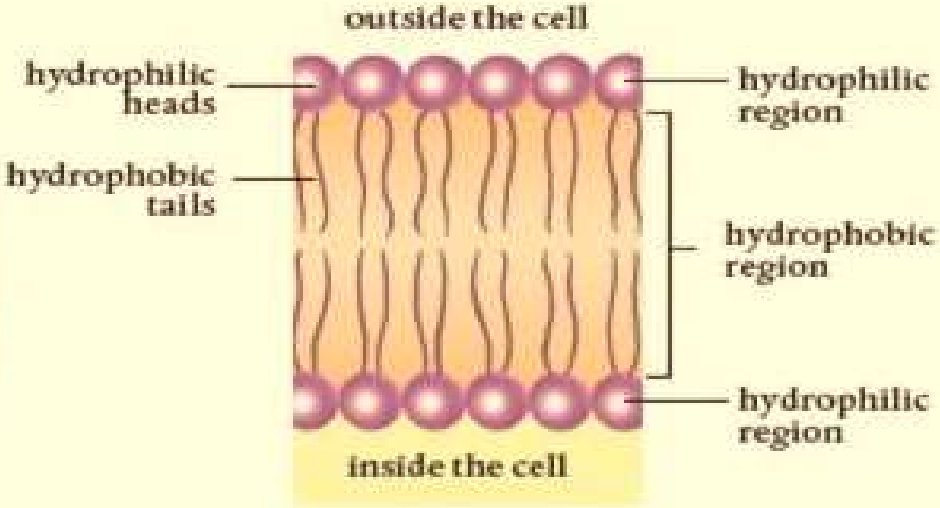
Healthy Plants Produce Healthy Soils

unlock the SECRETS IN THE SOIL

All Plant Cells have a Plasmalemma



phospholipid cell membrane



Benefits of Improving Soil Health

160 ppm

Transition Period

Soil Health

Dynamic Equilibrium State

Water Soluble Organic Carbon

Aggregation & Infiltration

Water & Nutrient Holding

Productivity

Air & Water Quality; Soil Biota Habitat

347 ppm

Time

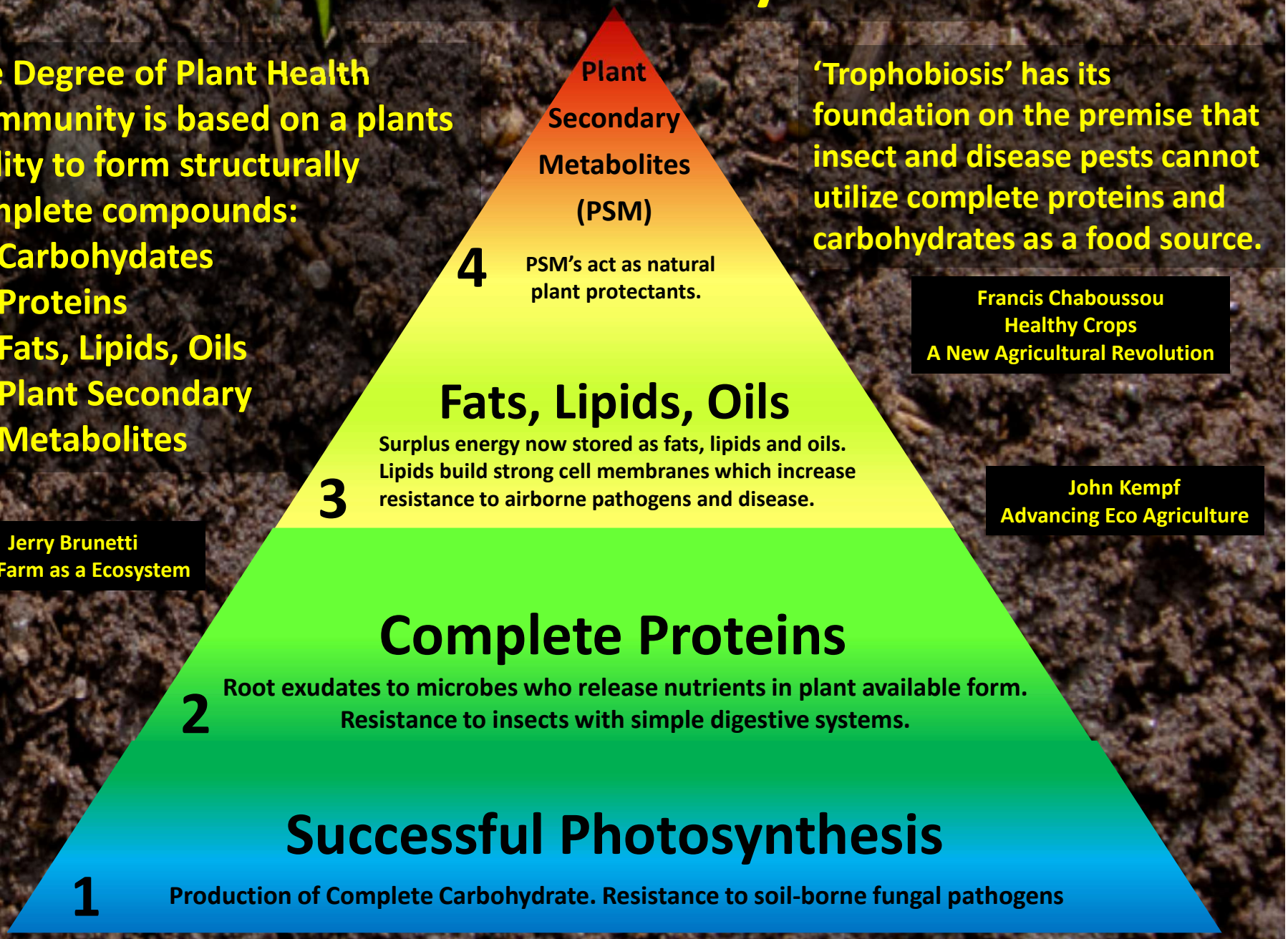
Biological

Plant Health Pyramid

The Degree of Plant Health & Immunity is based on a plants ability to form structurally complete compounds:

