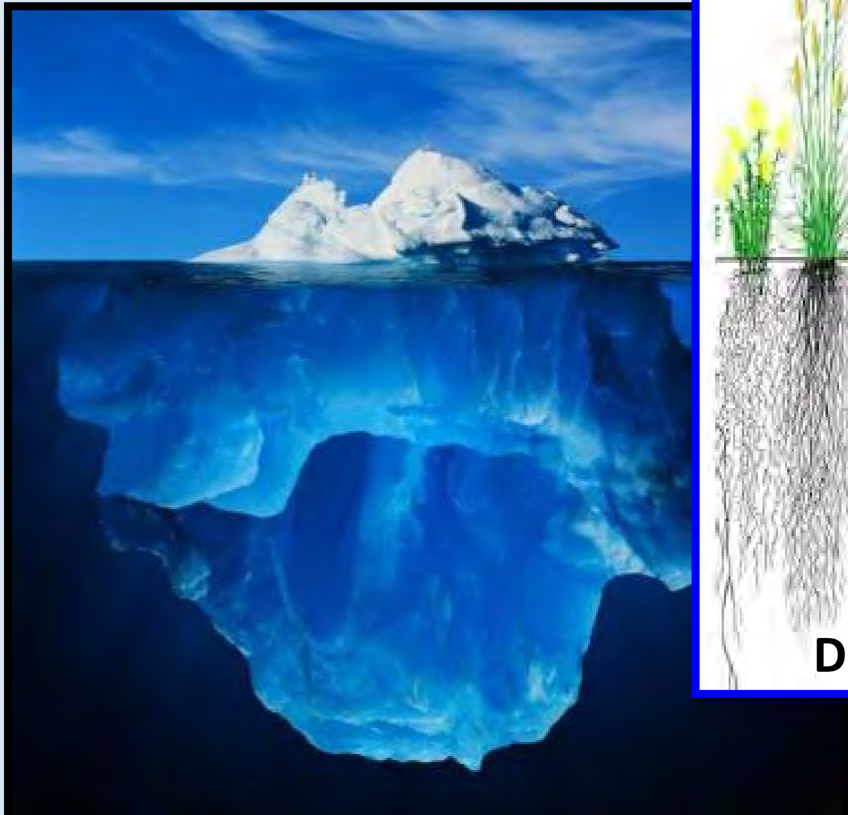
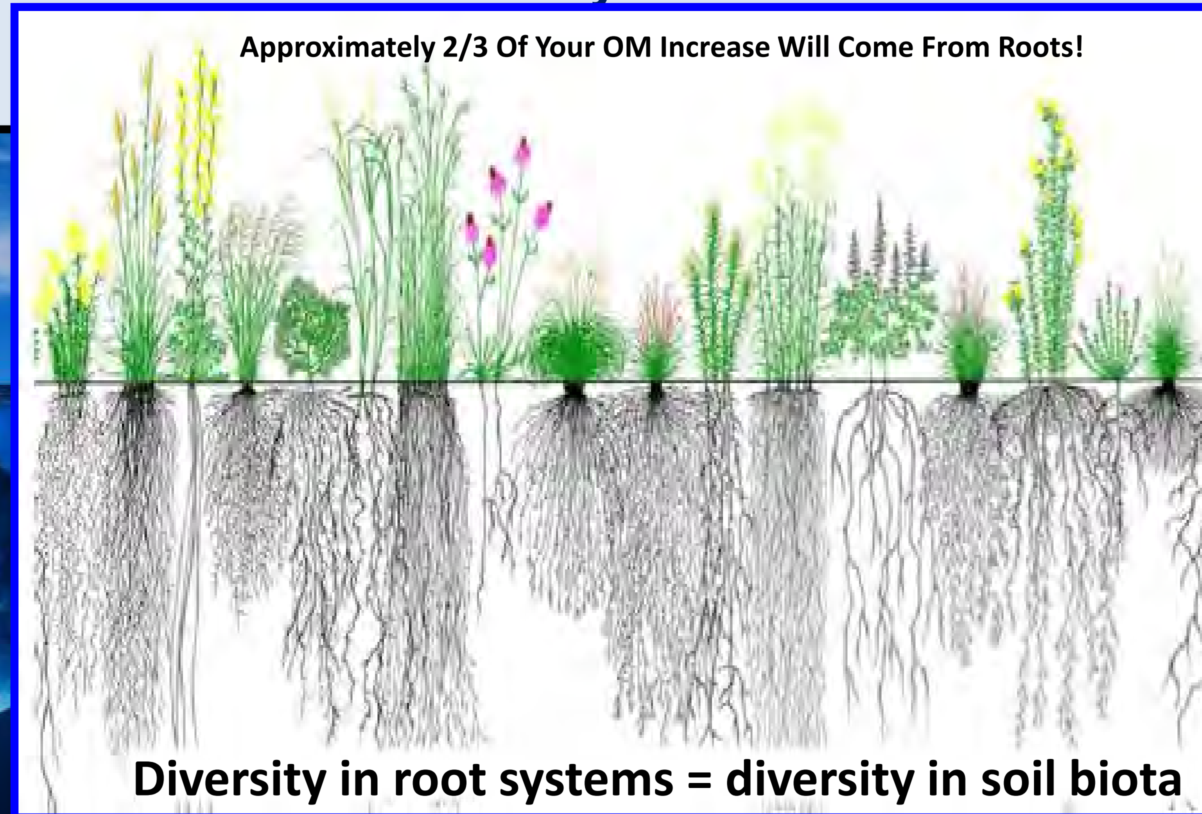
Soil Health and Sustainability

Changing our Paradigms

When you hear the word "soil" what do you think of?

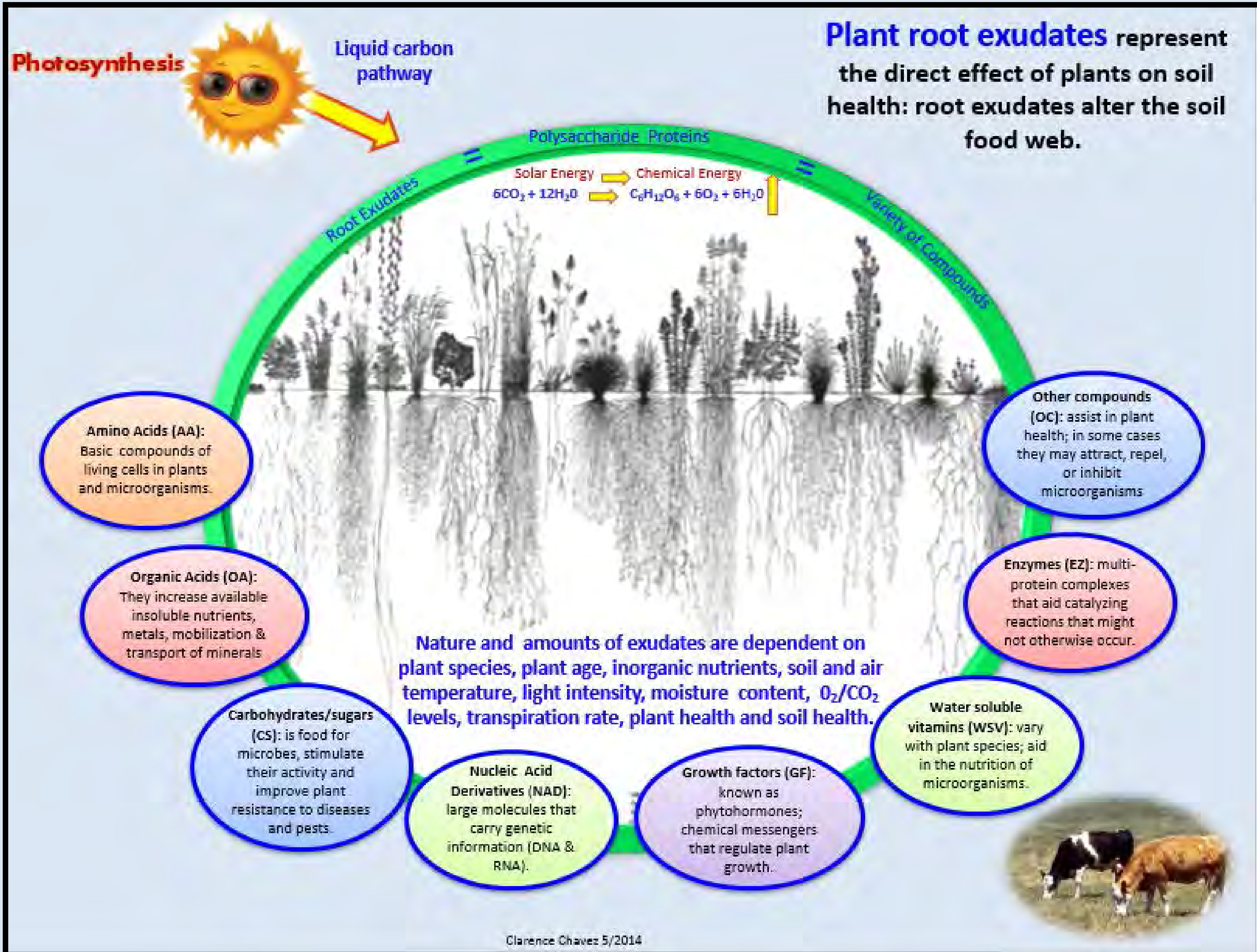




Change the way you think about soil. Specifically, what were you taught about fertility, nutrient management & weeds? AgLearn/traditional agronomy & nutrient management doesn't tell the whole story, as we concentrate on what is above ground (crop).

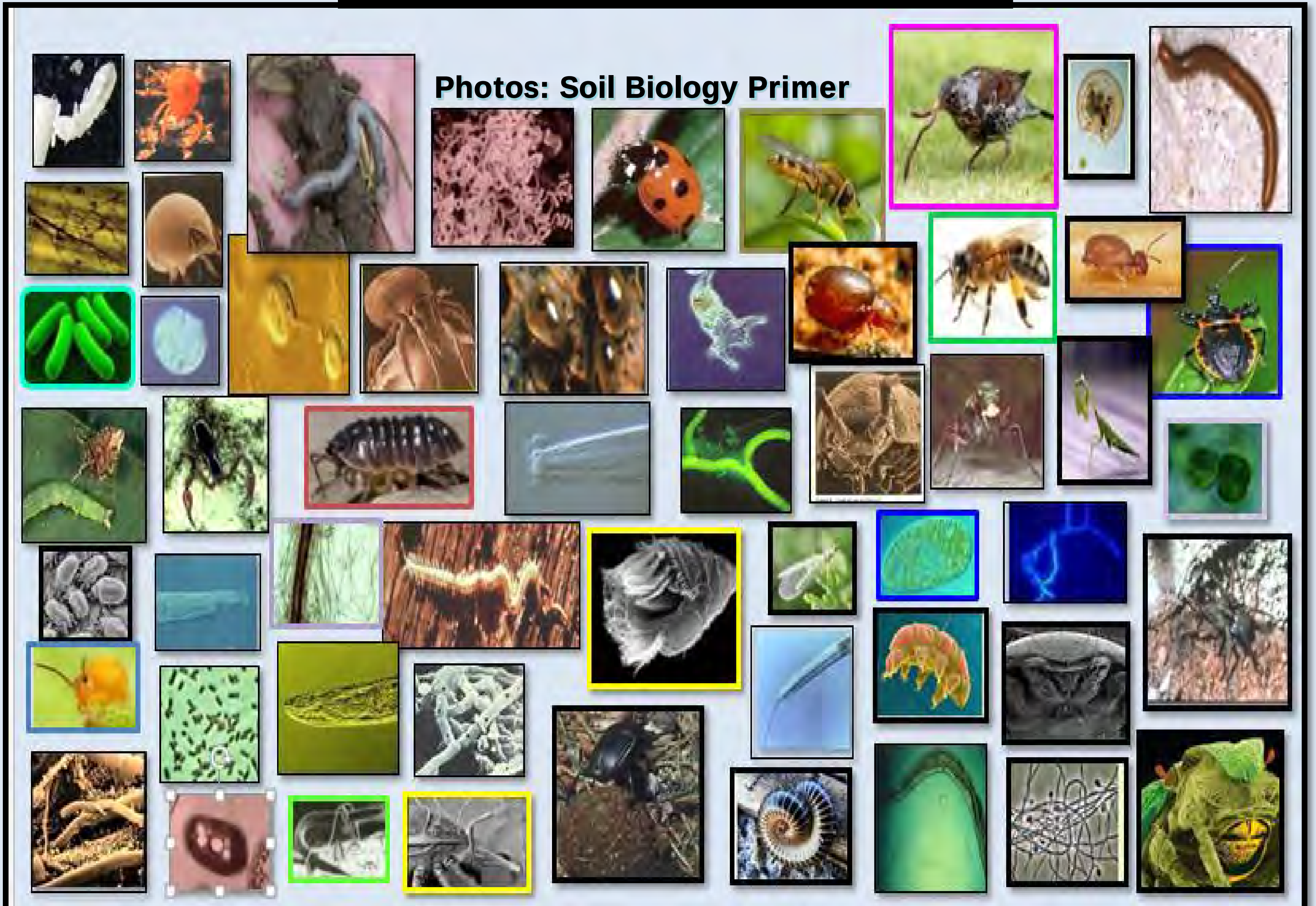
How well is your soil system feeding and watering your plants?

Rudy Garcia, Regional Soil Health Specialist (NM, CO, AZ, UT). Note: this presentation was adapted/modified from presentations given by the NRCS Soil Health and Sustainability Course instructors and from other Soil Health Professionals.



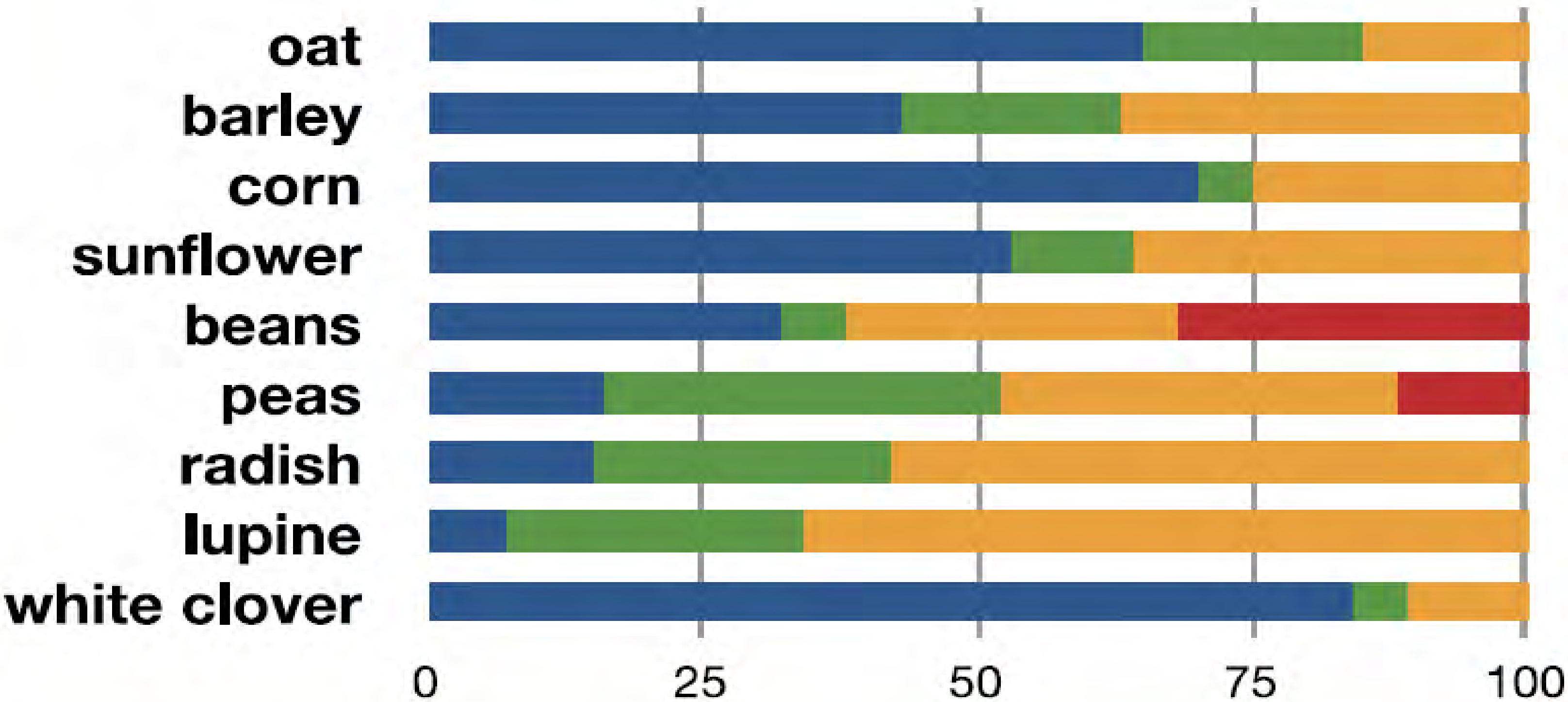
Photosynthesis
Liquid carbon pathway
Plant root exudates represent the direct effect of plants on soil health: root exudates alter the soil food web.
Polysaccharide Proteins
Root Exudates
Variety of Compounds
Solar Energy → Chemical Energy
$6CO_2 + 12H_2O$ → $C_6H_{12}O_6 + 6O_2 + 6H_2O$
Amino Acids (AA): Basic compounds of living cells in plants and microorganisms.
Organic Acids (OA): They increase available insoluble nutrients, metals, mobilization & transport of minerals
Carbohydrates/sugars (CS): is food for microbes, stimulate their activity and improve plant resistance to diseases and pests.
Nucleic Acid Derivatives (NAD): large molecules that carry genetic information (DNA & RNA).
Growth factors (GF): known as phytohormones; chemical messengers that regulate plant growth.
Water soluble vitamins (WSV): vary with plant species; aid in the nutrition of microorganisms.
Enzymes (EZ): multi-protein complexes that aid catalyzing reactions that might not otherwise occur.
Other compounds (OC): assist in plant health; in some cases they may attract, repel, or inhibit microorganisms
Nature and amounts of exudates are dependent on plant species, plant age, inorganic nutrients, soil and air temperature, light intensity, moisture content, O_2/CO_2 levels, transpiration rate, plant health and soil health.
Clarence Chavez 5/2014

Diverse Soil Organisms = Healthy Soil
(Are you feeding & caring for your Soil Livestock?)



Plant Signature

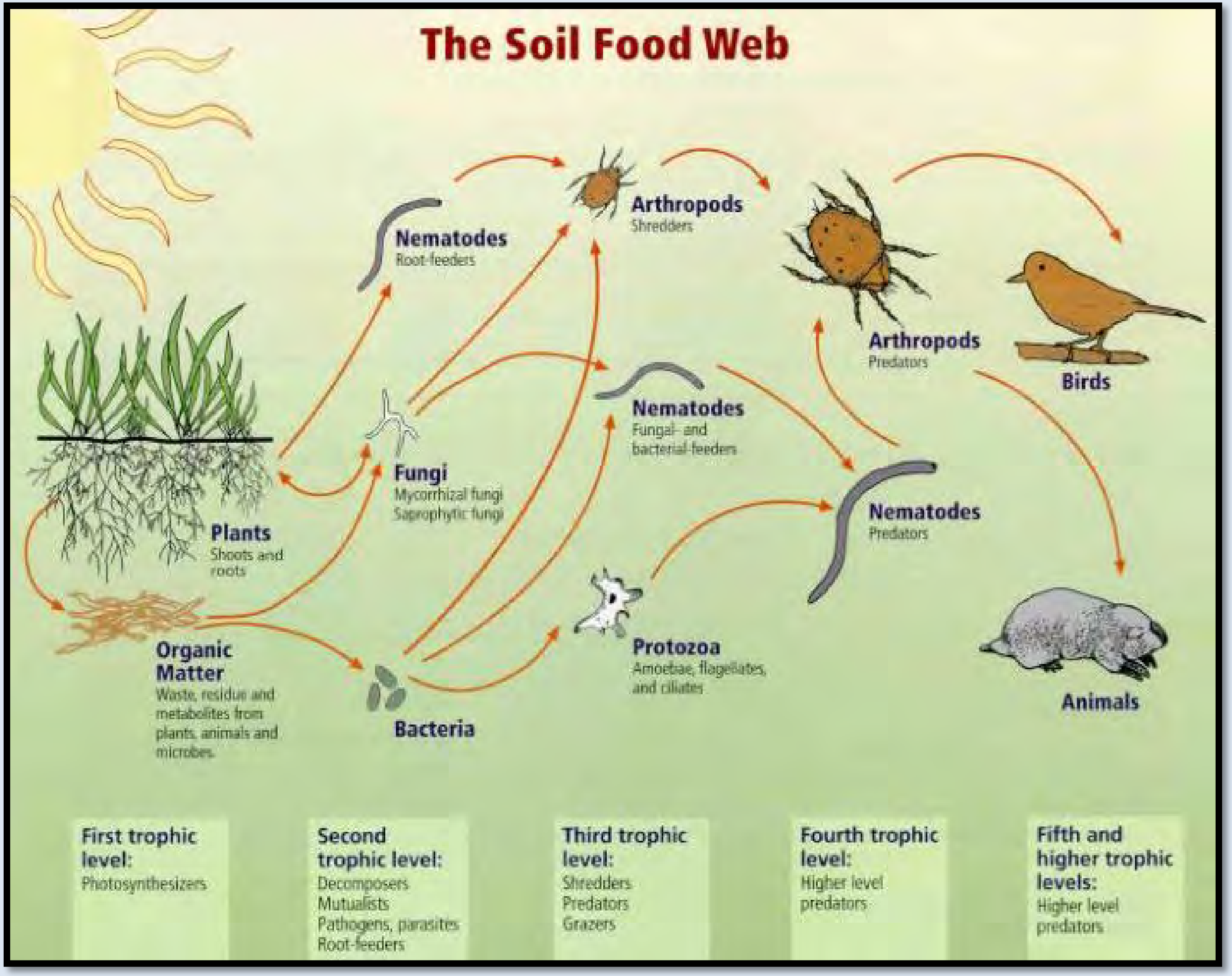
The percentage of N in the roots as nitrate (blue), amino acids (green), amides (yellow) and ureides (red). These compounds leak from the roots as exudates and are part of the plant's signature to create a unique rhizosphere.



