How Can I Tell if My Soil is Healthy?

Marlon Winger

NRCS Idaho, state agronomist

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

Typical Soil Test

unlock the SECRETS IN THE SOIL

Lab Results
lbs. per Acre

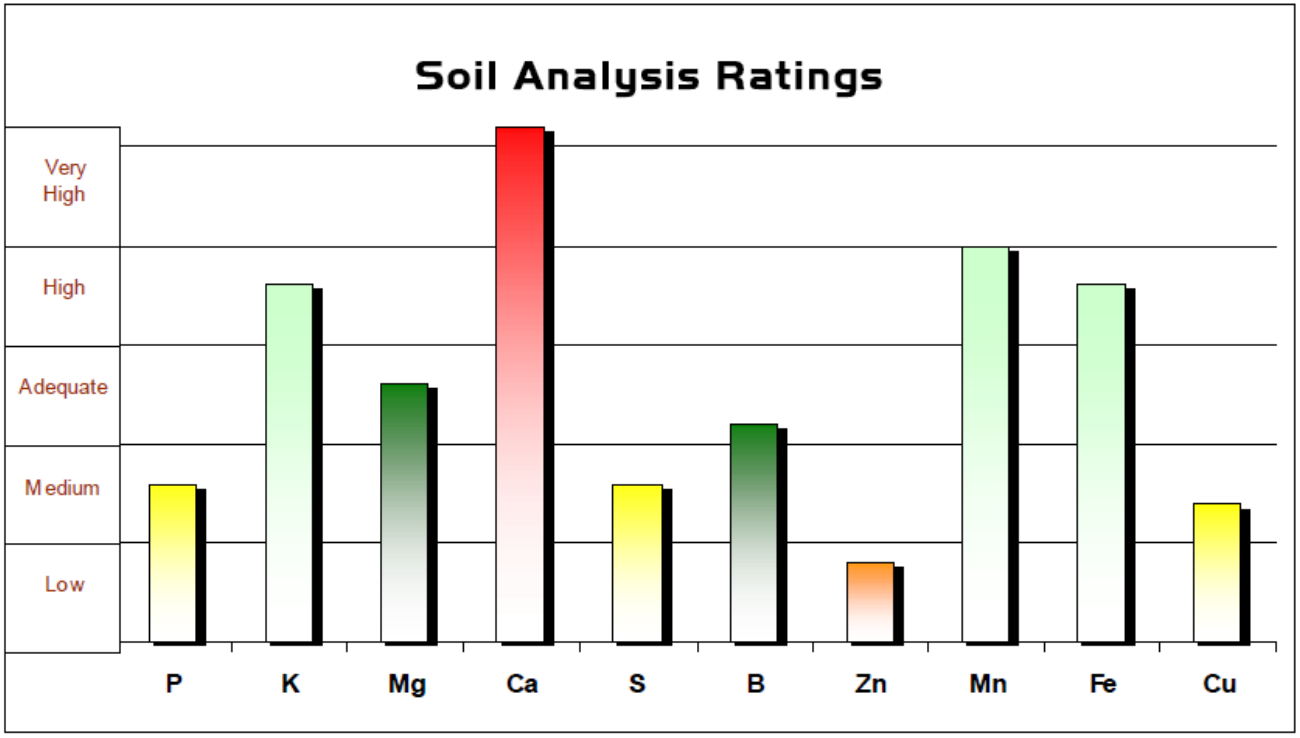
Lab Number: 135418SO

Target pH: 6.5

Test Method: Mehlich III

P Phosphorus	K Potassium	Mg Magnesium	Ca Calcium	Soil pH	Buffer pH	S Sulfur	B Boron	Zn Zinc	Mn Manganese	Fe Iron	Cu Copper
72 M	379 H	201 A	2407 VH	5.6	7.50	36 M	1.6 A	3.1 L	395 H	282 H	2.0 M

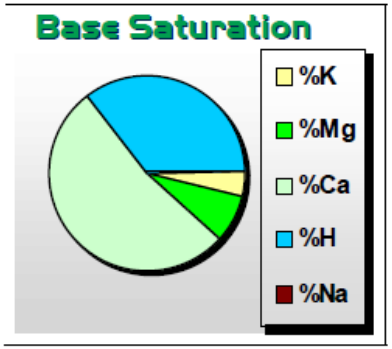
Aluminum	Sodium	Nitrate N	Soluble Salts mmhos/cm	Organic Matter	ENR
				3.02 %	60.4



Cation Exchange Capacity: 11.3 meq/100g

Base Saturation

K:	4.3 %
Mg:	7.4 %
Ca:	53.1 %
H:	35.3 %
Na:	%



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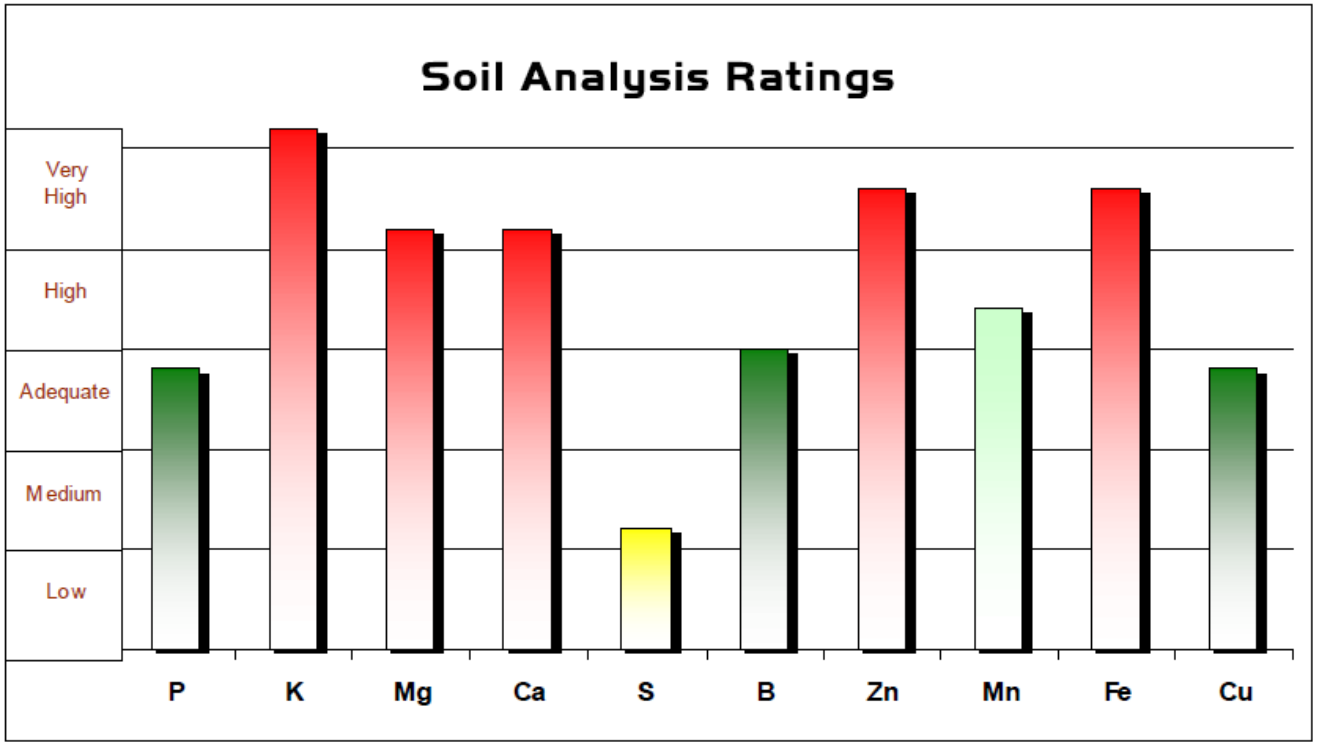
P Phosphorus	K Potassium	Mg Magnesium	Ca Calcium	Soil pH	Buffer pH	S Sulfur	B Boron	Zn Zinc	Mn Manganese	Fe Iron	Cu Copper
131 A	628 VH	309 VH	1951 VH	5.5	7.55	30 M	2.0 A	17.0 VH	260 H	509 VH	4.9 A

Aluminum	Sodium	Nitrate N	Soluble Salts mmhos/cm	Organic Matter	ENR
				3.98 %	79.6