1) Carbohydates
2) Proteins
3) Fats, Lipids, Oils
4) Plant Secondary Metabolites

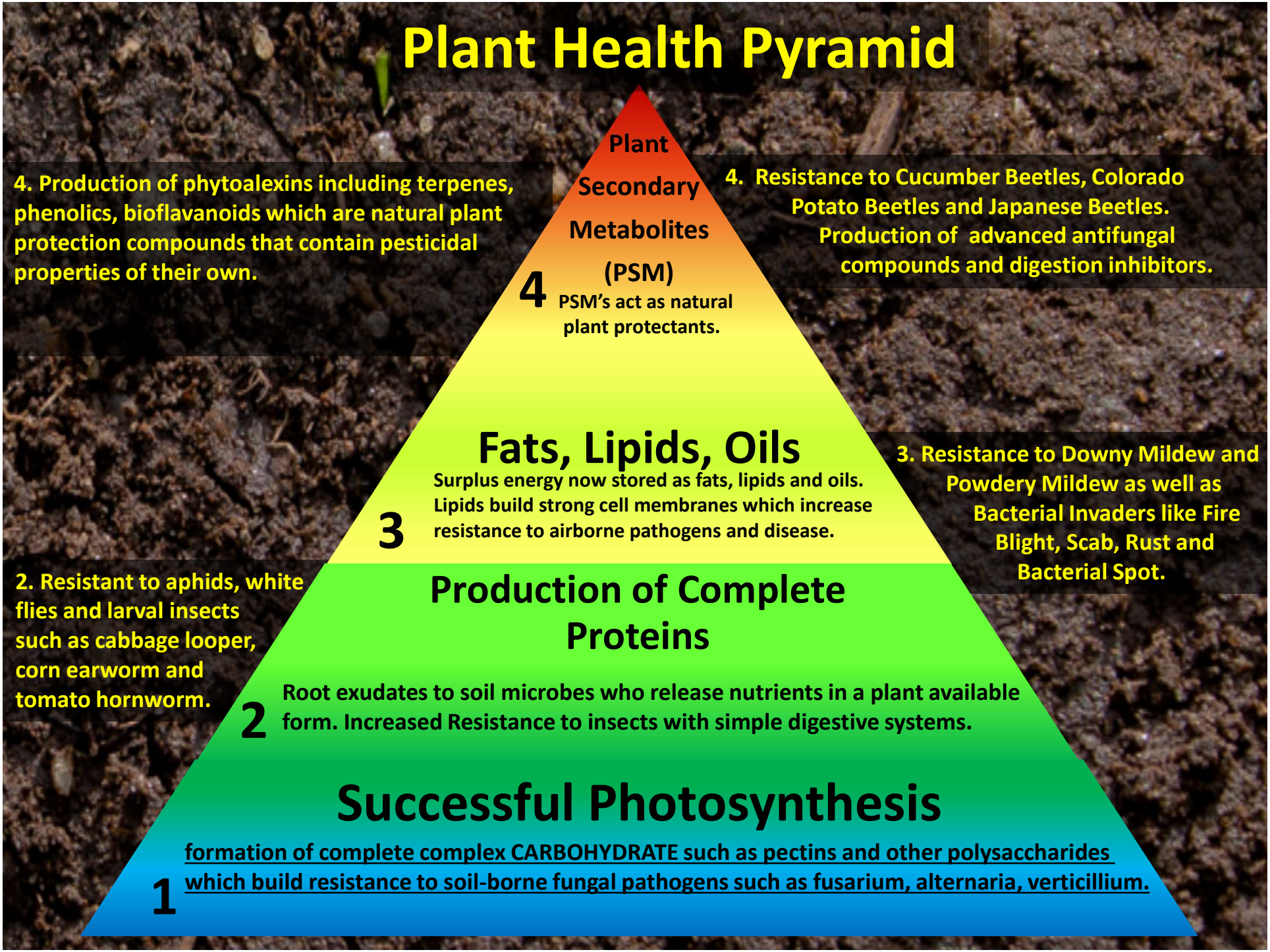
Jerry Brunetti
The Farm as a Ecosystem



'Trophobiosis' has its foundation on the premise that insect and disease pests cannot utilize complete proteins and carbohydrates as a food source.