Compounds leak from the roots as exudates and are part of the plants signature to create a unique rhizosphere.

Dr. Jill Clapperton

- All organisms that the plant requires are present and functioning
- Nutrients in the soil are in the proper form for plant up take
- Correct ratio of fungi to bacteria is present

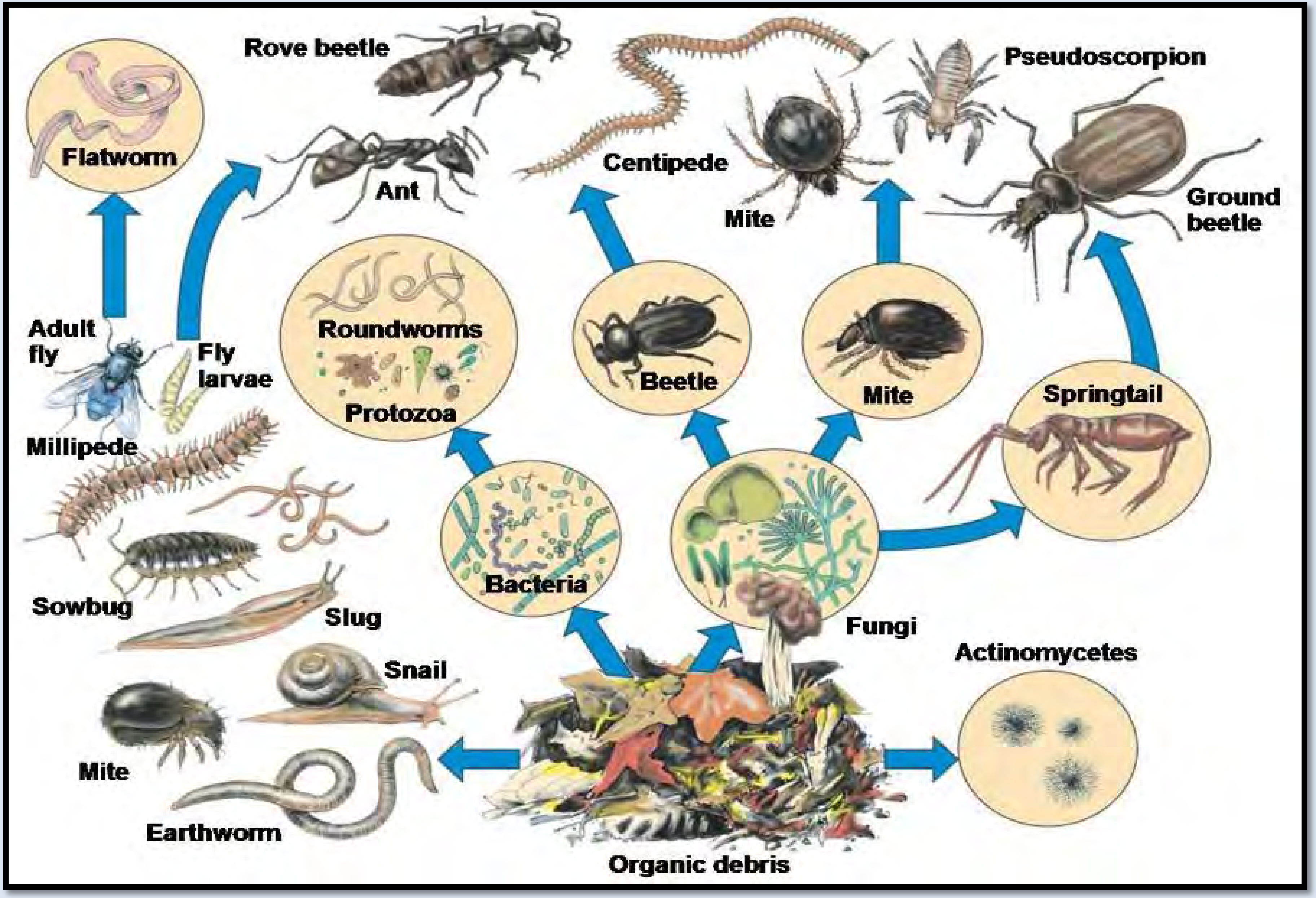


Most people are familiar with the above-ground food web: Plants are eaten by herbivores are eaten by carnivores, and so on. But **most plant matter is not eaten by herbivores; it is decomposed by the underground food web. All plants depend on the soil food web for their nutrition.**

File name: A-3 (145KB). (Also fw.jpg 574K, and fwb.jpg at 422K)
Image courtesy of the USDA-NRCS.

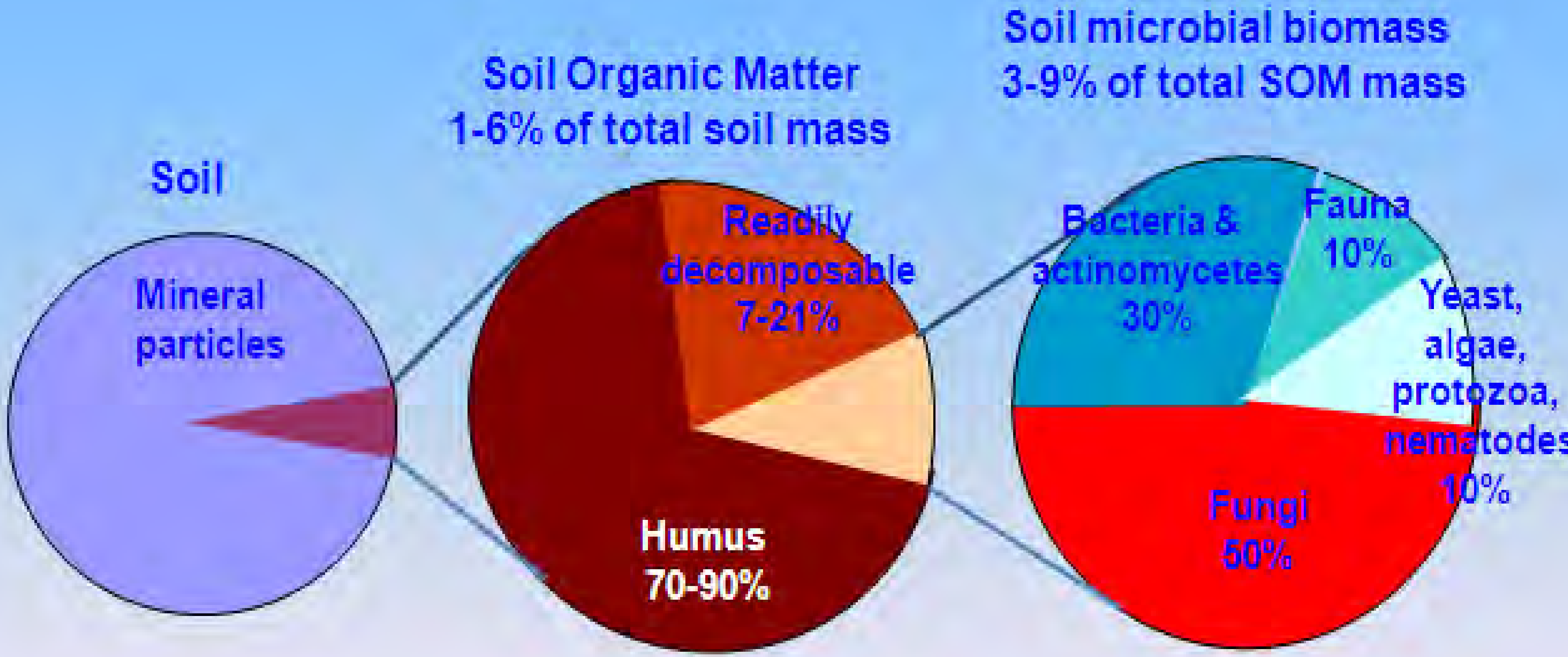
Soil Foodweb Inc. 2009

5% OF SOIL ORGANIC MATTER IS LIVING ORGANISMS



http://www.rw.ttu.edu/2302_butler/chapter6.htm

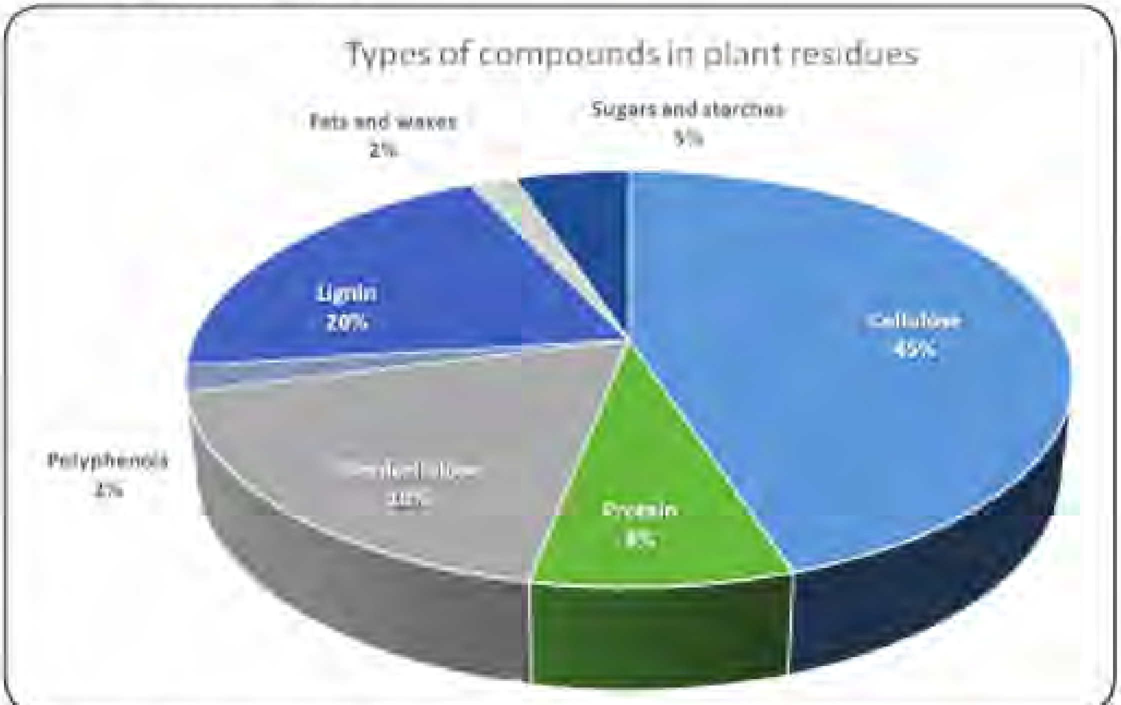
Soil Organic Matter



OM Composition

Biomass from:

- Plant Tissues
- Fungi
- Bacteria
- Animals



(Modified from Brady and Weil 2002, Figure 12.2)

Composed of:

- Cellulose
- Chitin
- Proteins
- Carbohydrates
- Lipids
- Nucleic Acids
- Salts

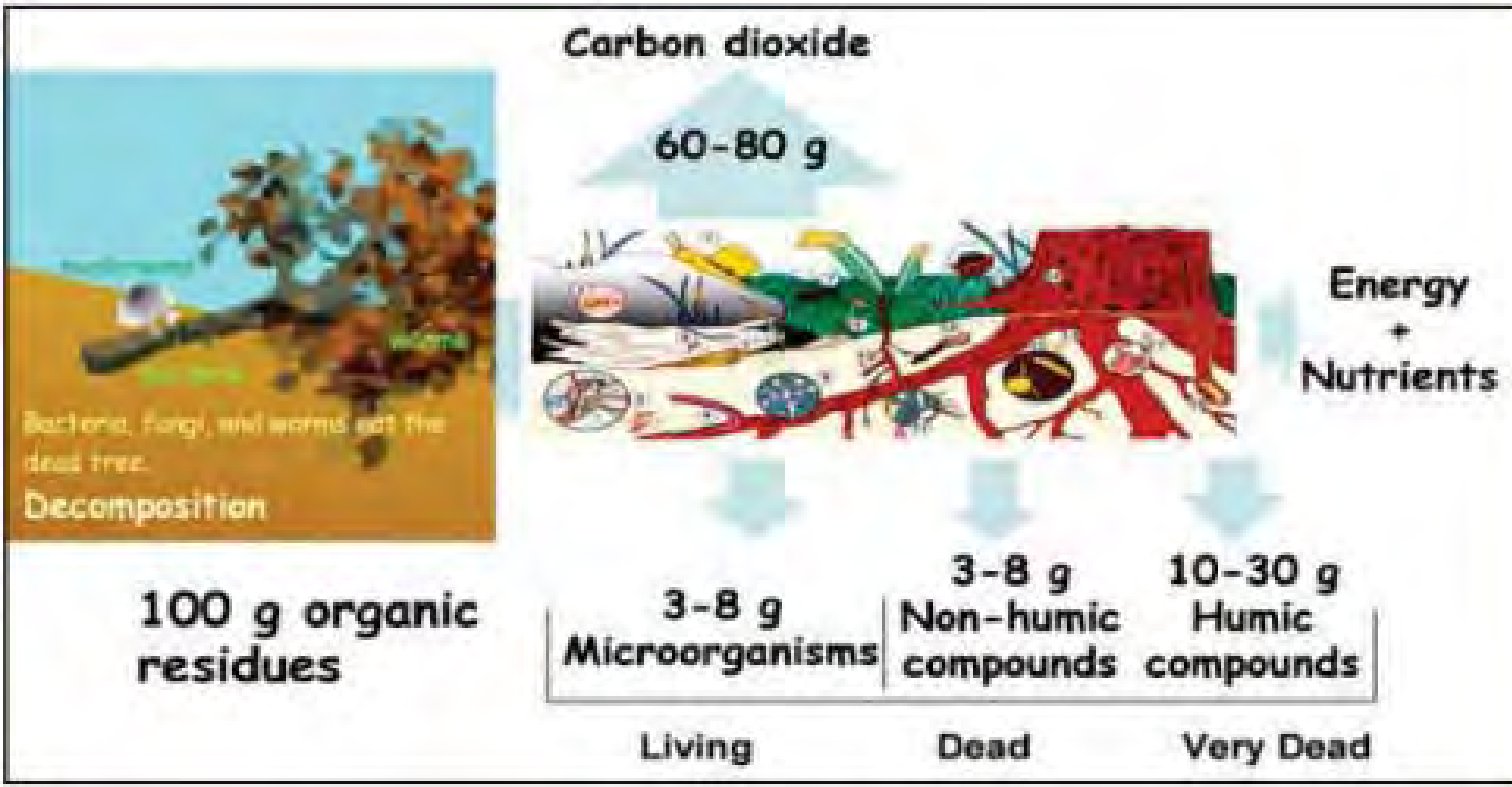
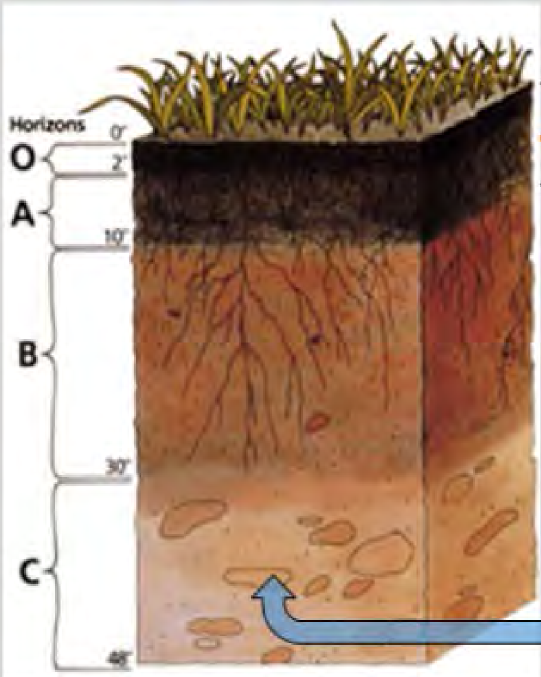


Diagram by Dr. Rafiq Islam

What part of the soil are we considering?



SOIL HEALTH

Topsoil (most active portion of the soil)

Subsoil

Soil Forming Factors

- Parent material
- Climate
- Topography
- Biological factors
- Time

SOIL CARBON is the key driver for the nutritional status of plants – and therefore the mineral density in animals and people

SOIL CARBON is the key driver for soil moisture holding capacity (frequently the most limiting factor for production)

Soil carbon is the key driver for farm **profit**

SOM Facts

Soil organic matter (SOM) is <6% of soil by weight but controls >90% of the function

Density of SOM: .6 g/cm³ Density of Soil: 1.45 g/cm³

SOM has less density than soil so it has more space for air and water storage.

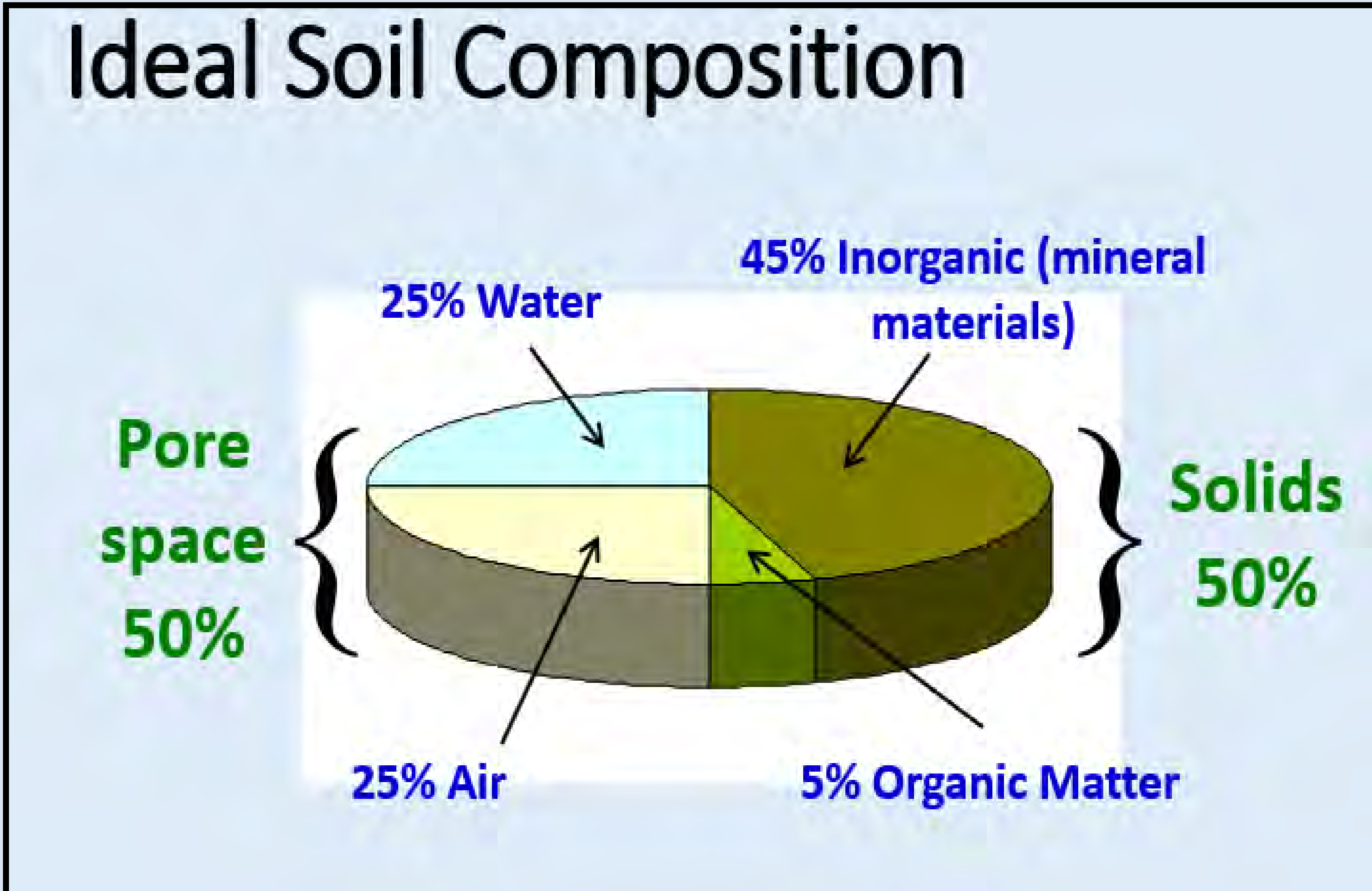
SOM is negatively charged, but binds both cations and anions

Every Pound SOM holds 18-20# of Water!

As soil organic matter increases from 1% to 3%, the available water holding capacity of the soil doubles (Hudson, 1994).

Soils stockpile 1500 gigatons of carbon in SOM, more than Earth's atmosphere and all the plants combined (Dance, 2008).

