SOIL HEALTH WHAT IS IT?

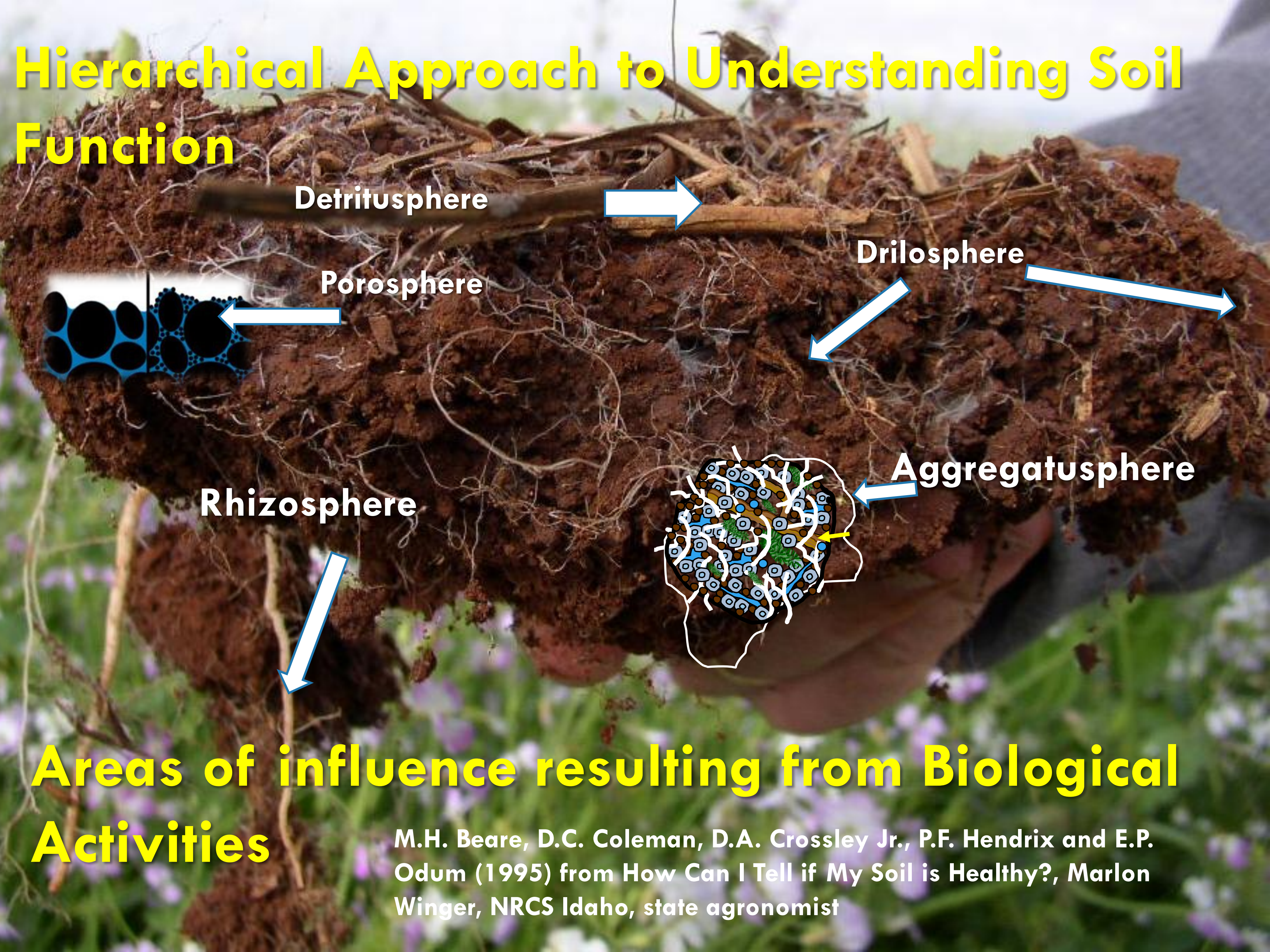
- THE CONTINUED CAPACITY OF THE SOIL TO FUNCTION AS A VITAL LIVING ECOSYSTEM THAT SUSTAINS PLANTS, ANIMALS, AND HUMANS
  - NUTRIENT CYCLING
  - WATER (INFILTRATION & AVAILABILITY)
  - FILTERING AND BUFFERING
  - PHYSICAL STABILITY AND SUPPORT
  - HABITAT FOR BIODIVERSITY

SOIL HEALTH INSTITUTE

Table 1. Selected indicators of soil properties chosen for the North American Project to Evaluate Soil Health Measurements (NAPESHM) along with each analytical method.

Properties	Indicators	Method	Reference
Soil physical	Soil texture	Pipette method with three size classes (2000-50, 50-2, and <2 μm)	Gee and Bauder, 1986
	Bulk density	Core method of 7.6 cm diameter and 7.6 cm depth	Blake and Hartge, 1986
	Aggregate stability	Wet sieve procedure with weight measurement	Kemper and Roseneau, 1986
	Available water holding capacity	Ceramic plate method measured at -33 kPa (-10 kPa for sandy soils) and -1500 kPa	Klute, 1986
	Soil stability index	Combination of wet and dry sieving at multiple sieve sizes	Franzluebbers et al., 2000
	Water infiltration rate K_{fs}	Two-ponding head method	Reynolds and Elrick, 1990
Soil chemical	Soil pH	1:2 soil:water	Thomas, 1996
	Soil electrical conductivity	1:2 soil:water	Rhoades, 1996
	Extractable phosphorus	Mehlich-3 extractant for all and Olsen extractant when soil pH≥7.2	Olsen and Sommers, 1982 or Sikora and Moore, 2014
	Extractable K, Ca, Mg, Na	Mehlich-3 extractant for all and ammonium acetate extraction when soil pH≥7.2	Knudsen et al., 1982 or Sikora and Moore, 2014
	Extractable Fe, Zn, Cu, Mn	Mehlich-3 extractant for all and DTPA when soil pH≥7.2	Lindsay and Norvell, 1978 or Sikora and Moore, 2014
	Cation exchange capacity	Sum of cations from Mehlich-3 extrant for all and ammonium acetate when soil pH≥7.2	Olsen and Sommers, 1982 or Sikora and Moore, 2014
	Base saturation	Calculation of cations from Mehlich-3 extractant for all and ammonium acetate when soil pH≥7.2	Olsen and Sommers, 1982 or Sikora and Moore, 2014
	Sodium adsorption ratio	Saturated paste extract followed by inductively coupled plasma spectroscopy	Miller et al., 2013
Soil biological	Soil organic carbon	Dry combustion, corrected for inorganic carbon, if present, using pressure-calcimeter	Nelson and Sommers, 1996 or Sherrod et al., 2002
	Active carbon	Permanganate oxidizable carbon (POXC) digestion followed by colorimetric measurement	Weil et al., 2003
	Short-term carbon mineralization	4-day incubation followed by CO_2-C evolution and capture at 50 % water-filled pore space	Zibilske, 1994
	Total nitrogen	Dry combustion	Nelson and Sommers, 1996
	Nitrogen mineralization rate	Short-term anaerobic incubation with ammonium and nitrate measured colorimetrically	Bundy and Meisinger, 1984
	Soil protein index	Autoclaved citrate extractable	Schindelbeck, 2016
	β-glucosidase	Assay incubation followed by colorimetric measurement	Tabatabai et al., 1994
	β-glucosaminidase	Assay incubation followed by colorimetric measurement	Deng and Popova, 2011
	Phosphatase	For soil pH≥7.2, alkaline phosphatase, otherwise acid phosphatase. Assay incubation followed by colorimetric measurement	Acosta-Martinez and Tabatabai, 2011
	Arylsulfatase	Assay incubation followed by colorimetric measurement	Klose et al., 2011
	Phospholipid Fatty Acid	Bligh-Dyer extractant, solid phase extraction, transesterification, and gas chromatography	Buyer and Sasser, 2012
	Genomics	16S rRNA, ITS, and shotgun metagenomics	Thompson et al., 2017 and Quince et al., 2017
Other	Reflectance	vis/NIR diffuse reflectance spectroscopy	Veum et al., 2015
	Crop yield	Obtained from historical plot yield	

