



# How Can I Tell if My Soil is Healthy?

Presentation prepared by the USDA-NRCS  
National Soil Health and Sustainability Team  
(modified from the original to accommodate notes with photos)

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New Mexico Integrated Cropping Systems and Water Management Handbook  
[http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nm/technical/?cid=nrcs144p2\\_068965](http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nm/technical/?cid=nrcs144p2_068965)

USDA-NRCS: Unlock the Secrets in the Soil  
<http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/>

# Soil Health What is It?



- The continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans.
  - Nutrient cycling
  - Water (infiltration & availability)
  - Filtering and Buffering
  - Physical Stability and Support
  - Habitat for Biodiversity

How we can evaluate a field's current soil health and looking at how it is functioning.

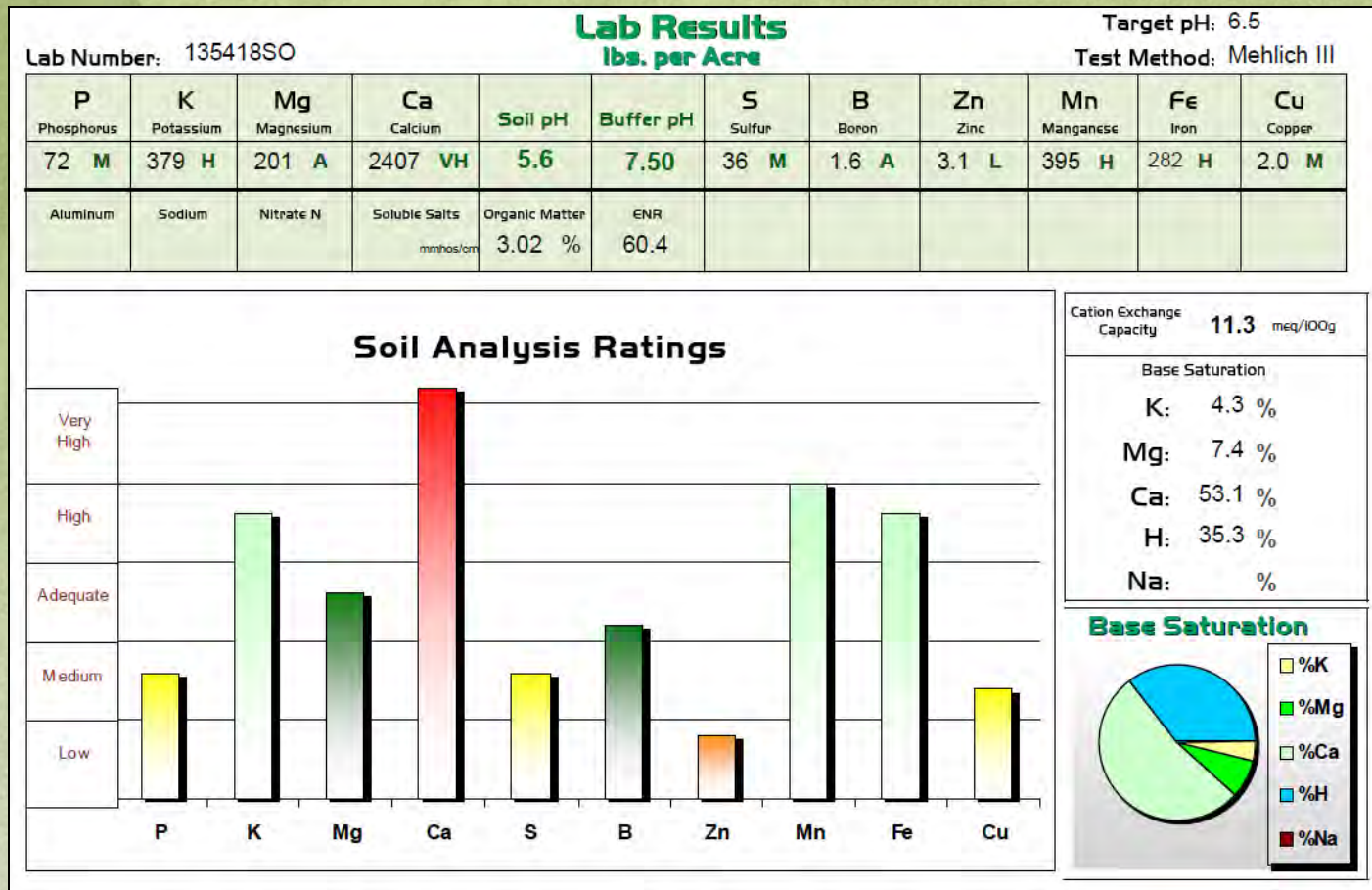
This is the definition of Soil health we are using. The term "Health" was purposely chosen instead of "quality".

- **Quality implies** analysis and quantifying
- **Health implies** management actions that leads to a condition or state, there is something that can be done to change it in a positive trend.

The key to the definition is that soil health is:

1. **Continued capacity**—implies rejuvenation and then sustainability.
2. **Soil is a living ecosystem**— folks need to recognize the ground beneath them is a living ecosystem.
3. **Soil function** – soils need to provide the basic functions below in order to meet our food & fiber production demands.
  - a) **Nutrient Cycling** - Soil stores, moderates the release of, and cycles nutrients and other elements. During these biogeochemical processes, analogous to the water cycle, nutrients can be transformed into plant available forms, held in the soil, or even lost to air or water.
  - b) **Water Relations** - Soil can regulate the drainage, flow and storage of water and solutes, which includes nitrogen, phosphorus, pesticides, and other nutrients and compounds dissolved in the water. With proper functioning, soil partitions water for groundwater recharge and for use by plants and soil animals.
  - c) **Biodiversity and Habitat** - Soil supports the growth of a variety of plants, animals, and soil microorganisms, usually by providing a diverse physical, chemical, and biological habitat.
  - d) **Filtering and Buffering** - Soil acts as a filter to protect the quality of water, air, and other resources. Toxic compounds or excess nutrients can be degraded or otherwise made unavailable to plants and animals.
  - e) **Physical Stability and Support** - Soil has the ability to maintain its porous structure to allow passage of air and water, withstand erosive forces, and provide a medium for plant roots. Soils also provide anchoring support for human structures and protect archeological treasures.

# Typical Soil Test

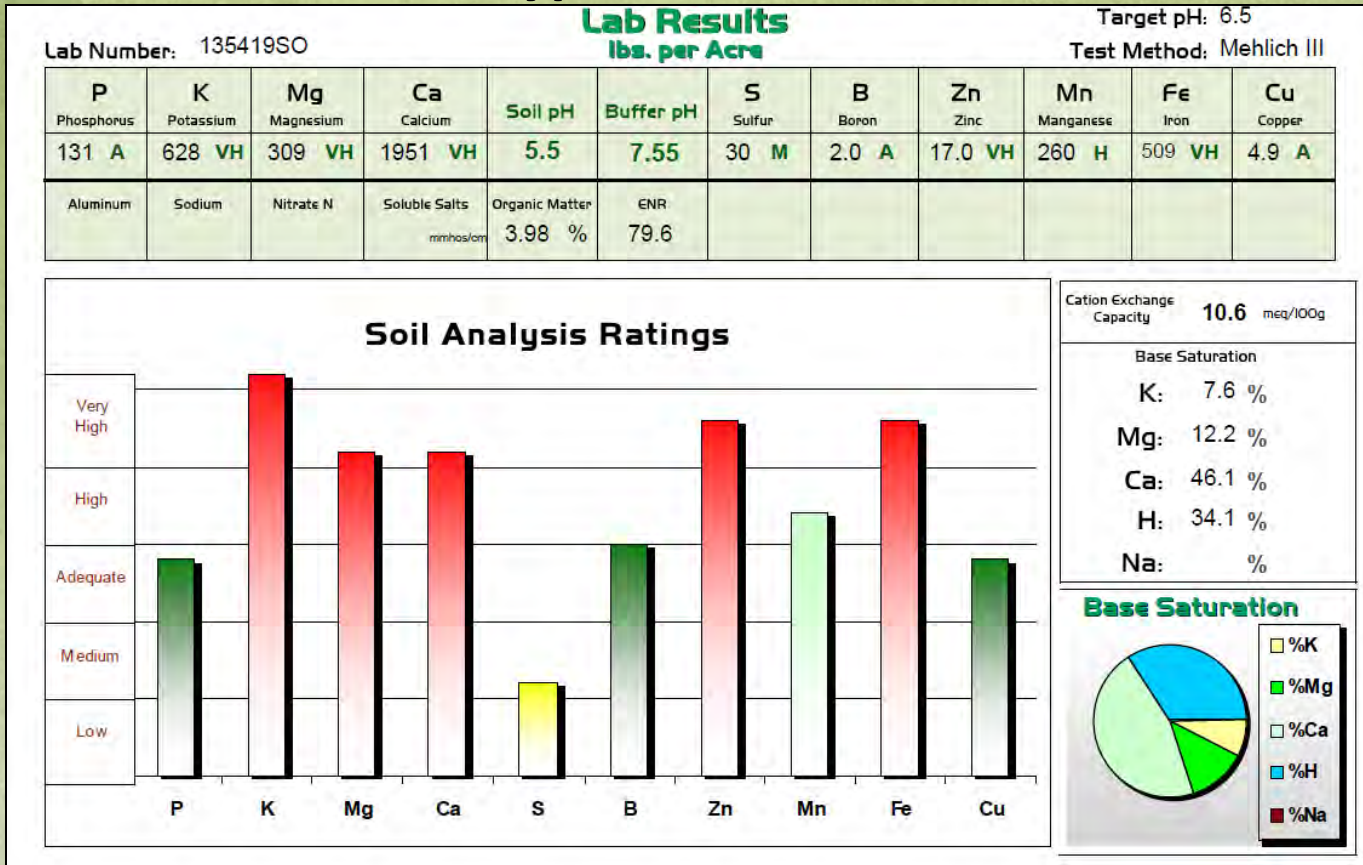


NRCS has used **soil testing** as the basis for many conservation practices, e.g. all seeding practices, nutrient management, etc. It gives a good snap shot view of the **current soil chemistry** in a field if sampling is done correctly.

## What does it tell us about how healthy a soil is?

- P level medium
- K level high
- pH low, with a high buffer
- OM 3.02% not bad for agricultural soils
- CEC is 11.3
- ENR – this is Estimated Nitrogen Release relatively new in soil test reports, estimates the amount of N to be released during the growing season, giving 20# N credit per 1% OM

# Typical Soil Test



We would judge this soil to be better because the chemistry is higher in all categories.

- OM is 3.98 pretty high
- ENR is 79.6

**But what does a soil test tell us about the soil functions necessary for food and fiber production?**

- Gives us nutrient analysis but **doesn't tell how well the nutrient cycle is functioning.**
- Doesn't tell anything about **water infiltration or holding capacity.**
- Nothing about **biodiversity**, etc.

You could make some assumptions based on OM, since it's relatively high one could assume that the fields have been managed to minimize disturbance.