The majority of the SOM is present in the top 10 cm of soil

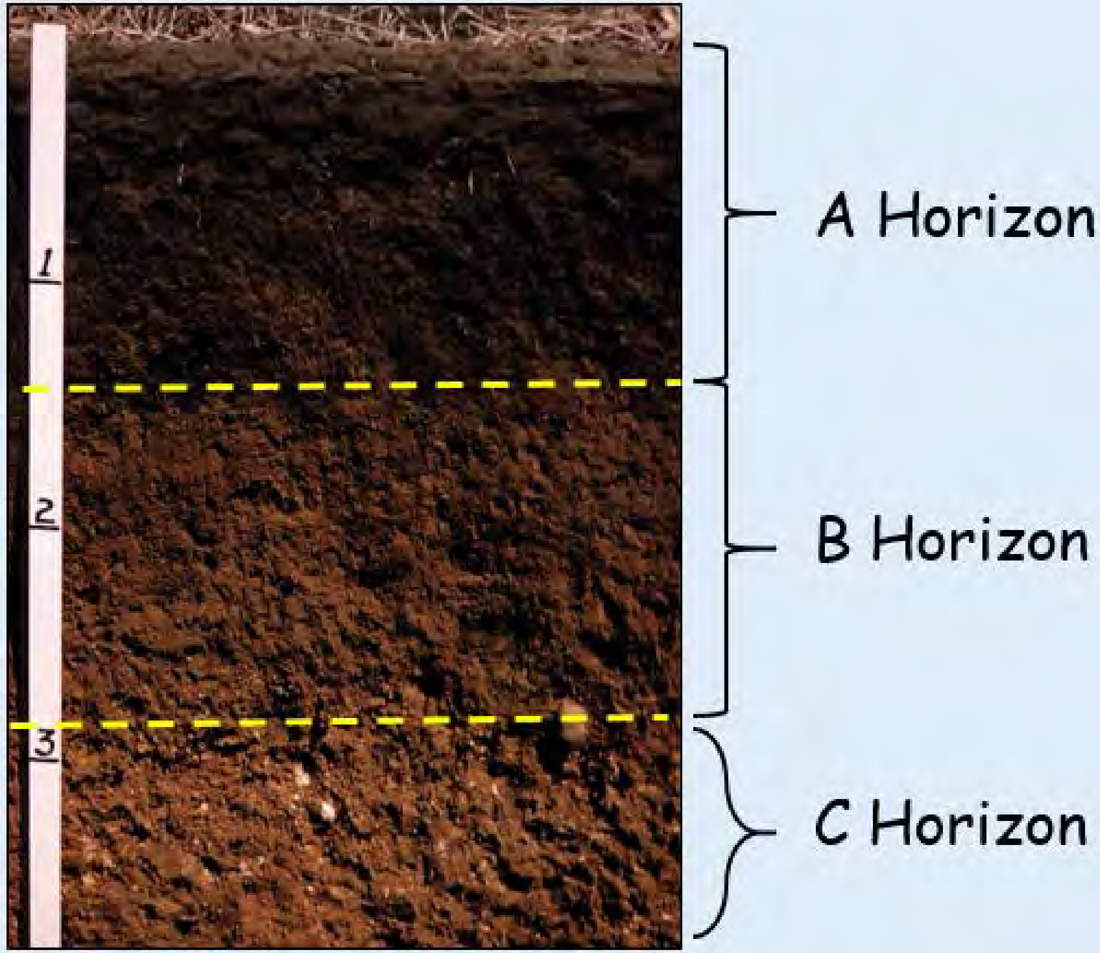


An average soil is composed of mineral matter, organic matter, and pore space, which may be occupied by air and/or water. The percentage of these four components can vary depending on how and where the soils were formed.

50% solids and 50% pore space; obviously, these are mixed in a natural environment and fluctuate greatly throughout the year.

Soil Profile

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

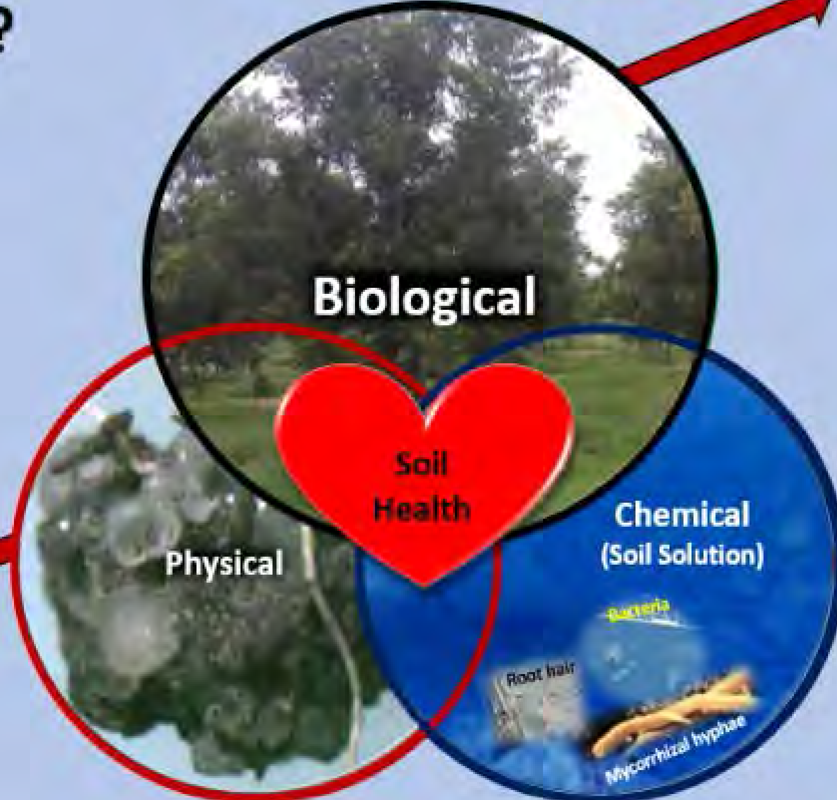


What does an NRCS Soil Survey tell us about soil health?

- 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 on series vs. another
- Can't be used to distinguish soil health based on actual field condition, doesn't account for farmer management influence
- Soils used in the demo are mapped the same soil series Clifford sandy clay loam (if you are using the NC soils for the soil health demos)
- 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.

Is your Soil Alive?

Does it have a Living Skin?



Biological: Living plants & Soil Food Web

IMPORTANT: Plants (Roots) & Soil Organisms build the Aggregates

Physical:
Water-stable Aggregates
(Aggregates are the HOUSE, where Roots & Soil Organisms live.)

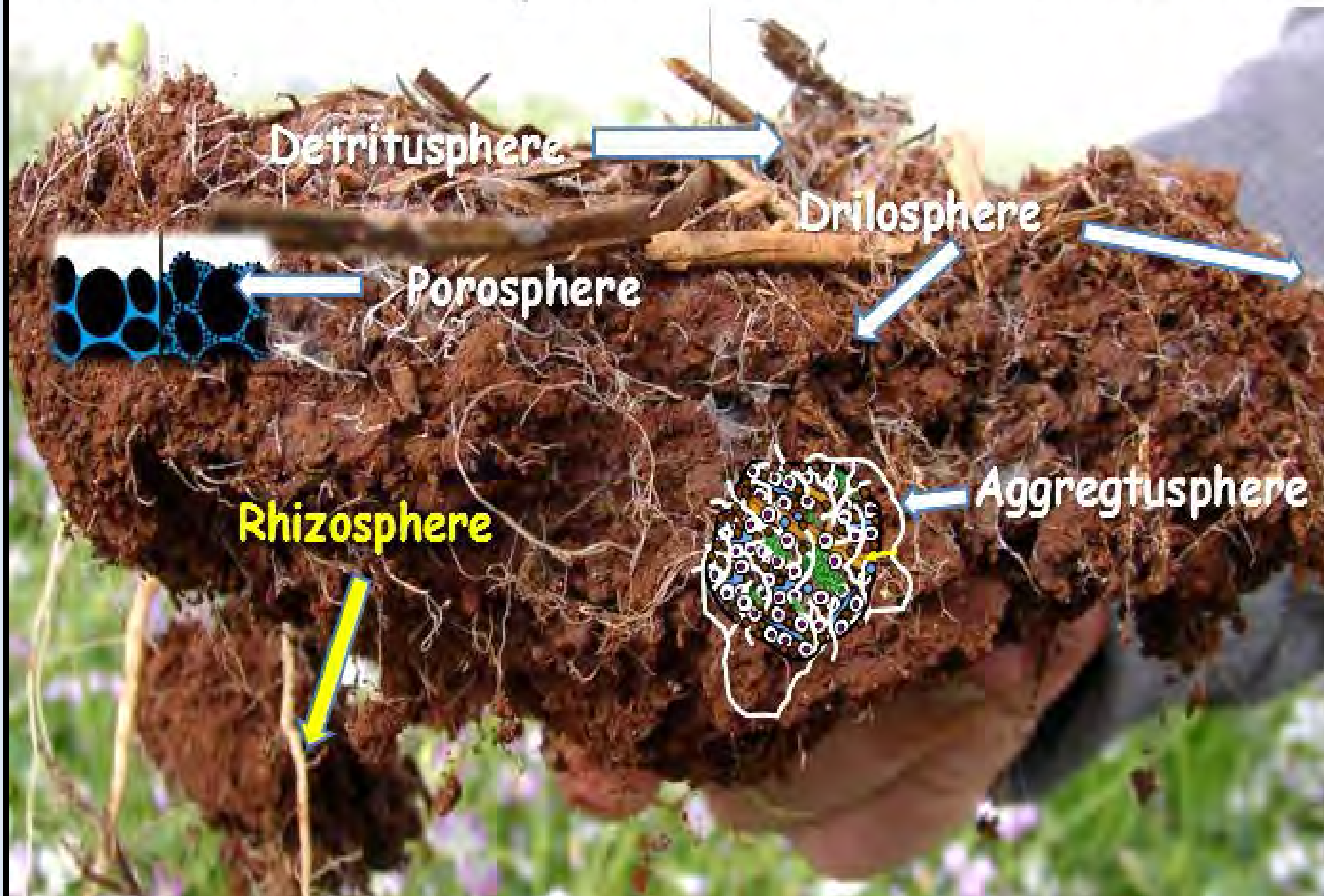
Chemical:
Soil Solution:
Soluble Nutrients & Soil Microorganisms
(Nutrient Cycling: Biochemical/Chemical Reactions take place in the Soil Solution)

The Soil Solution is held within the Aggregates

Water-stable Aggregates provide for the "Optimal" Chemical/Biochemical environment needed for Nutrient Cycling.

Philosophy of Soil Health: is an attempt to bring together different aspects of the soil with the understanding that they are inter-related and that they must operate in synergy for optimum and sustainable functioning of the soil media (Dr. John Idowu)

Influence of "Spheres" on Soil Function

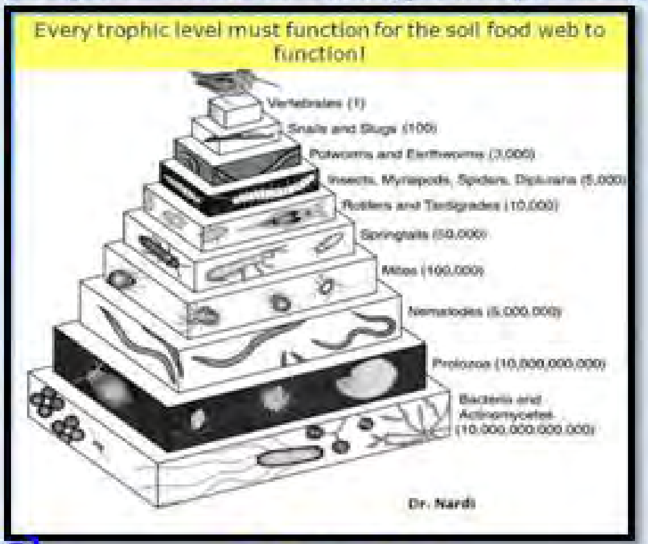


Are All the Biological Spheres Present?

Rhizosphere (including Mycorrhizosphere)

Soil Food Web

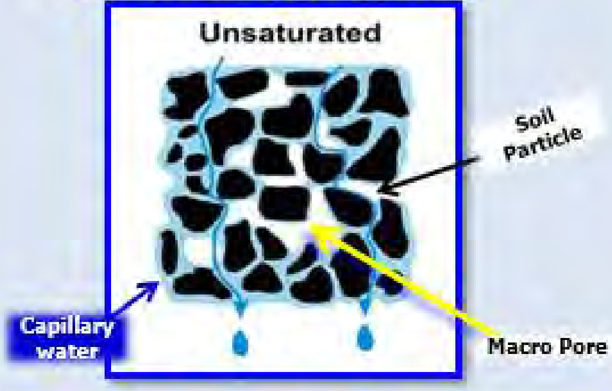
(requires all the Biological Spheres)



Detritusphere (Surface Residues)

Aggregatusphere (Macro- and Micro-Aggregates)

Porosphere (pores within & between aggregates)



Drilosphere: Zone of earthworm influence

Agro.Tech.Note.76 (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nm/technical/?cid=nrcs144p2_068965) rudy.garcia.2015

Aggregtusphere: Water stable macro-aggregates found in healthy soil.

Detritusphere: the layer that includes the litter and the adjacent soil …

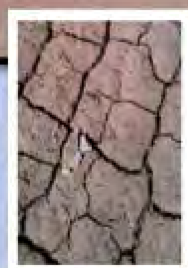
Drilosphere: part of the soil influenced by earthworm secretions and castings.[1] Specifically, it is the fraction of soil which has gone through the digestive tract of earthworms;[2] or the lining of an earthworm burrow.[3] The average thickness of the drilosphere (lining of an earthworm burrow) is 2mm.[4]

Porosphere: the pore system in the soil, consist of macro & micropores. Three basic water status conditions, aquatic (gravitational moisture); edaphic (capillary moisture best living conditions for soil organisms and aerial systems).

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.

Conventional Tillage
(Typical for most Pecan Orchards)

Photo of soil several days after irrigation



- Physical Disturbance
  - Tillage
  - Compaction
- Biological Disturbance
  - Lack of Plant Diversity
  - Over grazing
- Chemical Disturbance
  - Misuse of fertilizer, pesticides, manures and soil amendments

GOAL:

Reduce Biological, Physical & Chemical disturbances

Photo taken on September 8, 2013 (Anthony, NM)

Soil Health: Restoring a Living Skin

Pecan Orchard growing in a coarse sandy soil that was amended with compost (10-tons/ac)

Sandy Soil is beginning to develop soil structure & a Living Skin.

The Living Skin of the Top Soil RESTORES the Biological Spheres:

1) Rhizosphere
2) Aggregatusphere
3) Porosphere
4) Drilosphere
5) Detritusphere

Managing the Soil Food Web:

This entails working to maintain favorable conditions of **moisture**, **temperature**, **nutrients**, **pH**, and **aeration**. It also involves providing a steady food source of **raw organic material**.

Pecan Orchard south of Las Cruces, NM. (Temperature measurements with and without cover. Taken on April 20, 2015 at about 2:00 pm)

Air Temperature was 76 ^{0}F.

Surface Temperature: 77 ^{0}F

Surface Temperature: 133 ^{0}F

Bare Soil and Soil with Cover were only a few feet apart.

Soil with Cover

Soil Moisture was at Field Capacity

Soil Temperature: 74 ^{0}F at 1 inch depth

Bare Soil

Soil Moisture was at about 50% of Field Capacity

Soil Temperature: 100 ^{0}F at 1 inch depth

Soil Health What is It?

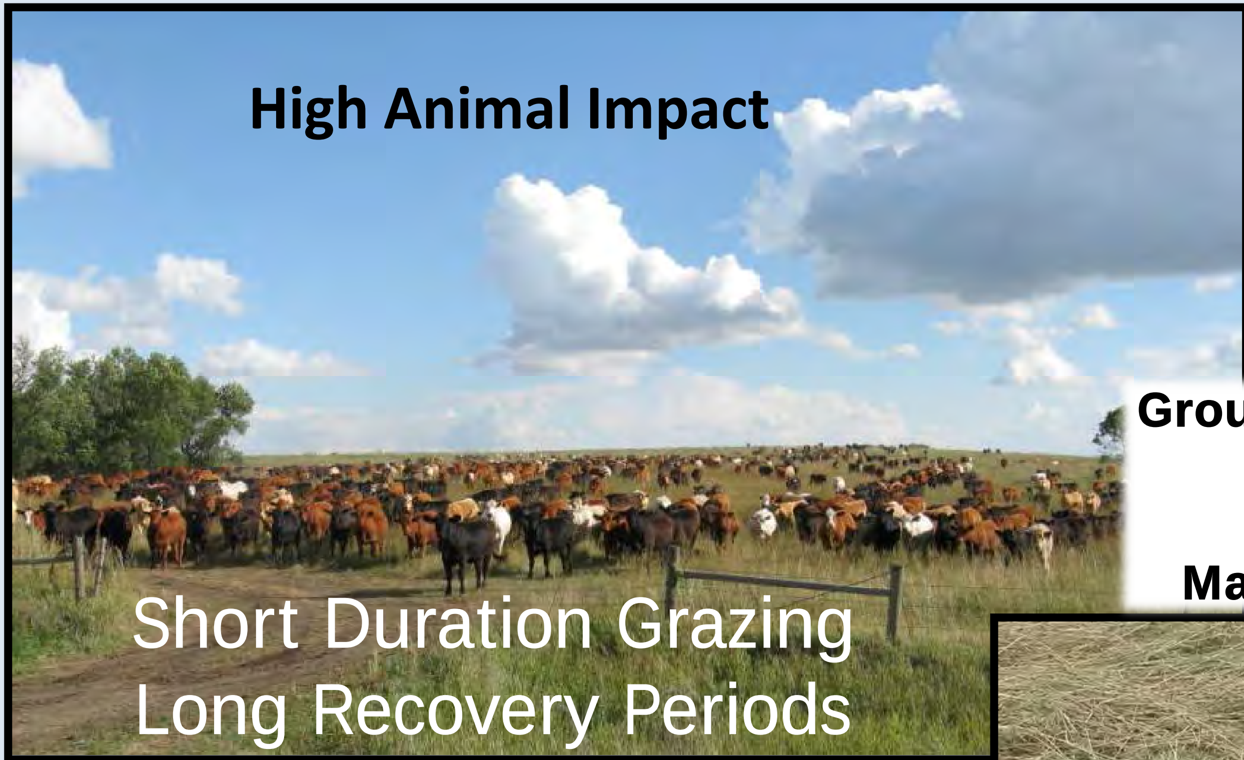
- The continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans
  - Nutrient cycling
  - Water (infiltration & availability)
  - Filtering and Buffering
  - Physical Stability and Support
  - Habitat for Biodiversity

Managing for Soil Health

- Minimize Disturbance of the soil
- Maximize Diversity of plants in rotation/cover crops
- Keep Living Roots in the soil as much as possible
- Keep the soil covered at all times with plants and plant residues
- *Create the most favorable habitat possible for the soil food web*

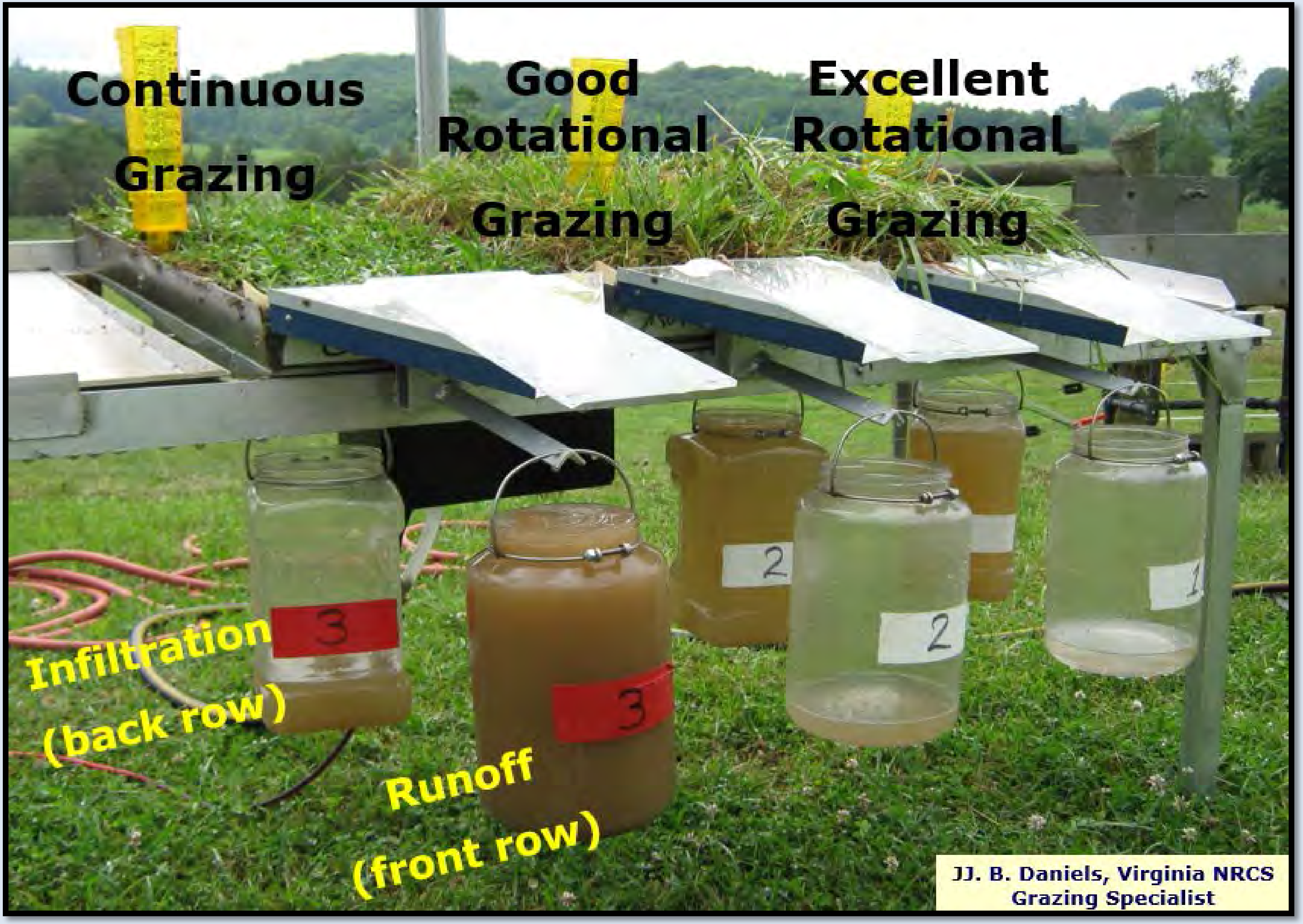
"High-throughput techniques for the direct evaluation of root systems in the field do not yet exist."

W. A.P., et al. Journal of Experimental Botany (2012)



Ground Cover After Grazing

High Litter
Manure and Urine spread


Continuous
Grazing
Good
Rotational
Grazing
Excellent
Rotational
Grazing
3
3
2
2
1
Infiltration
(back row)
Runoff
(front row)
JJ. B. Daniels, Virginia NRCS
Grazing Specialist

Rainfall Simulator Demonstration

Runoff and Erosion Results

Rainfall Simulator Demonstration

Infiltration Results


No Cover
With Cover Crop


Slake & Infiltration Tests: Is your soil healthy?
Ref.: Ray the Soil Guy
Rain Simulator & Infiltration Test
Slake Test (Ref.: Soil Quality Fact Sheet: Soil Glue)
Healthy soils are held together by soil glues, or glomalin, that are produced by fungi. Soils rich in soil biota hold together, while soils devoid of soil life fall apart and form a layer of sediment in the bottom of the jar. Pictured above, the soil on the left is from a field that has been managed using no-till for several years. The soil on the right is from a conventionally-tilled field.
Is your soil healthy?
Water stable aggregates
Only 0.4% difference in OM
LOW O.M.
HIGH O.M.
Crumbly soils (left) have more pores and channels than cloddy soils (right). Pores and channels allow air and water to move into the soil.
Does your top soil form crusts?