Hierarchical Approach to Understanding Soil Function



Areas of influence resulting from Biological Activities

M.H. Beare, D.C. Coleman, D.A. Crossley Jr., P.F. Hendrix and E.P. Odum (1995) from How Can I Tell if My Soil is Healthy?, Marlon Winger, NRCS Idaho, state agronomist

The Detritusphere: Influence of residue

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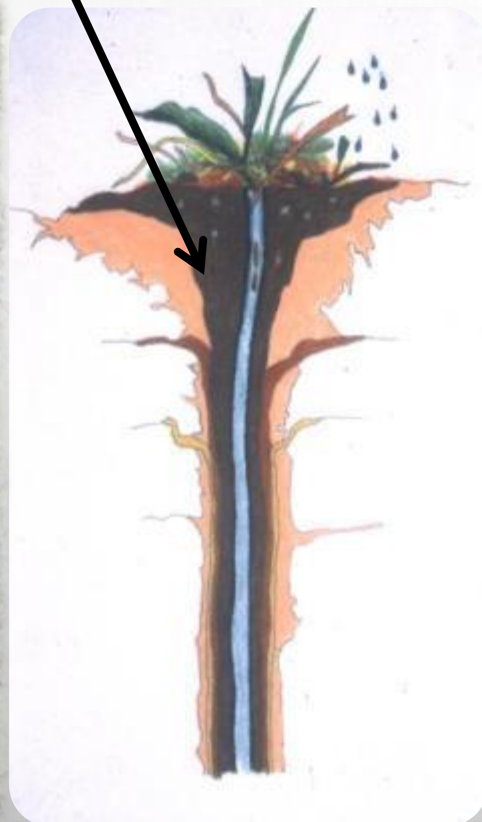
DRILOSPHERE: ZONE OF EARTHWORM INFLUENCE



•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)

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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) BAIT

- 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 other worms

Endogeic (Bohlen et al 2004) GARDEN

- 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

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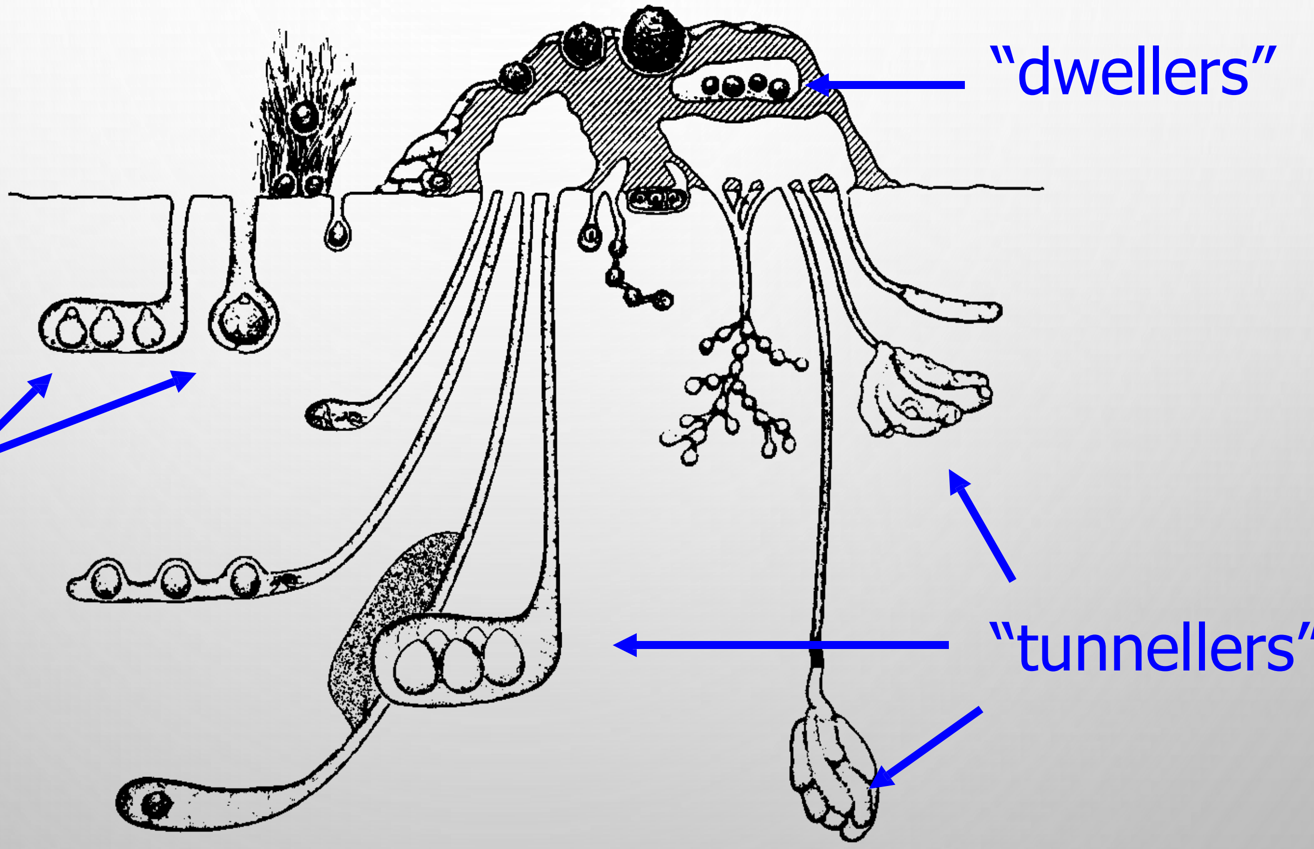
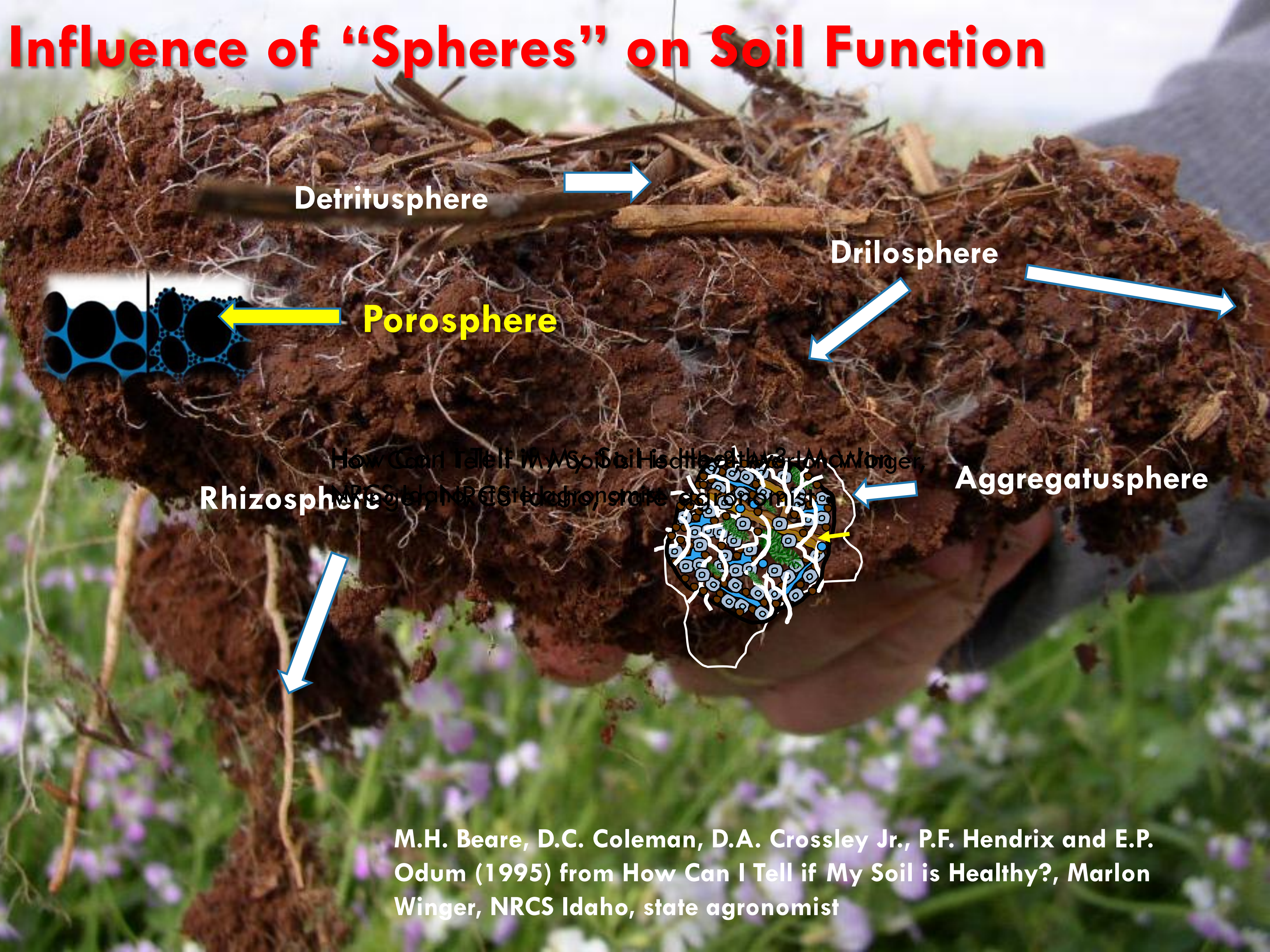
Dung-feeding beetles:



Kevin Floate, AAFC

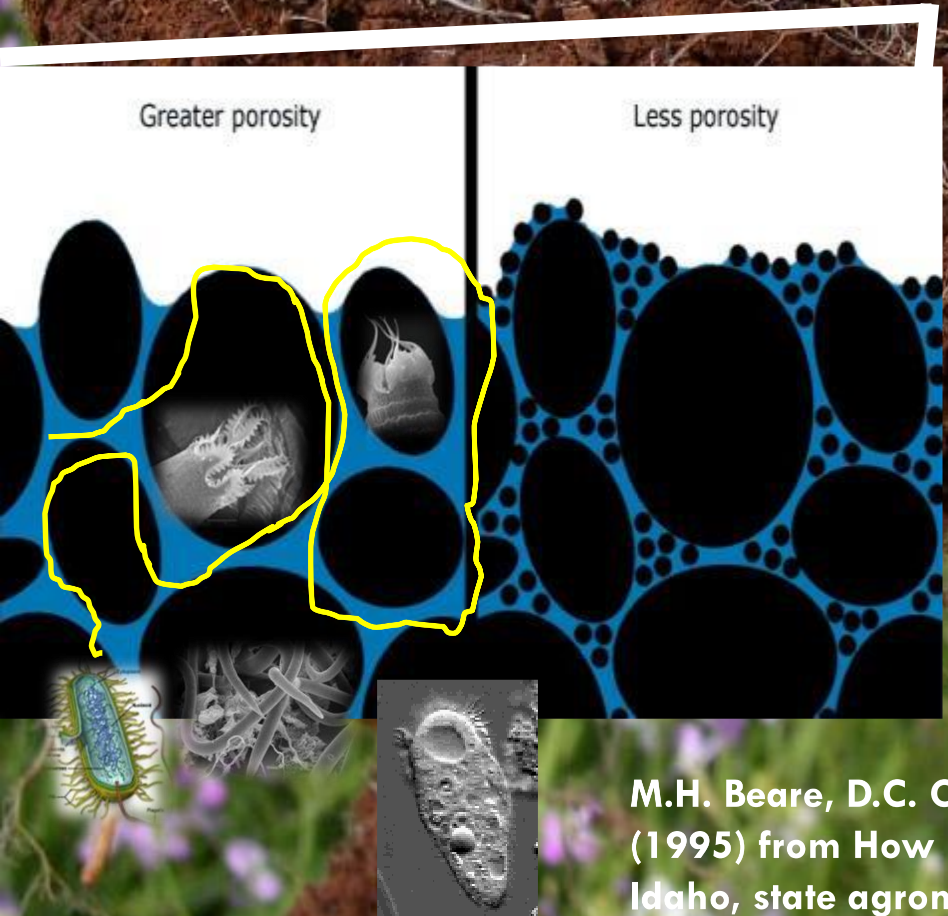
Influence of “Spheres” on Soil Function



M.H. Beare, D.C. Coleman, D.A. Crossley Jr., P.F. Hendrix and E.P. Odum (1995) from How Can I Tell if My Soil is Healthy?, Marlon Winger, NRCS Idaho, state agronomist

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) from How Can I Tell if My Soil is Healthy?, Marlon Winger, NRCS Idaho, state agronomist