Cation Exchange Capacity **10.6** meq/100g

Base Saturation

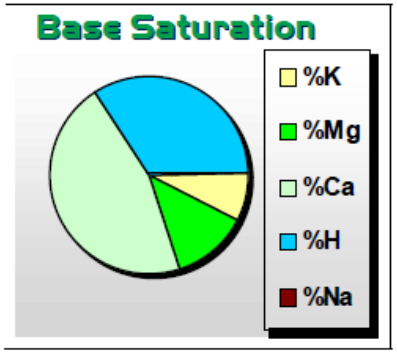
K: 7.6 %

Mg: 12.2 %

Ca: 46.1 %

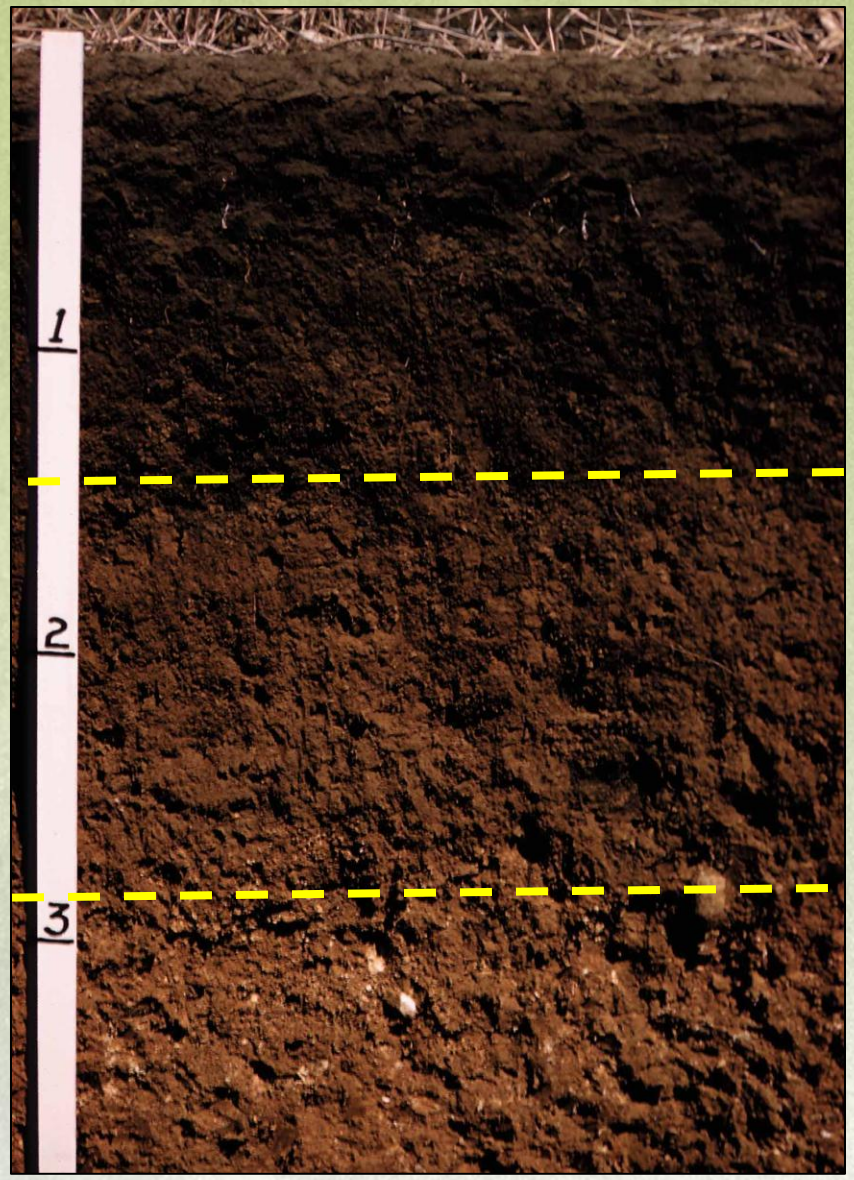
H: 34.1 %

Na: %

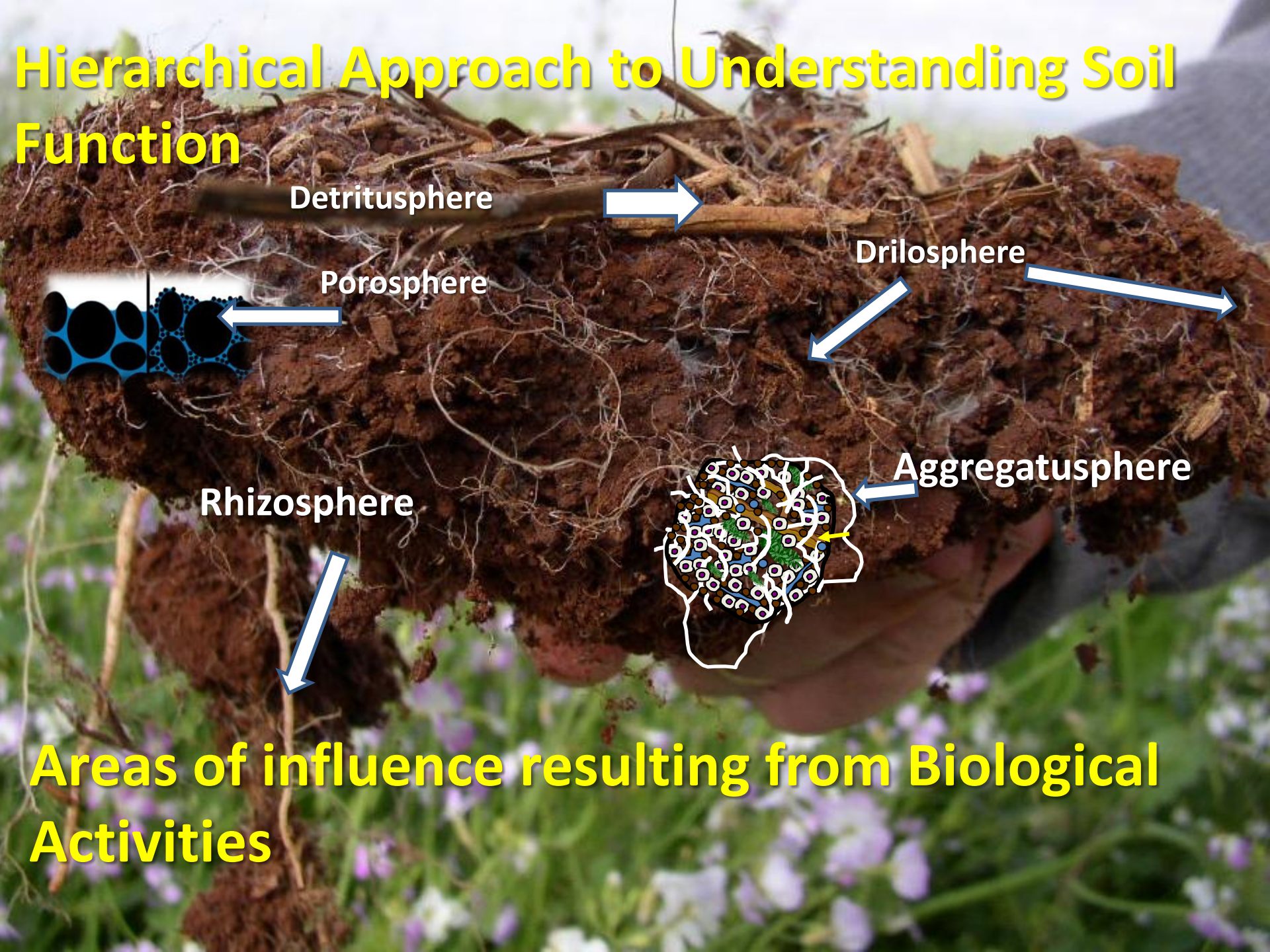


Soil Profile

Physical Characteristics
- Texture
- Structure
- Color
- Define horizon boundaries



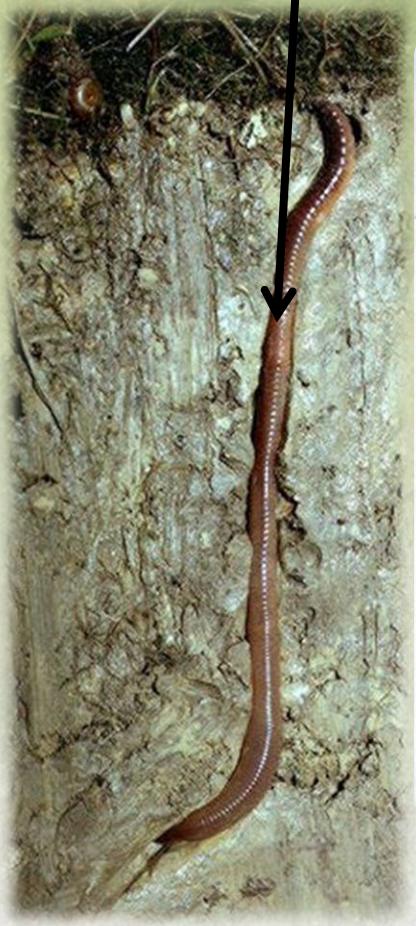
Hierarchical Approach to Understanding Soil Function

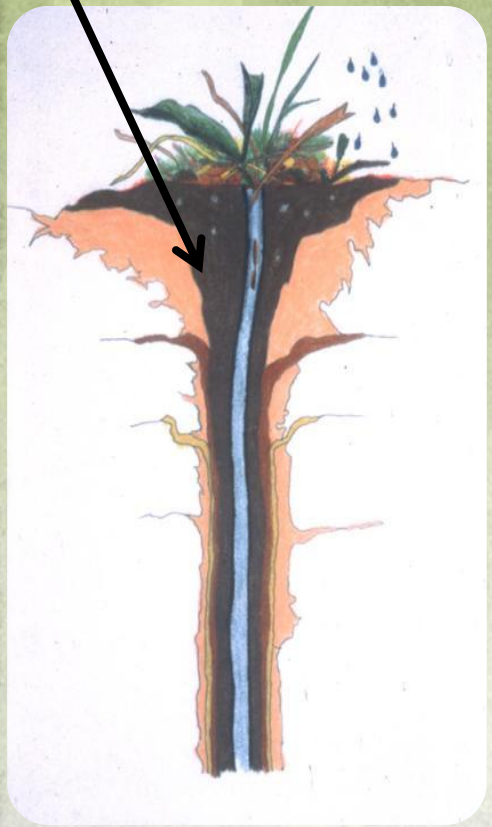


Areas of influence resulting from Biological Activities

The Detritusphere: Influence of residue

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)

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

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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