Tillage destroys Aggregates:

Tilled soil

No-till soil

Aggregatusphere: Influence of Soil Aggregates

Closed Habitat of Micropores

- Protects organic matter from decay
- Storage site for organic matter
- Habitat of Associative, 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:

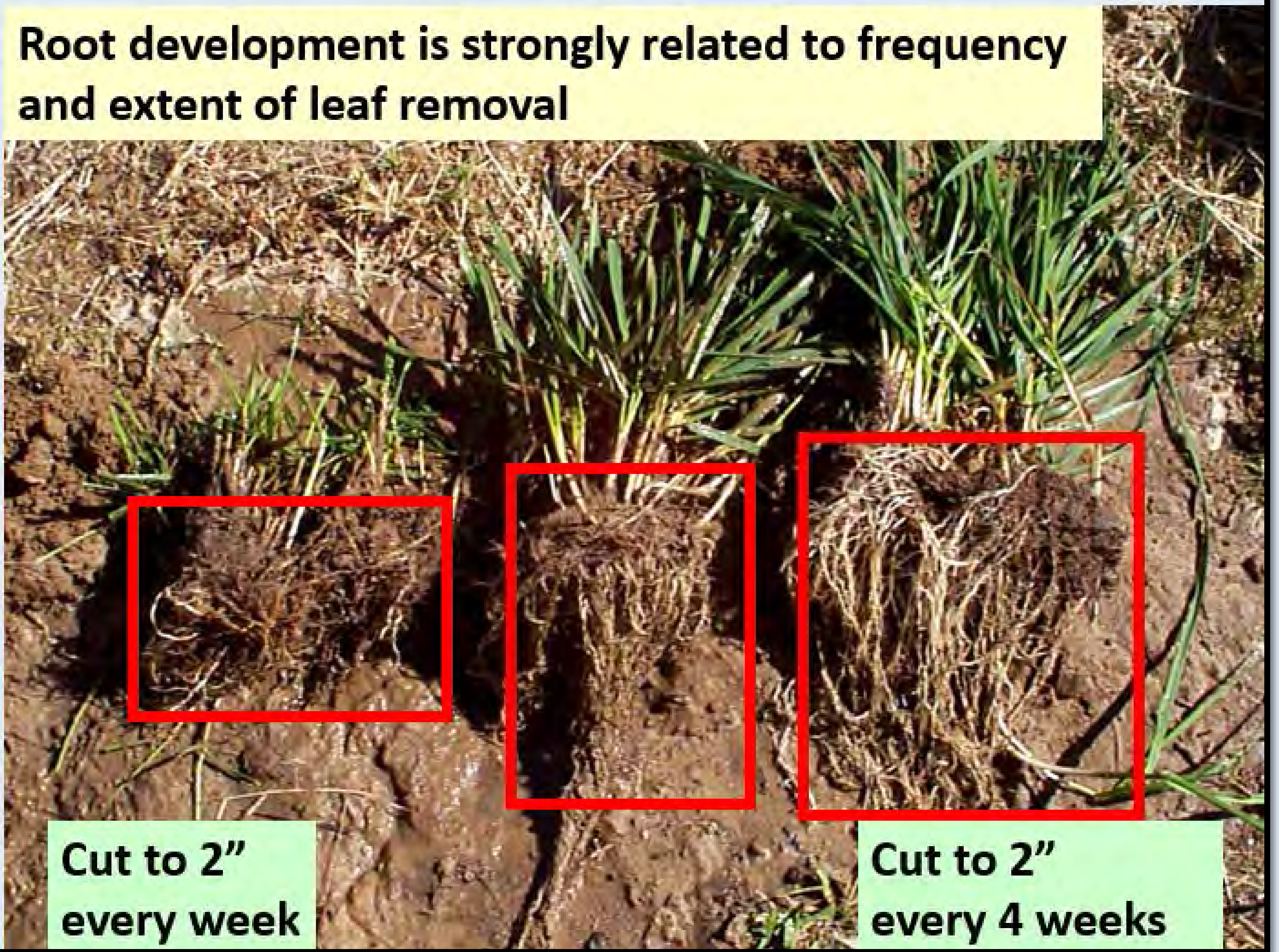
1. Restrict root growth
2. Provide poor root zone aeration
3. Have poor drainage

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 lose 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 development is strongly related to frequency and extent of leaf removal




Soil Biology – Plant Interaction
The Menoken Farm
10/18/2013

Rhizosheaths

Why Build Diversity?

Diversity conduit for energy and nutrients.







Nurture Nature with System Synergies

No Tillage

Minimum carbon loss

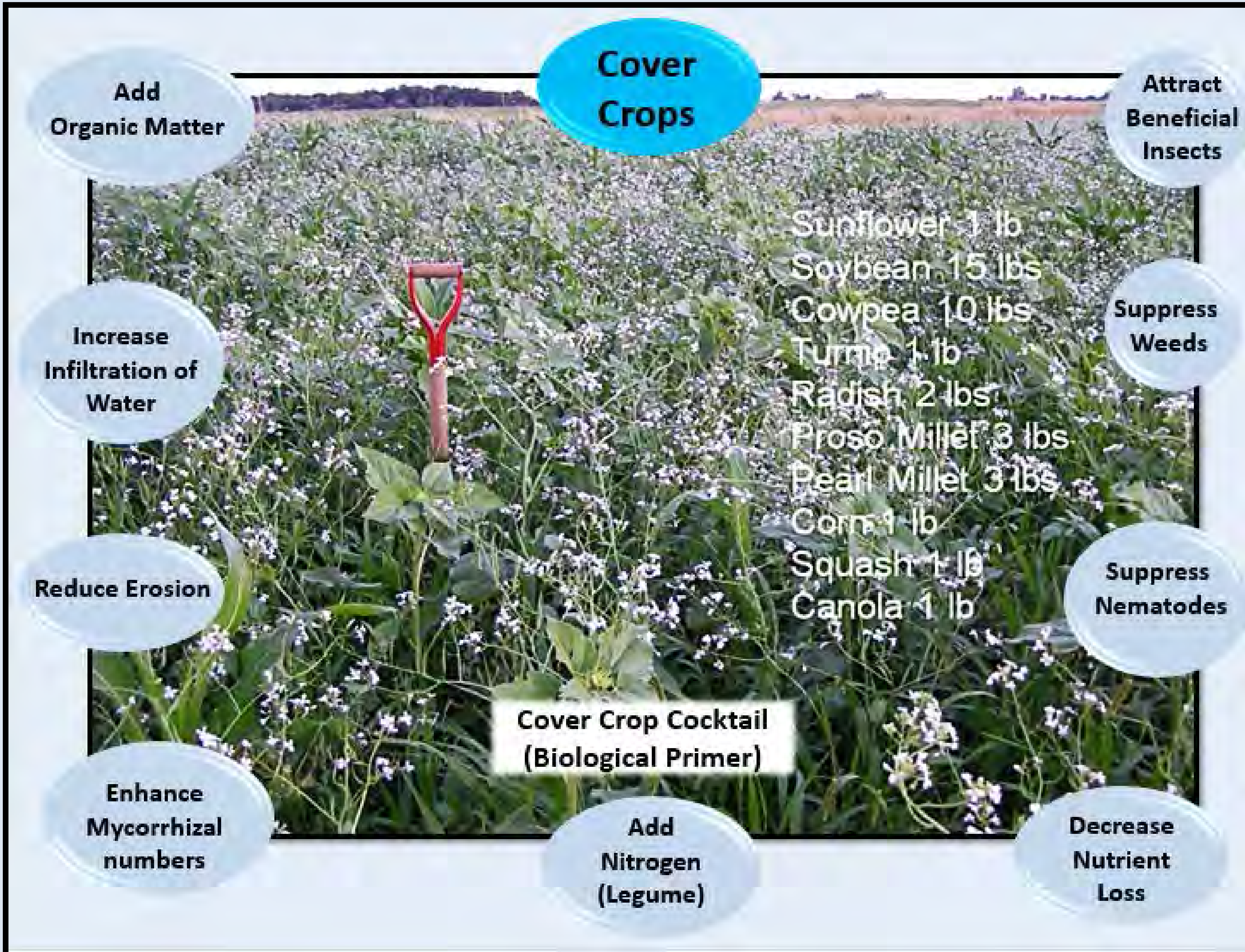
Cover Crops

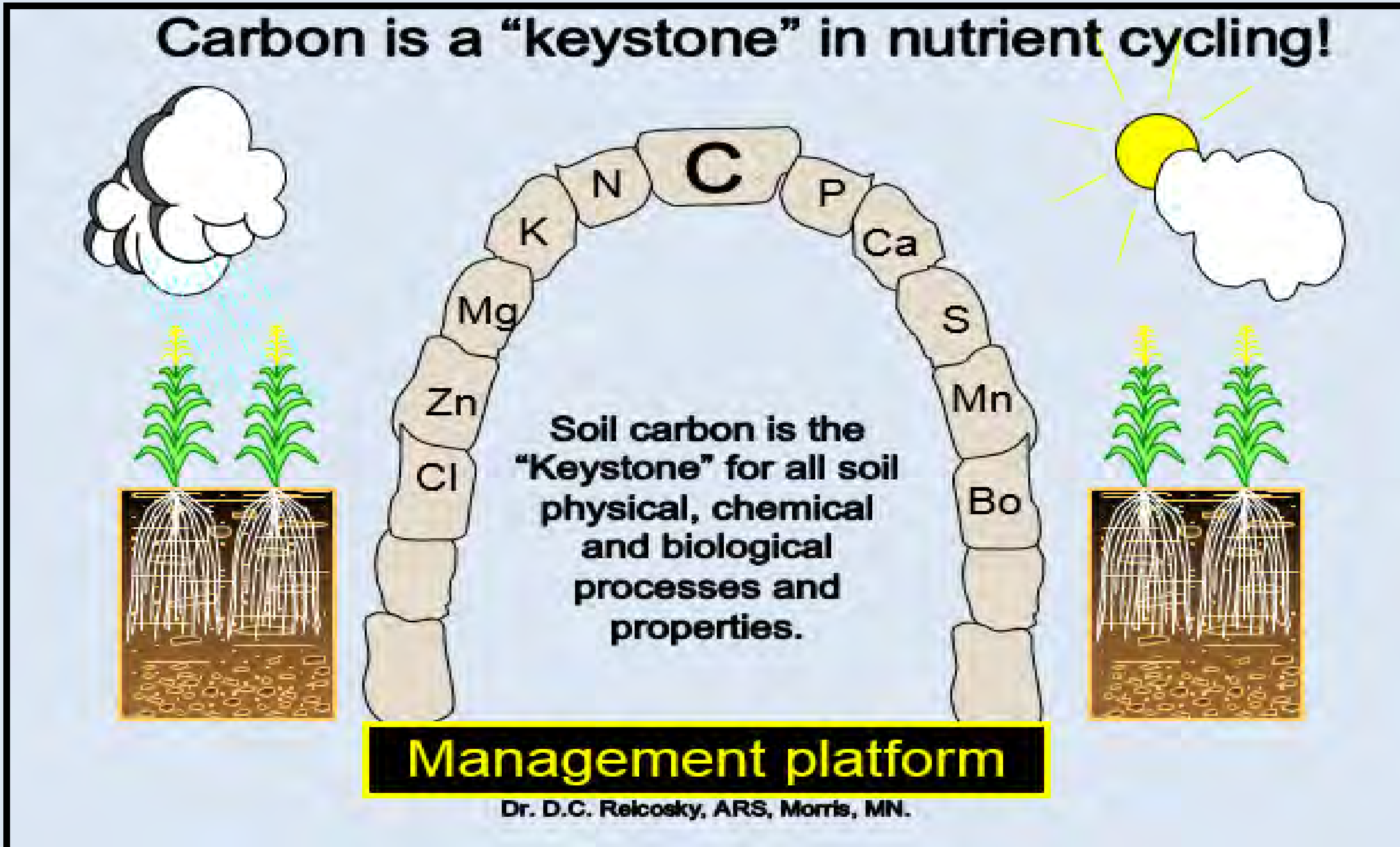
Maximum carbon input

Carbon management

Sustainability

Dr. Don Reicosky
ARS, Morris, MN

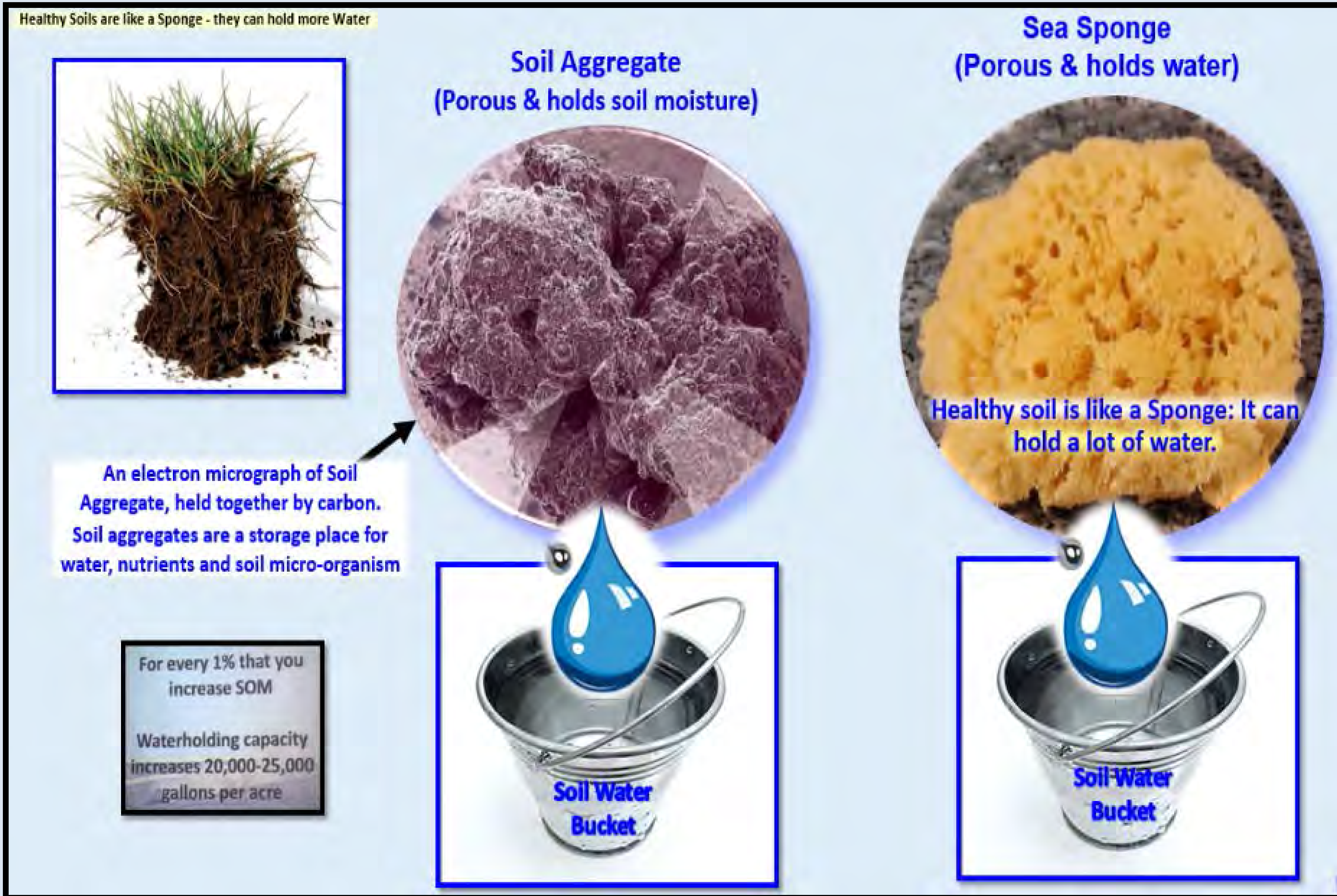

Cover Crops
Add Organic Matter
Attract Beneficial Insects
Increase Infiltration of Water
Suppress Weeds
Reduce Erosion
Suppress Nematodes
Enhance Mycorrhizal numbers
Add Nitrogen (Legume)
Decrease Nutrient Loss
Sunflower 1 lb
Soybean 15 lbs
Cowpea 10 lbs
Turnip 1 lb
Radish 2 lbs
Proso Millet 3 lbs
Pearl Millet 3 lbs
Corn 1 lb
Squash 1 lb
Canola 1 lb
Cover Crop Cocktail (Biological Primer)



Carbon is "key" to nutrient cycling in soil systems.
All forms of carbon are important, even humic acids, and all provide numerous functions important to agriculture and the environment.

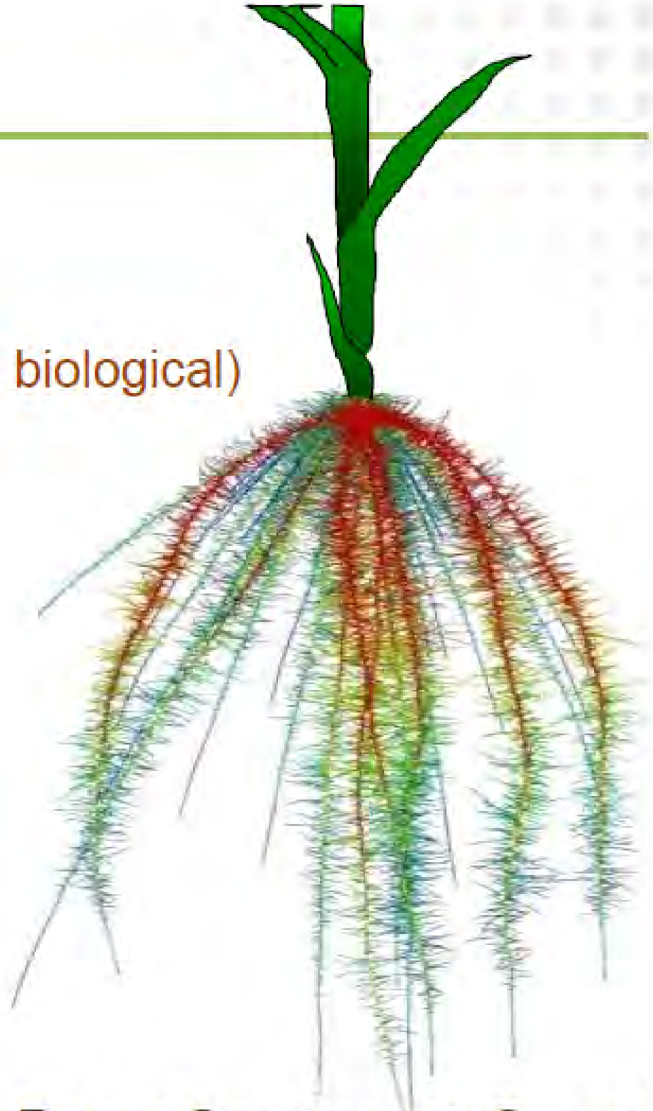
Carbon exists as SOM, Detritus, Humus – 50% of Humus is Carbon – in an active sense it is CO2 – this comes from micro-organisms – they consume the organic matter and each other – they release/respire CO2 – so, our CO2 comes from micro-organisms in the soil – we can measure CO2/Acre – that CO2 is picked up by the plant then recycled through plant photosynthesizes to make photosynthate – which a major portion is exuded through root system to feed biology in the soil **– in order for plants to take up nutrients they have to have carbon – it is a metabolic process not just a chemical process –**

Ability of crops to photosynthesize and use available nutrients they need CARBON – so our farming practices need to be CARBON oriented **– it's not just about NPK but CARBON/NPK/SECONDARY/MICRONUTRIENTS.** (Talk about this during Soil Pit Demonstration).


Healthy Soils are like a Sponge - they can hold more Water
Soil Aggregate
(Porous & holds soil moisture)
Sea Sponge
(Porous & holds water)
Healthy soil is like a Sponge: It can hold a lot of water.
An electron micrograph of Soil Aggregate, held together by carbon. Soil aggregates are a storage place for water, nutrients and soil micro-organism
For every 1% that you increase SOM
Waterholding capacity increases 20,000-25,000 gallons per acre
Soil Water Bucket
Soil Water Bucket

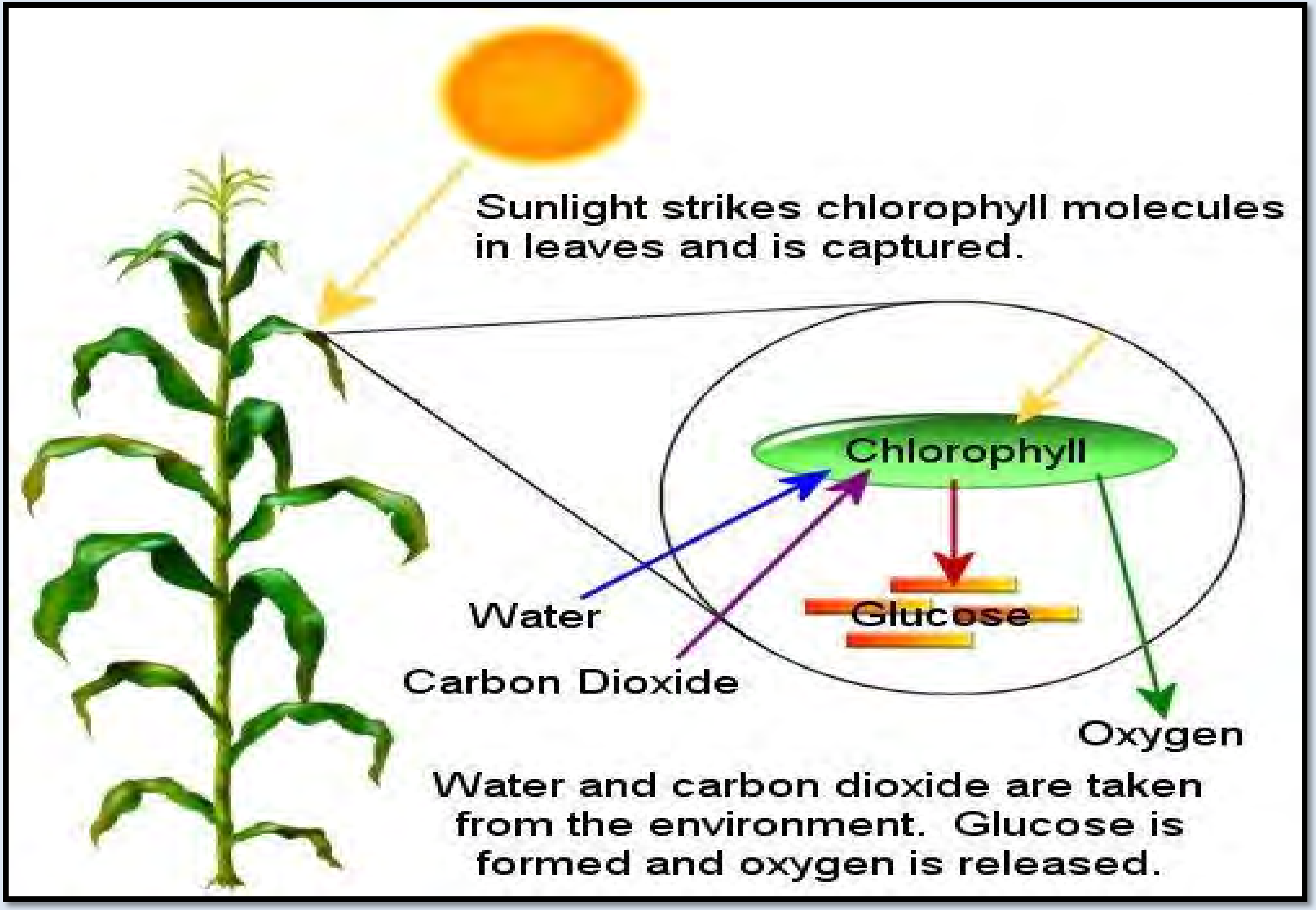
Roots are a Triple Win

1. **Carbon**:
   → Fix and Sequester Atmospheric CO_2
   → Enhance Soil Quality (physical, chemical, biological)
2. **Nitrogen**:
   → Improve Nutrient Use Efficiency
   → Reduce Fertilizer Runoff
   → Raise Crop Yield Potential
3. **Water**:
   → Boost Soil Water Holding Capacity
   → Provide Crop Yield Assurance
   → Enhance Crop Climate Resilience



DEEP, STEEP AND CHEAP!