**All in all soil test is limiting in the information it provides related to soil health.**

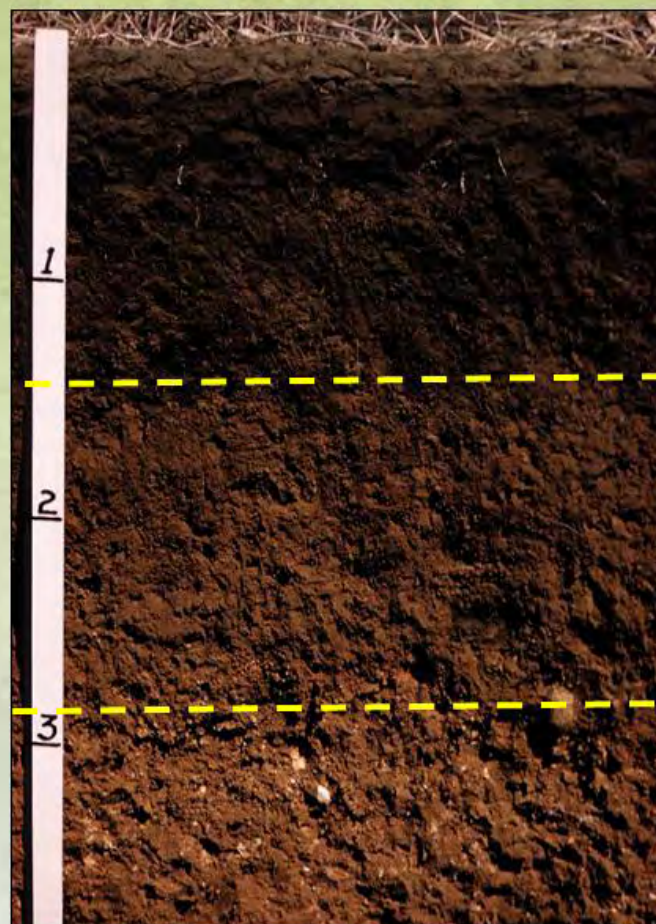
# Soil Profile

unlock the  
SECRETS  
IN THE  
SOIL

unlock the  
SECRETS  
SOIL

## Physical Characteristics

- Texture
- Structure
- Color
- Define horizon boundaries



A Horizon

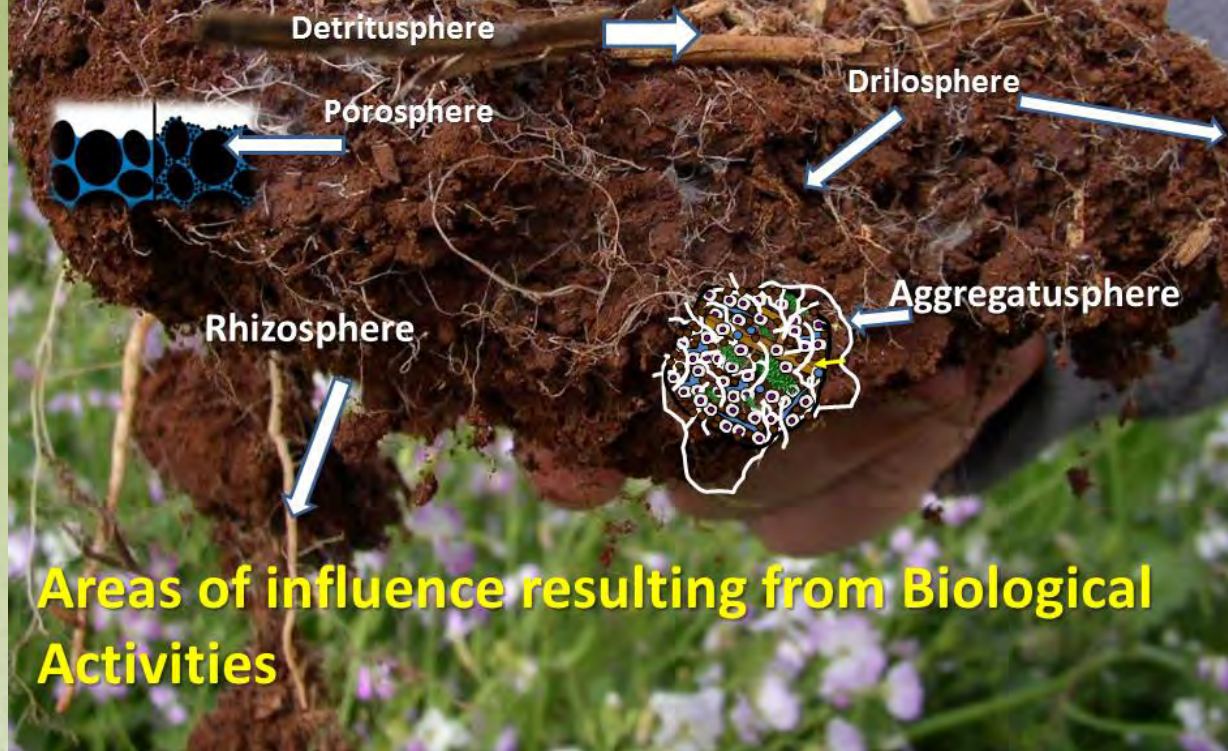
B Horizon

C Horizon

## What does an NRCS Soil Survey tell us about soil health?

- Gives the map units typical conditions related to a variety of soil properties and characteristics, e.g. permeability, texture, OM, etc.
- Can be used to compare soil series.
- **Can't be used to distinguish soil health based on actual field condition**, doesn't account for farmer management influence.
- Soils used in the soil stability (slake test) demo are mapped the same for conventional farming vs. soils with high soil health.
- Primary difference is how the soil have been managed over the past 40 years that have **impacted the dynamic soil properties**, e.g. OM, bulk density, infiltration, etc.

# Hierarchical Approach to Understanding Soil Function



## Areas of influence resulting from Biological Activities

To begin to understand how to evaluate the health of a soil from a biological perspective, we need to change our view on how soil functions. Instead of looking at profiles and texture we need to look at the biological processes or spheres of influence that are taking place and working in concert together. The following slides will run through each of these independently.

This information is taken from a paper entitled A hierarchical approach to evaluating the significance of soil biodiversity to biogeochemical cycling by M.H. Beare and others, below are some direct quotations:

- Soils can be viewed as being composed of a number of **biologically relevant spheres of influence that define much of their spatial and temporal heterogeneity.**
- **They are formed and maintained by biological influences that operate at different spatial and temporal scales.** Although not mutually exclusive, each sphere has fairly distinct properties that regulate the interactions among organisms and the biogeochemical processes that they mediate.
- Probably more than any other biological factor, **the composition and structure of plant communities determine, directly or indirectly, the physical, chemical and biological properties of soils.** Individual plants can have markedly different zones of influence in soils.

# The Detritosphere: Influence of residue

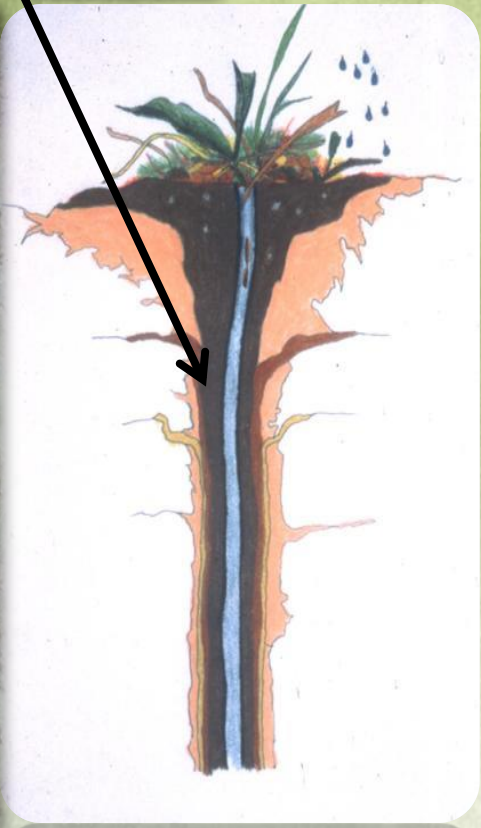


- Protects the soil aggregates (aggratusphere) and the pores (poroshpere) from the sun, wind and rain.
- Lowers temperture.
- Reduces evaporation
- Provides habitat and food for soil organisms.
- Enhances biogeochemical nutrient cycling.
- Builds soil structure and nutrient reserves.

**Detritosphere:** the zone of recognizable plant and animal detritus undergoing decay.

- Influenced by the chemical composition of the plant detritus.
- Disturbance of this layer reduces the habitat for microfungal communities, disrupts colonization.

# Drilosphere: Zone of earthworm influence



- Redistributes plant litter “Carbon” throughout the soil the profile.
- Soils are enriched with N,P, and humified organic matter.
- Increase water infiltration.
- Provide a bio pore for plant roots.
- Homogenize soil surface.
- Increase bio-diversity in soils.

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

**Drilosphere:** Zone of influence by earthworms and other microarthropods & millipedes.

- **Function to shred and redistribute plant litter** from the Detritosphere throughout the soil profile, horizontally and vertically.





**Epigeic – Red Worms (Bohlen et al 2004)**

- reddish in color.
- live and feed exclusively in the surface litter of the soil.
- limited mixing of mineral and organic soil layers.



**Anecic or Night crawlers (Bohlen et al 2004)**

- 10 to 15 centimeters in size.
- Eat fresh litter at the surface of the soil.
- Make burrows, sometimes up to 2 meters deep.
- Incorporate litter into the soil.
- Bring mineral soil from different depths to the surface.
- Soil mixing that is very different from worms.



**Endogeic (Bohlen et al 2004)**

- whitish gray and live and feed only in the soil or under logs.
- They almost never come to the surface.
- Feed on leaves or other organic material.
- Soil (i.e. excrement) they leave behind are called casts.
- Reside in the mineral or mixed soil layers.

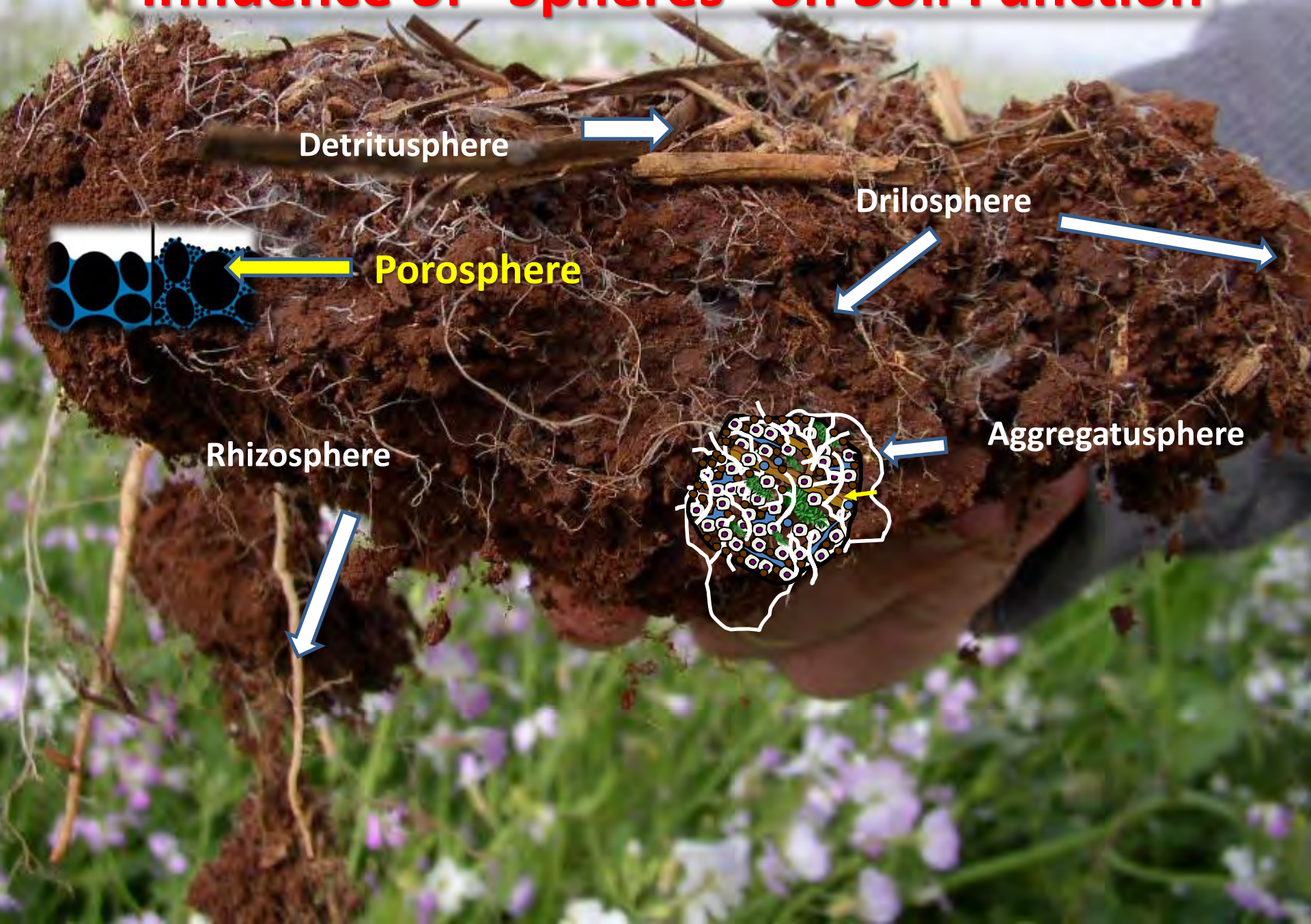
# Earthworms

- Poor soils contain 250,000 earthworms per acre while good soils contain 1,750,000 per acre.
- 1 or less per shovel indicates poor soil health.
- 10 or more per shovel indicates good soil health.
- Burrowing through lubricated tunnels forces air in and out of soil.
- Earthworm casts contain
  - 11% of the humus
  - 7X the nitrogen
  - 11X the phosphorus
  - 9X the potash

**More than the surrounding soil.**



# Influence of "Spheres" on Soil Function

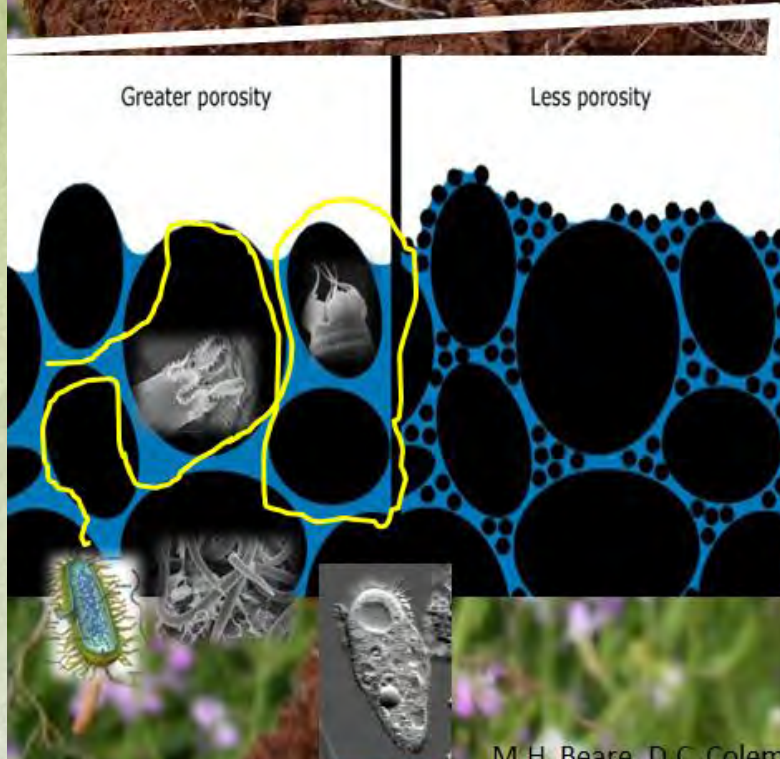


# Porosphere: Arrangement of Solids and Voids



Primary an Aquatic Habitat (water films): for protozoa, bacteria, Mycorrhizae, and nematodes

The lungs and circulatory system of the soil:

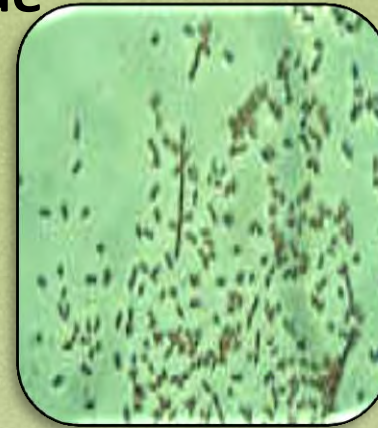


- Regulates water and air flow
- Impacts N, P Mineralization
- Impacts soil organism bio-mass and diversity
- Site of nutrient exchange
- Site of mycorrhizal entanglement and sequestration of water and nutrients
- Root interface
- Part of the water cycle

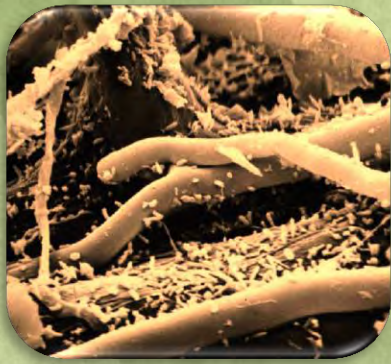
M.H. Beare, D.C. Coleman, D.A. Crossley Jr, P.F. Hendrix and E.P. Odum (1995)

1. Plant roots, earthworms and other arthropods can rearrange soil particles to create smooth, **cylindrically shaped macropores (biopores)**.
2. Biopores can extend considerable distance in the soil forming channels for preferential flow of water and nutrients.
3. **Good air exchange in the soil creates habitat in which aerobic organisms can thrive.**
4. Poor air exchange leads to **anaerobic conditions**, organisms that can tolerate this habitat tend to be those that cause disease and produce byproducts that inhibit root growth, e.g. alcohols.