Nature’s residue managers

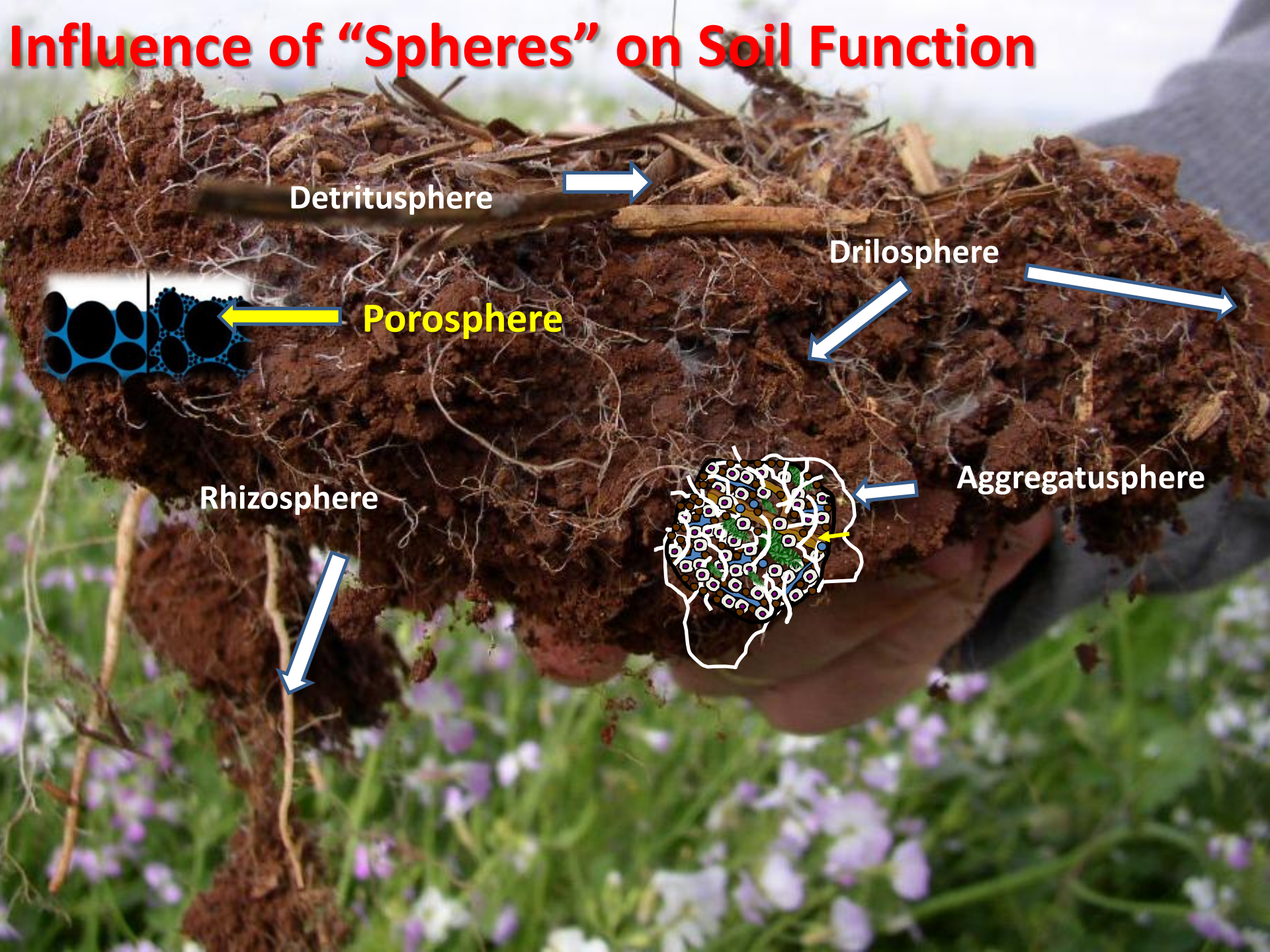
worm

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

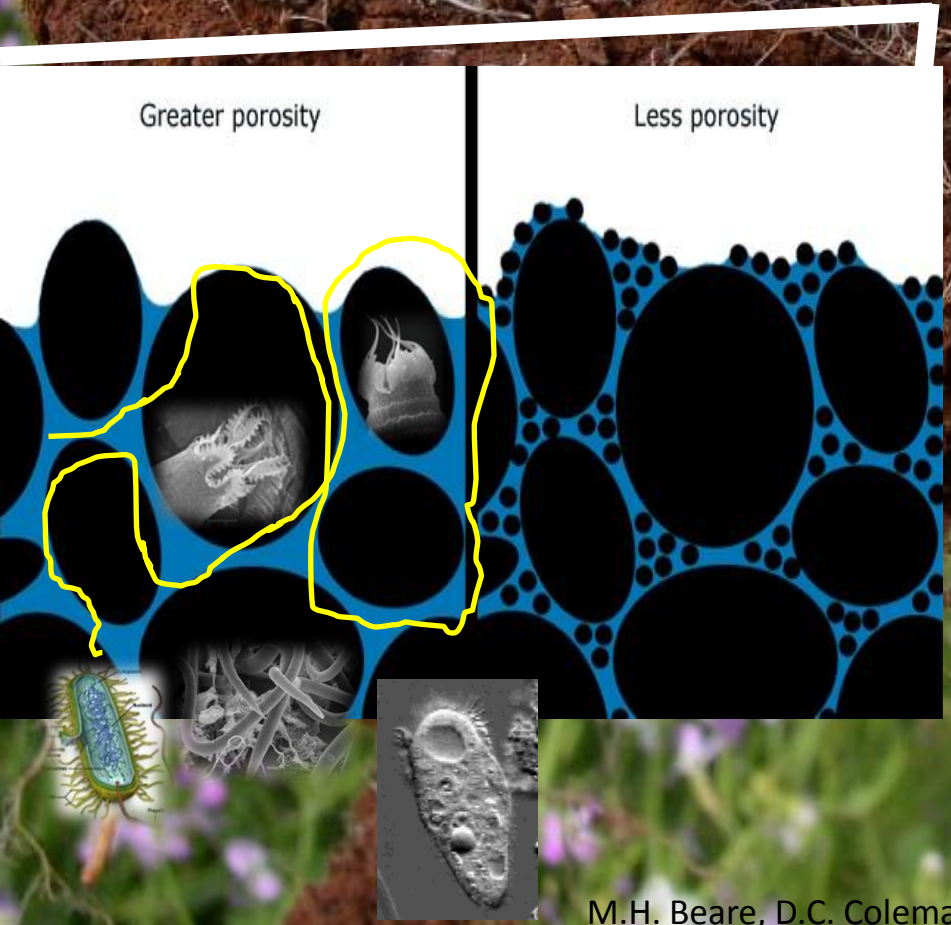
  than surrounding soil

Influence of “Spheres” on Soil Function



Porosphere: Arrangement of Solids and Voids

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



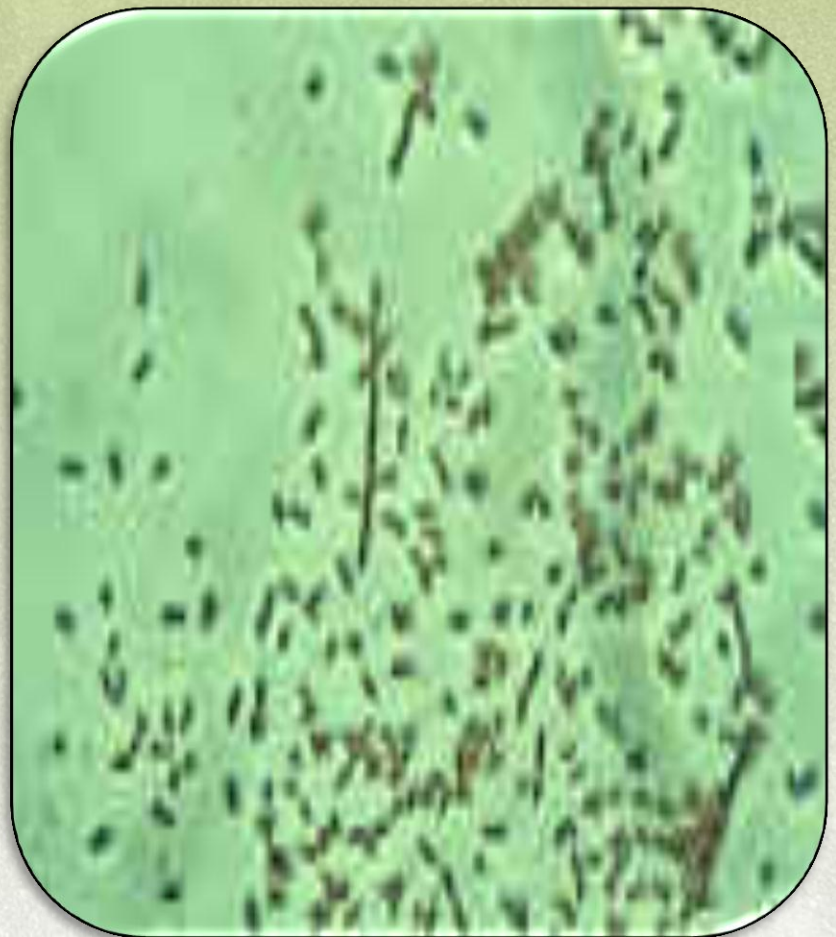
The lungs and circulatory system of the soil:

- **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)

Bacteria – Services they provide

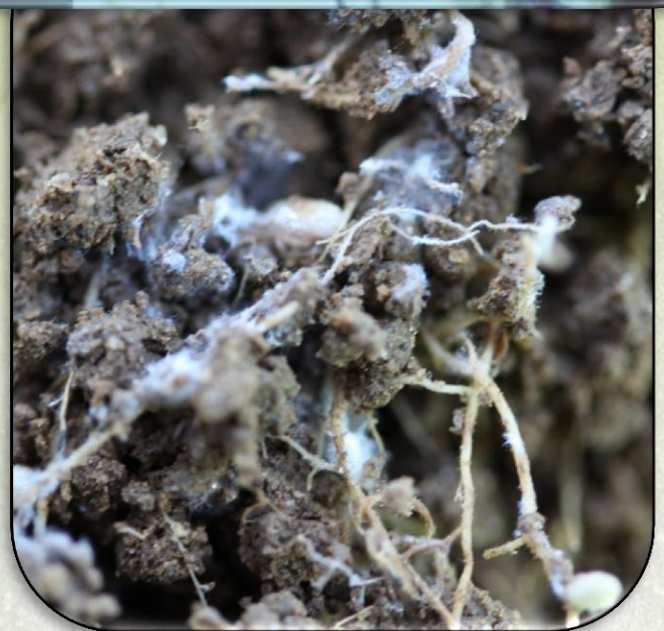
- Decomposition of OM
- Nutrient cycling
- Nitrogen fixation

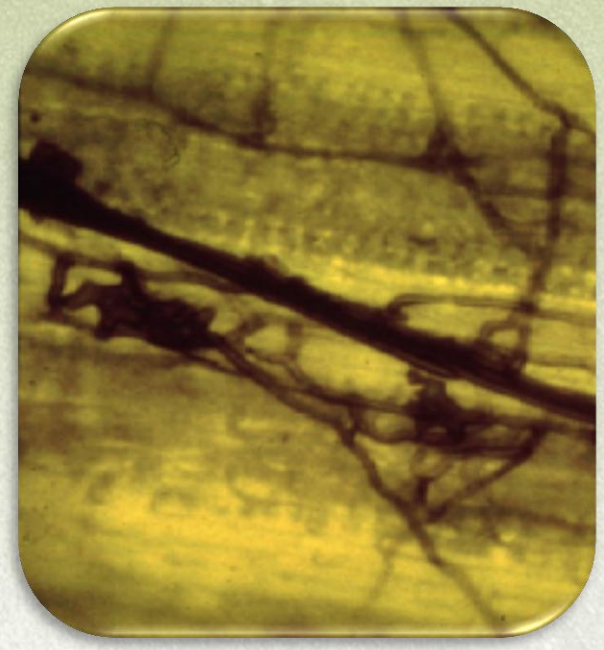


- Nitrification
- Denitrification
- Disease Suppression
- Breakdown of hard to decompose compounds