Photosynthesis



Photosynthesis continued

Let's go into a bit more Depth concerning Biological Nitrogen Fixation (BNF).

On a global scale, biological Nitrogen Fixation accounts for around 65% of the nitrogen used by crops and pastures. The supply of nitrogen is inexhaustible, as dinitrogen (N2) comprises about 78% of the earth's atmosphere. **The Key is to transform inert nitrogen gas to a biologically active form**.

It is important to recognize that the ability to fix nitrogen is not limited to bacteria associated with legumes. Chlorophyll is part of a protein complex – hence wherever you see green plants – there will also be an association with nitrogen-fixing bacteria. Examples include Azotobacter, Beijarinkia, Azospirillum – Unlike Rhizobial bacteria, most nitrogen fixing microbes are not able to be cultured in the laboratory. This presents challenges to assessing their ecological function. This is one of the reasons we need "New Testing Methods" like the Soil Health Nutrient Tool / Haney Test.

Now even though it is difficult to quantify amount of nitrogen fixed – we do know that diversity and abundance of nitrogen fixing microbes are much greater where there is living ground cover (especially plants in the grass family) throughout the year, compared to soils that are bare fallowed.

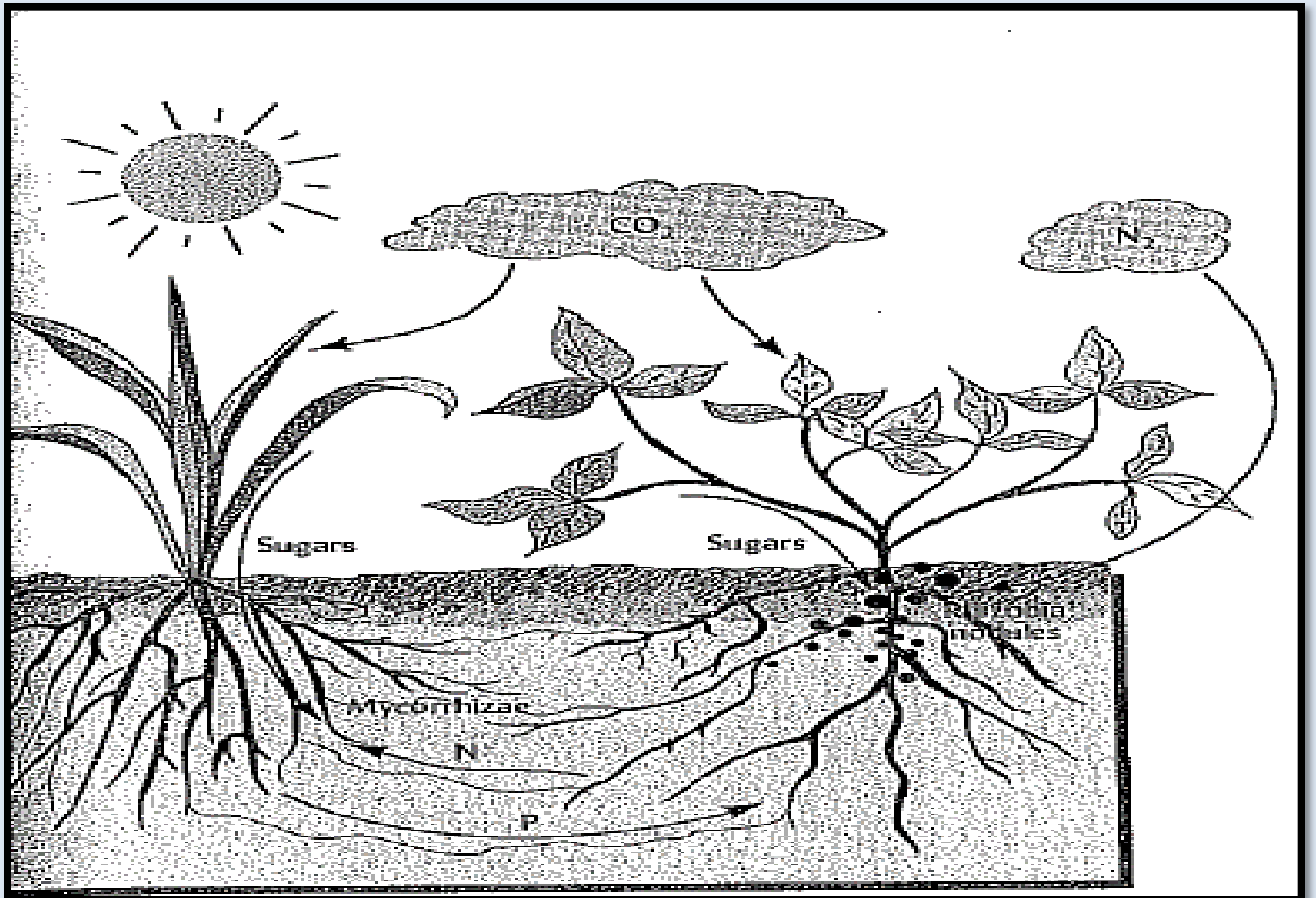
Also, Mycorrhizal Fungi are important to the nitrogen fixing process – even though MF do not fix nitrogen, they do transfer energy in the form of liquid carbon (Jones 2008) to associative nitrogen fixers and Phosphorus solubilizing bacteria -

Azotobacter (and a few other species of bacteria such as Klebsiella, Azospirillum, Beijarinkia) are free-living in soil and water and do not form symbioses. So how do they do it? **Like other nitrogenases, Azotobacter nitrogenase is oxygen-sensitive, but it is believed that the extremely high respiration rate of Azotobacter (possibly the highest of any living organism) soaks up free oxygen within the cells and protects the nitrogenase.**

Azotobacter species are relatively easy to isolate from soil by growing on nitrogen free media, where the bacteria are forced to use atmospheric nitrogen gas for cellular protein synthesis. Cell proteins are mineralized in soil after the death of the Azotobacter cells, contributing towards the nitrogen availability of the crop plants.

Plants Interacting with Mycorrhizal Fungi

- **Assists with P uptake from soil**
- **Moves P from the non-legume plant to the legume plant**
- **Moves N from the legume plant to the non-legume plant**
- **Increases area roots can reach.**

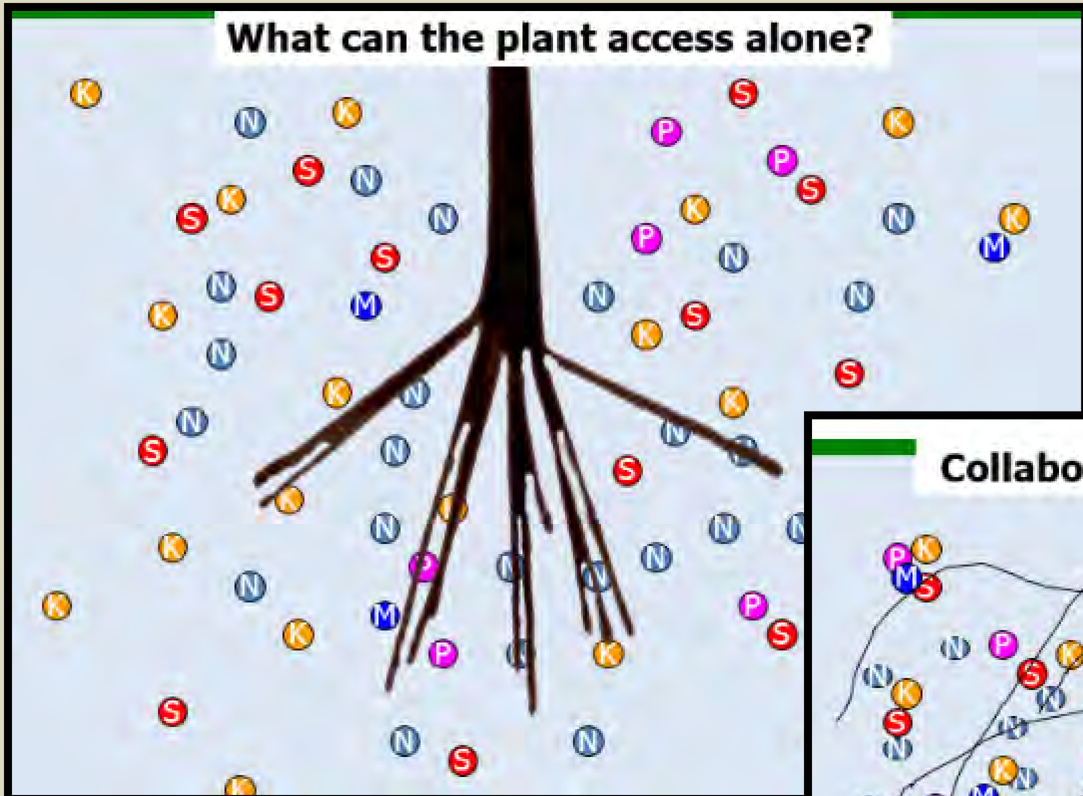


The Nature and Property of Soils, Brady and Weil

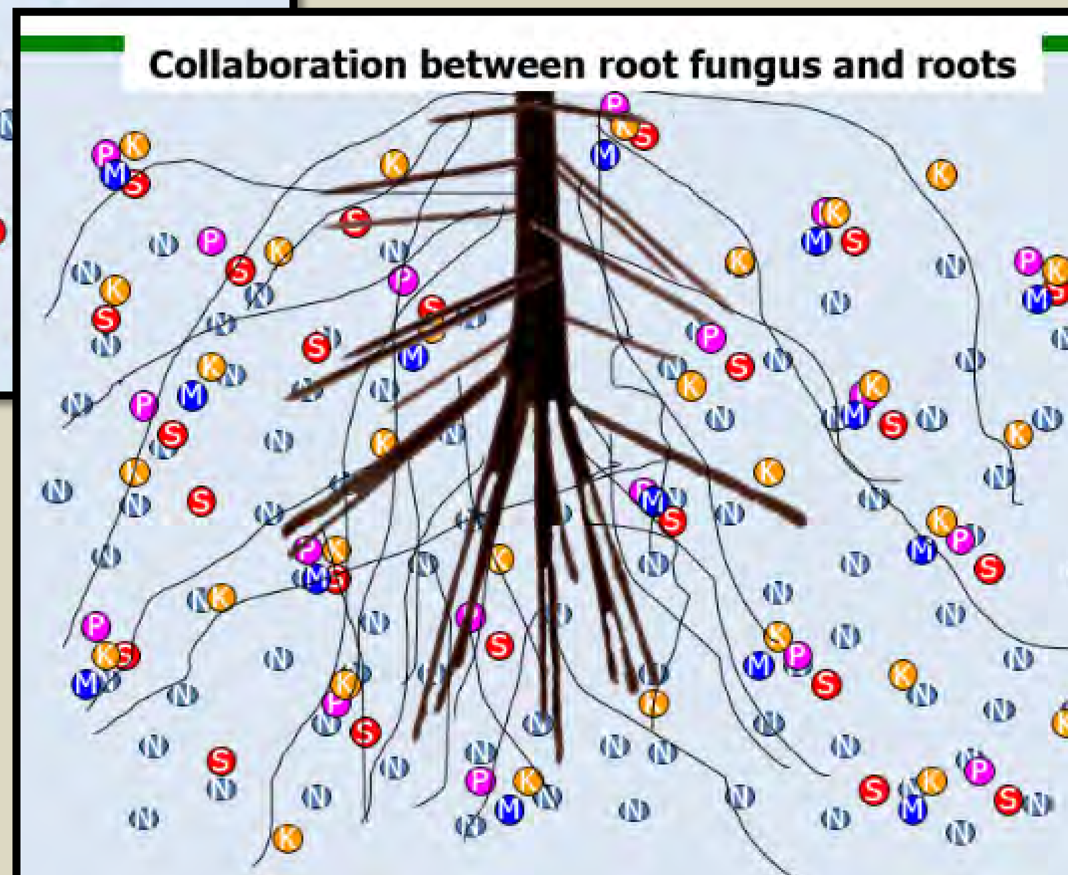
At hyphal tips- bacteria produce enzymes that make unavailable plant nutrients available. I.e. bacteria and fungi make nutrients available to plants that plants cannot access or extract.

MF- extends the reach of roots, small to us, but huge to a root. MF – like nutrient pipelines.

Mycorrhizal fungi - powerhouse of the soil < Dr. Christine Jones



This is what it looks like in the soil system when roots are trying to gather available nutrients. Plant roots are not very efficient at absorbing moisture and nutrients on their own. They need help.



Collaboration between roots and fungi in the soil increase surface area for nutrient absorption.

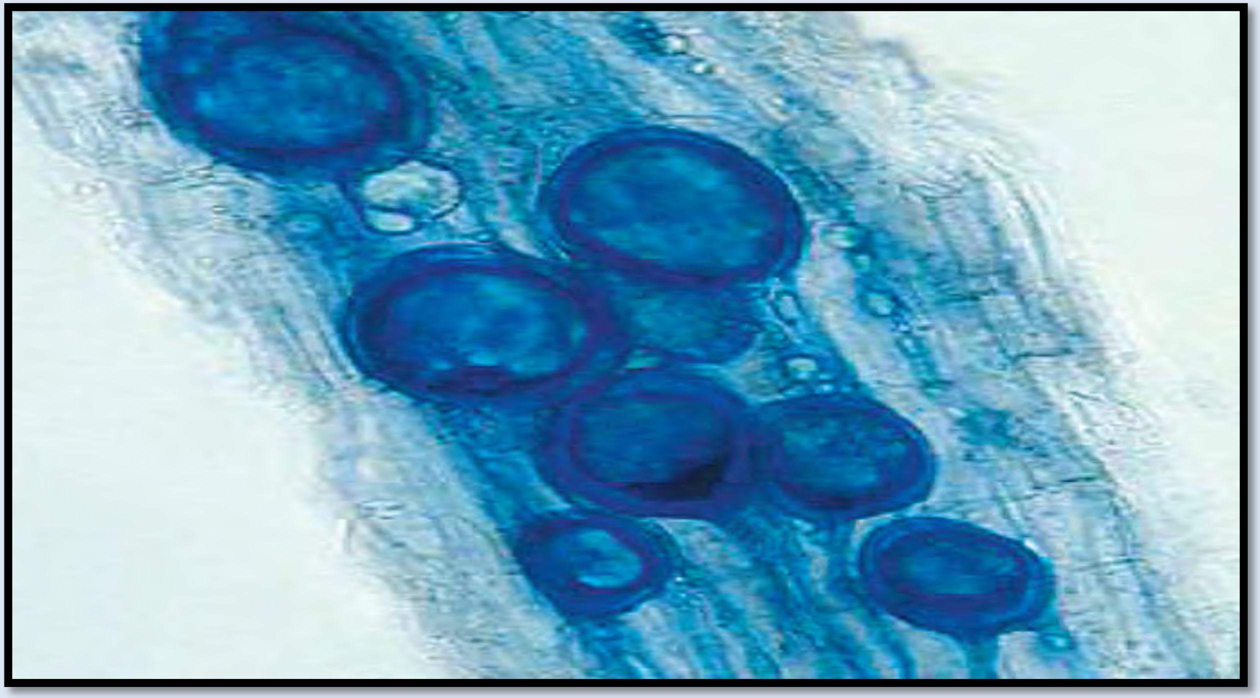
Mycorrhizal Fungi

Photo taken when Dave Brandt was in Texas – Mycorrhizal Fungi

Mycorrhizal Fungi

Close up of previous slide – Mycorrhizal Fungi

Mycorrhizae assist with Water Management



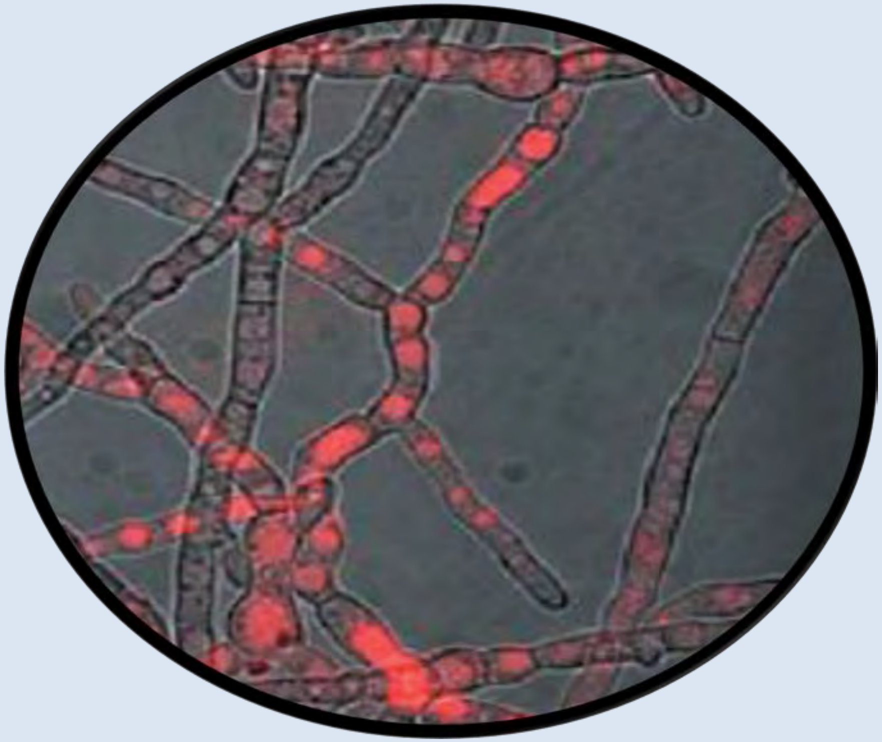
When moisture becomes limiting in a dryland period the mycorrhizal plant utilizes the water stored in root cell vesicles.

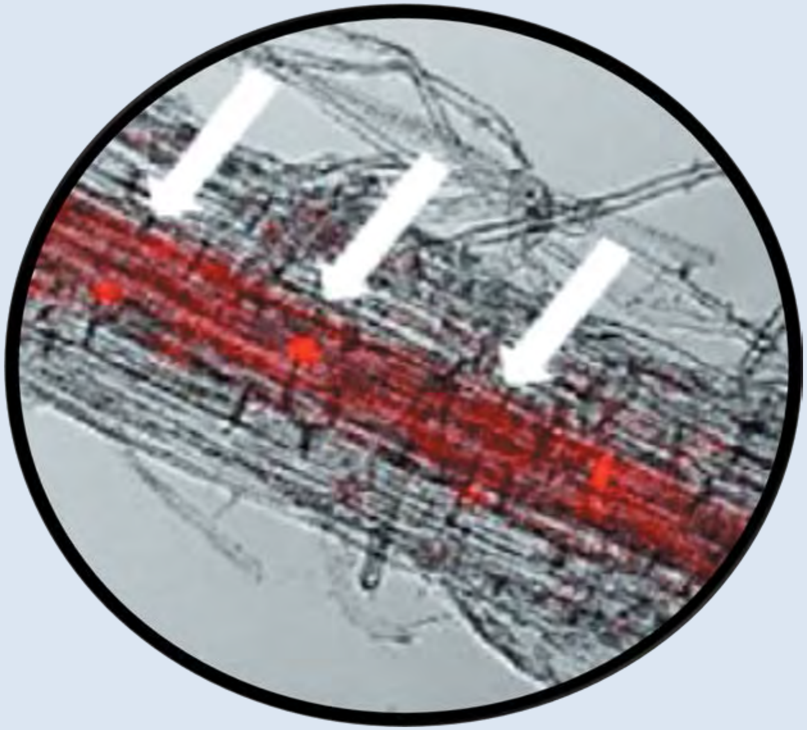
Helps find water
Mycorrhizae's significant assistance with nutrient uptake is important, but it is not the only crop-enhancing benefit offered by these amazing fungi. Another valuable feature is water management. **The expanded and enormous absorptive surface area connected to the roots is going to ensure that nearly all moisture in a plant's surrounding soil is accessed. But what then? Once the soil is dry, how can the plant survive?**

Mycorrhizae provide a mechanism inside the root cells that addresses this problem. **When a root cell becomes colonized by a mycorrhizal fungus, a special shared organ called a vesicle grows inside the root cell. The vesicle is essentially a storage container for water and dissolved nutrients that can be utilized in times of deficiencies, such as drought periods.**

When moisture and nutrients are abundant in the soil, surplus supplies are stored in the vesicle. When moisture and/or nutrient shortages occur, the plant begins to utilize the resources stored in the vesicles to avoid stress for extended periods – often weeks or even months longer than non-mycorrhizal plants.