Francis Chaboussou
Healthy Crops
A New Agricultural Revolution

John Kempf
Advancing Eco Agriculture

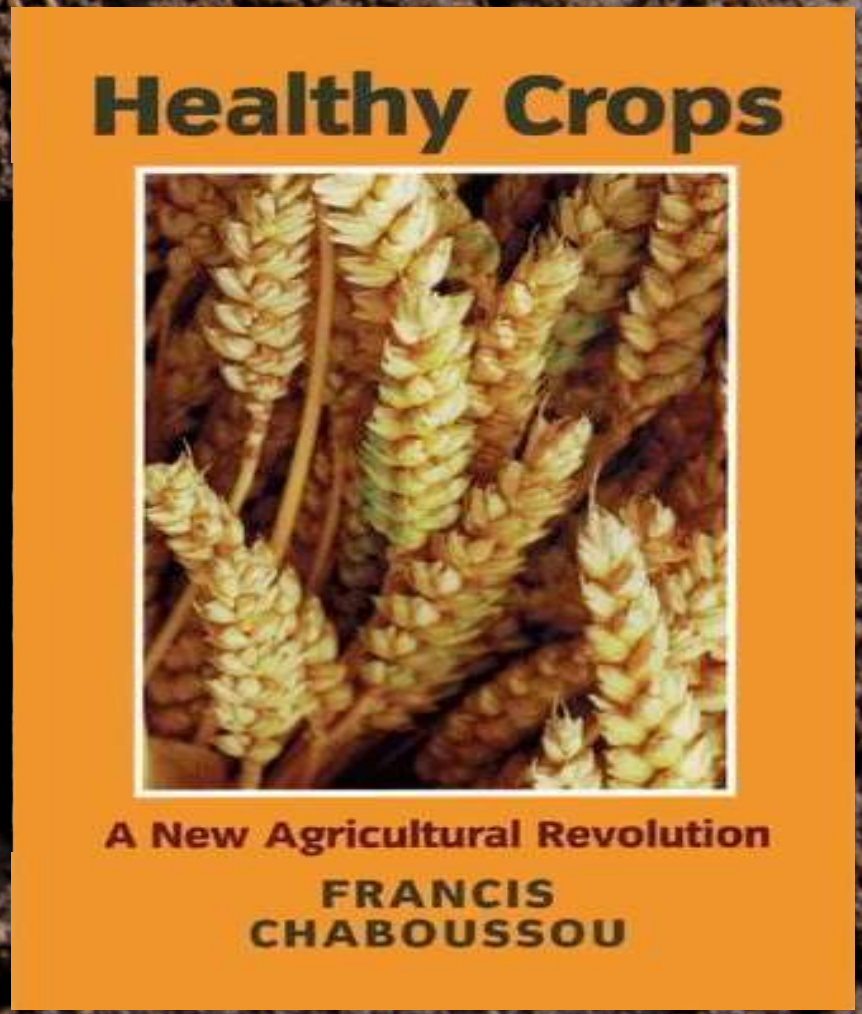

Plant Health Pyramid
4. Production of phytoalexins including terpenes, phenolics, bioflavanoids which are natural plant protection compounds that contain pesticidal properties of their own.
Plant Secondary Metabolites (PSM)
4
PSM's act as natural plant protectants.
4. Resistance to Cucumber Beetles, Colorado Potato Beetles and Japanese Beetles. Production of advanced antifungal compounds and digestion inhibitors.
Fats, Lipids, Oils
3
Surplus energy now stored as fats, lipids and oils. Lipids build strong cell membranes which increase resistance to airborne pathogens and disease.
3. Resistance to Downy Mildew and Powdery Mildew as well as Bacterial Invaders like Fire Blight, Scab, Rust and Bacterial Spot.