# Bacteria – Services they provide



- Decomposition of OM
- Nutrient cycling
- Nitrogen fixation
- Nitrification
- Denitrification
- Disease Suppression
- Breakdown of hard to decompose compounds



The following slides give a brief overview of organisms that live in the Porosphere.

A **ton of microscopic bacteria** may be active in each acre of soil. Bacteria are tiny, one-celled organisms – generally 4/100,000 of an inch wide (1  $\mu\text{m}$ ) and somewhat longer in length. What bacteria lack in size, they make up in numbers. A teaspoon of productive soil generally contains between 100 million and 1 billion bacteria. **That is as much mass as two cows per acre.**

**Bacteria fall into four functional groups. Most are decomposers** that consume simple carbon compounds, such as root exudates and fresh plant litter. By this process, bacteria convert energy in soil organic matter into forms useful to the rest of the organisms in the soil food web. A number of decomposers can break down pesticides and pollutants in soil. Decomposers are especially important in immobilizing, or retaining, nutrients in their cells, thus preventing the loss of nutrients, such as nitrogen, from the rooting zone.

A second group of bacteria are the **mutualists** that form partnerships with plants. The most well-known of these are **the nitrogen-fixing bacteria**. The third group of bacteria is the **pathogens**. Bacterial pathogens include *Xymomonas* and *Erwinia* species, and species of *Agrobacterium* that cause gall formation in plants. A fourth group, called **lithotrophs or chemoautotrophs**, obtains its energy from compounds of nitrogen, sulfur, iron or hydrogen instead of from carbon compounds. Some of these species are important to nitrogen cycling and degradation of pollutants.

**Bacteria from all four groups perform important services related to water dynamics, nutrient cycling, and disease suppression.** Some bacteria affect water movement by producing substances that help bind soil particles into small aggregates (those with diameters of 1/10,000-1/100 of an inch or 2-200 $\mu\text{m}$ ). Stable aggregates improve water infiltration and the soil's water-holding ability. **In a diverse bacterial community, many organisms will compete with disease-causing organisms in roots and on aboveground surfaces of plants.**

**Nitrogen-fixing bacteria form symbiotic associations with the roots of legumes.**

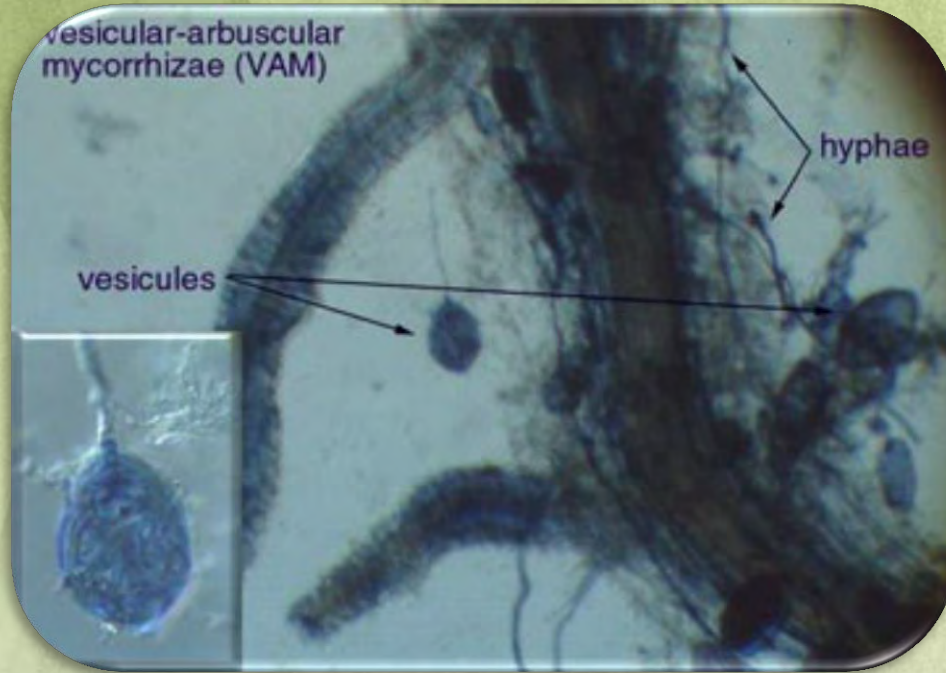
Nitrifying bacteria change ammonium ( $\text{NH}_4^+$ ) to nitrite ( $\text{NO}_2^-$ ) then to nitrate ( $\text{NO}_3^-$ ) – a preferred form of nitrogen for grasses and most row crops.

Denitrifying bacteria convert nitrate to nitrogen ( $\text{N}_2$ ) or nitrous oxide ( $\text{N}_2\text{O}$ ) gas. **Denitrifiers are anaerobic**, meaning they are active where oxygen is absent, such as in saturated soils **or inside soil aggregates.**

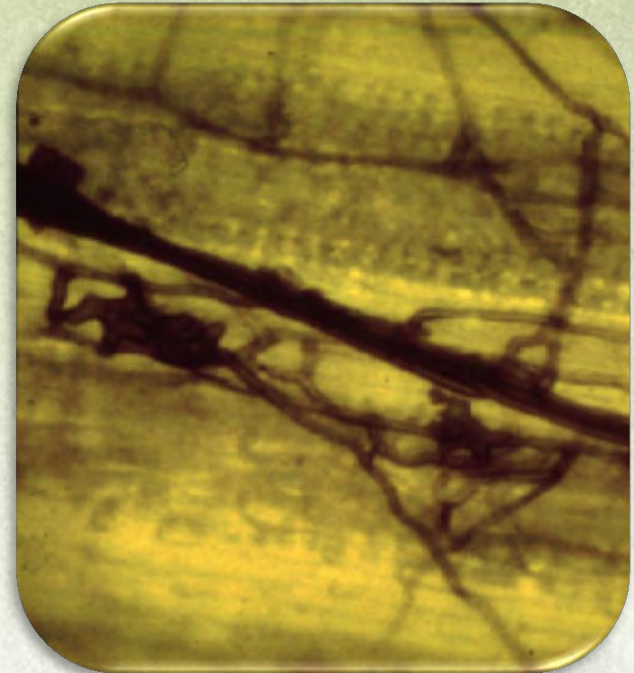
**Actinomycetes are a large group of bacteria that grow as hyphae like fungi.** They are responsible for the characteristically “earthy” smell of freshly turned, healthy soil. **Actinomycetes decompose a wide array of substrates, but are especially important in degrading recalcitrant (hard-to-decompose) compounds**, such as chitin and cellulose, and are active at high pH levels. Fungi are more important in degrading these compounds at low pH. A number of antibiotics are produced by actinomycetes such as Streptomyces.

*Credit: Michael T. Holmes, Oregon State University, Corvallis.*

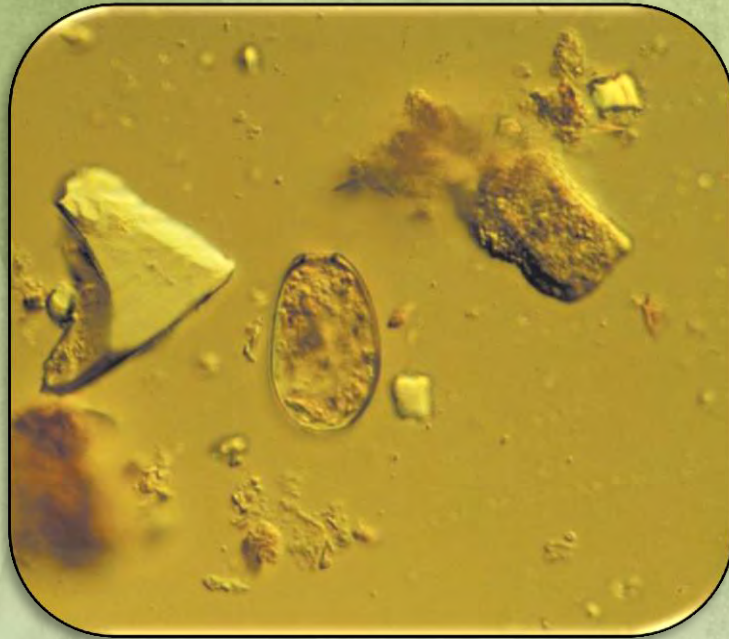
# Fungi- Service they provide



- Decompose Organic Matter
- Glomalin secretion develops soil structure
- Extract nutrients
- Hold nutrients



# Protozoa – Services they provide



- Nutrient mineralization
- Regulation of bacterial populations
- Food source themselves

**Protozoa are single-celled animals** that feed primarily on bacteria, but also eat other protozoa, soluble organic matter, and sometimes fungi. They are several times larger than bacteria – ranging from 1/5000 to 1/50 of an inch (5 to 500  $\mu\text{m}$ ) in diameter. **As they eat bacteria, protozoa release excess nitrogen that can then be used by plants and other members of the food web.**

**Protozoa play an important role in mineralizing nutrients**, making them available for use by plants and other soil organisms. Protozoa (and nematodes) have a lower concentration of nitrogen in their cells than the bacteria they eat. (The ratio of carbon to nitrogen for protozoa is 10:1 or much more and 3:1 to 10:1 for bacteria.) Bacteria eaten by protozoa contain too much nitrogen for the amount of carbon protozoa need. **They release the excess nitrogen in the form of ammonium ( $\text{NH}_4^+$ ).** This usually occurs near the root system of a plant. **Bacteria and other organisms rapidly take up most of the ammonium, but some is used by the plant.**

**Another role that protozoa play is in regulating bacteria populations.** When they graze on bacteria, protozoa stimulate growth of the bacterial population (and, in turn, decomposition rates and soil aggregation.) Exactly why this happens is under some debate, but grazing can be thought of like pruning a tree – a small amount enhances growth, too much reduces growth or will modify the mix of species in the bacterial community.

**Protozoa are also an important food source for other soil organisms and help to suppress disease by competing with or feeding on pathogens.**

**Protozoa need bacteria to eat and water in which to move**, so moisture plays a big role in determining which types of protozoa will be present and active. **Like bacteria, protozoa are particularly active in the rhizosphere next to roots.**

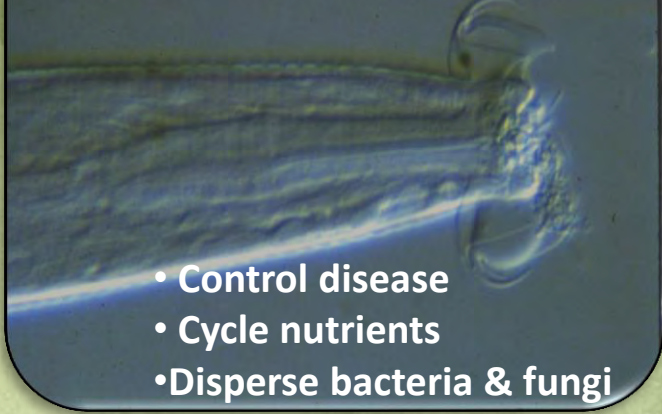
**Protozoa and bacterial-feeding nematodes compete for their common food resource: bacteria.** Some soils have high numbers of either nematodes or protozoa, but not both. The significance of this difference to plants is not known. Both groups consume bacteria and release  $\text{NH}_4^+$ .

**Protozoa graze on bacteria, fungi, and each other, and they release nutrients.**

# Nematodes – Services they provide



A bacteria-feeding nematode



- Control disease
- Cycle nutrients
- Disperse bacteria & fungi



A fungal-feeding nematode

**Nematodes are non-segmented worms** typically 1/500 of an inch (50  $\mu\text{m}$ ) in diameter and 1/20 of an inch (1 mm) in length. Those few species responsible for plant diseases have received a lot of attention, **but far less is known about the majority of the nematode community that plays beneficial roles in soil.** An incredible variety of nematodes function at several trophic levels of the soil food web. Some feed on the plants and algae (first trophic level); others are grazers that feed on bacteria and fungi (second trophic level); and some feed on other nematodes (higher trophic levels). Free-living nematodes can be divided into four broad groups based on their diet. **Bacterial-feeders consume bacteria. Fungal-feeders feed by puncturing the cell wall of fungi** and sucking out the internal contents. **Predatory nematodes eat all types of nematodes and protozoa. Root-feeders are plant parasites**, and thus are not free-living in the soil.