Mycorrhizae assist with Organic Nitrogen Uptake





Amino Acids inside mycorrhizal hyphae

Amino Acids have entered the root From mycorrhizal hyphae

Mycorrhizae assist with Organic Nitrogen Uptake: Continued

Another source of nitrogen unique to mycorrhizal symbiosis has recently been discovered – it involves direct transfer of nitrogen laden amino acids from the fungus into the cereal plant roots.

Scientists at the University of California, Irvine, recently discovered another source of NITROGEN uptake unique to mycorrhizal symbiosis. Using cutting-edge technology, nanometre-sized bits of semi-conducting material called quantum dots were attached to organic compounds such as nitrogen-laden amino acids.

For more than 100 years conventional scientific wisdom held that root absorption of nitrogen was restricted to inorganic forms of nitrogen such as N03, N02 and NH4. But to their surprise, the scientists saw the illuminated dots attached to amino acids enter the mycorrhizal hyphae and observed them as entire molecules moved into the root cell vacuoles and then continued systemically to the chloroplasts (in which nitrogen is used for photosynthesis).

In non-mycorrhizal rhizospheres, amino acids, which are the primary components of proteins, must undergo extensive and time-consuming decomposition processes by bacteria and other soil organisms before nitrogen is released in inorganic (NH4), plant-usable forms. Bacteria (Nitrosomonas/Nitrobacter) convert NH4 into NO3. In many cases, much of the nitrogen is consumed by the organisms, further delaying its plant availability.

This research demonstrates that mycorrhizal fungi allow their plant hosts to bypass this process, implementing quick and effective access to organic nitrogen sources.

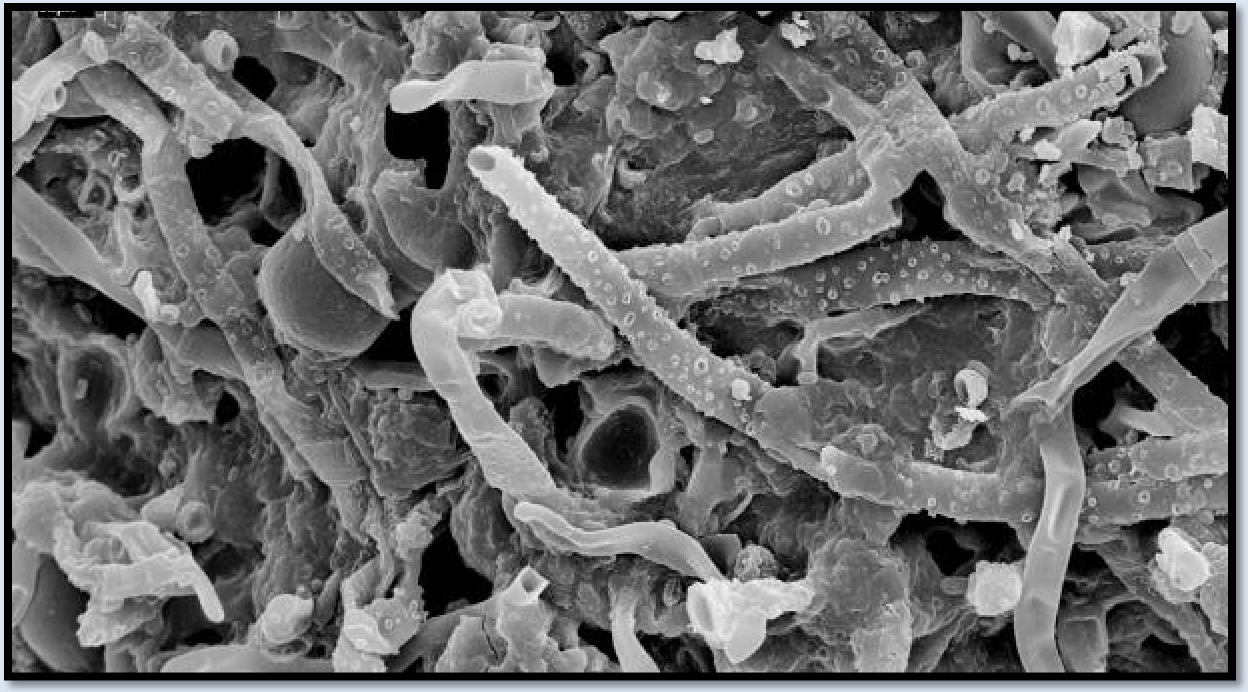
What this means to the farmer is that by utilising mycorrhizal fungi, naturally-occurring and introduced sources of organic nitrogen (such as found in fish-based fertilizers, green manures and compost) can provide a readily available source of nitrogen to promote crop growth and enhance yields.

In addition to phosphorus and nitrogen, the mass of hyphal filaments in the soil surrounding mycorrhizae-colonised roots is also capable of mobilising an array of other important plant nutrients, including calcium, iron, magnesium and critical micro-nutrients such as manganese, zinc and copper. Just as a lack of vitamins can impair human or animal health, crop yields and forage production are sometimes limited by insufficient supplies of these minor- and micro-nutrients, even when N-P-K is abundant.

Mycorrhizae's ubiquitous presence throughout the surrounding soil can access these relatively scarce resources and, in many cases, can release them from insoluble compounds via the production of specialised enzymes. **The management of micro-nutrients is becoming increasingly recognized as an important component of modern cropping science.**

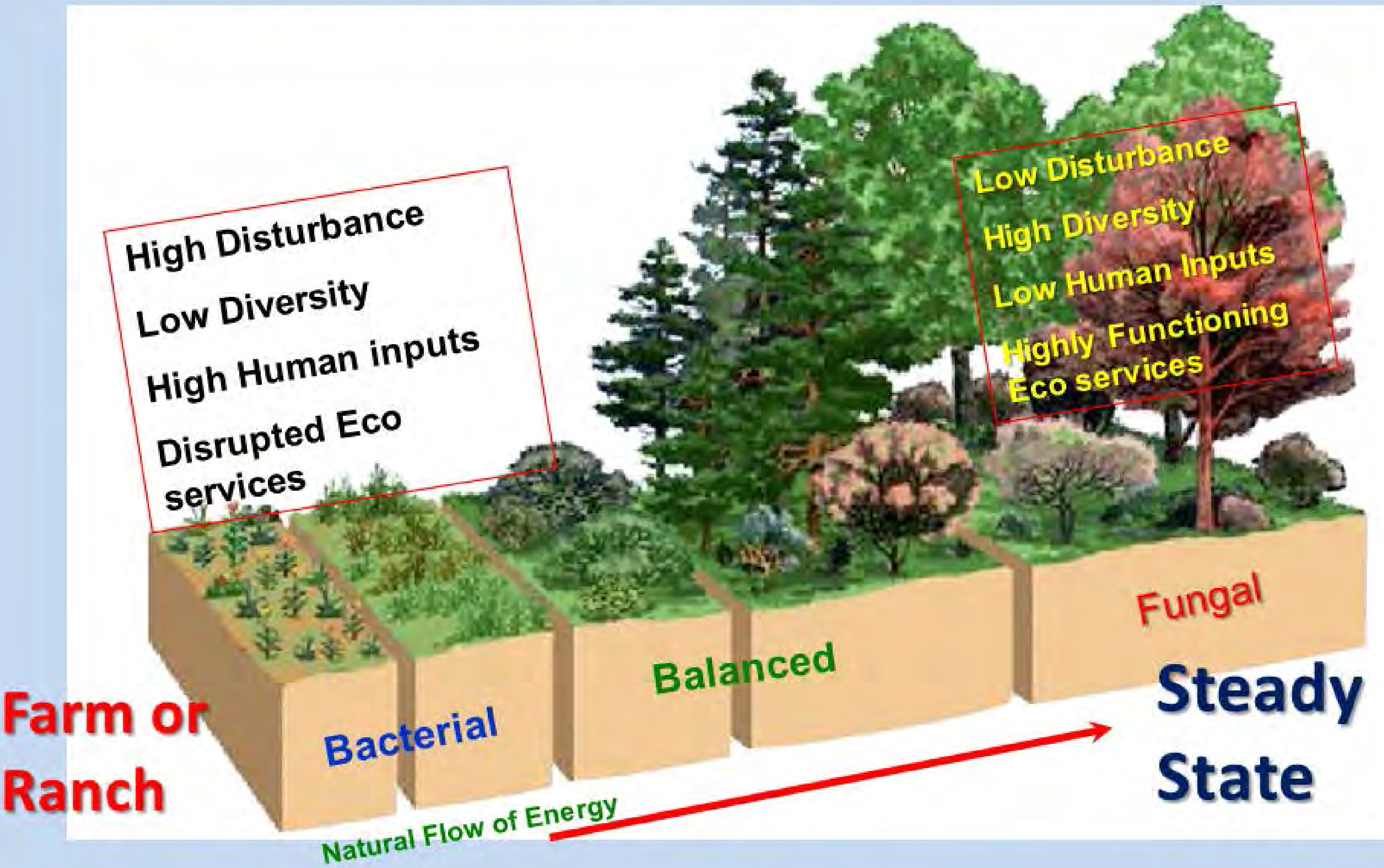
Mycorrhizal fungi can serve as useful tool to ensure that both natural and introduced sources of these nutrients are transferred efficiently from the soil to the plant.

Fungi holds on to Calcium



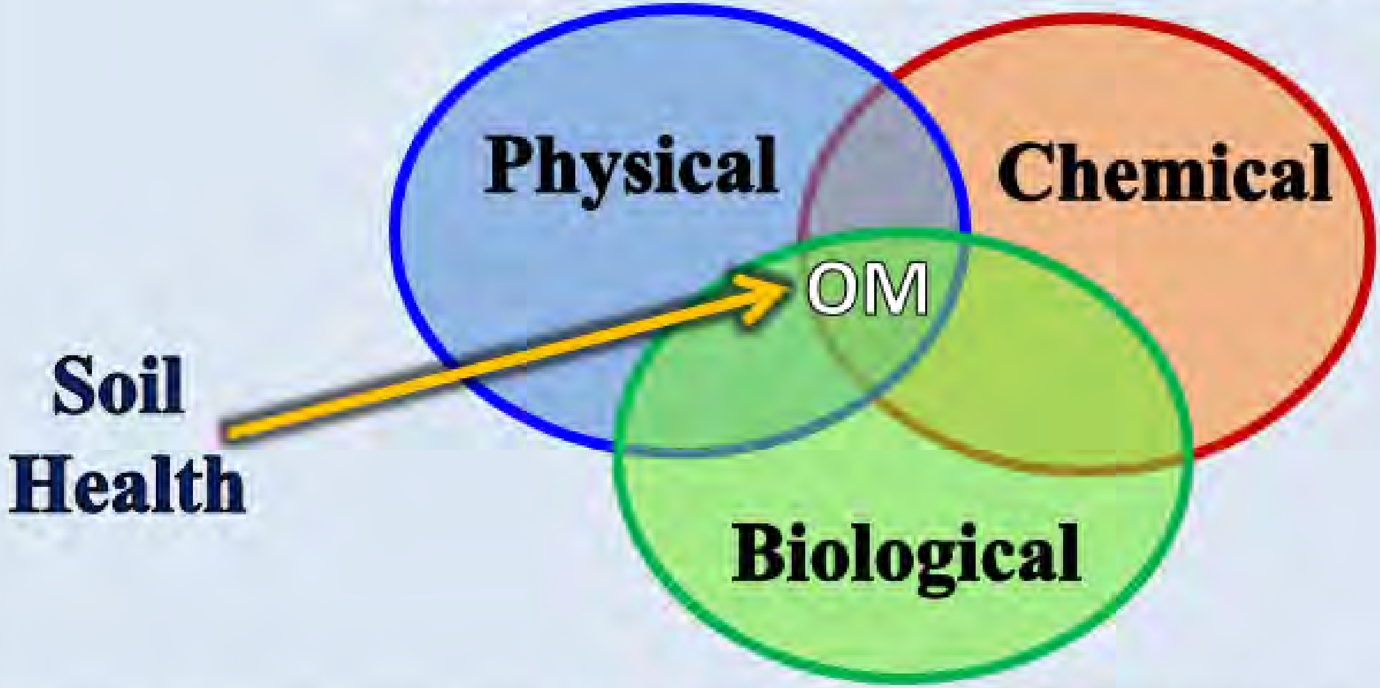
Fungus holds on to Calcium crystals. We know now that soil biology helps hold on to nutrients...like calcium. Look at crystals held by the fungus bodies.

Characteristics of a Stable Ecosystem



Evaluate How Your Soil System is Functioning

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



Understanding and enhancing biological activity in the soil helps us to change management dependent properties – those things that we can change relatively easy in the soil.

Soil Fertility – Plants do not have a internal digestive system like animals/humans – they depend on external digestive processes – micro-organisms transform organic nutrients into Inorganic nutrients—biology (bacteria/fungi) along with plant root exudates help to create porosity and infiltration to the soil. Essentially, this builds a good functioning digestive system for the plant.

Organic matter accumulation takes place slowly and is difficult to detect in the short term by measurements of total soil organic matter. However, even if you do not greatly increase soil organic matter (and it might take years to know how much of an effect is occurring), improved management practices such as adding organic materials, creating better rotations, and reducing tillage will help maintain the levels currently in the soil. And, perhaps more important, continuously adding a variety of residues results in plentiful supplies of "dead" organic matter—the relatively fresh particulate organic matter—that helps maintain soil health by providing food for soil organisms and promoting the formation of soil aggregates. **A recently developed soil test (SHNT) measures the amount of Water Soluble Organic Carbon. It is more sensitive to soil management than total organic matter and is thereby an earlier indicator for soil health improvement.**

Soil Health

The continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, air, water and humans (and microbes).

- Carbon Cycle (Energy Cycle)
- Biocommunity Cycle (Soil Food Web)
- Water Cycle (infiltration & availability)
- Nutrient cycling
- Physical Stability and Support
- Habitat for Biodiversity

The session is designed to discuss how we can evaluate a field's current soil health, looking at how it is functioning. **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 to a positive trend –**

Soil health is the continued capacity of the soil to function – that function is provided to us by microorganisms in the soil.

The Soil Demonstration shows you the difference between a functioning soil and a dysfunctional or non-functioning soil.

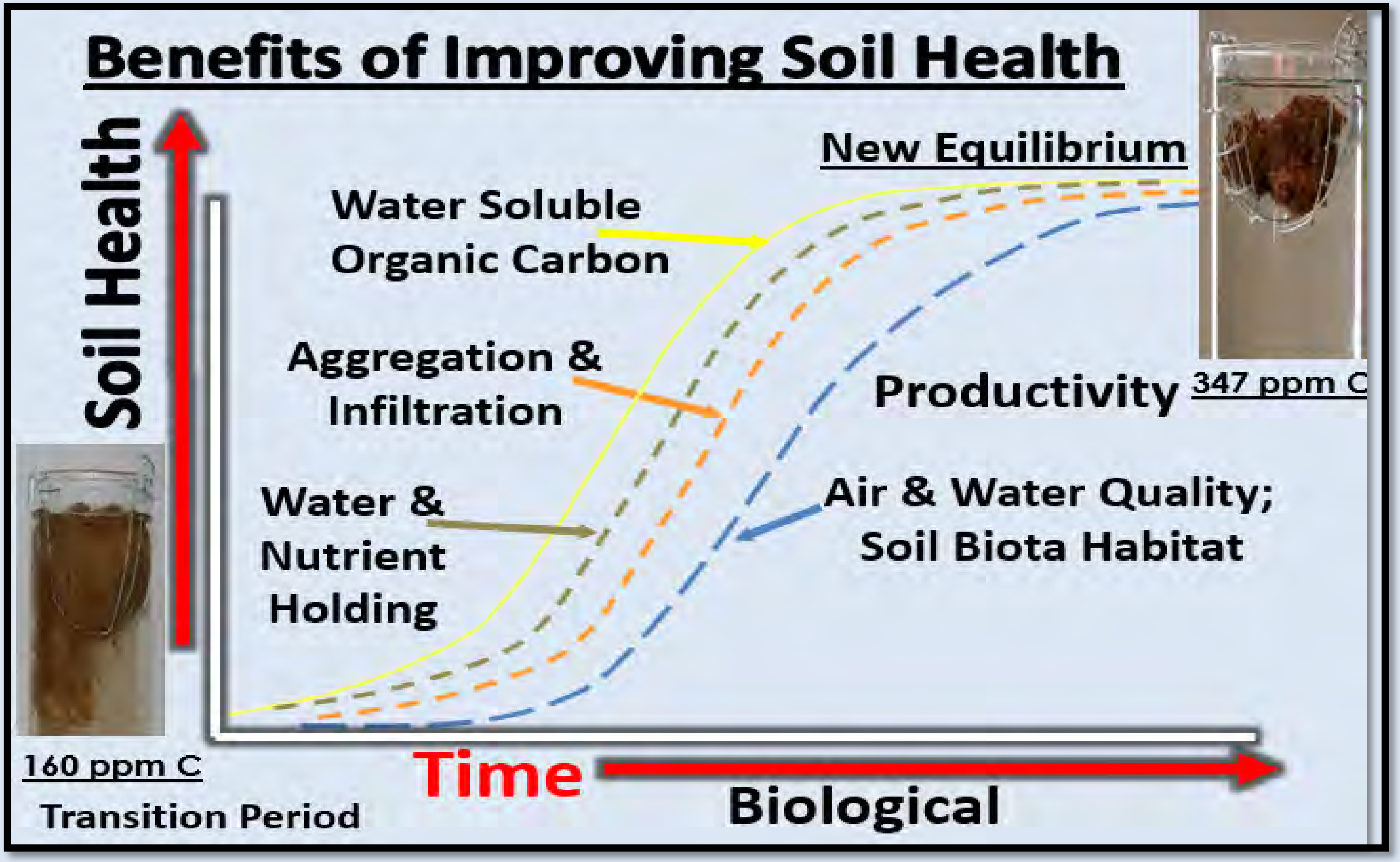
Consider all the soil dynamic properties that were enhanced to improve soil function.

Essentially, we look at the 4 Soil Ecosystems that must be improved: Carbon Cycle or Energy Cycle; Biocommunity Cycle; Water Cycle; Nutrient Cycle

If we understand how to enhance these 4 Soil Ecosystem processes, then the Ecosystem will provide the Physical Stability and Support along with Habitat for Biodiversity (Plants/Organisms) to sustain life or in this case your crops.

So, ask yourself – How well is your soil functioning to infiltrate water and cycle nutrients to water and feed growing plants?

Cover Crops are an integral part of this Process – they fill a void during a period in which there are no growing plants exuding carbon into the soil to feed the soil biology which builds soil structure, enabling you to have a proper Water and Nutrient Cycle.



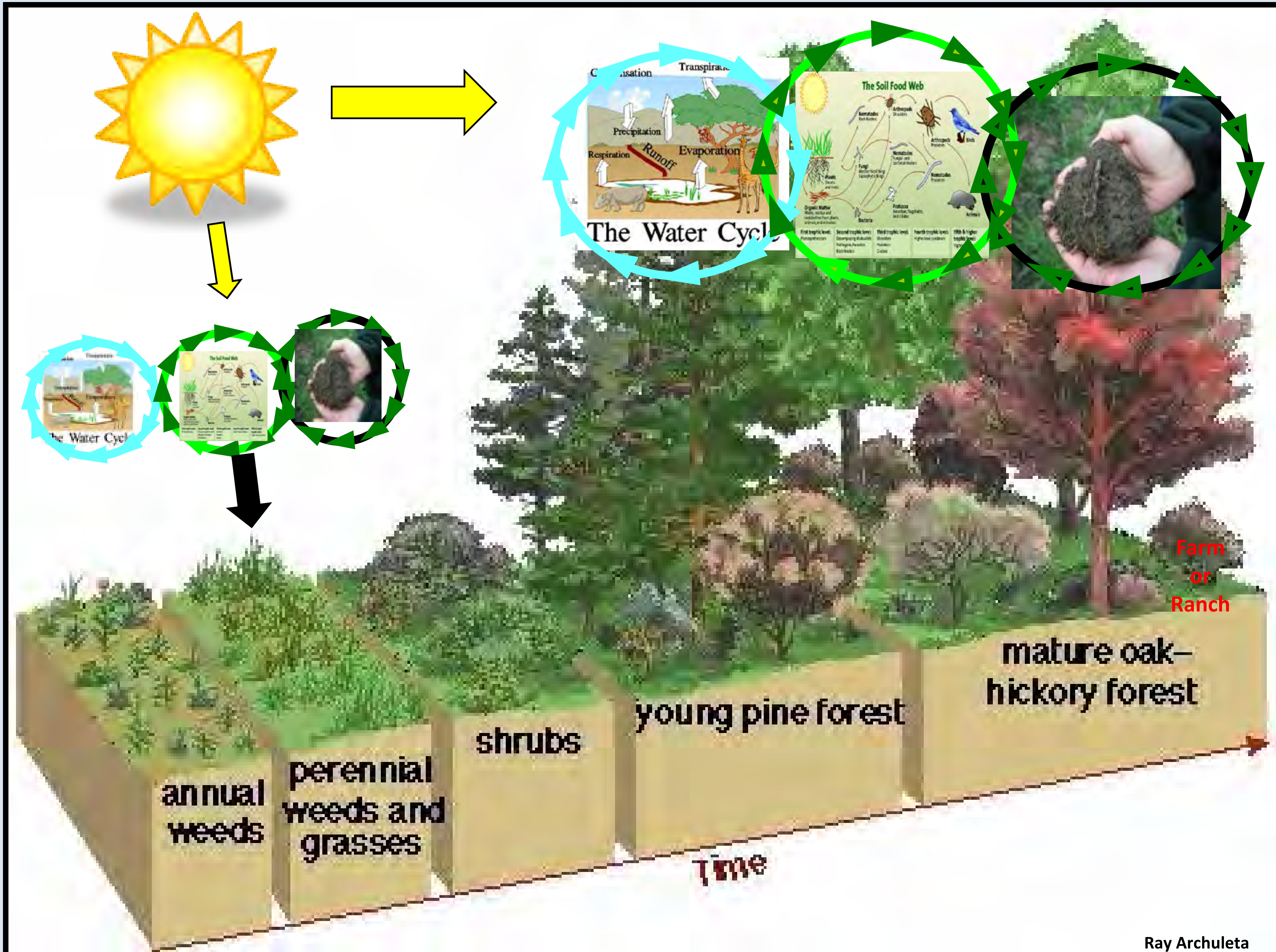
The Soil Health Demonstration actually showed you the benefits of Improving Soil Health! (Soil's Ability to Function)

One Key factor to grasp is that soil carbon is related to many soil functions.