2. Resistant to aphids, white flies and larval insects such as cabbage looper, corn earworm and tomato hornworm.
Production of Complete Proteins
2
Root exudates to soil microbes who release nutrients in a plant available form. Increased Resistance to insects with simple digestive systems.
Successful Photosynthesis
1
formation of complete complex CARBOHYDRATE such as pectins and other polysaccharides which build resistance to soil-borne fungal pathogens such as fusarium, alternaria, verticillium.

Trophobiosis Theory:
A Pest Starves on a Healthy Plant

unlock the SECRETS IN THE SOIL

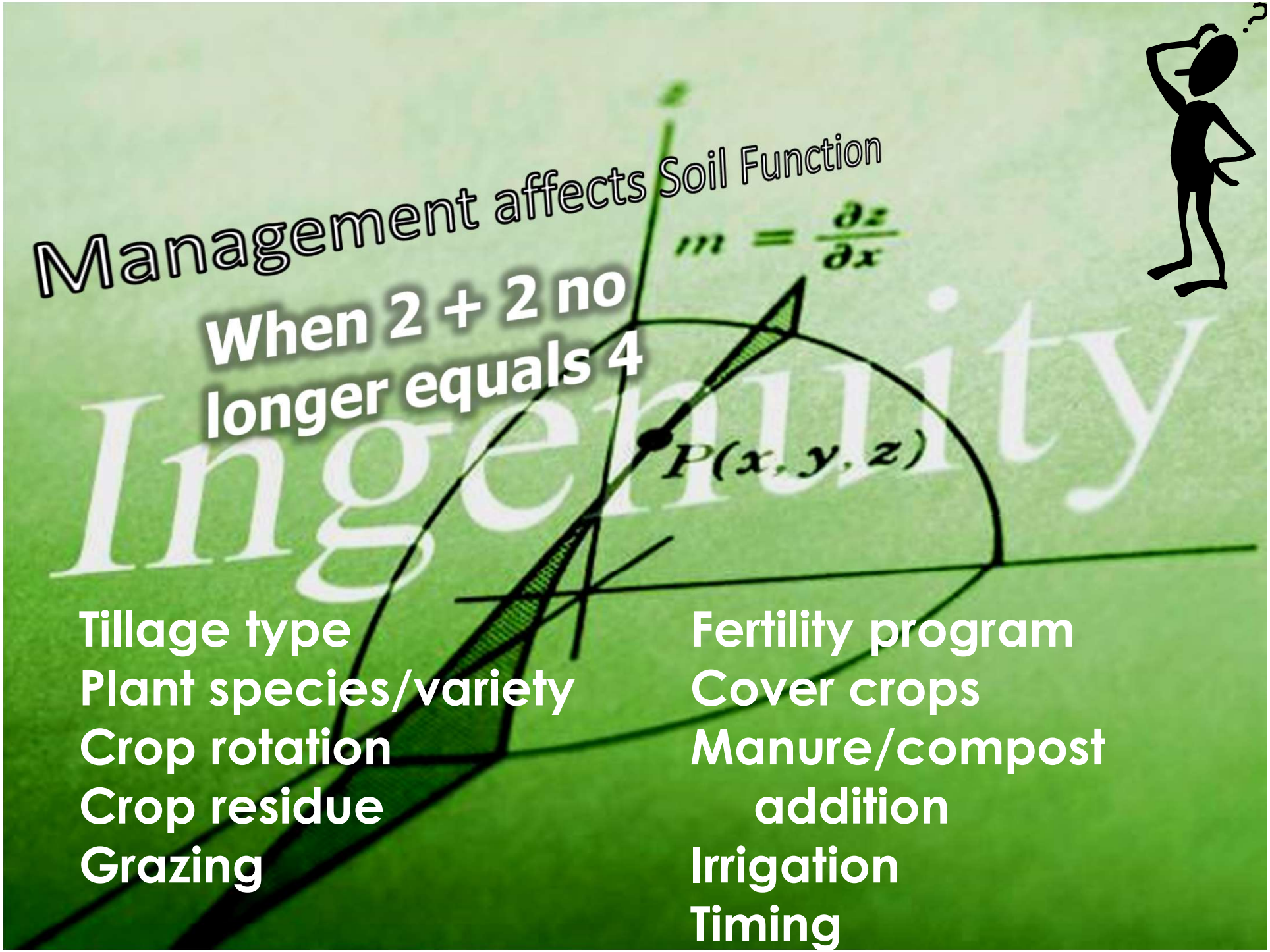
"a pest starves on a healthy plant". It is "a revolution in pathology and is a mortal blow to agrochemistry as commonly practiced in modern agriculture"