**Nutrient cycling.** Like protozoa, nematodes are important in mineralizing, or releasing, nutrients in plant-available forms. When nematodes eat bacteria or fungi, **ammonium ( $\text{NH}_4^+$ ) is released** because bacteria and fungi contain much more nitrogen than the nematodes require. At low nematode densities, **feeding by nematodes stimulates the growth rate of prey populations.** That is, bacterial-feeders stimulate bacterial growth, plant-feeders stimulate plant growth, and so on. At higher densities, nematodes will reduce the population of their prey. This may decrease plant productivity, may negatively impact mycorrhizal fungi, and can reduce decomposition and immobilization rates by bacteria and fungi. **Predatory nematodes may regulate populations of bacterial- and fungal-feeding nematodes, thus preventing over-grazing by those groups.** Nematode grazing may control the balance between bacteria and fungi, and the species composition of the microbial community.

**Dispersal of microbes.** Nematodes help distribute bacteria and fungi through the soil and along roots by carrying live and dormant microbes on their surfaces and in their digestive systems.

**Food source.** Nematodes are food for higher level predators, including predatory nematodes, soil microarthropods, and soil insects. They are also parasitized by bacteria and fungi.

**Disease suppression and development.** Some nematodes cause disease. Others consume disease-causing organisms, such as root-feeding nematodes, or prevent their access to roots. These may be potential biocontrol agents.

**Because of their size, nematodes tend to be more common in coarser-textured soils. Nematodes move in water films in large (>1/500 inch or 50  $\mu\text{m}$ ) pore spaces.**

**Nematodes may be useful indicators of soil quality because of their tremendous diversity and their participation in many functions at different levels of the soil food web.** Several researchers have proposed approaches to assessing the status of soil quality by counting the number of nematodes in different families or trophic groups. In addition to their diversity, nematodes may be useful indicators because their populations are relatively stable in response to changes in moisture and temperature (in contrast to bacteria), **yet nematode populations respond to land management changes in predictable ways.** Because they are quite small and live in water films, changes in nematode populations reflect changes in soil microenvironments.



# Bulk Density of Soils in New Jersey

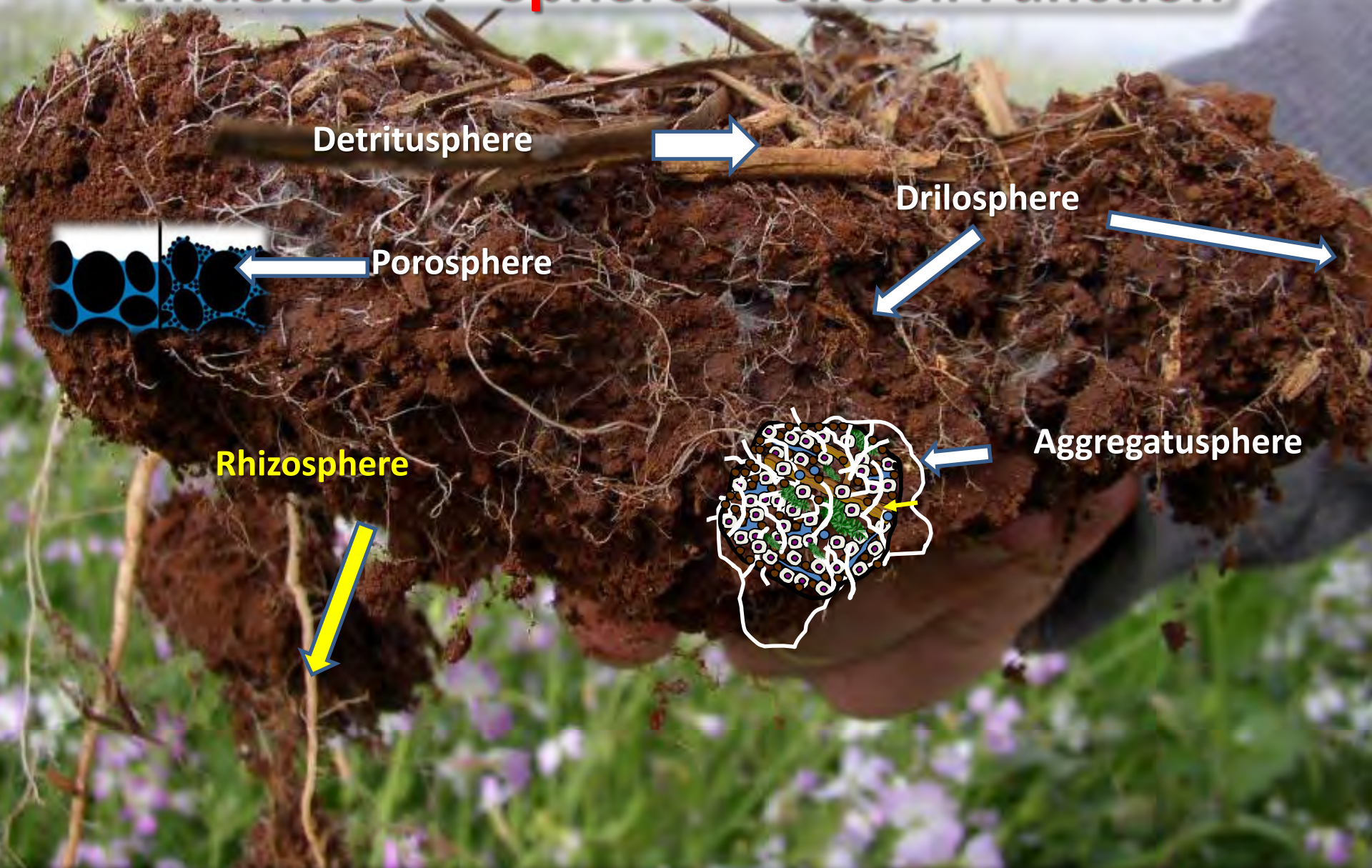


## Permeability Measurements of Sampled Layers within 20 " of Soil Surface

Site	Bulk Density (g/cm <sup>3</sup> )	Permeability (in/hr)
Woods	1.42	15
Pasture	1.47	9.9
Single House	1.67	7.1
Subdivision Lawn (1)	1.79	0.14
Garage Lawn	1.82	0.13
Cleared Woods	1.83	0.13
Subdivision Lawn (2)	2.03	0.03
Athletic field	1.95	0.01
Concrete	2.4	0.00

- This is from a study conducted in NJ that involved NRCS looking at bulk density under various land uses and vegetative covers.
- **It illustrates the relationship between porospaces and the affect that plants have on creating biopores.**
- **Those soils with the highest plant diversity, have the lowest bulk density (most porospaces) and highest permeability rate,** compared to those with low diversity and are managed in a way that discourages deep root penetration and the development of macropores have the highest bulk density and lowest permeability rates.

# Influence of "Spheres" on Soil Function



Rhizosphere: area in soil that is in the immediate vicinity of plant roots in which the abundance and composition of the microbial population are influenced by the presence of roots.

# Rhizosphere



- **Narrow region of soil directly around roots.**
- **Living roots release many types of organic materials.**
- **These compounds attract Bacteria that feed on the proteins & sugars.**



## **Rhizosphere is:**

- **Area immediately surrounding [0.5-1 inches (1-2 cm)] the plant roots.**
- **Has the highest biological activity due to the high concentration of photosynthetically-derived carbon (approx. 70%) – Juma, 1993.**
- **Has some of the greatest impact on soil structure.**
- **Most impacted by aboveground management.**

# Rhizosphere

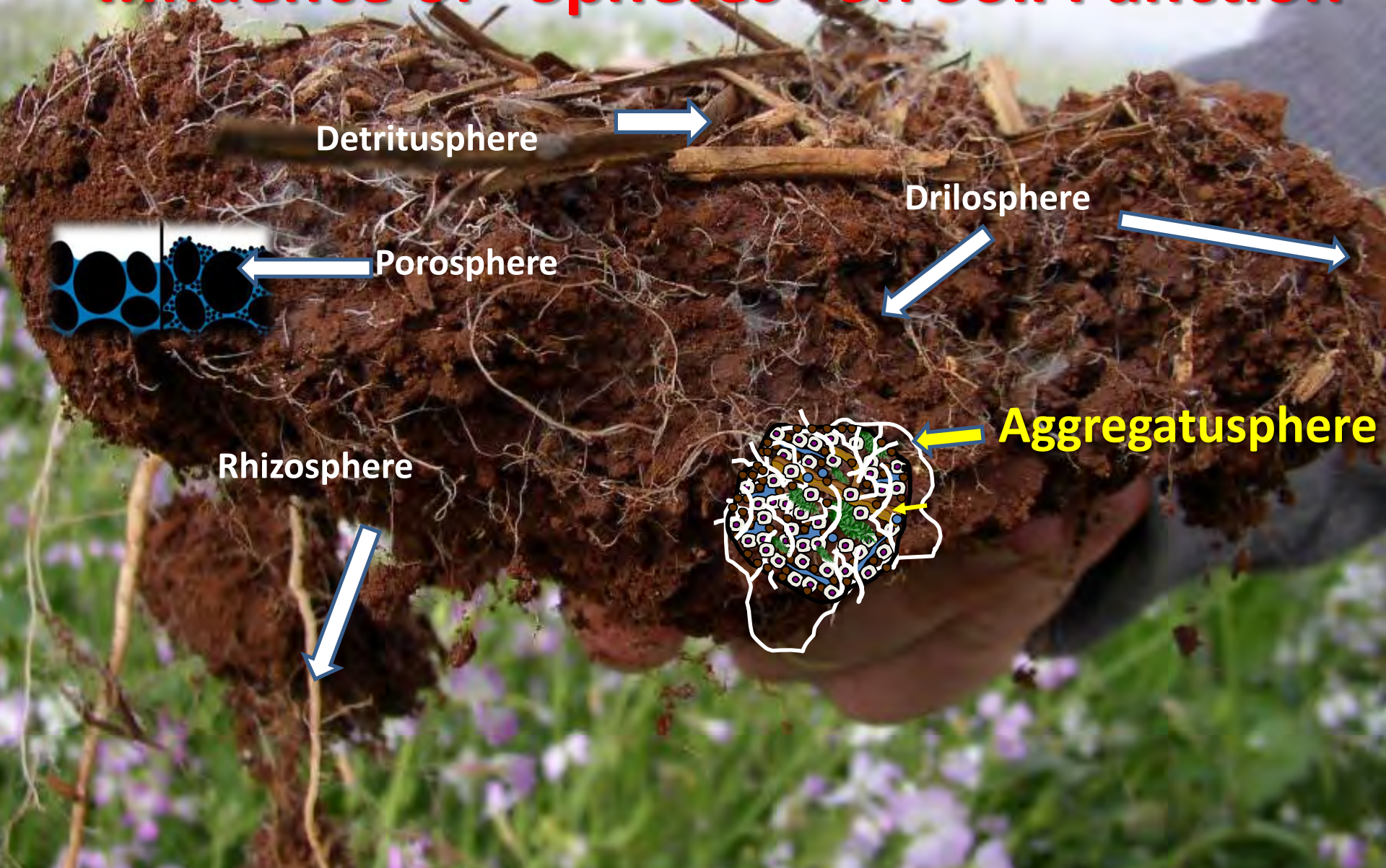


- Number of bacteria is from 5 to 2000 times larger than in the regular soil.
- Protozoa and Nematodes feed on the bacteria.
- Nutrient cycling & disease suppression start right here.



- The rhizosphere is teeming with bacteria that feed on sloughed-off plant cells and the proteins and sugars released by roots.
- The protozoa and nematodes that graze on bacteria are also concentrated near roots.
- nutrient cycling and disease suppression needed by plants occurs immediately adjacent to roots.

# Influence of "Spheres" on Soil Function

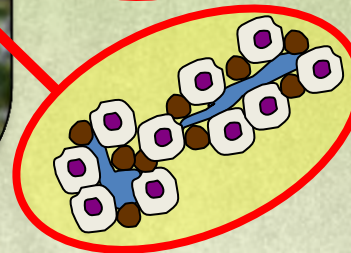
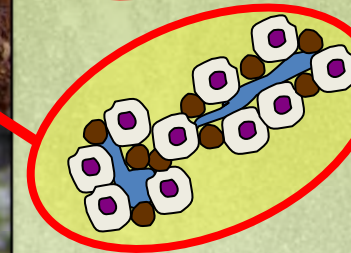
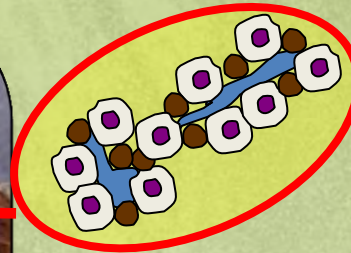


Aggregatusphere: the area of soil aggregates that encompasses all the organic matter constituents, primary soil particles and void that form micro and macro aggregates.

# Aggregatusphere: Influence of Soil Aggregates



## Closed Habitat of Micropores



- Protects organic matter from decay.
- Storage site for organic matter.
- Habitat of Oligotrophic and Copiotrophic bacteria.
- Protects and maintains the integrity of the porosphere.

They are linked mainly by fungi hyphae, roots fibers, polysaccharides, Glomalin, rhizo-deposition, and aromatic humic materials

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

Lack of good **soil aggregation** results in compacted soils that:

1. Restrict root growth
2. Provide poor root zone aeration
3. Have poor drainage

Soil compaction has always been thought of as a physical soil problem caused by excessive tillage and heavy equipment squeezing the soil pore space.

**Compaction is actually a result of loss of soil organic matter and destruction of soil aggregates.** These need to be replaced in the soil in order to provide a stable soil base in which to produce food & fiber.