Fungi- Service they provide

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

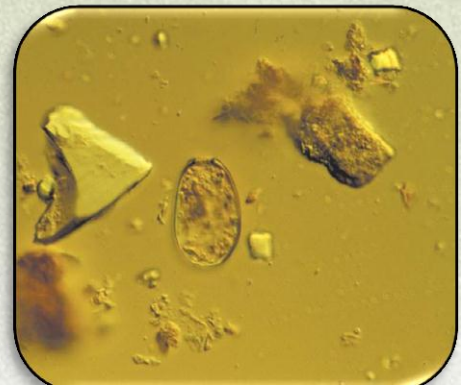




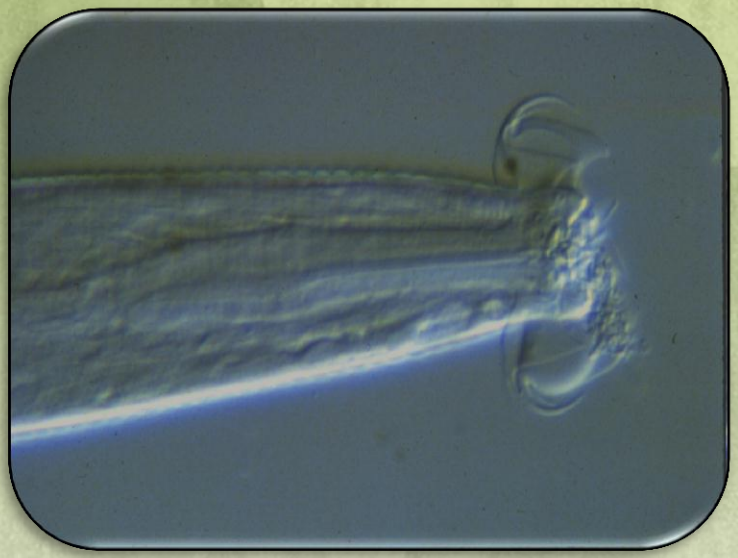
Protozoa – Services they provide

Protozoa feeding

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

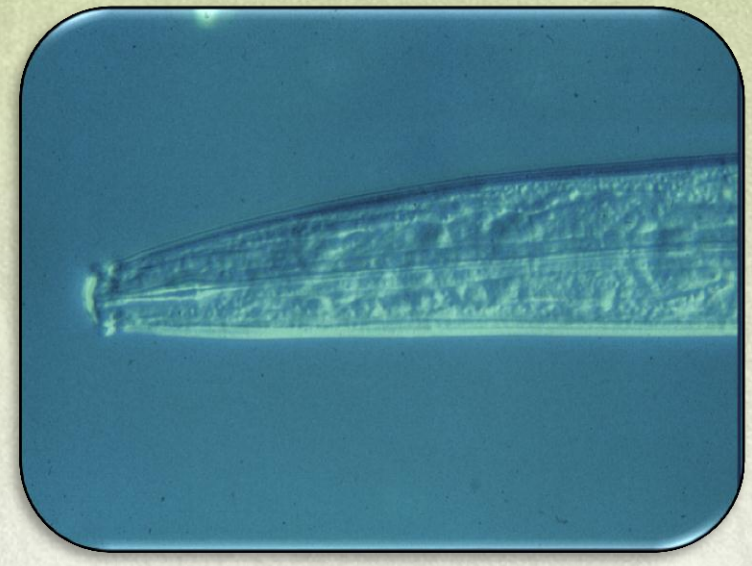


Nematodes – Services they provide



A bacteria-feeding nematode

- Control disease
- Cycle nutrients
- Disperse bacteria & fungi

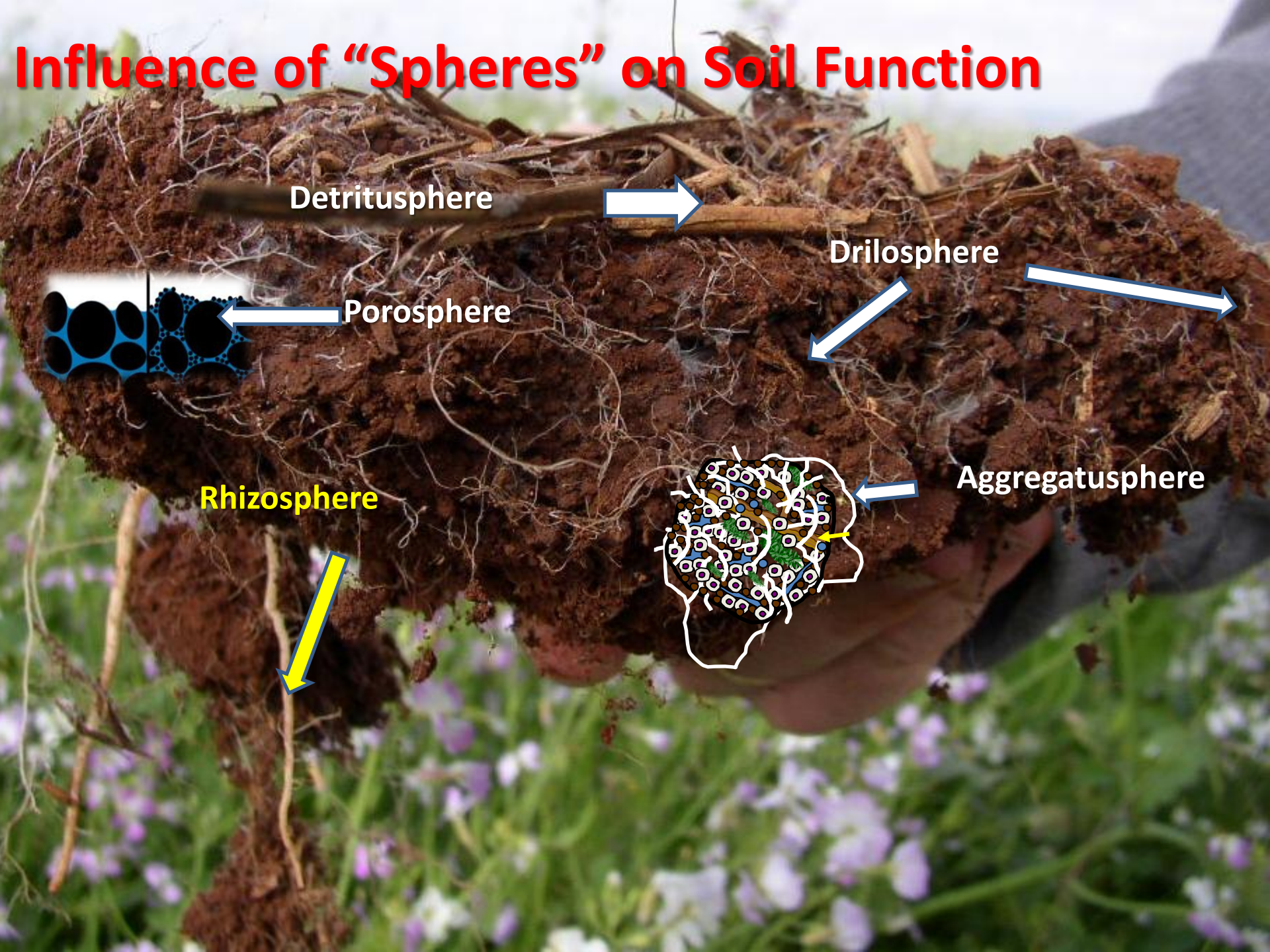


A fungal-feeding nematode

Bulk Density of Soils in New Jersey

Permeability Measurements of Sampled Layers within 20 " of Soil Surface		
Site	Bulk Density (g/cm3)	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

Influence of “Spheres” on Soil Function



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

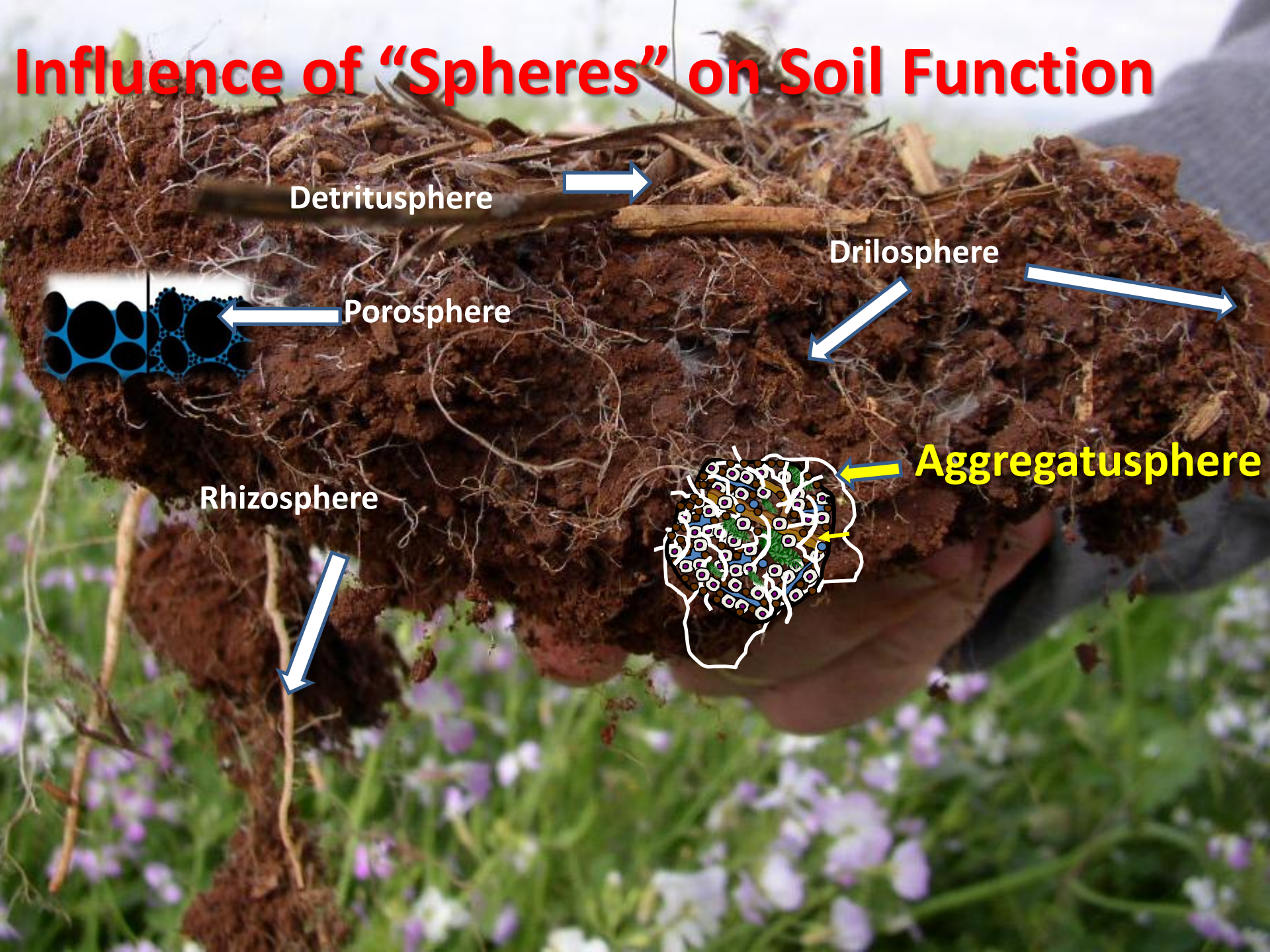
unlock the SECRETS IN THE SOIL

- 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 root is a Leverage Point: Engineering