Bulk Density Examples

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

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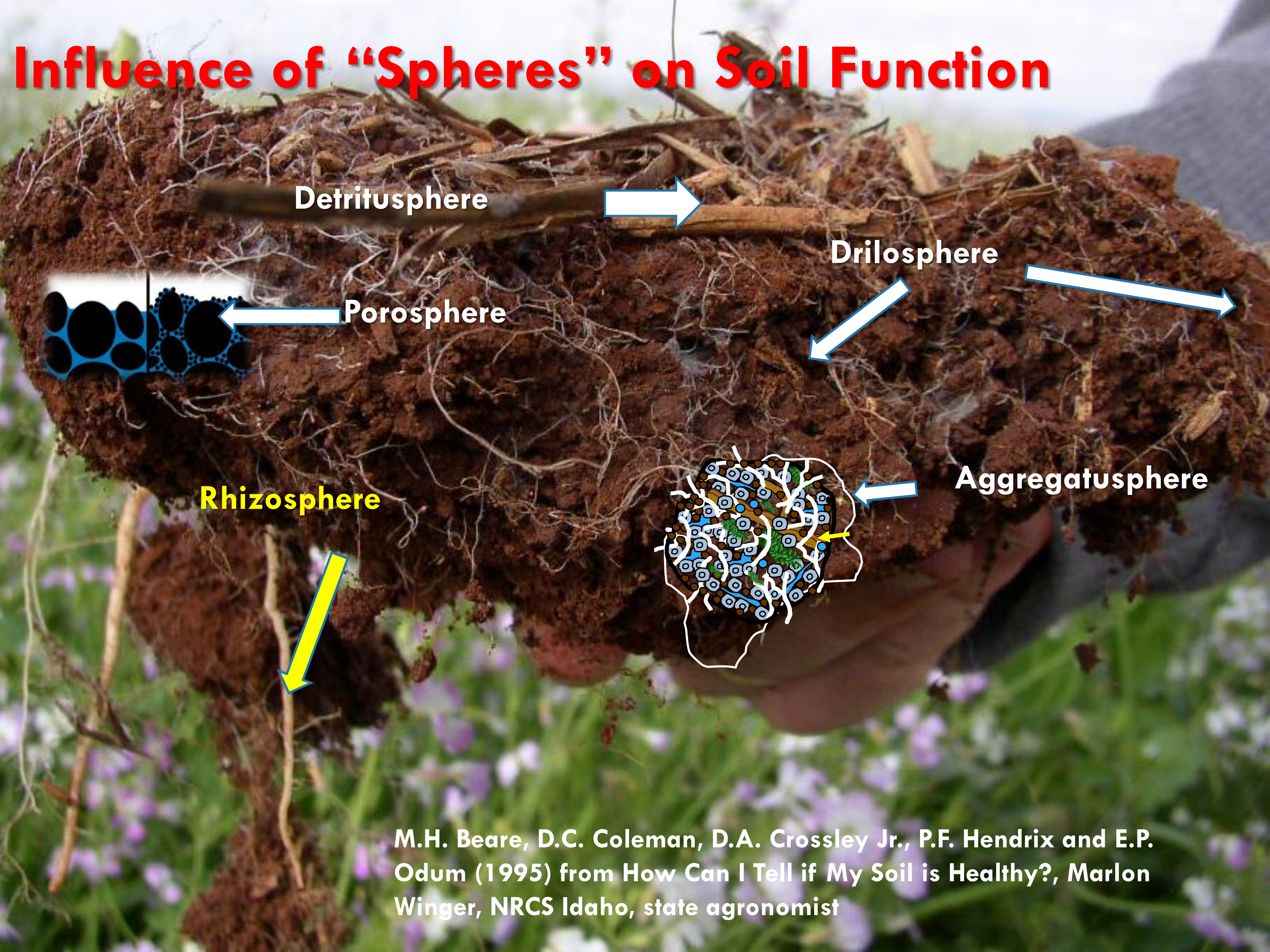
Influence of "Spheres" on Soil Function



M.H. Beare, D.C. Coleman, D.A. Crossley Jr., P.F. Hendrix and E.P. Odum (1995) from How Can I Tell if My Soil is Healthy?, Marlon Winger, NRCS Idaho, state agronomist

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

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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

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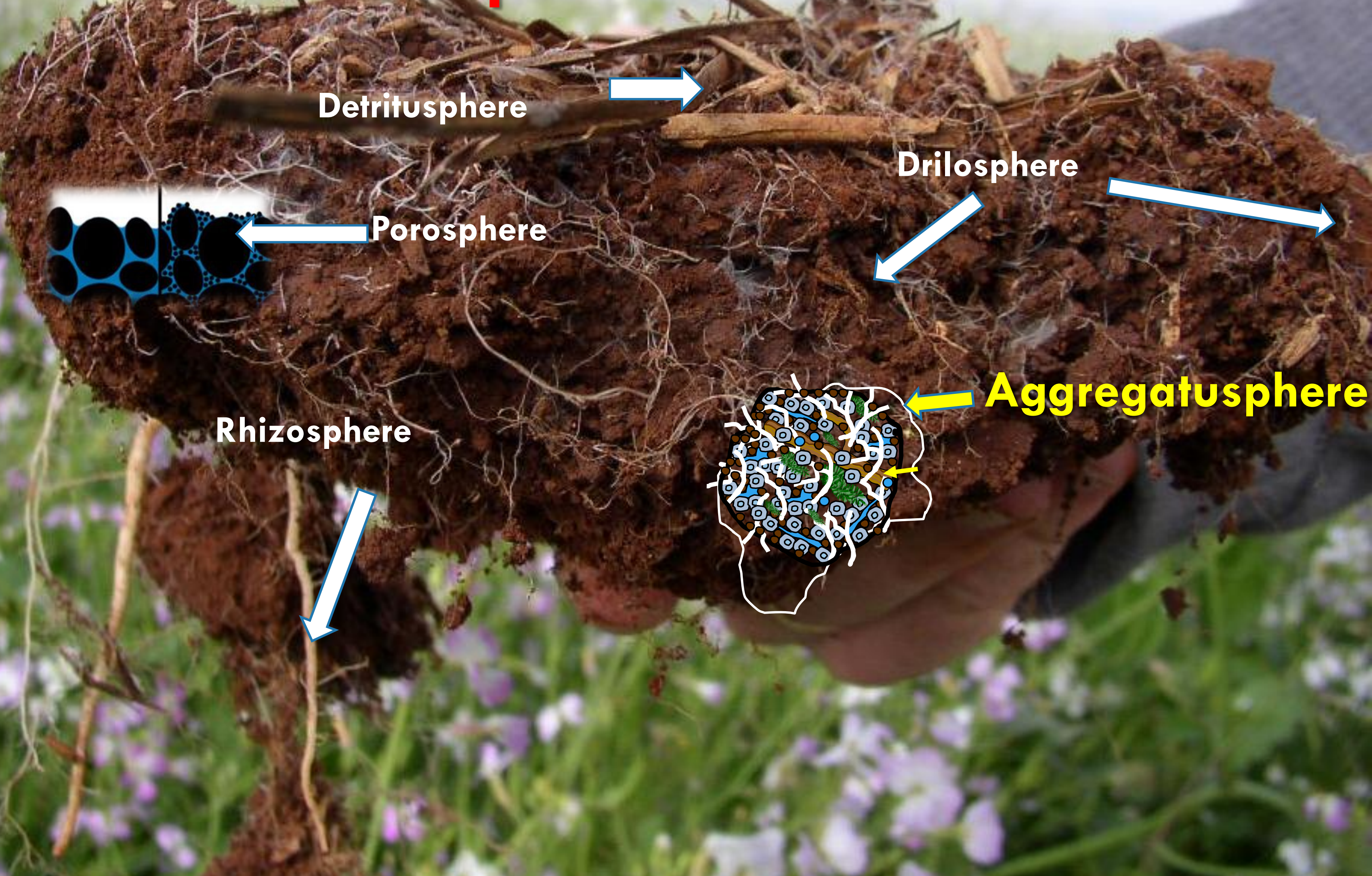
Influence of "Spheres" on Soil Function