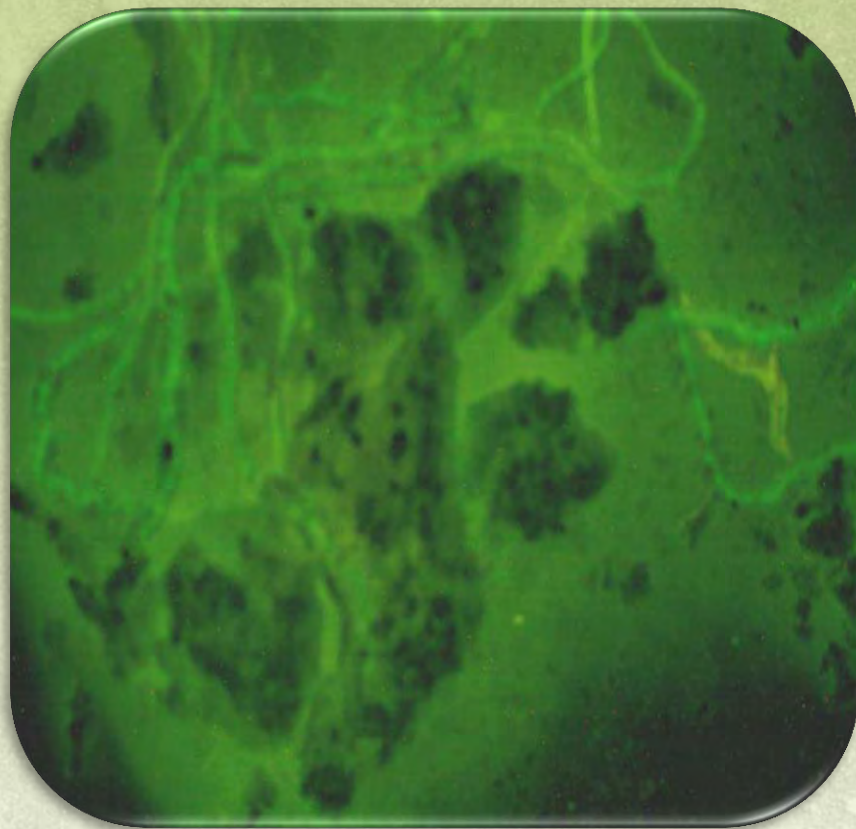
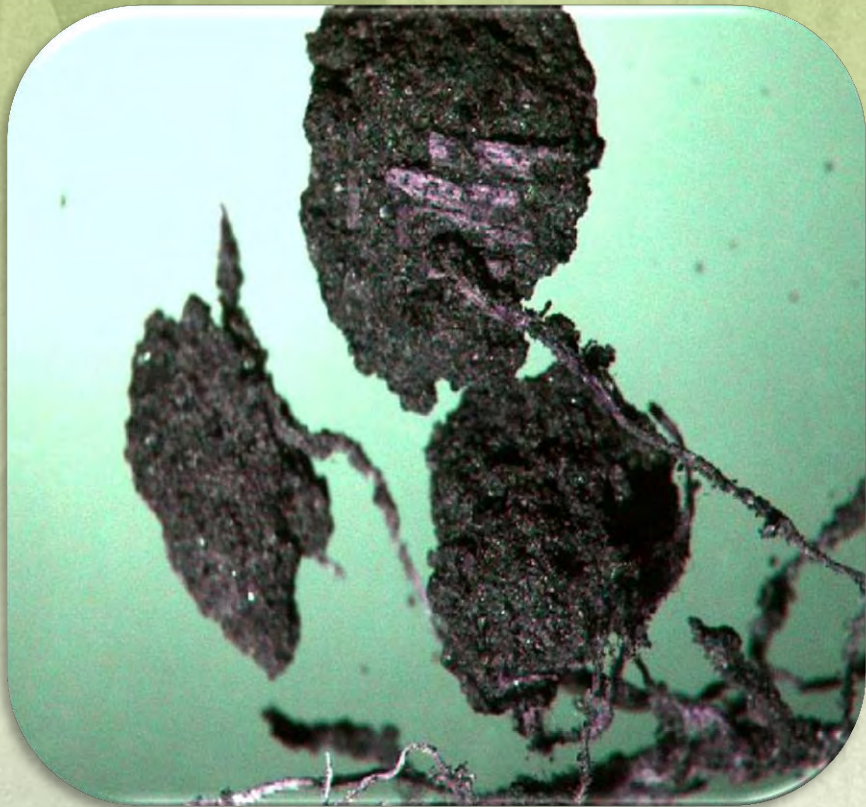
**Soil compaction is a biological problem related to decreased production of polysaccharides and glomalin in the soil.**

**Soil compaction is due to a lack of living roots and mycorrhizal fungus in the soil.**

# Root and Mycorrhizal Fungi Association:

Enlarged Soil aggregates

Glomalin and hyphae

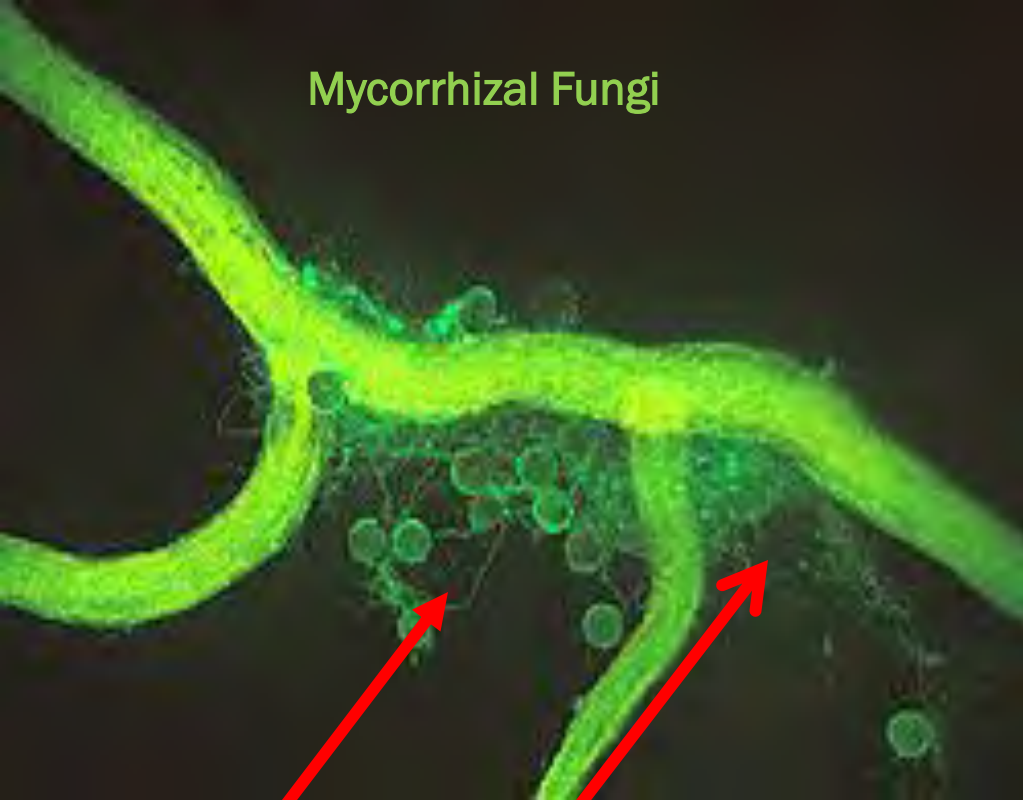


Dr. Kris Nichols, Microbiologist, ARS, Mandan, ND

**Biotic glue**

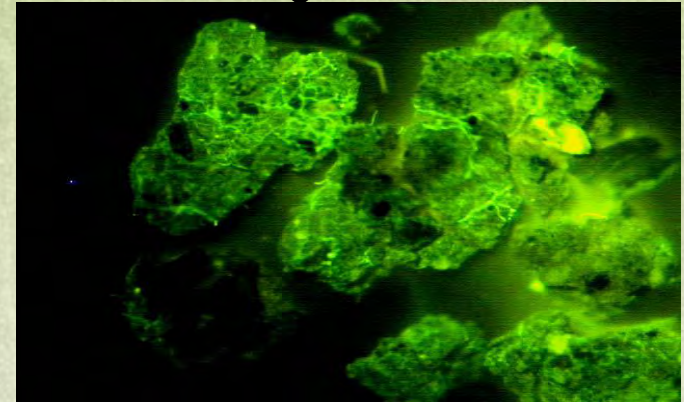
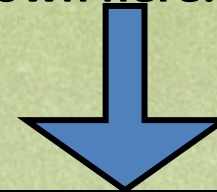
Photo on the left shows an **enlarged soil aggregates composed of plant roots, soil particles, fungal debris.**  
Photo on the right shows **biotic glues from the Mycorrhizal Fungi.**

## Mycorrhizal Fungi



## Fungal Hyphae

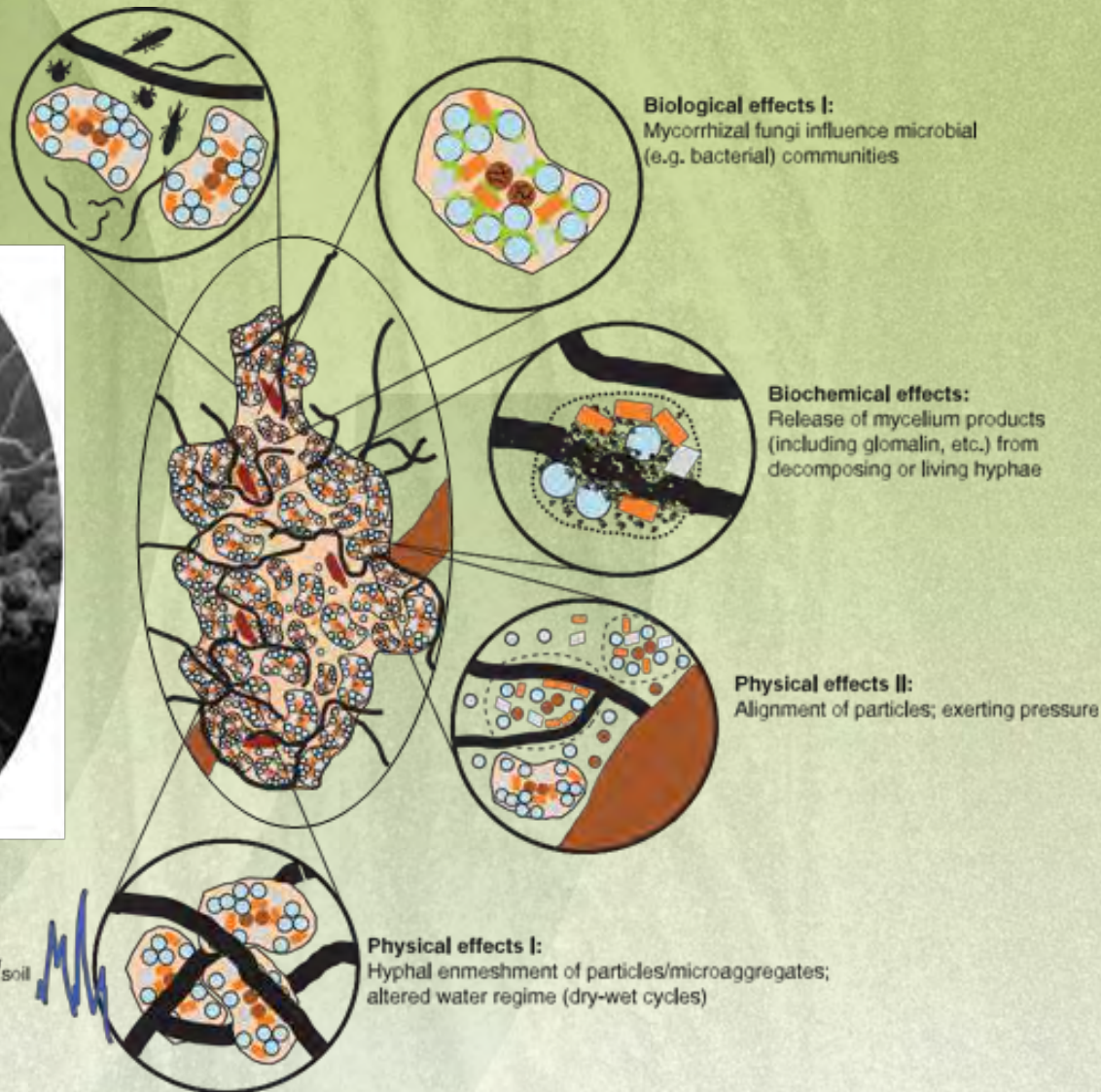
Glomalin is naturally brown. A laboratory procedure reveals glomalin on hyphae and soil aggregates as the bright green material shown here.



- A microscopic view of an **arbuscular mycorrhizal fungus** growing on a corn root.
- The **round bodies** are **spores**, and the **threadlike filaments** are **hyphae**.
- The **substance coating them** is **glomalin**, revealed by a green dye tagged to an antibody against glomalin.
- **Emphasize of the hyphae in comparison to root hairs.**
- **Hyphae can grow several centimeters (1 to 2 inches) beyond roots** (Fig. 1) and access more soil to acquire nutrients more efficiently.
- This is similar to a tree, where the branches (i.e. hyphae) grow out of the trunk (i.e. root). A tree forms branches to reach more of the sun's rays. Without enough sunlight, the tree would die.
- Belowground the plant forms a beneficial relationship with AMF or produces many fine roots to get the nutrients that it needs.
- Hyphae are not covered with bark like tree branches. **Instead AMF produce glomalin to coat hyphae to keep water and nutrients from getting lost on the way to and from the plant.**



# BUILDING A SOIL AGGREGATE



- Involves both:
- Biological**
- AMF communities form
  - Release of Glues

- Physical**
- Hyphae entangle soil particles
  - Create dry wet cycles
  - Squeeze particle together

Forming **soil aggregates** requires both a biological and physical actions

1. Need conditions that will allow for Arbuscular mycorrhizal fungi colonies to be established.
2. AMF release glues as hyphae work their way out through the soil.
3. Hyphae entangle soil particles, realign them.
4. Create alternating wetting/drying cycles helping to bind particles together.