This is where the video of the root as a leverage point would be shown

Influence of “Spheres” on Soil Function



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

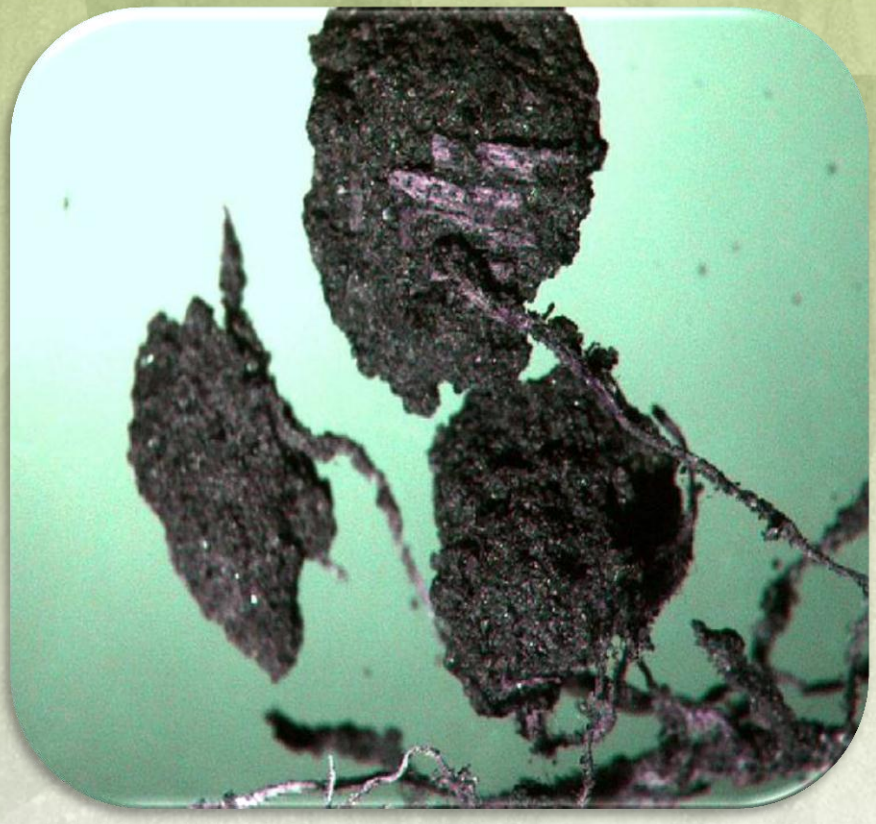
They are linked mainly by fungi hyphae, roots fibers, polysaccharides, Glomalin, rhizo-deposition, and aromatic humic materials

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

Root and Mycorrhizal Fungi Association:

unlock the SECRETS IN THE SOIL

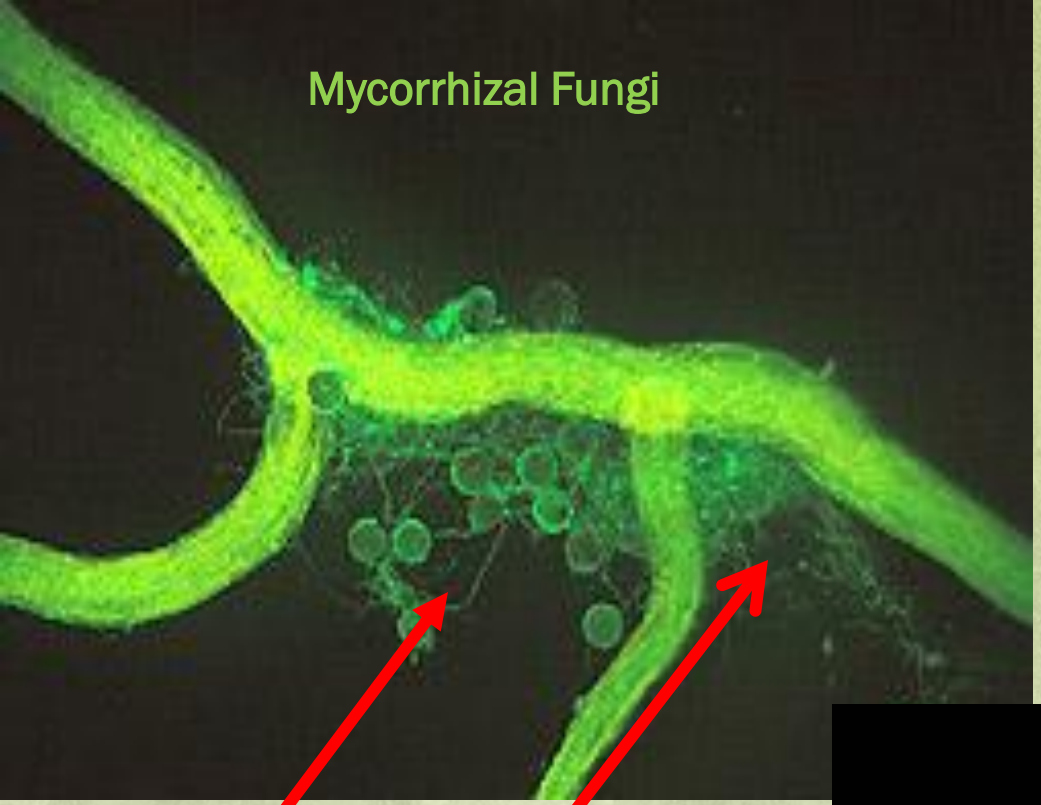
Enlarged Soil aggregates



Glomalin and hyphae

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

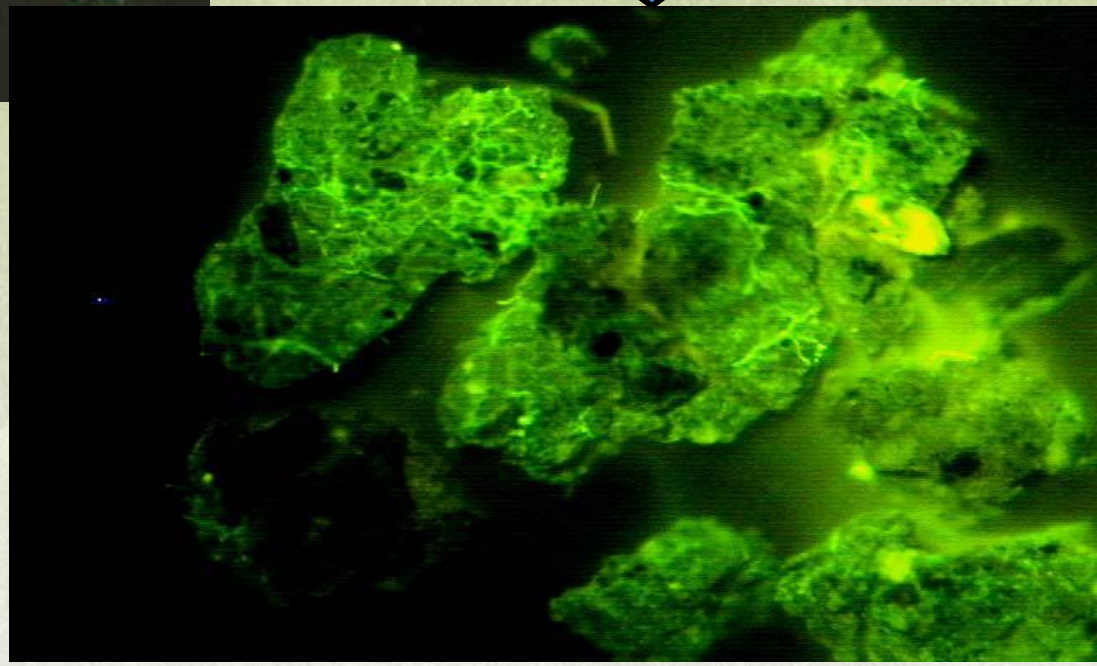
Mycorrhizal Fungi



unlock the SECRETS IN THE SOIL

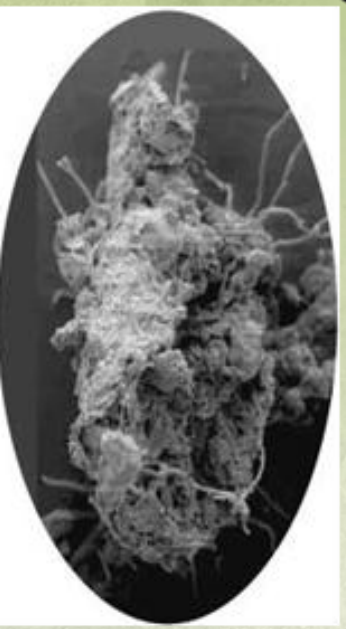
Glomalin is naturally brown. A laboratory procedure reveals glomalin on hypae and soil aggregates as the bright green material shown here.