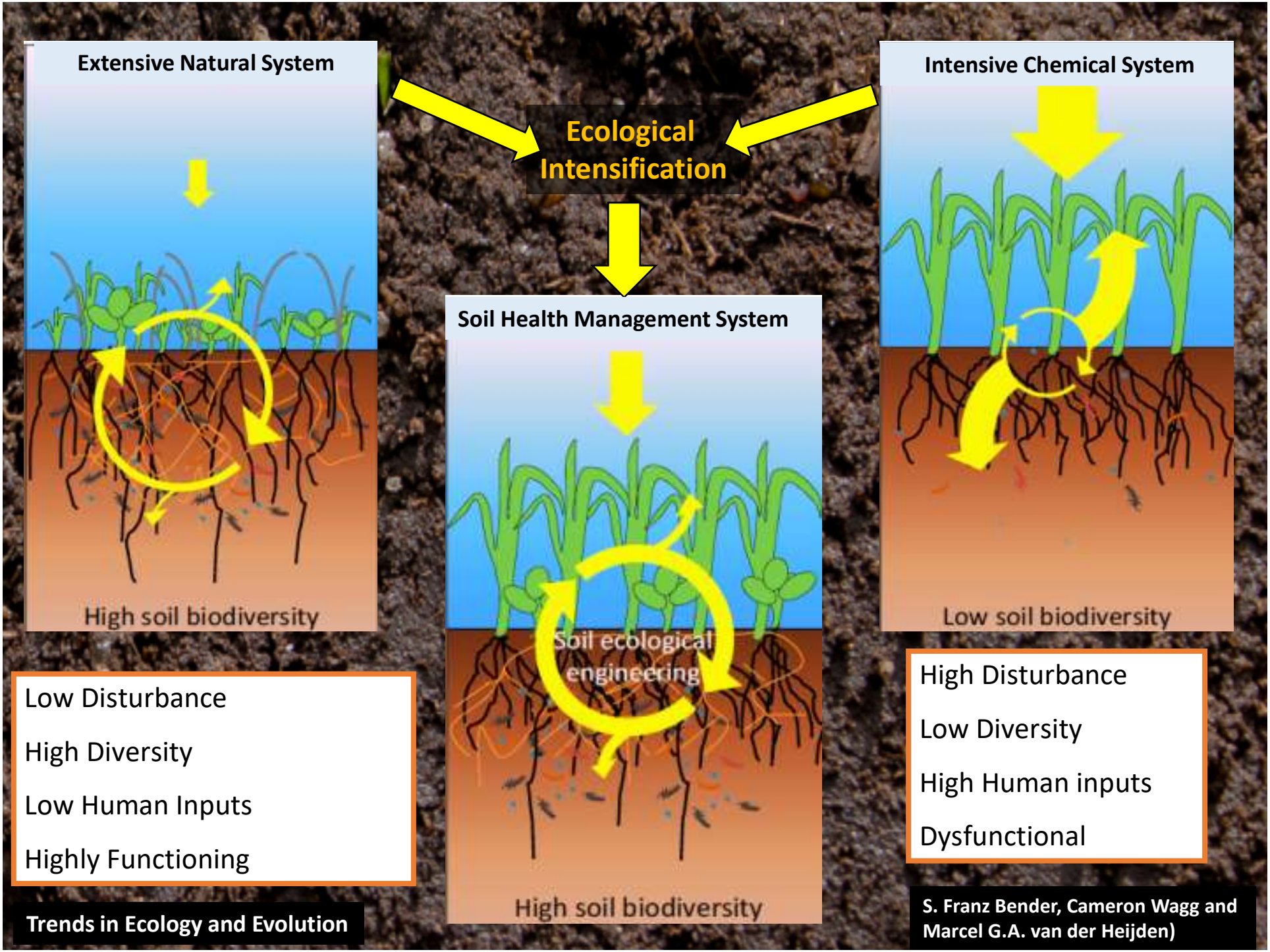
Jose Lutzenberger
Former Minister for the Environment in Brazil