# “Dig a Little, Learn a Lot”

Simple Test to  
determine soil  
health



Using a spade or shovel to examine the soil is the best soil health evaluation tool available.

# In-field soil assessment what to look at:



Utilize all your senses:

- Sight
- Smell
- Touch
- Taste????

Look at:

- Residue
- Soil Surface
- Soil Profile
- Plant Roots
- ???

In this section we are trying to get the participants to learn how to evaluate existing soil health conditions using our sense and general knowledge about soil health.

# What do you see? Healthy or Not?



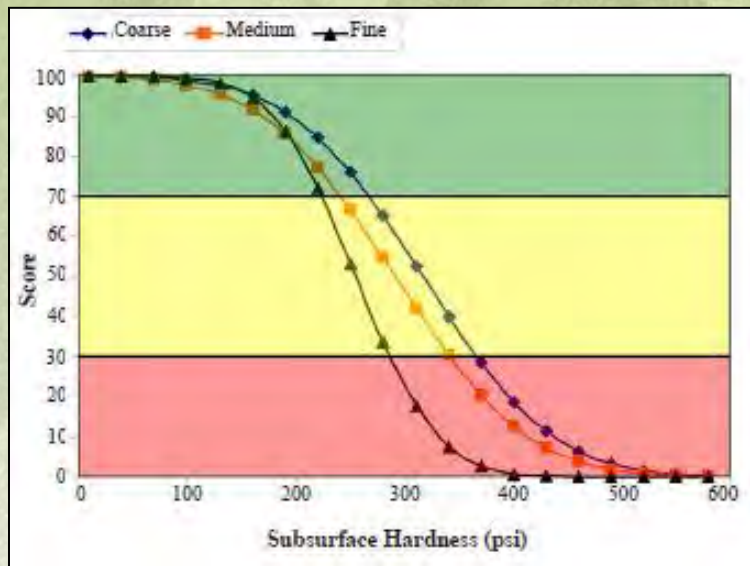
Photo is from an organic farm in KY, ask what they see that would indicate poor soil health:

1. Erosion
2. Crusting
3. Sediment deposition
4. Color
5. Tire tracks – compaction
6. ??

# How compressed is your soil?



Penetrometer -  
Measures pressure  
to penetrate soil



Used to identify:

- Surface crust
- Tightly packed crumbs
- Subsoil compacted layers

Effects of compaction

- Poor germination
- Reduced infiltration
- Poor root development
- Poor air exchange

From: Cornell Soil Health Manual

**Measuring compaction** in the field can be done using:

**Penetrometer:** measure pressure to penetrate soil on a given day, subject to current soil moisture levels, will vary from day to day.

Could use a survey flag or other type of rod to get a feel for where compacted layer occur, won't give pressure reading but good place to start discussions.

Shovel is another good tool, how hard is it to get into the ground, will stop at compacted layers.

# What's residue tell me about soil health?



Residue should be broken down and incorporated into the soil profile in a healthy soil!

**Residue** is thought to be a good indicator of soil health, lots of residue equals healthy soils, but this is only looking at the erosion aspect. Residue shouldn't stick around for multiple years, if so than there is something not functioning in the soil, poor microbial action.

# Brown's Ranch

## Same Field



**June 16, 2009**

**Corn planted into previous years'  
cover crop residue**



**July 1, 2009**

**Rapid residue decomposition**

# Residue Consumed by Soil Life



- **Residue is meant to be consumed by soil microbes and incorporated into the soil.**
- How we manage cover crops and can have a great affect on residue decomposition.
- The faster crop residues are consumed by soil microorganisms the less time those residues will be covering the soil surface.
- **Crop residues on the soil surface are important for protecting soil aggregates from the destructive force of raindrops hitting the soil, conserving soil moisture, and providing habitat for arthropods that shred crop residue and eat weed seeds.**
- **While it is important to maintain soil cover, it is also essential that those same residues decompose to release plant nutrients and build soil organic matter.**
- **Therefore, it is important to pay attention to crop residue C:N ratios to maintain soil cover when desired, yet allow the cover to ultimately break down and be recycled.**





# Managing Cover Crops to Feed Soil Microorganisms

- **C:N ratio 24:1 Ideal for Microbes**
- **Higher C:N**
  - Microbes don't get enough N result in tying up N
  - Residue doesn't decompose
  - Accumulates on the surface
  - Microbe populations decline
- **Lower C:N**
  - Microbes get excess N result in N being available
  - Residue decomposes quickly
  - Microbe population explode then die off
- **Need to Balance C:N through cover crop mixes**

- **Soil microorganisms** have a C:N ratio near 8:1.
- They must acquire enough carbon and nitrogen from the environment in which they live to maintain that ratio of carbon and nitrogen in their bodies.
- **Soil microorganisms burn carbon as a source of energy**, not all of the carbon a soil microorganism eats remains in its body; a certain amount is lost as carbon dioxide during respiration.
- To acquire the carbon and nitrogen a soil microorganism needs to stay alive (body maintenance + energy) it needs a diet with a C:N ratio near 24:1, with 16 parts of carbon used for energy and eight parts for maintenance.

# C:N Ratio for Various Crops



Material	C:N Ratio
rye straw	82:1
wheat straw	80:1
oat straw	70:1
corn stover	57:1
rye cover crop (anthesis)	37:1
pea straw	29:1
rye cover crop (vegetative)	26:1
mature alfalfa hay	25:1
<b>Ideal Microbial Diet</b>	<b>24:1</b>
rotted barnyard manure	20:1
legume hay	17:1
beef manure	17:1
young alfalfa hay	13:1
hairy vetch cover crop	11:1
soil microbes (average)	8:1



Relative  
Decomposition  
Rate



## Rye

- High C:N
- Ties up N
- Compounds problem following another high C:N crop

## Hairy Vetch

- Low C:N
- Release lots of N
- Decomposes Fast

## Rye & Hairy Vetch Mix

- Balance C:N ratio
- Control decomposition
- Ideal cover crop mix

- **Cover crops added to a cash crop rotation can help manage nitrogen and crop residue cover in a cropping sequence.**
- A low C:N ratio cover crop containing legumes (pea, lentil, cowpea, soybean, sunn hemp, or clovers) and/or brassicas (turnip, radish, canola, rape, or mustard) can follow a high C:N ratio crop such as corn or wheat, to help those residues decompose, allowing nutrients to become available to the next crop.
- Similarly, a high C:N ratio cover crop that might include corn, sorghum, sunflower, or millet can provide soil cover after a low residue, low C:N ratio crop such as pea or soybean, yet decompose during the next growing season to make nutrients available to the following crop.
- **Understanding carbon to nitrogen ratios of crop residues and other material applied to the soil is important to manage soil cover and crop nutrient cycling.**
- **Providing quality habitat for soil microorganisms should be the goal of producers interested in improving soil health.**
- **Soil is a biological system that functions only as well as the organisms that inhabit it.**

# A Spade Deep, what it tells You



- Good Soil Tilth
- Sufficient depth



- Shredded Residue
- Signs of life



Looking at a **spade full of soil** should begin to show evidence of soil health:

- How hard was it to put the spade in the ground?
- Were you able to get to a sufficient depth, 5" to 7"?
- Is there sign of life, e.g. worms, millipedes, etc.?
- Is the residue shredded?
- These are all indicators of what's happened in the past to impact soil health.

# What About Color?



- Darker color higher OM
- Topsoil & Subsoil same color
  - Not building OM
  - Mixing of soil profiles
  - Poor soil health
- Topsoil clearly defined
  - No mixing
  - Deeper layer
  - OM is accumulating

**Color** is an indicator of soil organic matter, should be concentrated in the surface with a clear defined, no line means mixing has been done (unless your dealing with a Mollisol).

# Does your soil smell?



- Earthy/Sweet Smell
  - Geosmin from Actinomycetes Bacteria
  - Decompose residue
  - Cycle nutrients
  - Important part of soil foodweb
- Metallic/Kitchen sink cleanser
  - Soil dominated by Anaerobic bacteria
  - Indicate anaerobic conditions
  - Hydrogen Sulfide H<sub>2</sub>S rotten egg smell
  - NH<sub>3</sub> Ammonia strong urine smell
  - Drives pH low, release Al
- No soil aroma
  - Little active life in the soil
  - because it is too hot, cold, wet, dry or degraded to have many active soil organisms present at that time.
  - Poor Habitat

# Do you have “Crumbly” Soil?



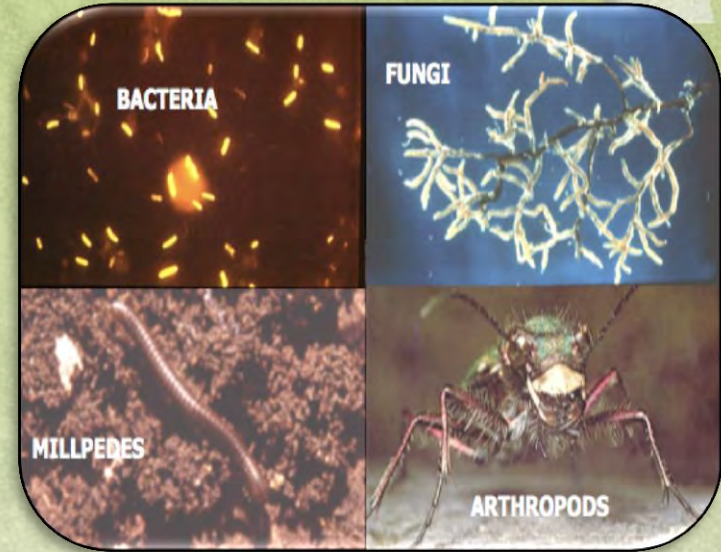
- Crumbles easily under finger pressure-GOOD
- Need a hammer to crush- BAD

Using touch or feel can tell how healthy soils are: good soil aggregates should crumble easily under finger pressure, poor aggregates need more pressure to crush.

Good aggregates are a result of following the 4 soil health principles.

# What's under the residue?

Residue should be shredded



Cobwebs evidence of microbe activity



**Brushing back the residue should show evidence of soil organisms breaking down residue.** Remember this is habitat and if you provide it the organisms will come.

# What do Your Roots Say?



## Unhealthy Roots:

- **Restricted root growth**
- **Few fine roots**
- **Short thick roots**
- **Discolored & Lesions (root pathogens present)**

## Healthy Roots:

- **Uninhibited root growth**
- **Lots of fine roots**
- **White (no root pathogens)**

- **Roots are a great indicator of soil conditions**, especially related to compaction.
- Roots should grow uninhibited into the soil profile, generally they hit a compacted layer at varying depths.
- Compacted layers that exceed 300 psi will restrict root growth
- Roots need a pore space greater than 0.1 mm



# Healthy Soil allows for Straight Roots



# Compacted Layers



Roots run laterally on top of a compacted layer

# Soil Health Testing



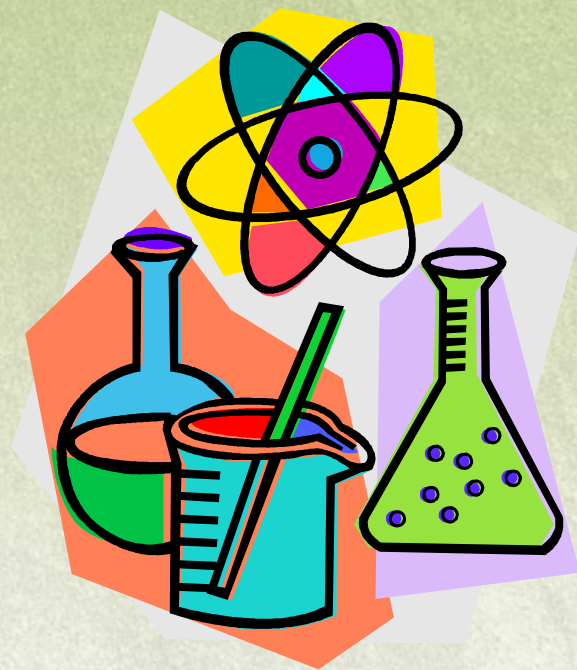
- Chemical
  - Standard soil test, e.g. P, K, pH, etc.
- Physical
  - Aggregate stability
  - Available water capacity
  - Surface and Subsurface hardness
- Biological
  - Organic matter
  - Active Carbon
  - Potential mineralizable N
  - Respiration
  - Microbe analysis

**Soil testing** for soil health generally includes information for:

- Chemical (standard soil test) composition.
- Physical attributes aggregate stability, available water, and hardness of different layers.
- Biological or various ways to account for the biological activity in the soil:
  - **Organic matter** usually part of a standard soil test, has impact on most soil function necessary for food and fiber production.
  - **Active Carbon a measurement of that fraction of OM that is readily available as a carbon sources for soil microbes.**
  - Mineralizable N measure of the potential of soil microbes to mineralize N into forms available to plants ( $\text{NH}_4^+$ ).
  - **Respiration a measurement of  $\text{CO}_2$  being released by soil microbes.**
  - **Microbe analysis** is a measurement of the microbe composition in the soil, e.g. bacteria, fungi, protozoa & nematodes.
- All testing for soil health utilize some or all of these elements in their analysis .