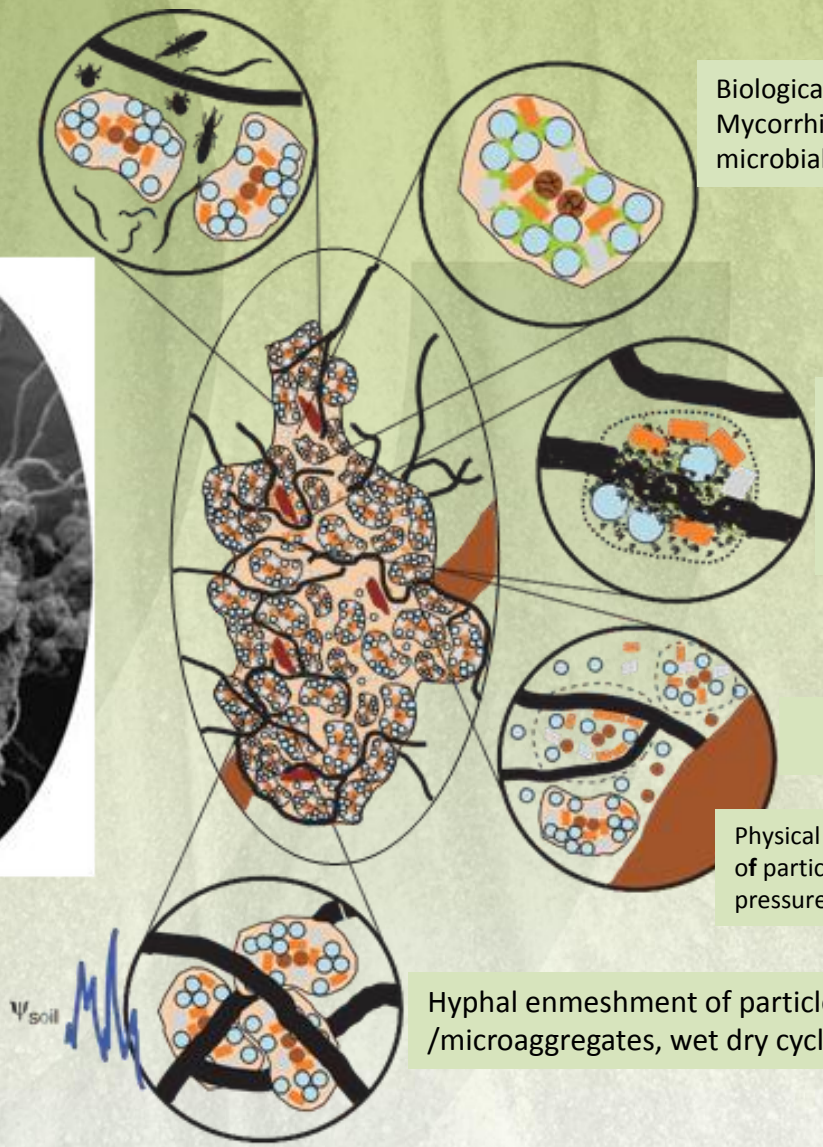
Fungal Hyphae



Dr. Kris Nichols – Microbiologist - USDA ARS

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

“Dig a Little, Learn a Lot”

Simple Test to determine soil health

In-field soil assessment what to look at:

Utilize all your senses:

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

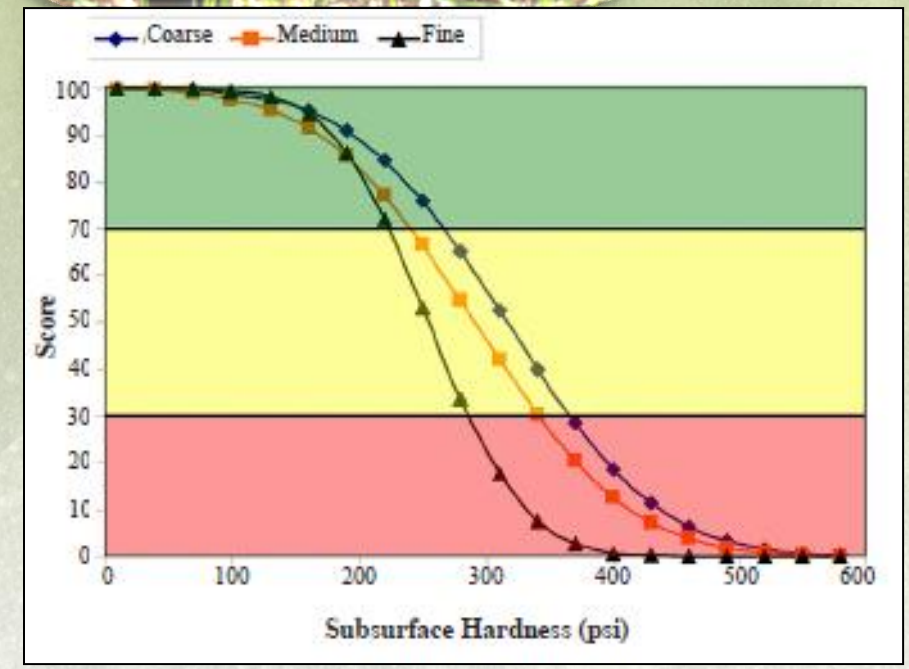
Look at:

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

What do you see? Healthy or Not?

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

What's residue tell me about soil health?

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

Brown's Ranch

Same Field

June 16, 2009
Corn planted into previous years' cover crop residue

July 1, 2009
Rapid residue decomposition

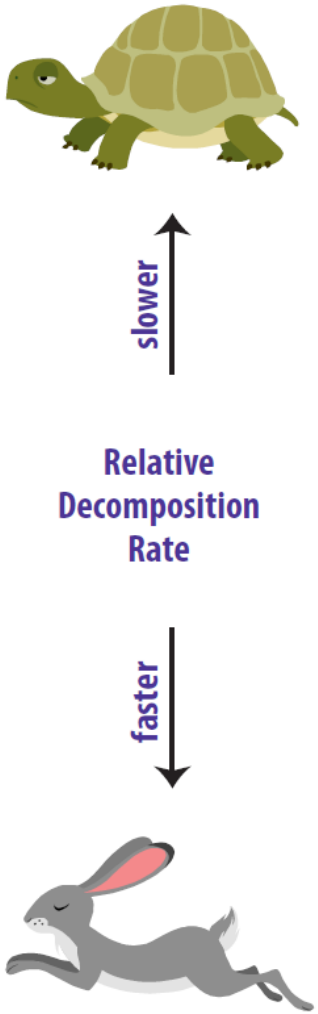
Residue Consumed by Soil Life

Managing Cover Crops to Feed Soil Microorganisms

- C:N ration 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

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
Ideal Microbial Diet	**24:1**
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



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

A Spade Deep, what it tells You

- Good Soil Tilth
- Sufficient depth

- Shredded Residue
- Signs of life

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

Does your soil smell?

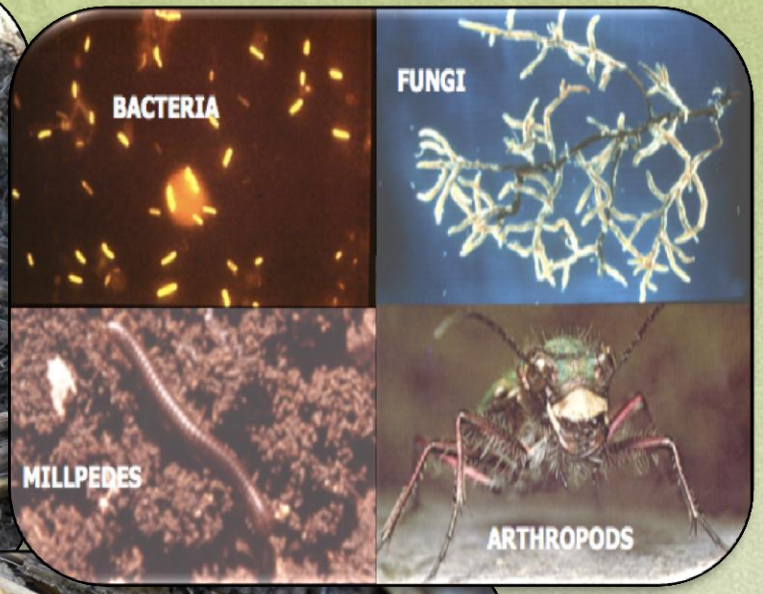
- Earthy/Sweet Smell
  - Geosmin from Actinomycetes Bacteria
  - Decompose residue
  - Cycle nutrients
  - Important part of soil foodweb
- Metallic/Kitchen sink cleanser
  - Soil dominated by Anaerobic bacteria
  - Indicate anaerobic conditions
  - Hydrogen Sulfide H2S rotten egg smell,
  - NH3 Ammonia 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

What's under the residue?

Residue should be shredded



Cobwebs evidence of microbe activity

What do Your Roots Say?

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

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

Healthy Soil allows for Straight Roots

Compacted Layers

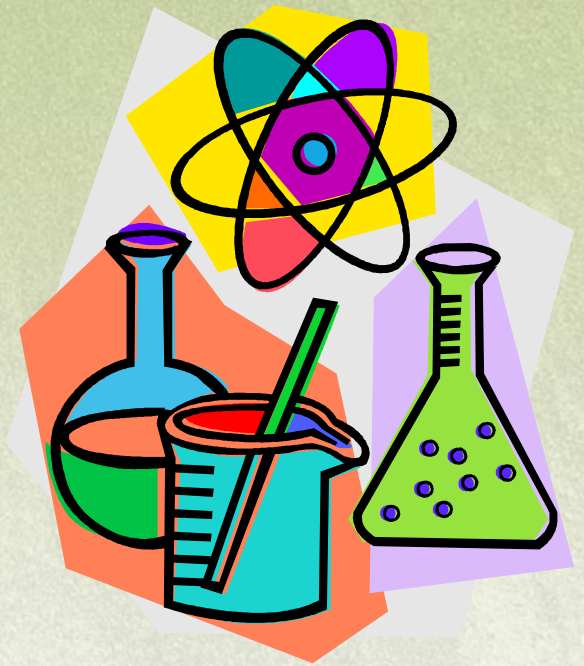
Roots run laterally on top of a compacted layer

Soil Health Testing

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

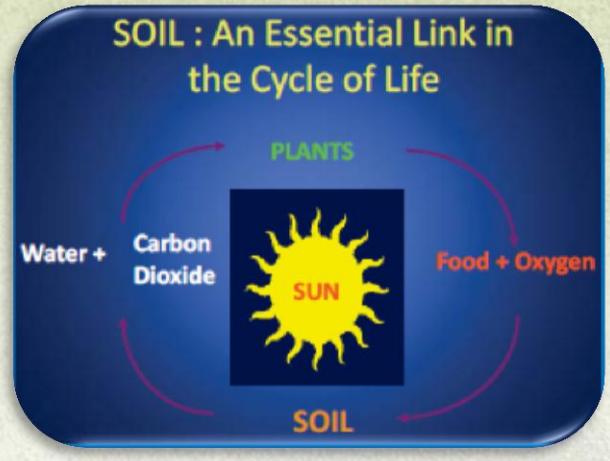
Soil Health Testing in the Lab

- Solvita CO_2 Burst Test
- Haney Test (ARS developed)
- PLFA (Phospholipid fatty acids)
- Cornell Soil Health Assessment
- Earthfort (Soil Foodweb)