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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 romatic

humic materials

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

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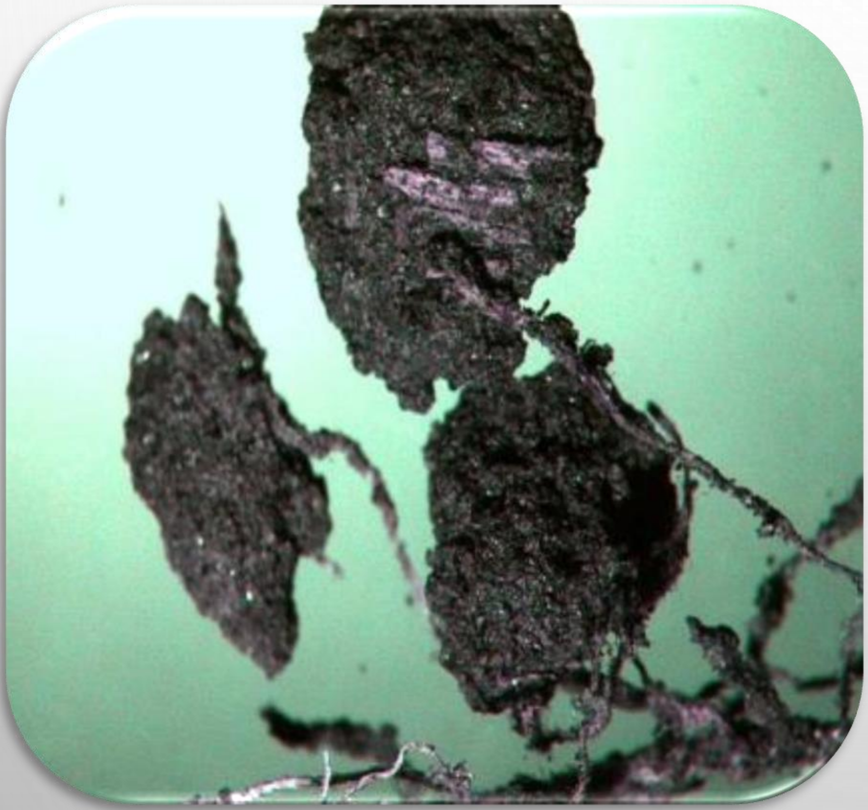
Root and Mycorrhizal Fungi Association:

ENLARGED SOIL AGGREGATES



Glomalin and hyphae

Dr. Kris Nichols, Microbiologist

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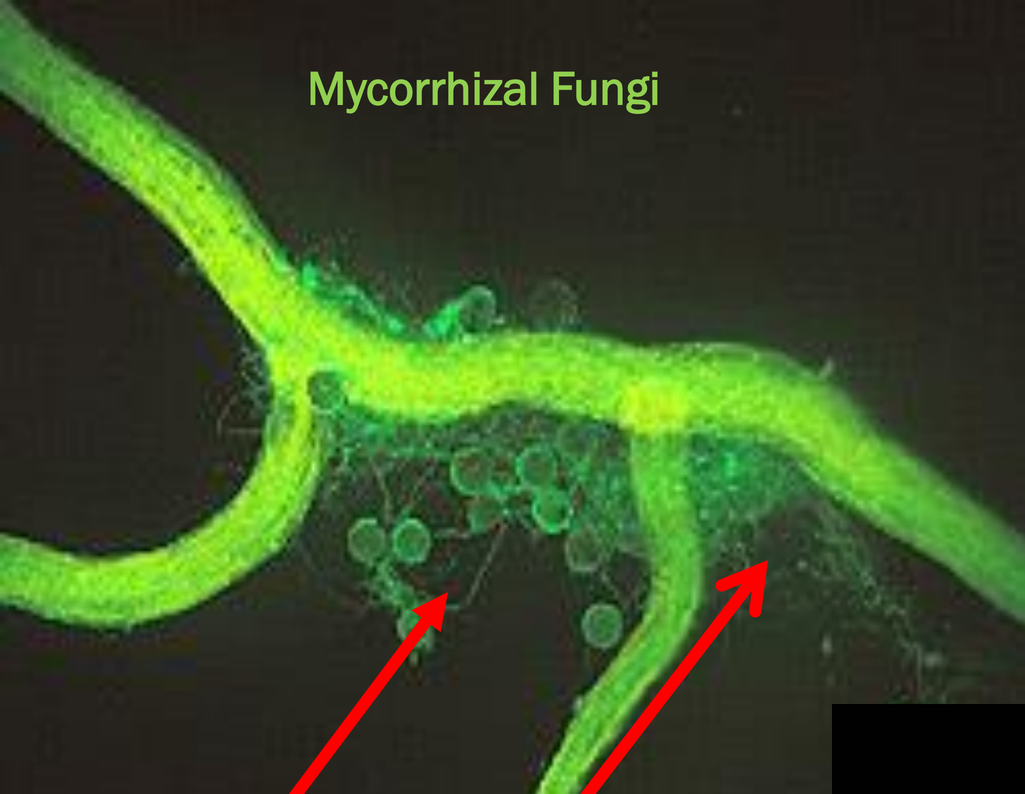
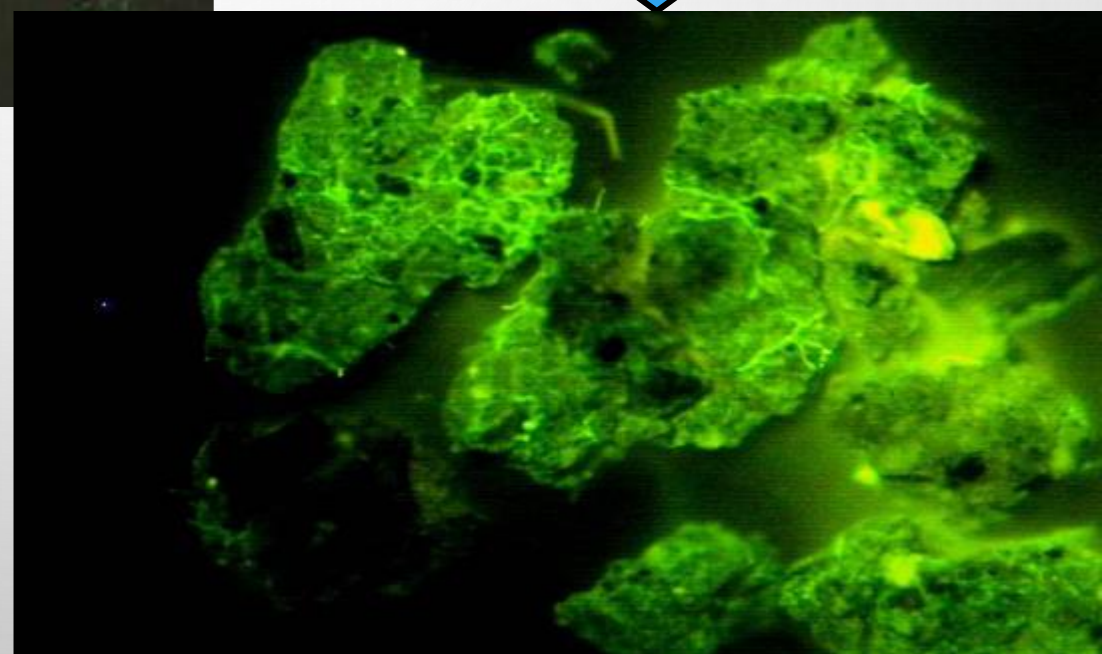


Glomalin is naturally brown. A laboratory procedure reveals glomalin on hyphae and soil aggregates as the bright green material shown here.