Fertilizer Impact

unlock the SECRETS IN THE SOIL


Management affects Soil Function
When 2 + 2 no longer equals 4
Ingenuity
$m = \frac{\partial z}{\partial x}$
$P(x, y, z)$
Tillage type
Plant species/variety
Crop rotation
Crop residue
Grazing
Fertility program
Cover crops
Manure/compost addition
Irrigation
Timing


Extensive Natural System
High soil biodiversity
Low Disturbance
High Diversity
Low Human Inputs
Highly Functioning
Ecological Intensification
Soil Health Management System
Soil ecological engineering
High soil biodiversity
Intensive Chemical System
Low soil biodiversity
High Disturbance
Low Diversity
High Human inputs
Dysfunctional
Trends in Ecology and Evolution
S. Franz Bender, Cameron Wagg and Marcel G.A. van der Heijden)

Importance of Soil Biology: Release Plant-Available Nutrients

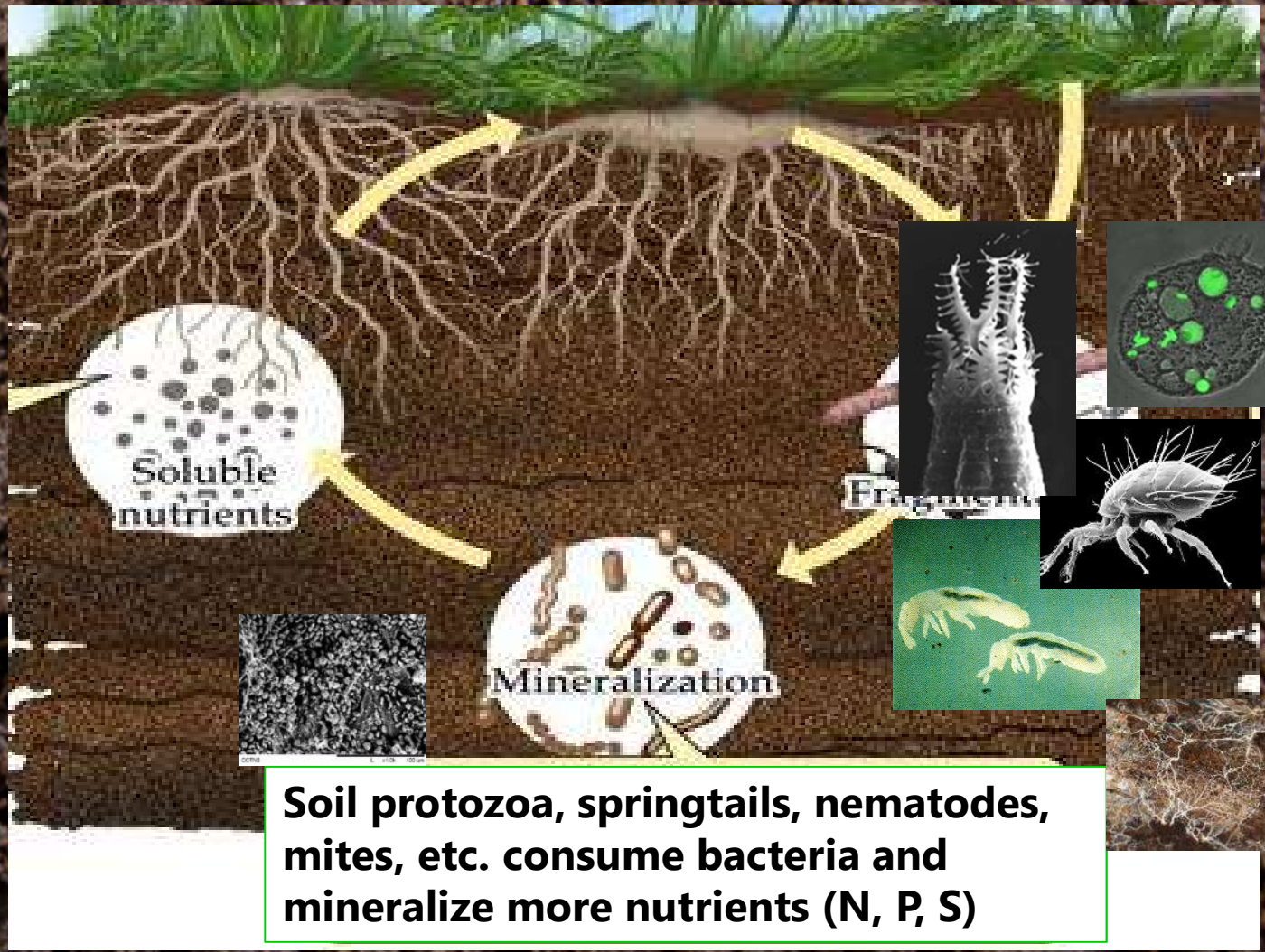
unlock the SECRETS IN THE SOIL

Soil Function

Nitrogen mineralization

Plant-available N release

Reduction in fertilizer needs



Soil protozoa, springtails, nematodes, mites, etc. consume bacteria and mineralize more nutrients (N, P, S)

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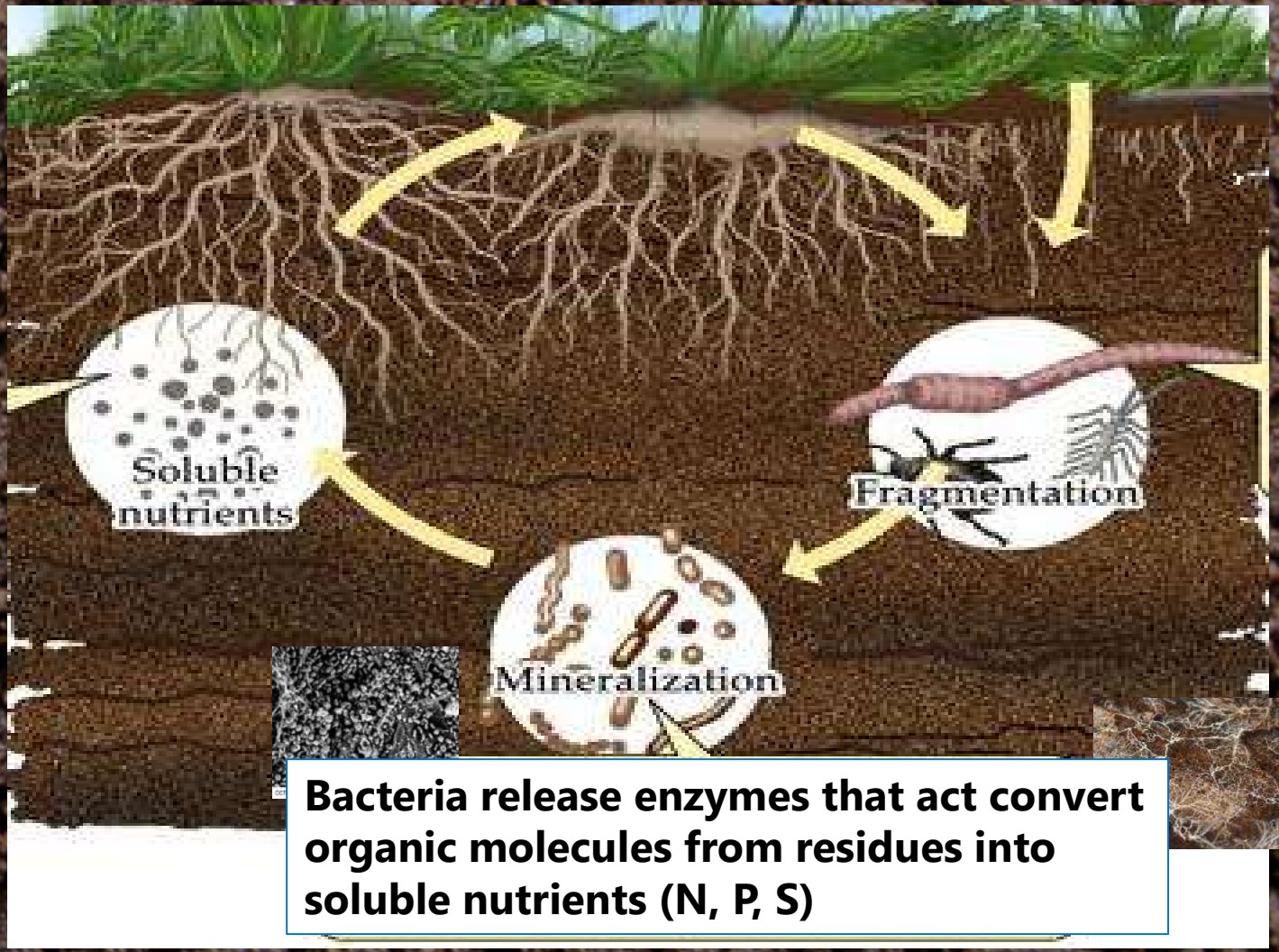