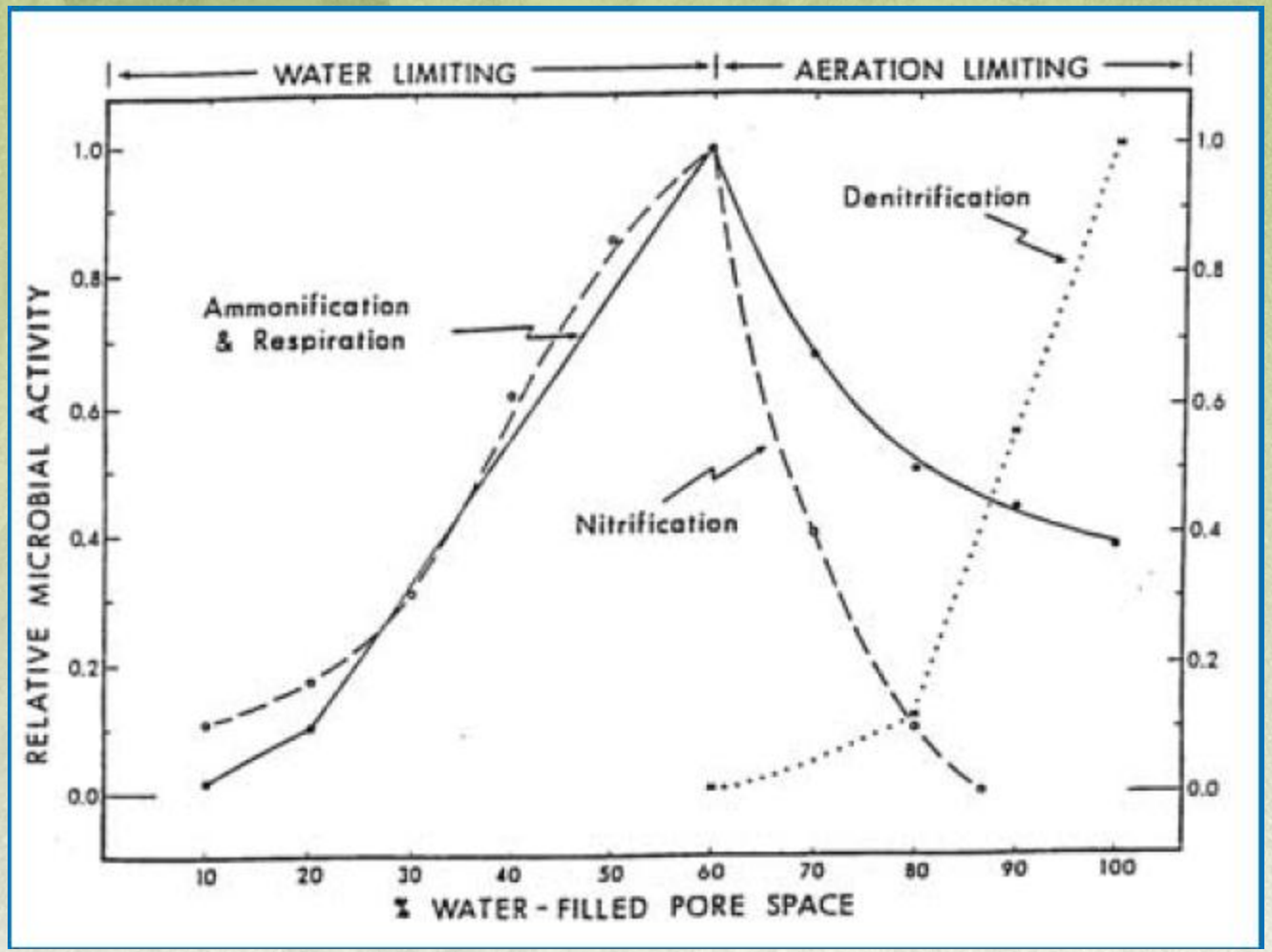


Soil CO_2 Respiration

- Measures soil respiration
  - Rate of CO_2 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_4
    - Nitrate as NO_3
    - Sulfate as SO_4



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

Solvita CO_2 Basal Respiration

- Measure the CO_2 at field moisture conditions
- Uses paddle to trap CO_2
- Uses color system to measure

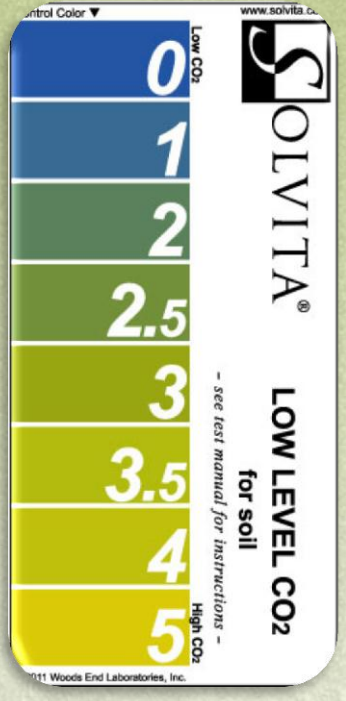


Table 2. Basic soil biological quality.

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 - Yello
Soil Respiration Activity				
Very Low Soil Activity	Moderately Low Soil Activity	Medium Soil Activity	Ideal Soil Activity	Unusually Activ
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/Exc organic m additi
***Approximate Level of CO_2 – Respiration**				
<300 mg CO_2/kg soil/wk	300-500 mg CO_2/kg soil/wk	500-1000 mg CO_2/kg soil/wk	1,000-2,000 mg CO_2/kg soil/wk	>2,000 mg soil/w
< 9.5 lbs CO_2-C/acre-3"/d	9.5 - 16 lbs CO_2-C/acre-3"/d	16-32 lbs CO_2-C/acre-3"/d	32-64 lbs CO_2-C/acre-3"/d	>64 lbs C/acre-
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 l

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

CO_2 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_2
- CO_2 Burst is proportional to:
  - microbial biomass
  - Potential carbon
  - Nitrogen mineralization
- Uses Solvita Digital Color Reader

CO_2 Burst Results

- Soil Microbial biomass is related to CO_2 Burst
  - Generally 20 times burst
  - N released is .7 of the CO_2

Table 3. Soil respiration levels and interpretations.

Sample Site	Median 24-hr Soil or Room Temp.	Time-frame	Start Time	End Time	Gel Color & Colorimetric Number	Soil Activity Rating (Table 1)	Avg. respiration level lbs CO_2-C/acre-3"/d	Quantity of Nitrogen Released (lbs/ac/yr)
Example 1	77F (25C)	4/30-5/1/12	8 AM	8:15 AM	GryGreen – 2.5	Moderately Low to Medium	16 lbs	20 lbs

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?