# Soil Health Testing in the Lab

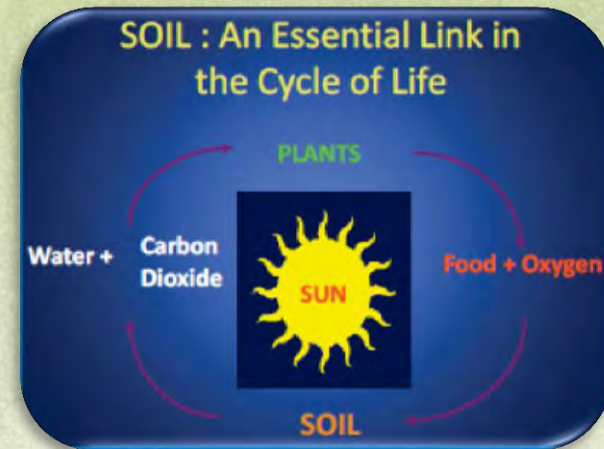
- Solvita CO<sub>2</sub> Burst Test
- Haney Test (ARS developed)
- PLFA (Phospholipid fatty acids)
- Cornell Soil Health Assessment
- Earthfort (Soil Foodweb)



# Soil CO<sub>2</sub> Respiration

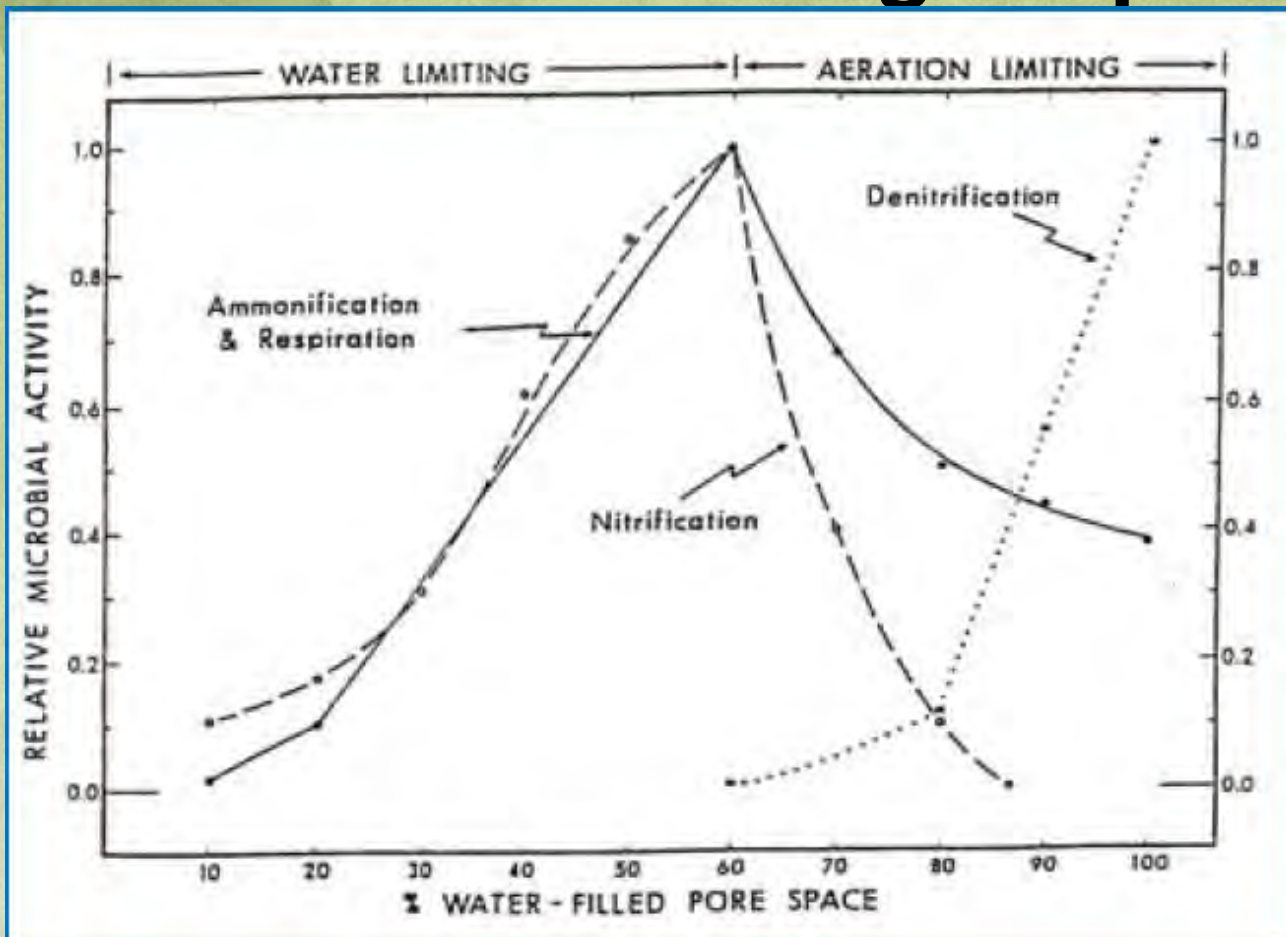


- Measures soil respiration
  - Rate of CO<sub>2</sub> released from decomposition of OM by soil microbes
  - Indicates the level of microbial activity
  - Correlates to the nutrients contained in OM in forms available to plants
    - Phosphate as PO<sub>4</sub>
    - Nitrate as NO<sub>3</sub>
    - Sulfate as SO<sub>4</sub>



- Respiration is the production of CO<sub>2</sub> as a result of biological activity in the soil by microbes, live roots and macroorganisms (earthworms).
- CO<sub>2</sub> is colorless and odorless.
- Amount emitted annually by the soil is greater than ALL human activities.
- Respiration is impacted by soil moisture and temperature.
- Inherent soil respiration rates depend on amount and quality of SOM, temperature, moisture, salinity, pH, and aeration.
- Biological activity of soil organisms varies seasonally, as well as daily.
- Microbial respiration more than doubles for every 10°C (18°F) soil temperatures rise up to a maximum of 35 to 40°C (95 to 104°F).
- Beyond which soil temperature is too high, limiting plant growth, microbial activity and soil respiration.

# Factor Affecting Respiration



- Respiration peaks at field capacity
- 60% of pore spaces field
- >80% pore space water filled
- Anaerobic organisms use Nitrate instead of Oxygen

- **Soil respiration** increases with soil moisture up to the level where pores are filled with too much water **limiting oxygen availability** which interferes with soil organism's ability to respire.
- **Ideal soil moisture is near field capacity, or when approximately 60 percent of pore space is filled with water.**
- Respiration declines in dry soils due to the lack of moisture for microbes and other biological activity.
- **As soil water-filled pore space exceeds 80 percent, soil respiration declines to a minimum level and most aerobic microorganisms "switch tracks" and use nitrate (NO<sub>3</sub>), instead of oxygen. This results in loss of nitrogen, as nitrogen gases (N<sub>2</sub> and nitrogen oxides). This results in emission of potent greenhouse gases, yield reduction, and increased N fertilizer expense.**

# Solvita CO<sub>2</sub> Basal Respiration



- Measure the CO<sub>2</sub> at field moisture conditions.
- Uses paddle to trap CO<sub>2</sub>.
- Uses color system to measure.



**Table 2. Basic soil biological quality.**

Color/Colorimetric Number				
0 - 1 Blue-Gray	1.0 - 2.5 Gray-Green	2.5 - 3.5 Green	3.5 - 4.0 Green-Yellow	4 - 5 Yellow
Soil Respiration Activity				
Very Low Soil Activity	Moderately Low Soil Activity	Medium Soil Activity	Ideal Soil Activity	Unusually High Soil Activity
Associated with dry sandy soils, and little or no organic matter	Soil is marginal in terms of biological activity and organic matter	Soil is in a moderately balanced condition and has been receiving organic matter additions	Soil is well supplies with organic matter and has an active population of microorganisms	High/Excessive organic matter additions
*Approximate Level of CO <sub>2</sub> – Respiration				
<300 mg CO <sub>2</sub> /kg soil/wk	300-500 mg CO <sub>2</sub> /kg soil/wk	500-1000 mg CO <sub>2</sub> /kg soil/wk	1,000-2,000 mg CO <sub>2</sub> /kg soil/wk	>2,000 mg CO <sub>2</sub> /kg soil/wk
< 9.5 lbs CO <sub>2</sub> -C/acre-3"/d	9.5 - 16 lbs CO <sub>2</sub> -C/acre-3"/d	16-32 lbs CO <sub>2</sub> -C/acre-3"/d	32-64 lbs CO <sub>2</sub> -C/acre-3"/d	>64 lbs CO <sub>2</sub> -C/acre-3"/d
Approximate quantity of nitrogen (N) release per year (average climate)				
<10 lbs/acre	10-20 lbs/acre	20-40 lbs/acre	40-80 lbs/acre	80- >160 lbs/acre

\* Source: Doran, J. (2001) USDA-ARS Soil Quality Institute correlation of Solvita® and field soil respiration. Calculations based on a 3-inch soil core (7.6 cm).

Chart from **Solvita** Official Guideline Soil Respiration Test manual:

- **The rate of CO<sub>2</sub> released is expressed as CO<sub>2</sub>-C lbs/acre-3"/day** (or kg/ha-7.6cm /d).
- **High soil respiration rates are indicative of high biological activity .**
- This can be a good sign of a healthy soil that readily breaks down organic residues and cycles nutrients needed for crop growth.
- Solvita® response may go from an inactive condition (0-1 blue-gray) to a very active state (3.5-4.0 green-yellow) as soil respiration increases. This can be due to desirable management measures such as diverse crop rotations, and no-till. In some cases, heavily manured soils or soils high in organic content can attain a very high rate (5 yellow). This high reading can be detrimental when decomposition **of stable organic matter occurs.**
- **It is generally desirable to have at least green color 3. It typically takes several years for a soil to improve from a low biological status to a more active one.**
- **With proper residue management, diverse crop rotations, organic matter additions and avoidance of destructive tillage practices, the time to reach a more optimum condition is shortened.**



# CO<sub>2</sub> Burst (Haney Briton Method)

- Follows a Standard Lab Protocol.
- Dried, weighed samples are moistened.
- Uses a specific amount of water to trigger the flush of CO<sub>2</sub>.
- CO<sub>2</sub> Burst is proportional to:
  - microbial biomass
  - Potential available carbon
  - Nitrogen mineralization
- Uses Solvita Digital Color Reader.



This process gives a more consistent measurement that allows you to compare fields, since a standard weight and volume of water is used after soil has been dried.





# Soil Health Tool

USDA-ARS Temple, Texas  
(Haney Test)

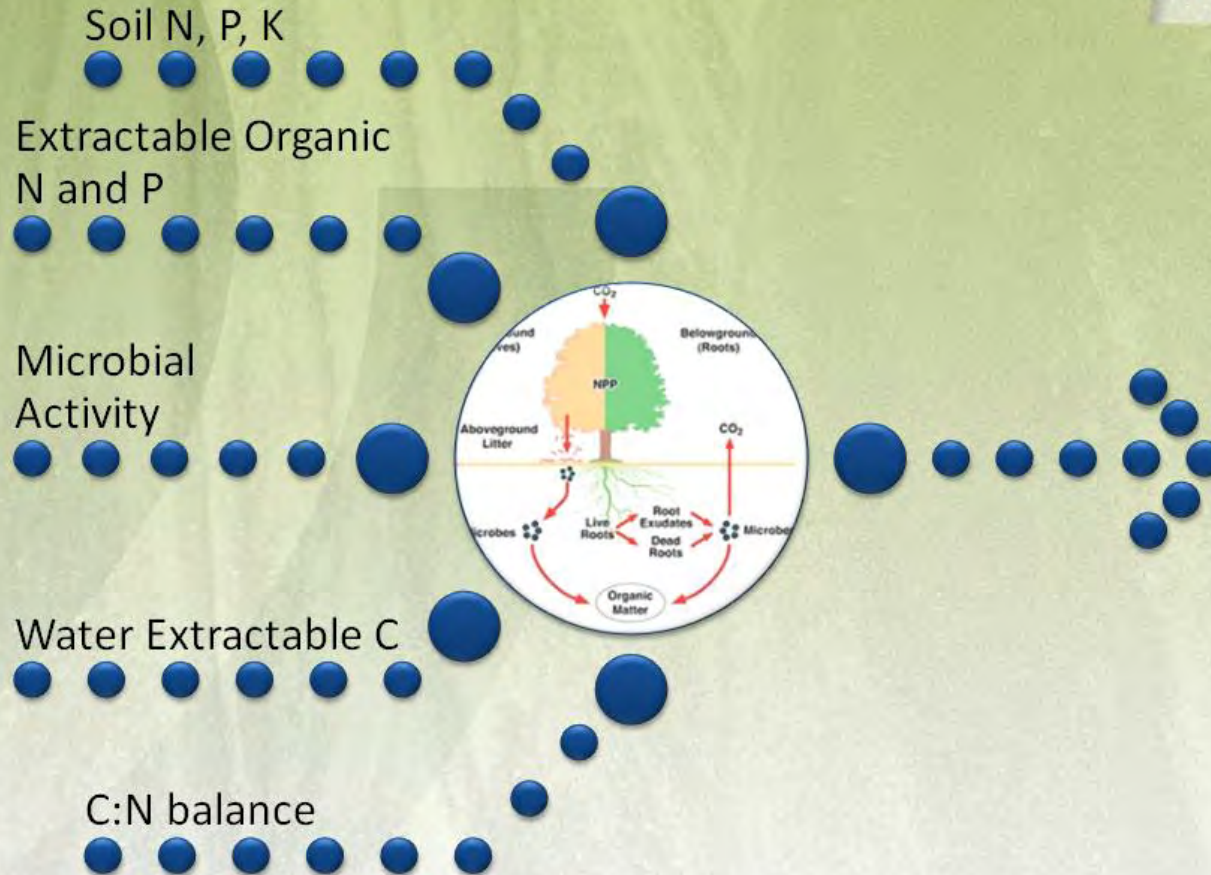
Measure soil health and NPK availability by **asking** our soil the right questions:

- What is your condition?
- Are you in balance?
- How active are your microbes?
- What can we do to help?