Bacteria release enzymes that act convert organic molecules from residues into soluble nutrients (N, P, S)

Importance of Soil Biology: Release Plant-Available Nutrients

unlock the SECRETS IN THE SOIL

Soil Function

Nitrogen mineralization

Plant-available N release

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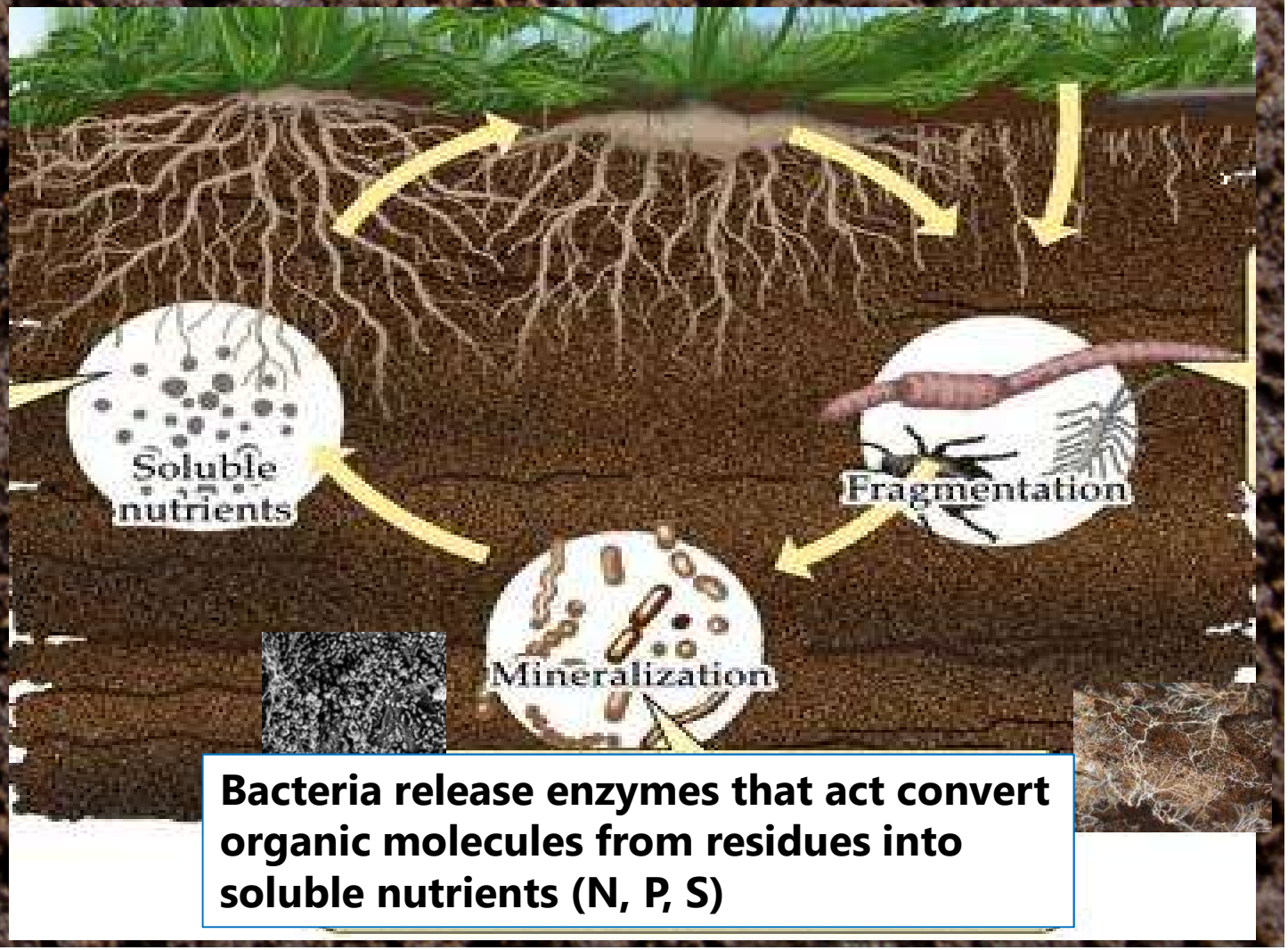

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