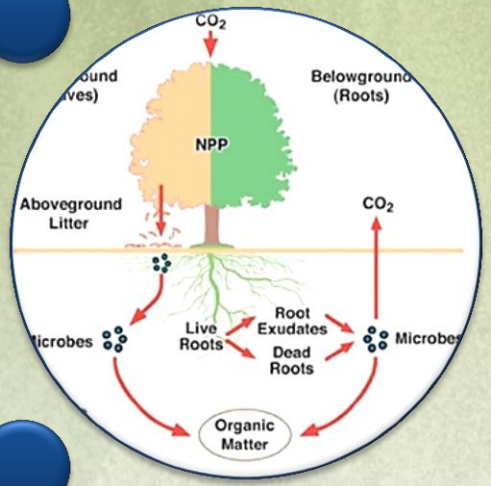
New Soil Testing Methods

soil testing in nature's image

Soil N, P, K

Extractable Organic N and P

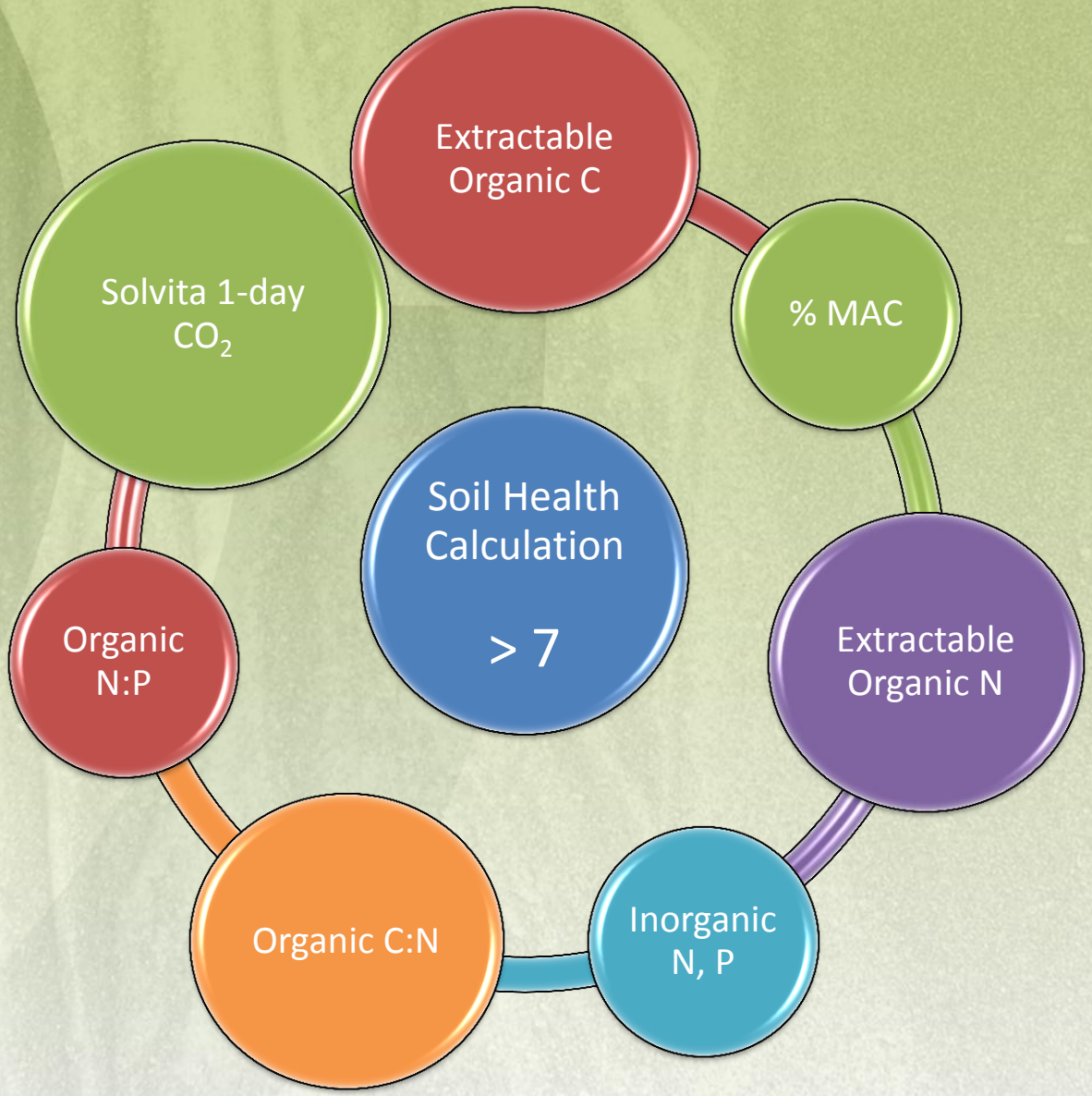
Microbial Activity



Water Extractable C

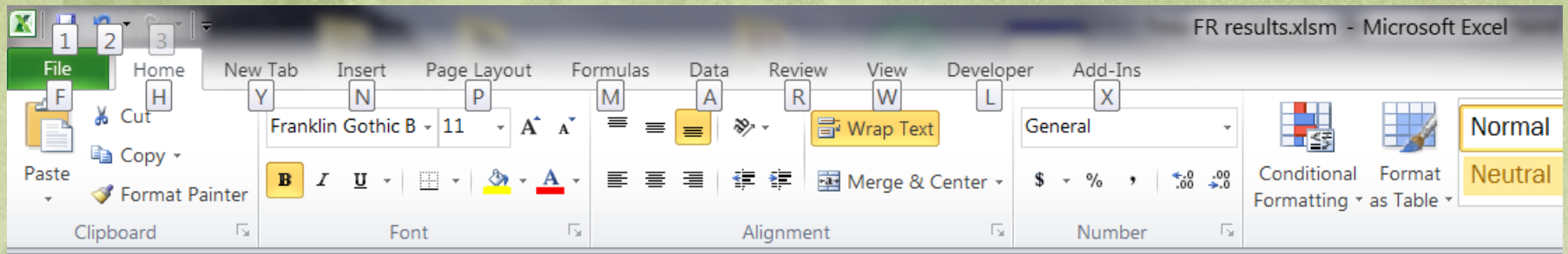
C:N balance

Soil Test Integration



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.**



A1 | Sample ID all lbs per acre

	A	B	C	D	E	F	G	H	I	J	K	L
1	**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												

Soil Nutrient Assessment Program

SNAP Home | Optional Details | About

Field Information

State: Texas

County: Bell

Crop: Corn

Field Area (Acres): 1000

Yield Goal: 80

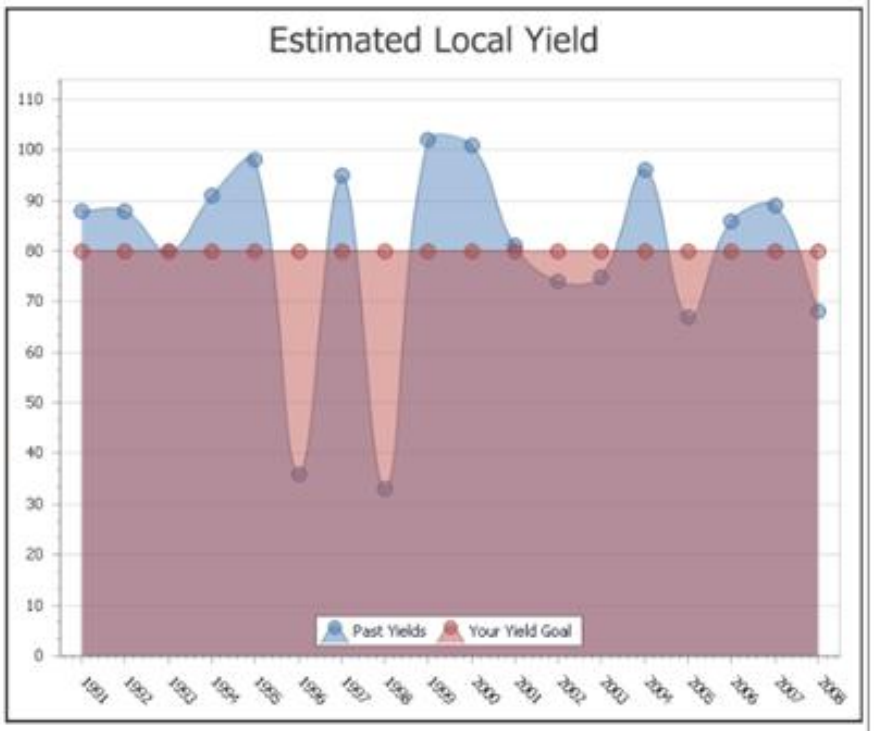
Soil Test Results

Nitrogen (lb N/acre): 25

Phosphate (lb P2O5/acre): 20

Potassium (lb K2O/acre): 50

Update



Results

	N	P2O5	K	Cost/Acre	Total Cost
Crop Requirements	80.0	40.0	40.0	$88.00	$88000
Soil Test Based Requirements	55.0	20.0	0	$44.50	$44500

Chance of Success %

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

Rick Haney

Soil Scientist

USDA – ARS

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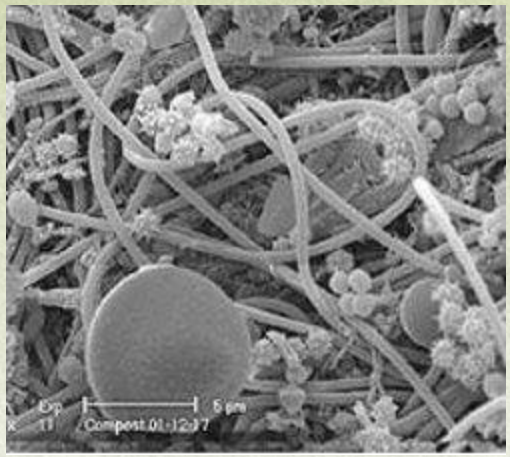


PLFA
(Phospholipid fatty acids)

- 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

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

Cornell University
Cooperative Extension

	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	25	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	72	
	*Minor Elements		100	
	OVERALL QUALITY SCORE (OUT OF 100):		64.1	**Medium**

Measured Soil Textural Class:==> silt loam

SAND (%): 41.4 SILT (%): 50.6 CLAY (%): 8.0

Location (GPS): Latitude=> Longitude=>

* 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

unlock the SECRETS IN THE SOIL

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.nacdnet.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
(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)	Hyphal Diameter (µm)
Results		0.850	46.3	405	5.24	274	2.5
Comments		To Wet	Excellent	Excellent	Low	Good	
Expected Range	Low	0.45	15	100	15	100	
	High	0.85	25	300	25	300	

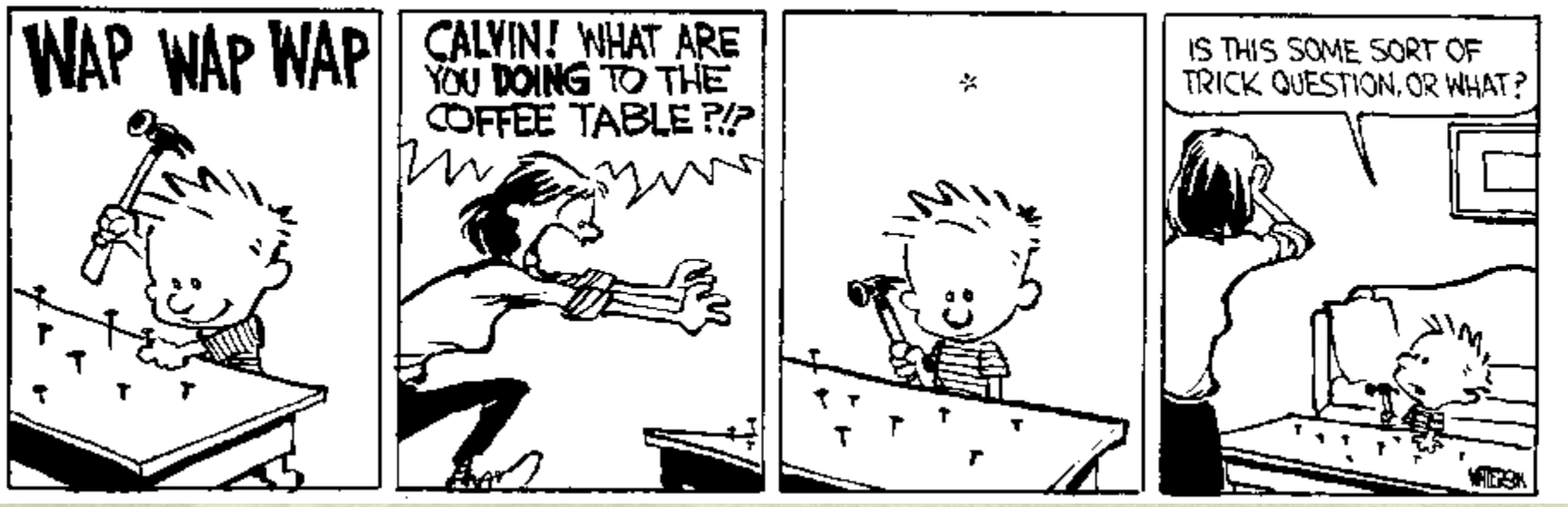
	Protozoa Numbers/g			Total Nematodes #/g	Percent Mycorrhizal Colonization	
	Flagellates	Amoebae	Ciliates		ENDO	ECTO
Results	178500	9736	331	4.45	31%	0%
Comments	High	Low	High	Low	Low	Low
Expected Range Low	10000	10000	50	20	40%	40%
Expected Range High			100	30	80%	80%

Organism Biomass Ratios		Total Fungal to Total Bacterial	Active to Total Fungal	Active to Total Bacterial	Active Fungal to Active Bacterial	Plant Available N Supply
Results		0.68	0.02	0.11	0.11	200+
Comments		Low	Low	Low	Low	
Expected Range	Low	0.8	0.25	0.25	0.75	
	High	1.5	0.95	0.95	1.5	

Nematodes per Gram of Soil
Identification to genus

Bacterial Feeders		
Acrobeles		0.81
Acrobeloides		0.18
Cephalobus		0.45
Cervidellus		0.18
Rhabditidae		0.45
Fungal Feeders		
Eudorylaimus		0.09
Fungal/Root Feeders		
Aphelenchoides	Foliar nematode	0.54
Aphelenchus		0.45
Ditylenchus	Stem & Bulb nematode	0.54
Filenchus		0.09

Questions?


WAP WAP WAP
CALVIN! WHAT ARE YOU DOING TO THE COFFEE TABLE?!?
IS THIS SOME SORT OF TRICK QUESTION, OR WHAT?