Fungal Hyphae



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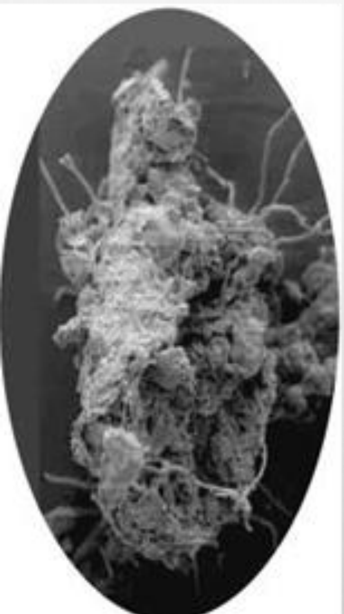
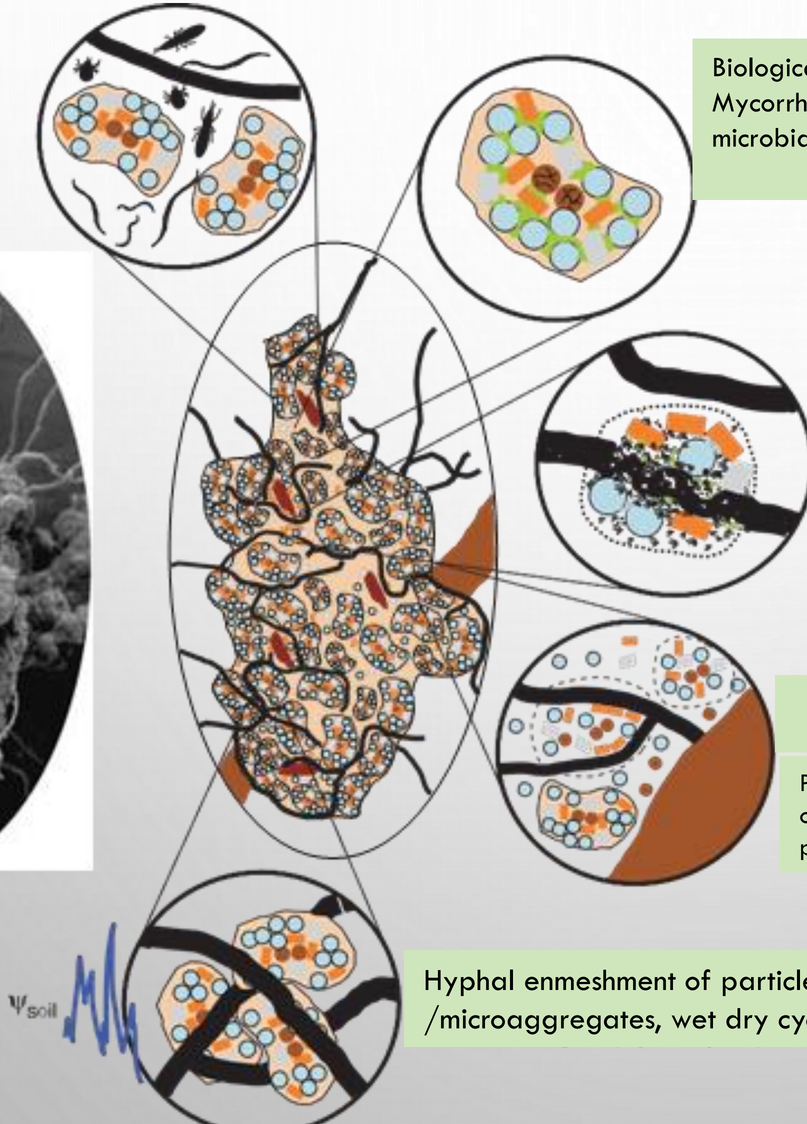
Dr. Kris Nichols – Microbiologist - USDA ARS

BUILDING A SOIL AGGREGATE





Biological effects:
Mycorrhizal fungi influences microbial communities

Biochemical effects:
Release of mycelium, glomalin ect. from decomposing or living hyphae

Physical effects: Alignment of particles, exerting pressure

Hyphal enmeshment of particles /microaggregates, wet dry cycles

Involves both:

Biological

- AMF communities form
- Release of Glues

Physical

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

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"Dig a Little, Learn a Lot"

Simple Test to determine soil health

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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
- ???

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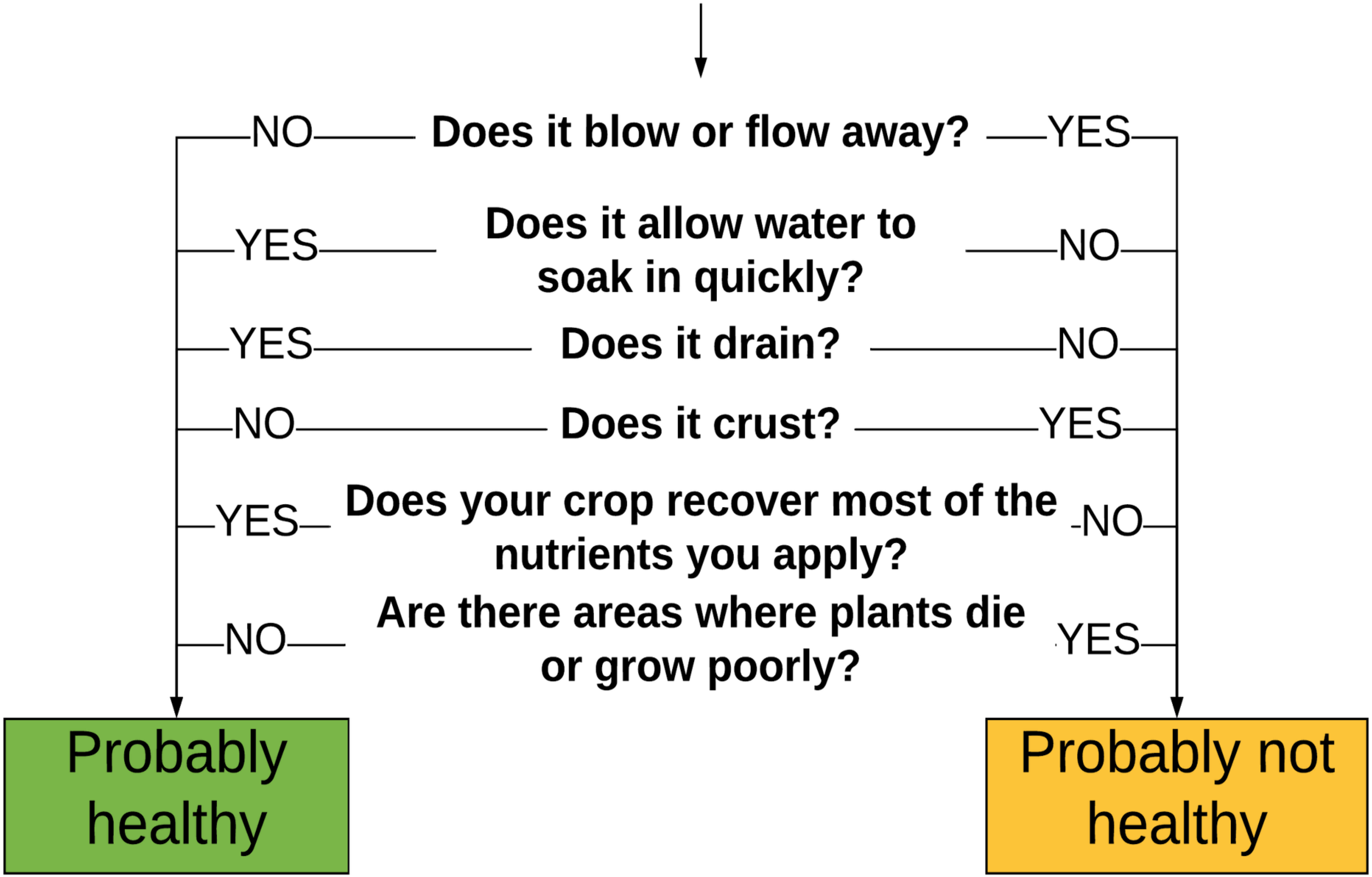
Is your soil healthy?



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WHAT DO YOU SEE? HEALTHY OR NOT?

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IS LITTER AND PLANT RESIDUE FAIRLY ABUNDANT?