1) **As carbon increases in soil, biological activity and physical structure changes lead to increased aggregation and infiltration**;
2) Water holding capacity is increased; Nutrient retention is increased as carbon and organic matter increases. Increased CEC is important for Clay, as well as sandier soils.
3) As these soil dynamic properties change, productivity increases often follow. Understand it is a process that requires time **– build the habitat for your microorganisms to do the work of improving soil health.**
4) Finally, as water and nutrient retention is increased, the soil's ability to act as a natural filter is improved, leading to positive effects on water and air quality and wildlife habitat.

It's important to note that many of these changes occur even before changes in total organic carbon are detectable.

The more ephemeral pools of carbon, like microbial carbon, register change at a faster rate than total soil carbon. (this is the soil glue – polysaccharides).



The Water Cycle
The Soil Food Web
Farm
or
Ranch
annual
weeds
perennial
weeds and
grasses
shrubs
young pine forest
mature oak–
hickory forest
time
Ray Archuleta

Water Cycle / Carbon (SFW) Cycle / Nutrient Cycle: Continued

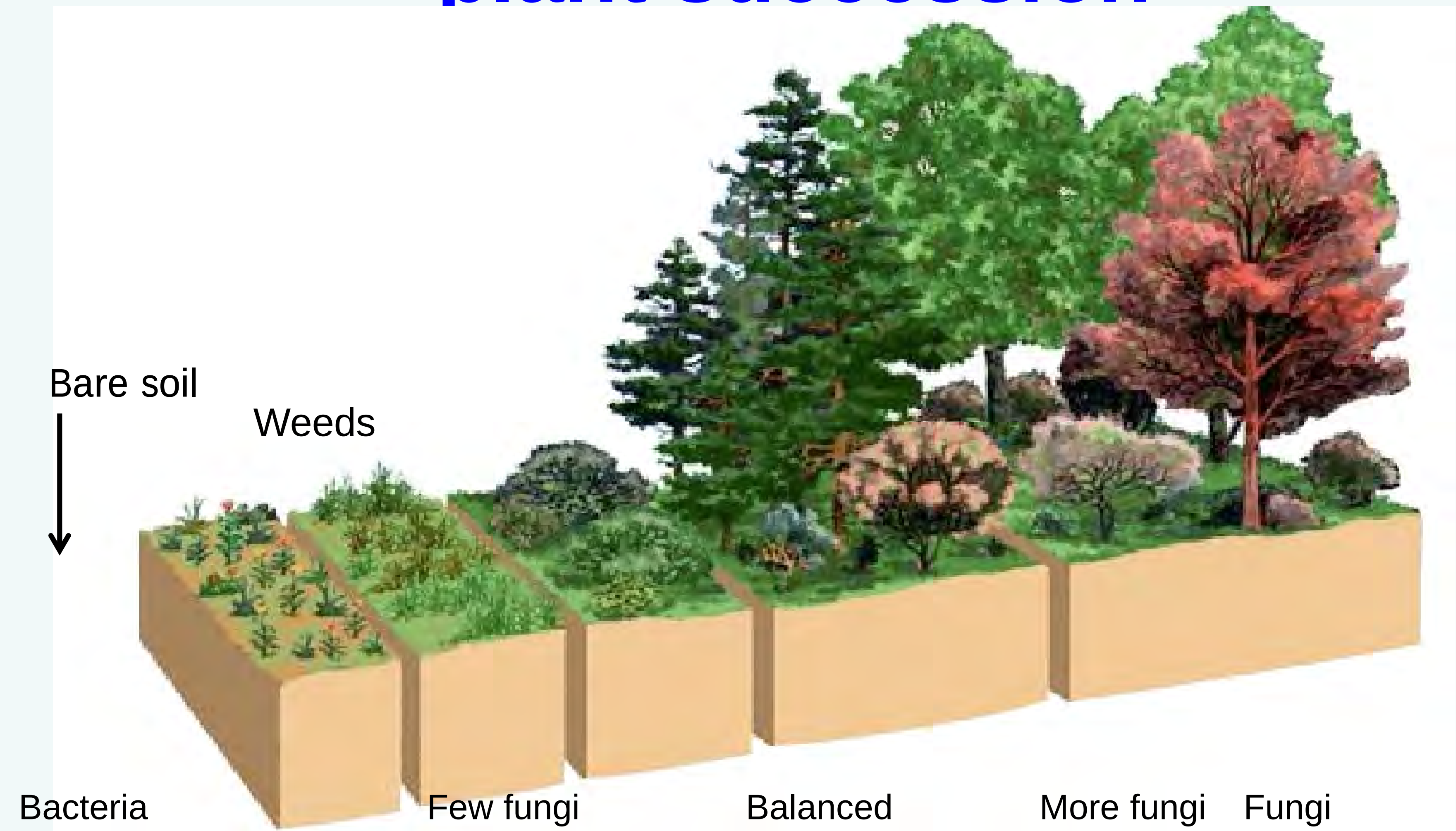
Key Points

1. This slide shows the natural successional progress from agricultural lands through to a steady state climax community,
2. These will differ across the country but are characterized by having highly functioning ecosystems services, e.g. nutrient, & water cycle and soil food web
3. **Most agricultural lands are characterized by having poor functioning ecosystem services**
4. **These services are driven by sunlight**
5. As succession takes place changes occur in the plant communities and soil biota over time, e.g. plants go from annual to perennials,

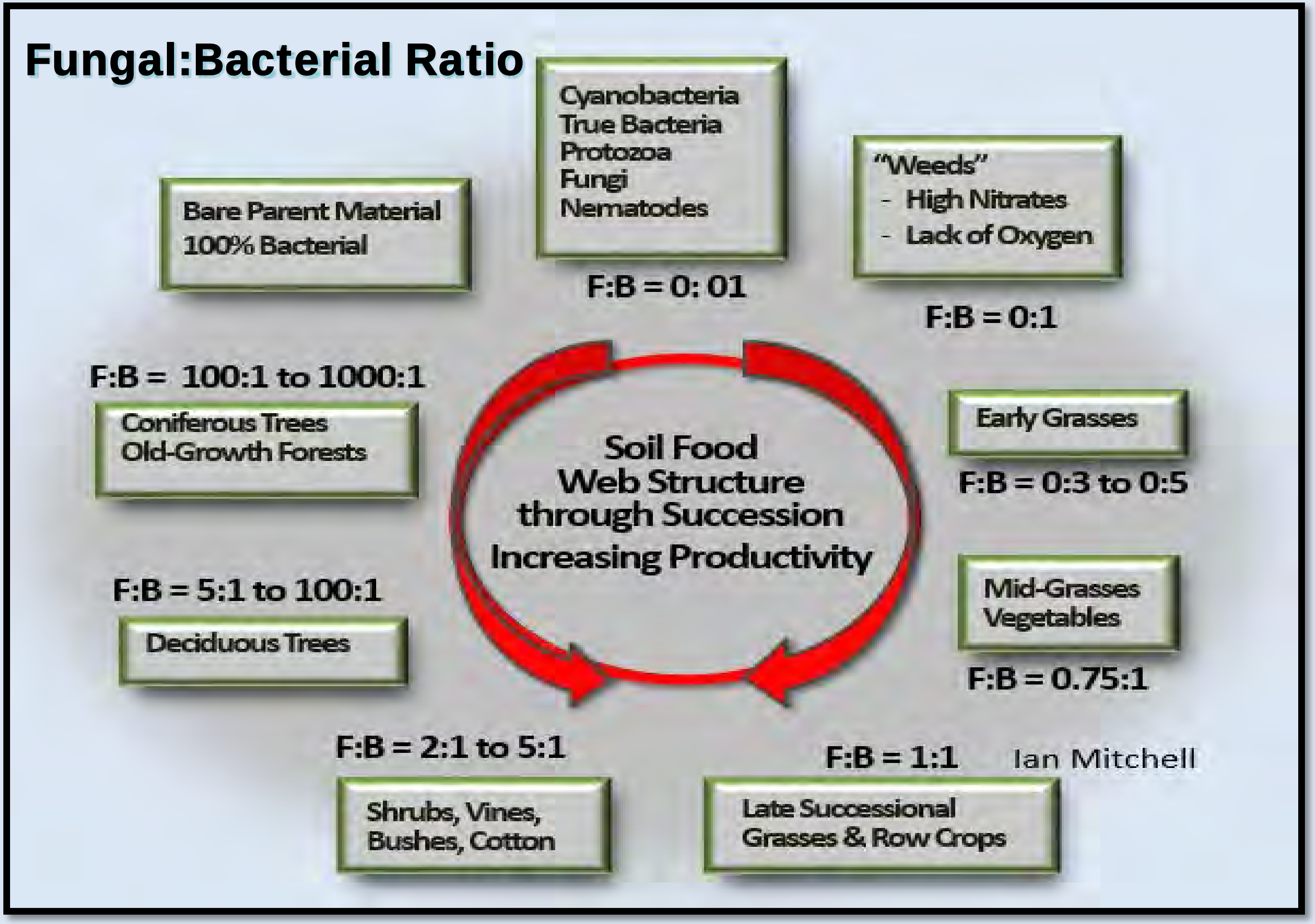
Nature wants to get to a steady state community

- Soil is the integrator between different ecosystems.
- Agricultural lands (crop, grazing, etc.) are part of the earth's ecosystems or biomes
- **In natural ecosystems**, the vegetative cover of a forest or grassland prevents soil erosion, replenishes ground water and controls flooding by enhancing infiltration and reducing water runoff (Perry, 1994).
- **In agricultural systems, biodiversity performs ecosystem services beyond production of food, fiber, fuel, and income. Examples include recycling of nutrients, control of local microclimate, regulation of local hydrological processes, regulation of the abundance of undesirable organisms**.
- These renewal processes and ecosystem services are largely biological; therefore their persistence depends upon maintenance of biological diversity (Altieri, 1994).
- **The net result of biodiversity simplification for agricultural purposes is an artificial ecosystem that requires constant human intervention, whereas in natural ecosystems the internal regulation of function is a product of plant biodiversity through flows of energy and nutrients**, and this form of control is progressively lost under agricultural intensification (Swift and Anderson, 1993).

Soil biological succession and plant succession



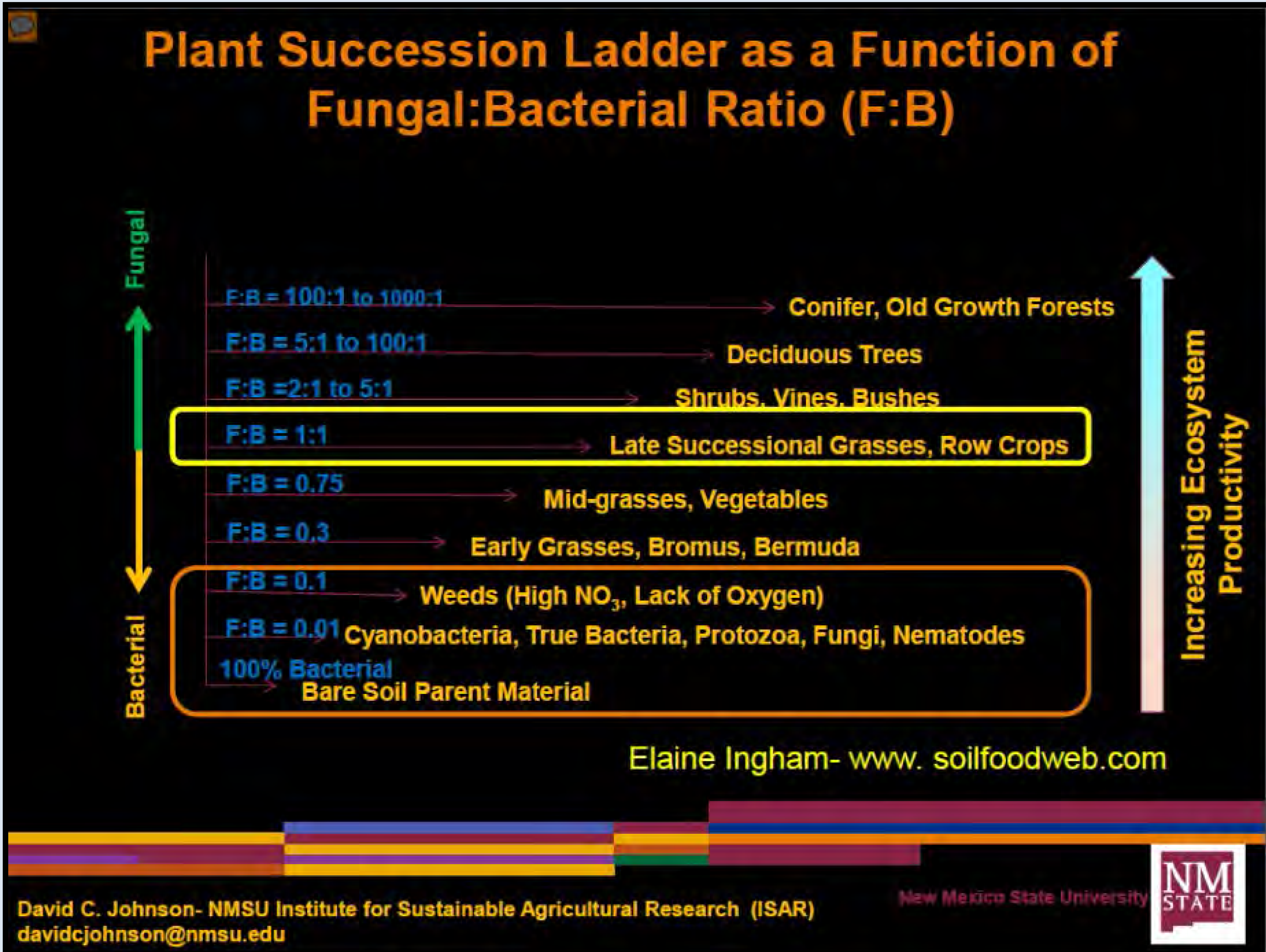
Fungi	0 µg	10 µg	250 µg	600 µg	800 µg	7000 µg
Bacteria	10 µg	100 µg	500 µg	600 µg	500 µg	700 µg

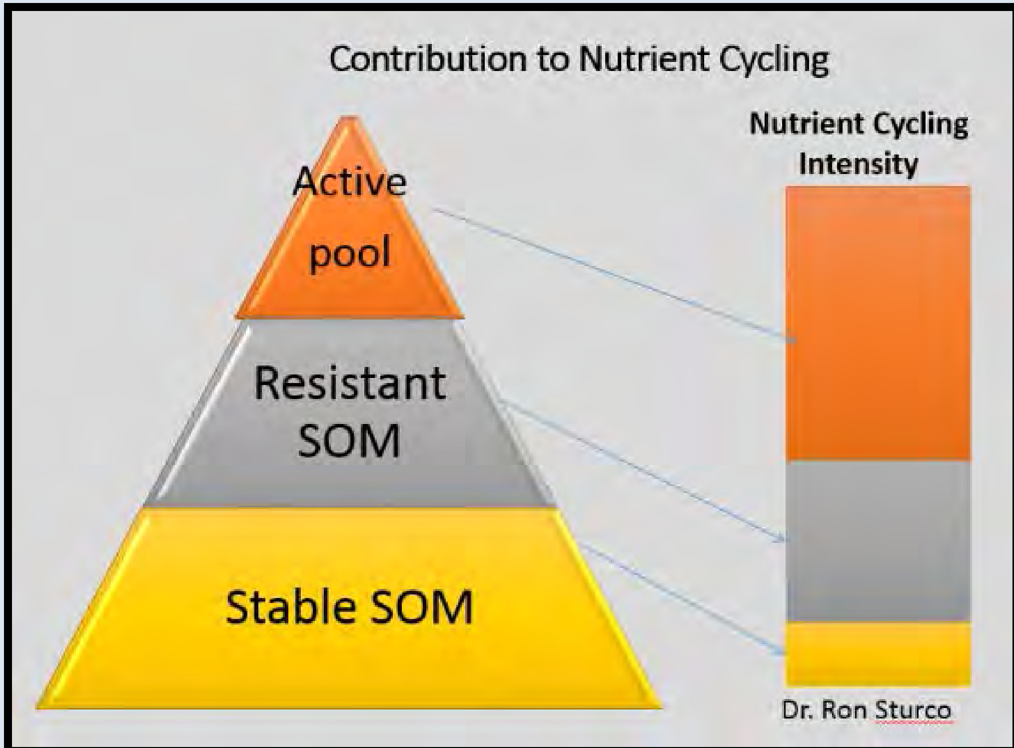


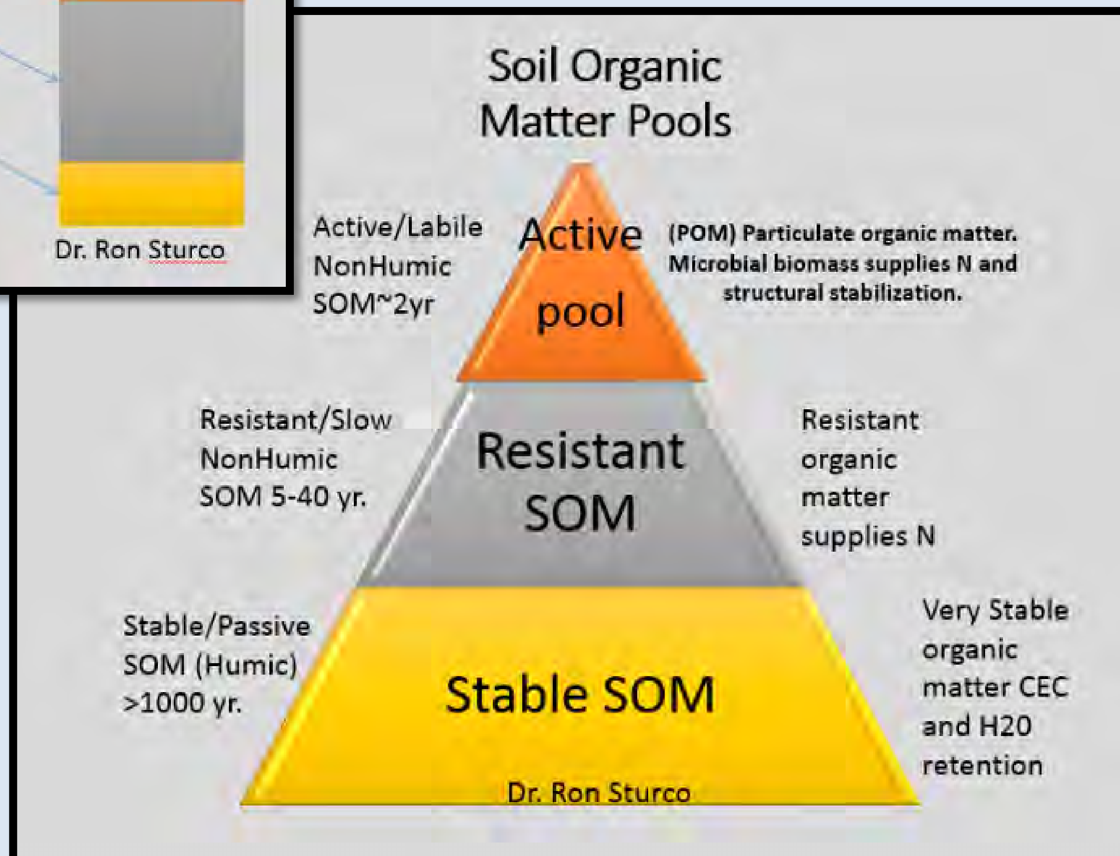
Why is this important: This tell us the rate that energy and nutrients are transformed and stored. **Fungal systems cycle nutrients slower and bacterial systems cycle nutrient quicker and tend to be more leaky.**

Ian Mitchell – Holistic Management Educator –

Permanent grassland sits somewhere in the middle, tending to have a balance of both bacteria and fungi in its soils. **In a bacteria-dominated soil, annual weeds thrive.** In a fungal soil, perennial woody shrubs do best. This allows us, as land managers, to study the weed species growing in our swards and fields to determine what is out of balance**. In theory, if we get closer to the desirable ratios for grasslands, then desirable grass species will thrive and less desirable 'weed' species will not!**


Plant Succession Ladder as a Function of Fungal:Bacterial Ratio (F:B)
Fungal
Bacterial
F:B = 100:1 to 1000:1
Conifer, Old Growth Forests
F:B = 5:1 to 100:1
Deciduous Trees
F:B =2:1 to 5:1
Shrubs, Vines, Bushes
F:B = 1:1
Late Successional Grasses, Row Crops
F:B = 0.75
Mid-grasses, Vegetables
F:B = 0.3
Early Grasses, Bromus, Bermuda
F:B = 0.1
Weeds (High NO_3, Lack of Oxygen)
F:B = 0.01
Cyanobacteria, True Bacteria, Protozoa, Fungi, Nematodes
100% Bacterial
Bare Soil Parent Material
Increasing Ecosystem Productivity
Elaine Ingham- www. soilfoodweb.com
David C. Johnson- NMSU Institute for Sustainable Agricultural Research (ISAR)
davidcjohnson@nmsu.edu
New Mexico State University
NM STATE

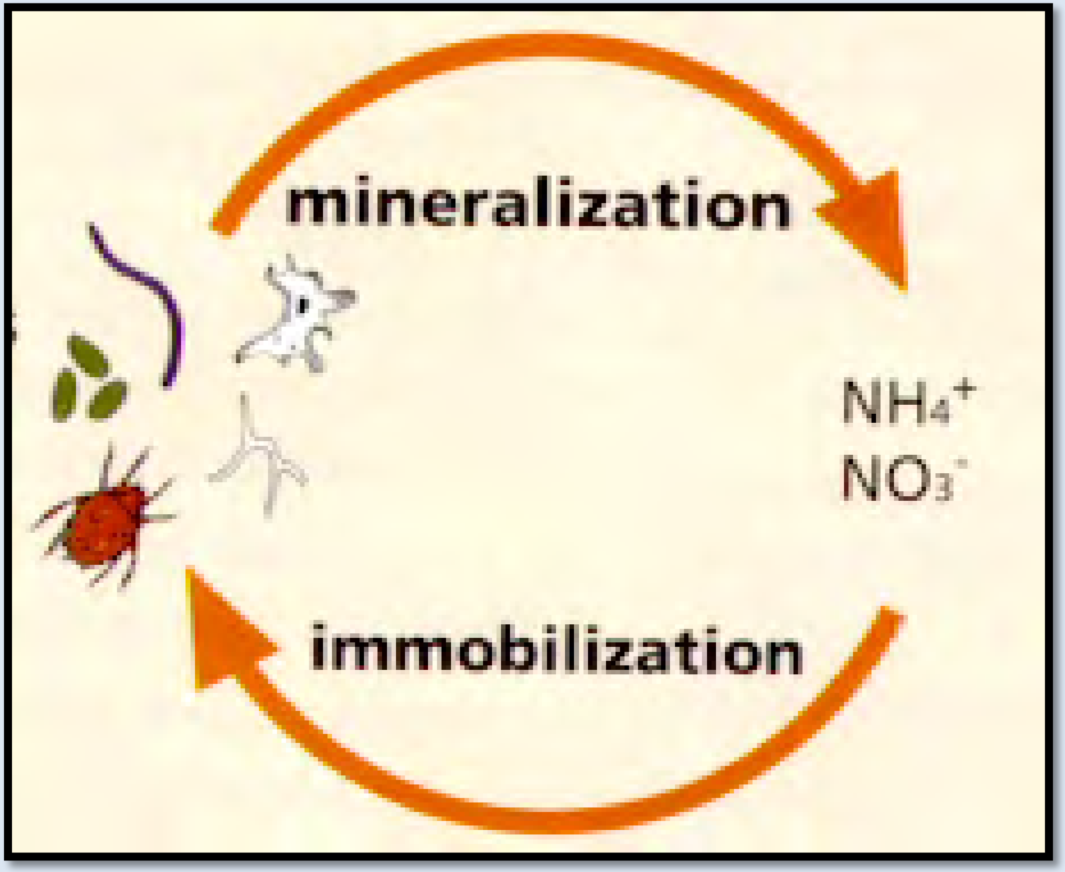

Contribution to Nutrient Cycling
Nutrient Cycling Intensity
Active pool
Resistant SOM
Stable SOM
Dr. Ron Sturco


Soil Organic Matter Pools
Active/Labile NonHumic SOM~2yr
Active pool
(POM) Particulate organic matter. Microbial biomass supplies N and structural stabilization.
Resistant/Slow NonHumic SOM 5-40 yr.
Resistant SOM
Resistant organic matter supplies N
Stable/Passive SOM (Humic) >1000 yr.
Stable SOM
Very Stable organic matter CEC and H20 retention
Dr. Ron Sturco

Mineralization and Immobilization

Organisms consume other organisms and excrete inorganic wastes.