- The **Soil Health Tool** is designed to work with any soil under any management scenario because the program asks these simple, universally applicable questions.
- **This method uses green chemistry, in that, the soil analysis is performed using a soil microbial activity indicator, a soil water extract (nature's solvent), and H3A extractant, which mimics organic acids produced by living plant roots to temporarily change the soil pH thereby increasing nutrient availability.**
- These organic acids are then broken down by soil microbes since they are an excellent carbon source.

# New Soil Testing Methods

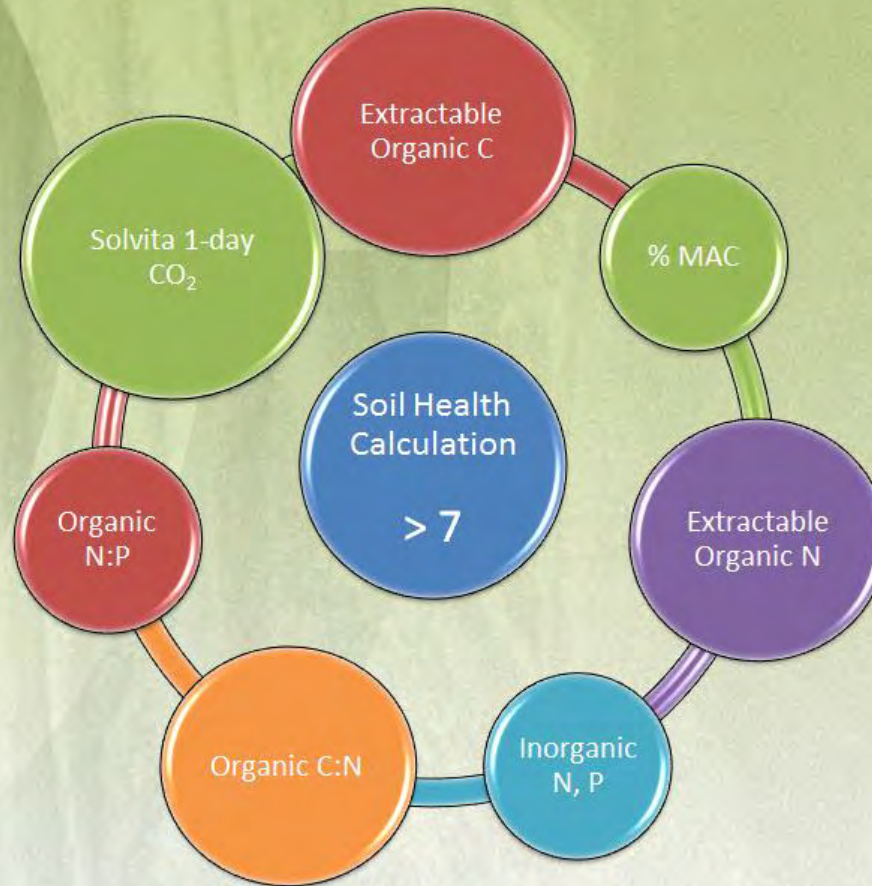
soil testing in nature's image



This test looks at a soil sample from a multiple views:

- **N-P-K** represent the amount of N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O presently in soil in lbs/ac.
- **Extractable Organic N & P** numbers include the inorganic, NH<sub>4</sub>-N, NO<sub>3</sub>-N, and PO<sub>4</sub>-P from the H3A extractant, **as well as the amount of N and P that the soil microbes will provide based on soil microbial activity** (Solvita 1-day CO<sub>2</sub>-C), **the organic C: N ratio**, and N from the plant available organic N pool.
- **Microbial Activity** amount of CO<sub>2</sub>-C released in 24 hrs. from soil microbes.
- **Water extractable organic C**: This number (in ppm) is the amount of organic C extracted from your soil with water. **This C pool is roughly 80 times smaller than the total soil organic C pool (% Organic Matter) and reflects the energy source fueling soil microbes.**
- **Organic C: N**: This number is the ratio of organic C from the water extract to the amount of organic N in the water extract.

# Soil Test Integration



**Test integrates** all data collected to generate an over all Soil Health Calculation.

- This number is calculated as 1-day CO<sub>2</sub>-C divided by the organic C: N ratio plus WEOC/100 + WEON/10 to include a weighted contribution of water extractable organic C and organic N. It represents the overall health of your soil system.
- It combines 5 independent measurements of your soil's biological properties.
- **The calculation looks at the balance of soil C and N and their relationship to microbial activity.** This soil health calculation number can vary from 0 to more than 50. We like to see this number increase over time.
- This number indicates the current soil health and what it needs to reach its highest sustainable state.
- **Keeping track of this Soil Health number will allow you to gauge the effects of your management practices over the years.**

# Tab 1 - NPK



- **Nitrogen:** from both Inorganic and Organic N pools.
- **Phosphate:** from both Inorganic and Organic P pools. Converted to P2O5.
- **Potassium converted to K2O.**
- **Nutrient value per acre:** Current fertilizer prices multiplied by the nutrients present in your soil.

FR results.xlsm - Microsoft Excel

File Home New Tab Insert Page Layout Formulas Data Review View Developer Add-Ins

Clipboard Font Alignment Number

Normal Neutral

A1 Sample ID all lbs per acre

	A	B	C	D	E	F	G	H	I	J	K	L
	Sample ID all lbs per acre	N lbs per acre	P2O5 lbs per acre	K2O lbs per acre	Nutrient value per acre		Crop	Yield Goal	lbs N needed	lbs P2O5 needed	lbs K2O needed	
2	Sample 1	28.85	15.16	74.88	\$72.85		grass	2	71	25	5	
3	Sample 2	25.47	14.51	89.70	\$79.26	Run	cotton	2	75	45	0	
4	Sample 3	29.89	14.67	104.26	\$90.76		wheat	35	12	3	0	
5	Sample 4	21.72	13.55	106.47	\$86.40		sorghum	60	26	16	0	
6	Sample 5	47.71	55.41	161.20	\$164.13		sunflowers	40	0	0	0	
7	Sample 6	55.66	91.54	202.80	\$219.15		soybeans	40	0	0	0	
8	Sample 7	21.84	8.92	63.18	\$57.26		corn	90	59	45	0	
9	Sample 8	57.70	120.25	223.60	\$252.95		cotton	2	42	0	0	
10	Sample 9	58.46	197.45	165.10	\$272.35		cotton	4	142	0	0	
11	Sample 10	35.62	44.31	100.75	\$112.84		oats	60	6	0	0	
12												
13												

Sample of a results report sent as an excel spreadsheet.

Give s nutrient recommendations along with value of existing Nutrients in the soil.

# SOIL NUTRIENT ASSESSMENT PROGRAM

SNAP Home    Optional Details    About



## Field Information

State  
Texas

County: Bell

Crop: Corn

Field Area (Acres): 1000

Yield Goal: 80

## Soil Test Results

Nitrogen (lb N/acre): 25

Phosphate (lb P2O5/acre): 20

Potassium (lb K2O/acre): 50

Update

## Estimated Local Yield



## Results

	N	P2O5	K	Cost/Acre	Total Cost	Chance of Success %
<b>Crop Requirements</b>	80.0	40.0	40.0	\$88.00	\$88000	
<b>Soil Test Based Requirements</b>	55.0	20.0	0	\$44.50	\$44500	

Chance of Success %



Working on an interactive website.

State and county specific.

Use sample results and farmer yield goal along with NASS county level yield data to forecast the chance of success.

<http://research.brc.tamus.edu/snap/>

**Rick Haney**

**Soil Scientist**

**USDA – ARS**

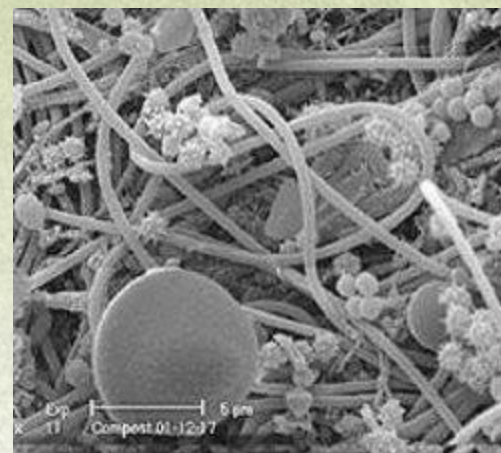
**Grassland, Soil & Water Research Laboratory**

**808 E. Blackland Road**

**Temple, TX 76502**

**(254) 770-6503**

**rick.haney@ars.usda.gov**





# PLFA

## (Phospholipid fatty acids)



- PLFA is a snapshot of soil community structure and abundance.
- Based 'signature' lipid biomarkers from the cell membranes and walls of microorganisms.
- Bacterial groups make 'signature' fatty acids, that can be used to characterize the microbial community.
- Used to compare management techniques with respect to overall better microbial community health.

• **PLFA** is a snapshot of soil community structure and abundance at the time of sampling.

• Based on the extraction of 'signature' lipid biomarkers from the cell membranes and walls of microorganisms.

• Certain bacterial groups make 'signature' fatty acids, so a profile of the PLFA in a sample can be used to characterize the microbial community according to which fatty acids are found and in what concentrations.



# Cornell Soil Health Assessment

## Physical

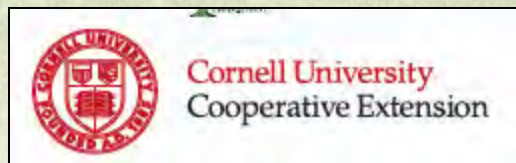
- Aggregate Stability– ability of aggregates to resist falling apart
- Available Water Capacity – water plant can use
- Surface Hardness – penetration resistance 0”- 6”
- Subsurface Hardness - penetration resistance 6” - 18”

## Biological

- Organic Matter
- Active Carbon – carbon available for microbes
- Potentially Mineralizable Nitrogen – from soil microbes
- Root Health Rating – measure quality and function of roots

## Chemical

- Standard Soil Test Analysis



- Combination of multiple existing test into an overall soil health assessment.
- Uses standard chemical solution to determine nutrient levels.
- Looks at all three areas of potential soil disturbance that occur on agricultural fields.



Indicators		Value	Rating	Constraint
PHYSICAL	Aggregate Stability (%)	17	18	aeration, infiltration, rooting
	Available Water Capacity (m/m)	0.21	85	
	Surface Hardness (psi)	48	93	
	Subsurface Hardness (psi)	214	79	
BIOLOGICAL	Organic Matter (%)	2.6	15	energy storage, C sequestration, water retention
	Active Carbon (ppm) [Permanganate Oxidizable]	615	50	
	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	7.8	9	N Supply Capacity
	Root Health Rating (1-9)	6.6	38	
CHEMICAL	*pH	7.0	100	
	*Extractable Phosphorus (ppm) [Value <3.5 or >21.5 are downscored]	10.0	100	
	*Extractable Potassium (ppm)	58	71	
	*Minor Elements		100	
OVERALL QUALITY SCORE (OUT OF 100):			64.1	Medium
<i>Measured Soil Textural Class:==&gt; silt loam</i>				
<i>SAND (%): 41.4      SILT (%): 50.6      CLAY (%): 8.0</i>				
<i>Location (GPS): Latitude=&gt;      Longitude=&gt;</i>				

\* See Cornell Nutrient Analysis Laboratory report for recommendations



# Earthfort

## (formally Soil Foodweb)

- Offers a variety of soil biology assessment packages.
  - Each package contains more assays for soil organisms.
- Measure the Biomass of Total Populations in general categories of the functional groups.
- Represent a comprehensive picture of the health and utility of the soil.

# Long Term No-Till



## Soil Foodweb Analysis

### Report prepared for:

Burleigh Co. Soil Conservation  
 Vicki Bailey  
 1511 E. Interstate Avenue  
 Bismarck, ND 58503-0560 US  
 (701) 250-4363  
 vicki.bailey@nd.nacdn.net

Report Sent: 07/29/2005  
 Sample#: 01-100984  
 Unique ID: GB1  
 Plant: Corn  
 Invoice Number: 8357  
 Sample Received: 07/14/2005

For interpretation of this report please contact:

Local Advisor: or regional lab  
 Soil Foodweb, Inc  
[info@soilfoodweb.com](mailto:info@soilfoodweb.com)  
 (541) 752-5066

*Consulting fees may apply*

Organism Biomass Data	Dry Weight	Active Bacteria (µg/g)	Total Bacterial (µg/g)	Active Fungal (µg/g)	Total Fungal (µg/g)	Hypal Diameter (µm)	Nematodes per Gram of Soil
<b>Results</b>	0.850	46.3	405	5.24	274	2.5	<b>Identification to genus</b>
Comments	To Wet	Excellent	Excellent	Low	Good		Bacterial Feeders
<b>Expected Range</b>	Low: 0.45 High: 0.85	15 25	100 300	15 25	100 300		Acrobelus 0.81 Acrobeloides 0.18 Cephalobus 0.45 Cervidellus 0.18 Rhabditioae 0.45
		Protozoa Numbers/g		Total Nematodes #/g	Percent Mycorrhizal Colonization		
		Flagellates	Amoebae		ENDO	ECTO	
<b>Results</b>		178500	9736	331	4.45	31%	0%
Comments		High	Low	High	Low	Low	Low
<b>Expected Range</b>	Low: 10000 High:	10000	10000	50 100	20 30	40% 80%	40% 80%
Organism Biomass Ratios	Total Fungal to Total Bacterial	Active to Total Fungal	Active to Total Bacterial	Active Fungal to Active Bacteria	Plant Available N Supply		
<b>Results</b>	0.68	0.02	0.11	0.11	200+		
Comments	Low	Low	Low	Low			
<b>Expected Range</b>	Low: 0.8 High: 1.5	0.25 0.95	0.25 0.95	0.75 1.5			

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This as example from the OLD **Soil Food Web report.**

Gives total biomass by functional group (bacteria, fungal, etc.).

Also makes an estimate of the amount of Available N supply.

This samples bacteria to fungal ratio is .7 to 1 indicates a health soil that has had good soil health management applied.

# Questions?