- APPROPRIATE LITTER AND SOIL ORGANIC MATTER IMPROVE THE WATER HOLDING CAPACITY OF SOIL, IMPROVE WATER INFILTRATION, REDUCE EVAPORATION, AND RETURN NUTRIENTS TO THE SOIL.
- LITTER FROM PRODUCTIVE TAME FORAGES IN HIGHER RAINFALL AREAS BREAKS DOWN RAPIDLY IN THE SOIL.
- GROWING PLANTS, DEAD AND DECAYING PLANT MATERIAL, AND MULCH SHOULD BE PRESENT AND EVENLY DISTRIBUTED WITH LITTLE BARE SOIL PRESENT.

IS NUTRIENT CYCLING OCCURRING?

- ENSURE SOIL NITROGEN, PHOSPHORUS, POTASSIUM, AND SULFUR LEVELS ARE ADEQUATE THROUGH FERTILIZATION, APPLYING MANURE, OR WINTER FEEDING ON PASTURES.
- GRAZING LIVESTOCK RECYCLE LARGE AMOUNTS OF NUTRIENTS THROUGH MANURE AND URINE.
- 10 TO 20 LBS/ACRE OF N PER %OM IS LEAKED BACK INTO THE SYSTEM MOSTLY THROUGH THE ANIMAL. (DR. MATT POORE USDA 2020)

MANURE SHOULD BE DISTRIBUTED **UNIFORMLY** AND **DECOMPOSE RELATIVELY QUICKLY.**

FORAGE SHOULD BE UNIFORM IN COLOR AND PRODUCTION.

WHAT'S RESIDUE TELL ME ABOUT SOIL HEALTH?

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

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RESIDUE CONSUMED BY SOIL LIFE

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A SPADE DEEP, WHAT IT TELLS YOU

- Good Soil Tilth
- Sufficient depth

- Shredded Residue
- Signs of life

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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

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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_2S ROTTEN EGG SMELL,
  - NH_3 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

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DO YOU HAVE "CRUMBLY" SOIL?

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

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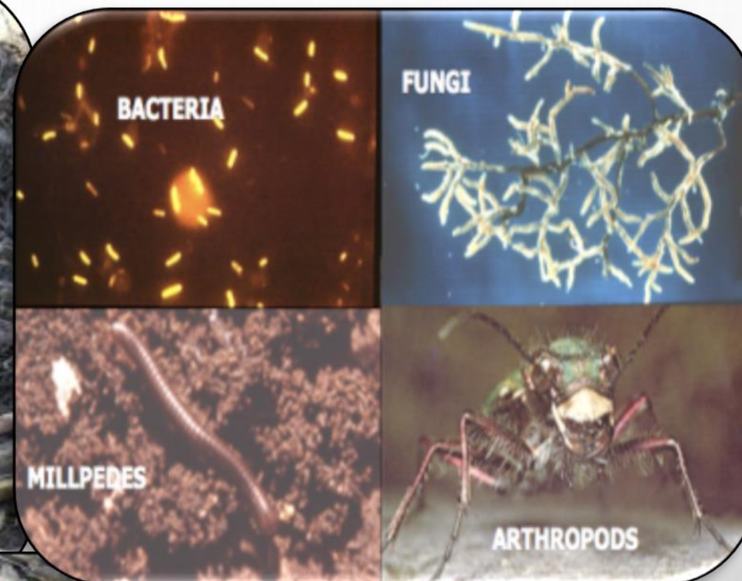
WHAT'S UNDER THE RESIDUE?

Residue should be shredded



Cobwebs evidence of microbe activity

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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)

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HEALTHY SOIL ALLOWS FOR STRAIGHT ROOTS

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COMPACTED LAYERS

Roots run laterally on top of a compacted layer

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MANAGEMENT

FERTILITY

Remember what plant growth costs your soil.

Grass has a relatively high demand for nutrients. Table 1 provides approximate amounts of nutrient removed per ton of dry matter. Removal will vary depending on grass species and growing conditions.

Table 1. Nutrient removal per ton of grass

Nutrient	**Nutrient removed (lb/ton – dry matter basis)** [Z]
Nitrogen (N)	30 to 35
Phosphorus (P)	4
Phosphate (P_2O_5) [Y]	10
Potassium (K)	40
Potash (K_2O) [X]	50
Calcium (Ca)	7
Magnesium (Mg)	5
Sulphur (S)	5
Boron (B)	0.08
Copper (Cu)	0.01
Iron (Fe)	0.3
Manganese (Mn)	0.1
Molybdenum (Mo)	0.002
Zinc (Zn)	0.05

Z Amounts of removal are approximate and vary depending on grass species and growing season conditions.
Y To convert P to P_2O_5, multiply P by 2.3
X To convert K to K_2O, multiply K by 1.6

How is this being replaced?

NITROGEN IN SOIL OM

N IN SOIL OM OCCURS IN DIFFERENT POOLS

- MICROBIAL BIOMASS
  - WILL BECOME LABILE WHEN MICROORGANISM DIES
- LABILE ORGANIC N
  - MINERALIZATION MAKES THIS AVAILABLE FOR PLANTS
- RESISTANT N
  - NOT AVAILABLE

- LAND MANAGEMENT INFLUENCES THE PROPORTIONS OF EACH

C:N RATIO' S

- BECAUSE OF C:N RATIOS, FORAGES CAN MAKE OM MORE OR LESS AVAILABLE IN THE SOIL
- FORAGES HELP SOIL MICROORGANISMS MEET THEIR N REQUIREMENTS (C:N RATIO) FOR OM BREAKDOWN
  - MANURE DOES THE SAME THING
  - WHEN N LEVELS ARE HIGHER, THE SOIL CAN SUPPORT MORE MICROBES
- SOIL MICROBES WANT TO HAVE A C:N = 8:1
- STRAW (CEREAL) IS ABOUT 80:1
  - STRAW AND DECAYING PLANT MATERIAL IS ADDED TO THE SOIL EACH YEAR
- WOOD CHIPS IS ABOUT 400-600:1
  - STRAW AND DECAYING PLANT MATERIAL IS ADDED TO THE SOIL EACH YEAR
- MANURE 5-25:1
  - STRAW AND DECAYING PLANT MATERIAL IS ADDED TO THE SOIL EACH YEAR
- ASH IS ABOUT 25:1
  - STRAW AND DECAYING PLANT MATERIAL IS ADDED TO THE SOIL EACH YEAR
- SAW DUST ABOUT 300:1

C:N RATIOS

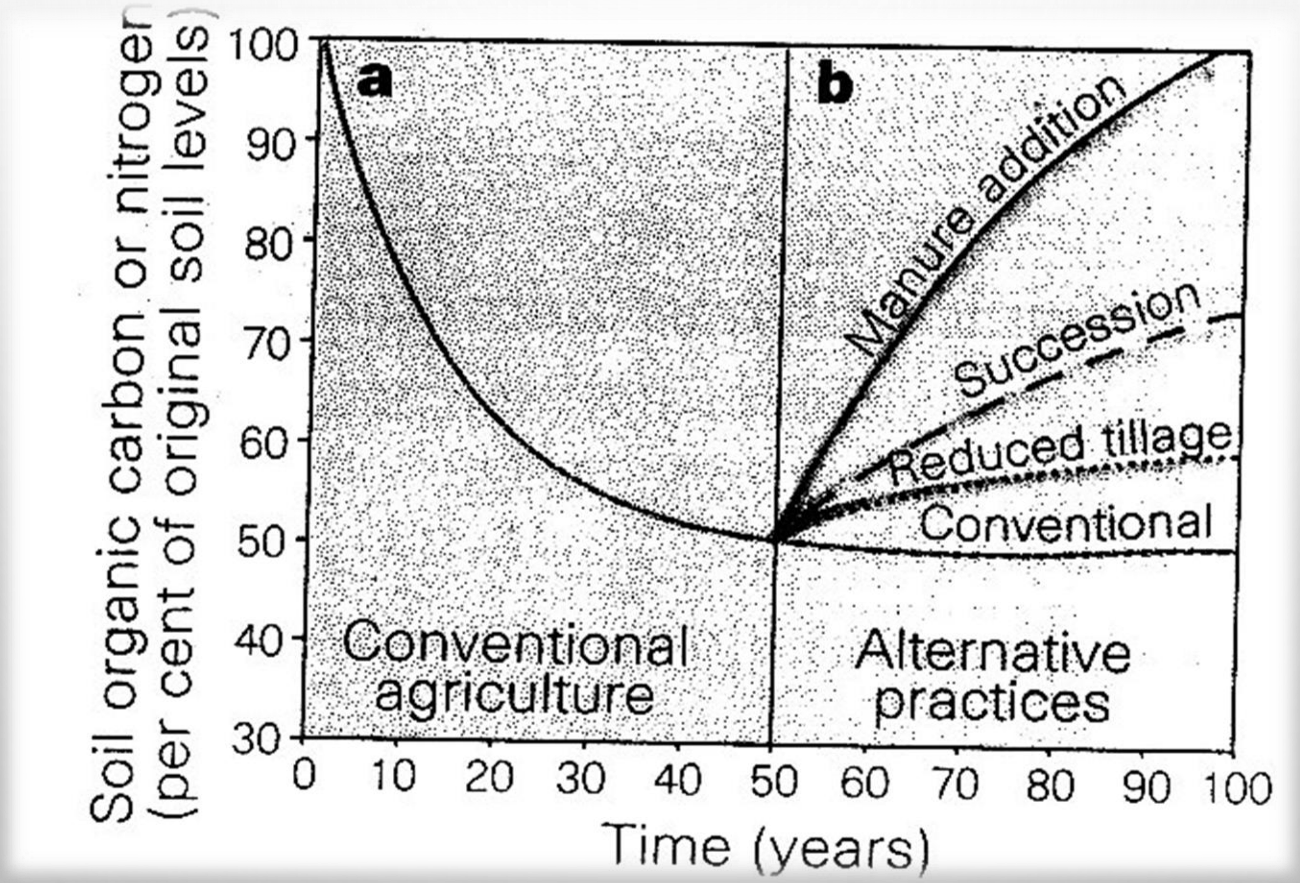
- FOR MICROBES TO BREAK DOWN STRAW (HIGH C) THEY NEED SO FIND A SOURCE OF N (TO BALANCE THEIR DESIRED LOWER C:N RATIO)
- MICROBES ACCESS NITROGEN FROM THE SOIL N POOL (INORGANIC) AND MAKE IT INTO ORGANIC N
- MAKES N UNAVAILABLE FOR PLANTS (IMMOBILIZED)
  - IMMOBILIZATION IS THE CONVERSION OF INORGANIC N (THE KIND USEABLE TO PLANTS) INTO ORGANIC N (NOT USEABLE BY PLANTS) BY SOIL MICROBES
  - THE OPPOSITE PROCESS IS ALSO PERFORMED BY SOIL MICROBES (MOBILIZATION OR MINERALIZATION) → CONVERTS ORGANIC N (OM) INTO INORGANIC N
- MOST CROPPING SYSTEMS APPLY ENOUGH N TO COMPENSATE FOR CROP NEED AND IMMOBILIZATION

C:N RATIO' S…

- YOUNG LEGUME PLANTS = 10:1
- OLDER LEGUME PLANTS = 20:1 ???
- BECAUSE OF THE LOWER C:N RATIO OF LEGUME STRAW (COMPARED TO CEREAL STRAW), MICROBES IMMOBILIZE LESS N WHEN BREAKING DOWN LEGUME BIOMASS
- MORE INORGANIC N REMAINS IN SOIL POOL – AVAILABLE FOR PLANTS
  - IN FACT, WITH C:N RATIOS LESS THAN 20, OFTEN LITTLE TO NO IMMOBILIZATION OCCURS

MANAGEMENT CAN CHANGE SOIL HEALTH

- Convention agriculture= tillage
- No-till/reduced tillage has been widely opted in western Canada since the 1980s



SOIL MANAGEMENT PRACTICES (AND IMPACT ON SOIL HEALTH)

- **TILLAGE**
  - DECREASES LABILE AND MICROBIAL BIOMASS
  - INCREASES RESISTANT N
  - DECREASE IN OM
  - GREATER RELIANCE ON FERTILIZER

Decreases N supplying ability of soil

- **ADDITION OF MANURE**
  - REINTRODUCES OM
  - INCREASES LABILE AND MICROBIAL BIOMASS

Increases N supplying ability of soil

C:N ratio recovery in
45 years

SOIL MANAGEMENT PRACTICES (AND IMPACT ON SOIL HEALTH)

C:N ratio recovery in 200 years

- **SUCCESSION**
  - ABANDONED FIELDS GRADUALLY RETURN TO NATURAL VEGETATION
  - NO OM REMOVAL BUT ALSO NO SIGNIFICANT INPUTS
- **REDUCED TILLAGE**
  - STILL REMOVING NUTRIENTS (HARVESTING A CROP)
  - REPLACES 20% OF LOST C/N

IS NUTRIENT CYCLING OCCURRING?

- IF YOU WANT TO LOWER YOUR INPUTS YOU MUST ENSURE THAT OM INPUTS>OM OUTPUTS
- HAYING????
- WHITEHEAD (2000) ESTIMATED THAT A MODERATELY GRAZED PASTURED REMOVED 22 LBS OF N AND 2 LBS/ACRE OF P PER YEAR COMPARED TO A 180 BS/ACRE CORN CROP WHICH REMOVED 134 LBS OF N AND 27 LBS OF P. SWITCHING TO BEEF PRODUCTION REDUCED THE EXPORT OF N BY 84% AND P BY 92%.
- A PERENNIAL LEGUME GRASS PASTURE WAS FOUND TO GAIN 50 LBS/AC OF N WITHOUT INPUTS. MOST OF THIS N COMES FROM ABOVE GROUND HERBAGE, MANURE AND URINE.
- MOST N IN IS STORED IN THE TOPGROWTH OF A LEGUME (75 TO 80%) EVENTHOUGH IT IS FIXED BY RHIZOBIA BACTERIA (DR. JENNINGS UNIVERSITY OF ARKANSAS)

BALE GRAZING

- The reaction of N was greater than for either P or K
- N concentrations were elevated (up to 8X greater) in the fall following bale grazing
- Within 3 years N levels were back to baseline or near baseline levels
- The reaction of phosphorus concentrations was as expected and the breakdown of phosphorus from the feed and manure residue was slower than for nitrogen with some not showing up in the soil profile for up to 3 years post bale grazing

SWATH GRAZING

- Higher ammonia (NH_4^+), nitrate (NO_3^-), phosphate and potassium supply rates were evident under the swath compared to between swaths

Over time

- NH_4^+ levels were flat both under and between swaths while bedding are showed higher levels over all three years.
- NO_3^- levels (0-15cm) trended downward possibly due to crop utilization.

CARBON

BALE GRAZING

- Total Carbon increased from 2016 to 2017 at both sites

SWATH GRAZING

- Carbon levels were lower and relatively stable at the top of the slope and rose over time at the toe of the slope