Organic nutrients are stored in soil organisms and organic matter.

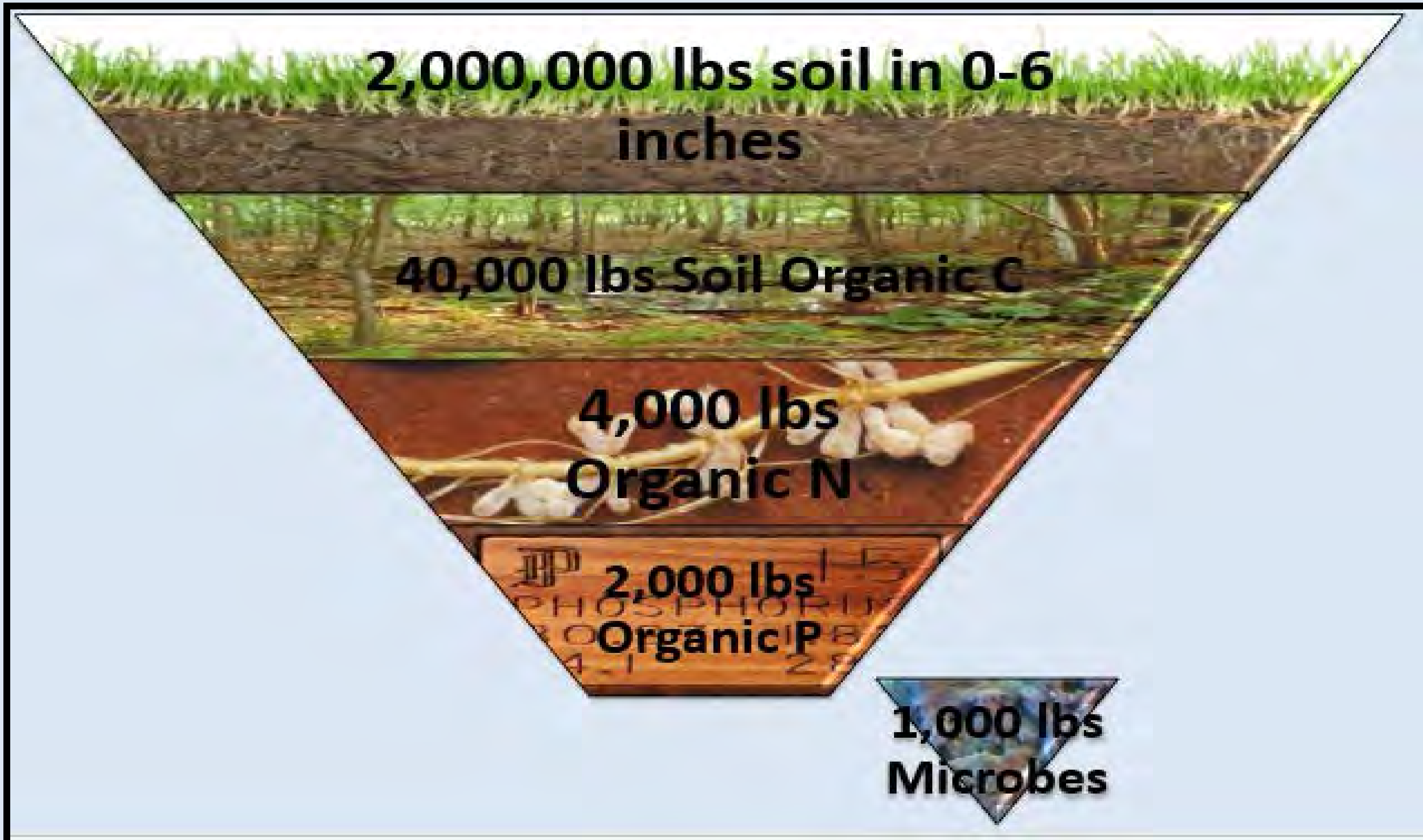


Inorganic nutrients are usable by plants, and are mobile in soil.

Organisms take up and retain nutrients as they grow.

File name: MinImmB.jpg, 51K. (Also: MinImmA.jpg at 100K, and E-2 at 375KB)
Image courtesy of USDA-Natural Resources Conservation Service

We can Unlock the Secrets in the Soil



Typical slide from a 2% O.M. Soil – taken from Dr. Rick Haney's Slide presentation – Used to illustrate the potential of Organic Matter to supply nutrients in Organic form. **Key is to enhance or pay attention to the Microbial activity – this is what transforms Organic Nutrients into InOrganic Nutrients that are available to plants.**

O.M. is 58% Carbon – so if you have 1.0% OM that means you have 5.8 tons or 11,600 lbs of Carbon/Acre – which equates to .58 tons of N (1,160 lbs). Which equates to 116 lbs of P –

Common C:N:P = 100:10:1

Microbial Diversity

Degraders of Cellulose (Stubble Digestion)

- Bacillus, Arthrobacter, Rhodococcus
  (primary organic matter builders lives on soil surface)

Nitrogen fixers

- Azotobacter, Cyanobacter, Anabaena

Antibiotic producers Disease fighting

- Pseudomonas Putida, P. florescens, Actinomycetes, Streptomyces
  (build antibiotics for plants and mankind)

Phosphate freeing

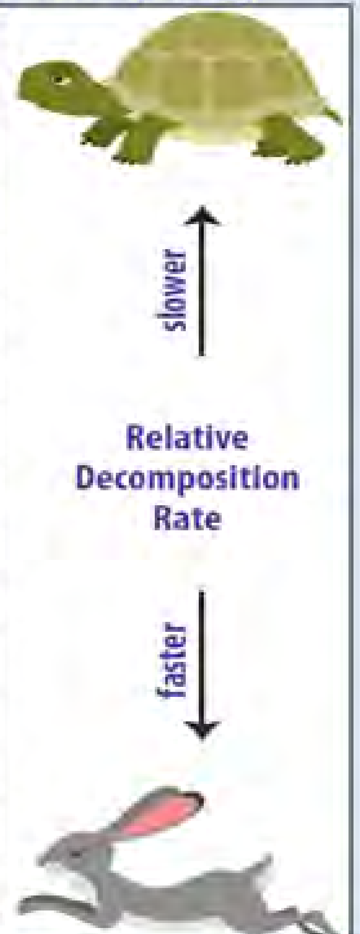
- Acinetobacter, Pseudomonas Putida, Pseudomonas Alcaligenes

Water purifying and salt eating

- Flavobacterium, Bacillus ,Rhodococcus

C:N Ratio for Various Crops (Nutrient Cycling)

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

- 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 mange 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.

Reasons to Improve Soil Health:

Nutrient Cycling (C:N)

• Bacteria	5:1
• Fungi	20:1
• People	30:1
• Green Leaves	30:1
• Protozoa	30:1
• Nematodes	100:1
• Brown plant material	150 – 200:1
• Deciduous wood	300:1
• Conifer wood	500:1

Soil Organic Matter
Nutrient Bank Account.

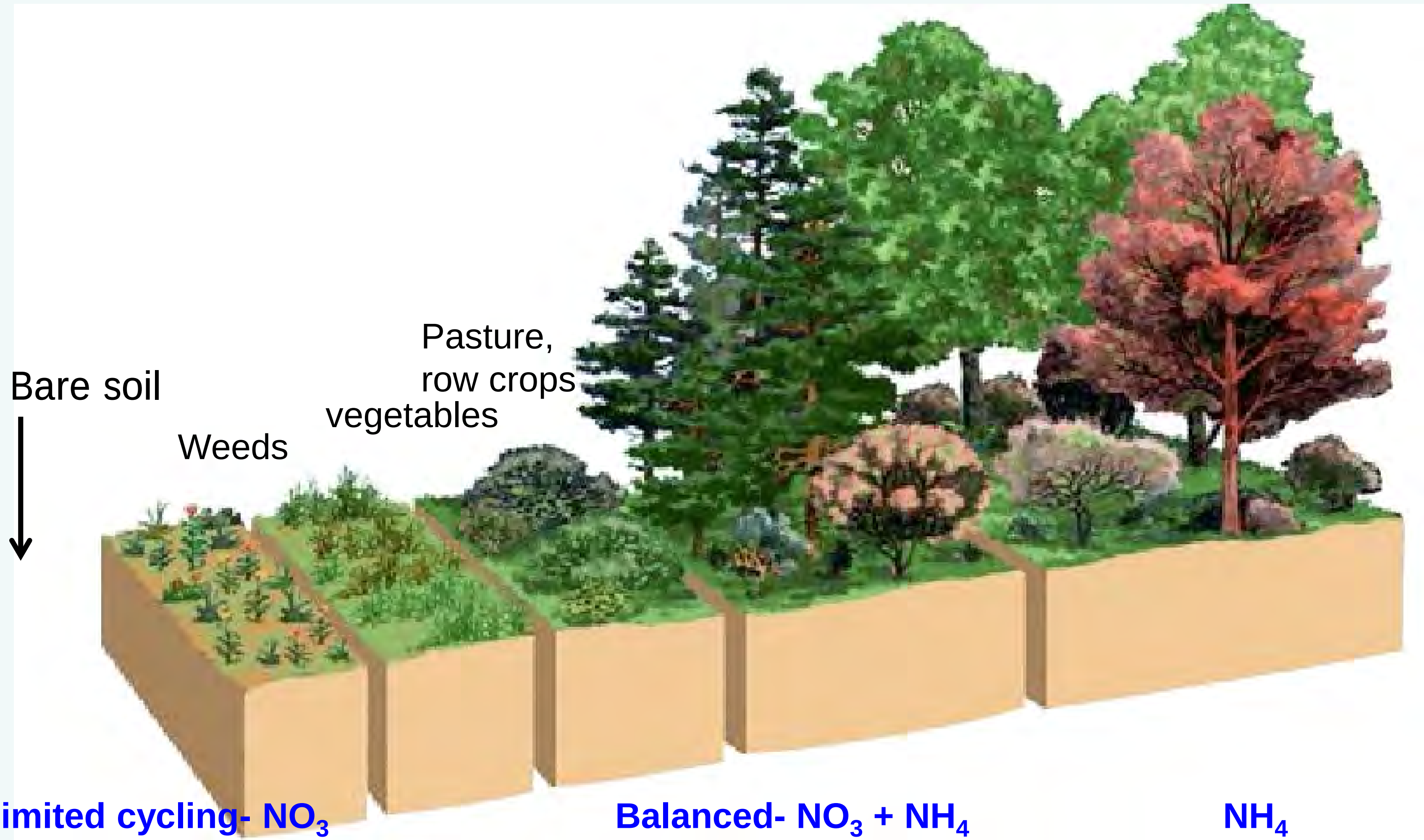
- **1.0% OM = 20,000 #**
  - **10,000 # Carbon (5 ton) @ $4/ton = $20**
  - **1,000 # Nitrogen @ $.50/# = $500**
  - **100 # Phosphorous @ $.70/# = $70**
  - **100# Potassium @ $.40/# -=$40**
  - **100 lbs of Sulfur @ $.50/# = $ 50**
  - **Total $680**
- **Mineralization Rate = 2-3% from Organic N to Inorganic N.**
- **Resulting in 20 to 30 lbs of useable N per acre.**

This is self explanatory, it shows the potential nutrients available in the SOM that can be tapped as soil health is improved and microbe activities are accelerated or enhanced.

Typical C:N:P ratio of 100:10:1

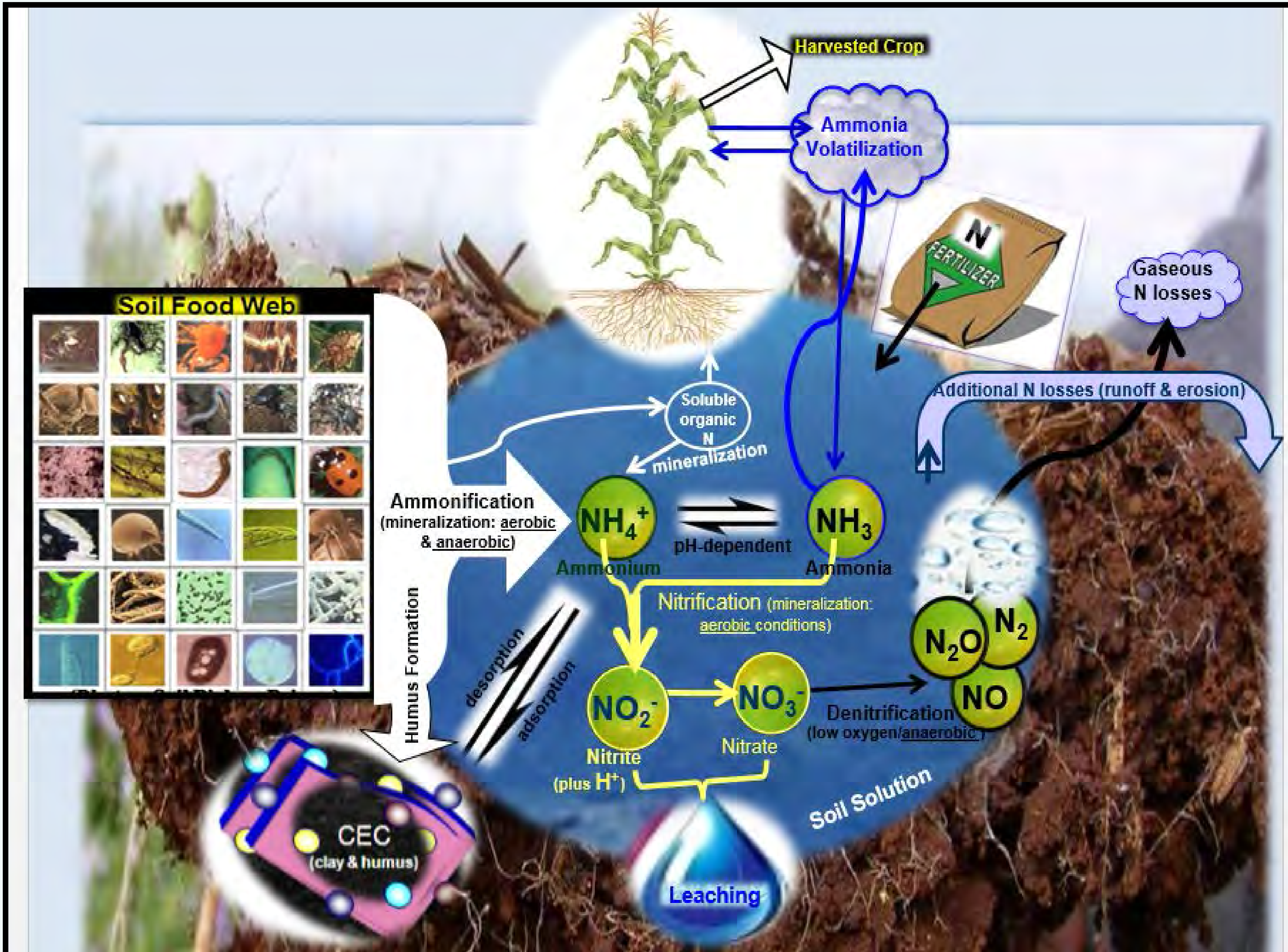
Dr. Rick Haney

Forms of nutrients and succession

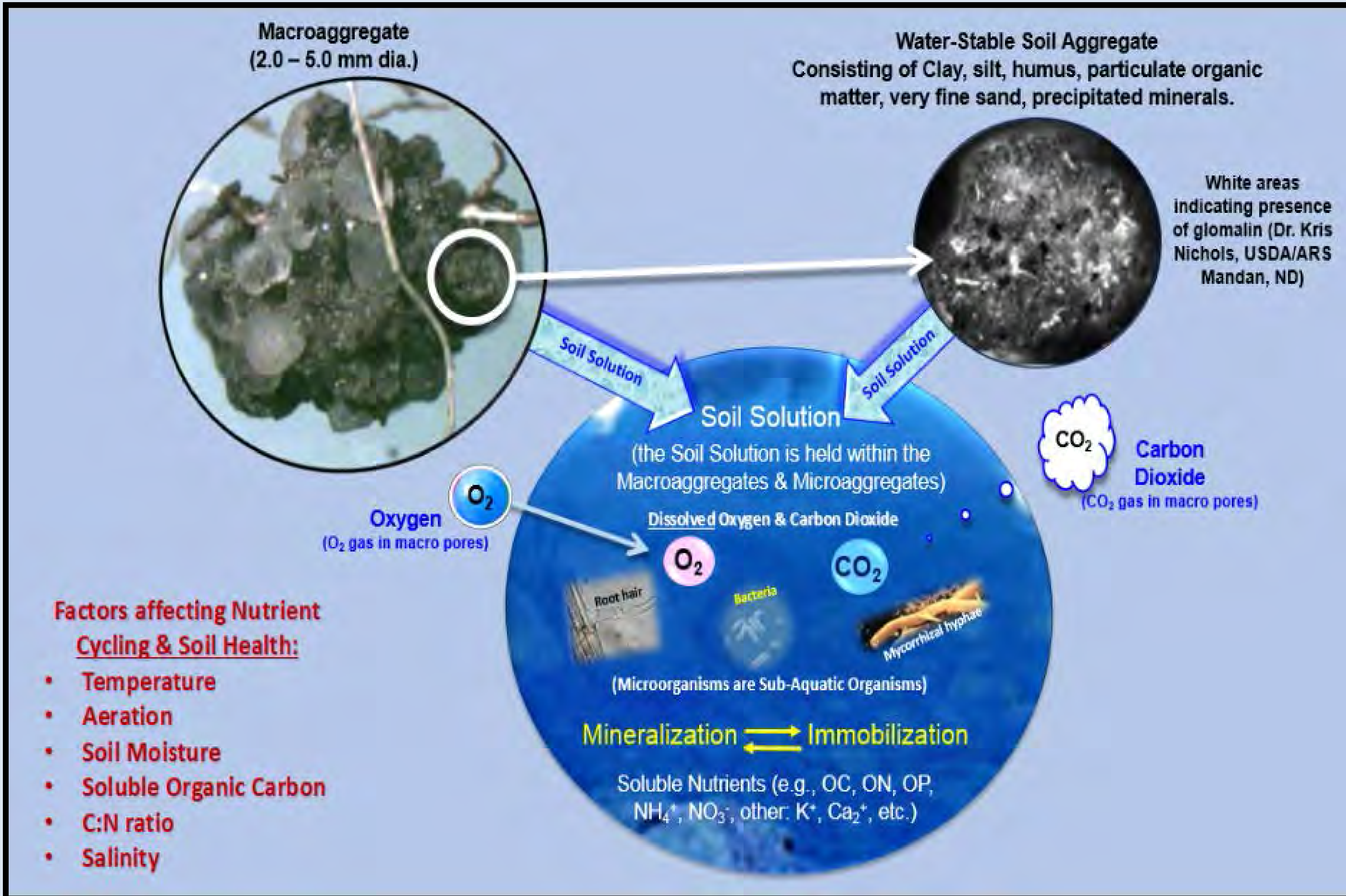


Limited cycling- NO_3 **Balanced- $NO_3 + NH_4$** **NH_4**

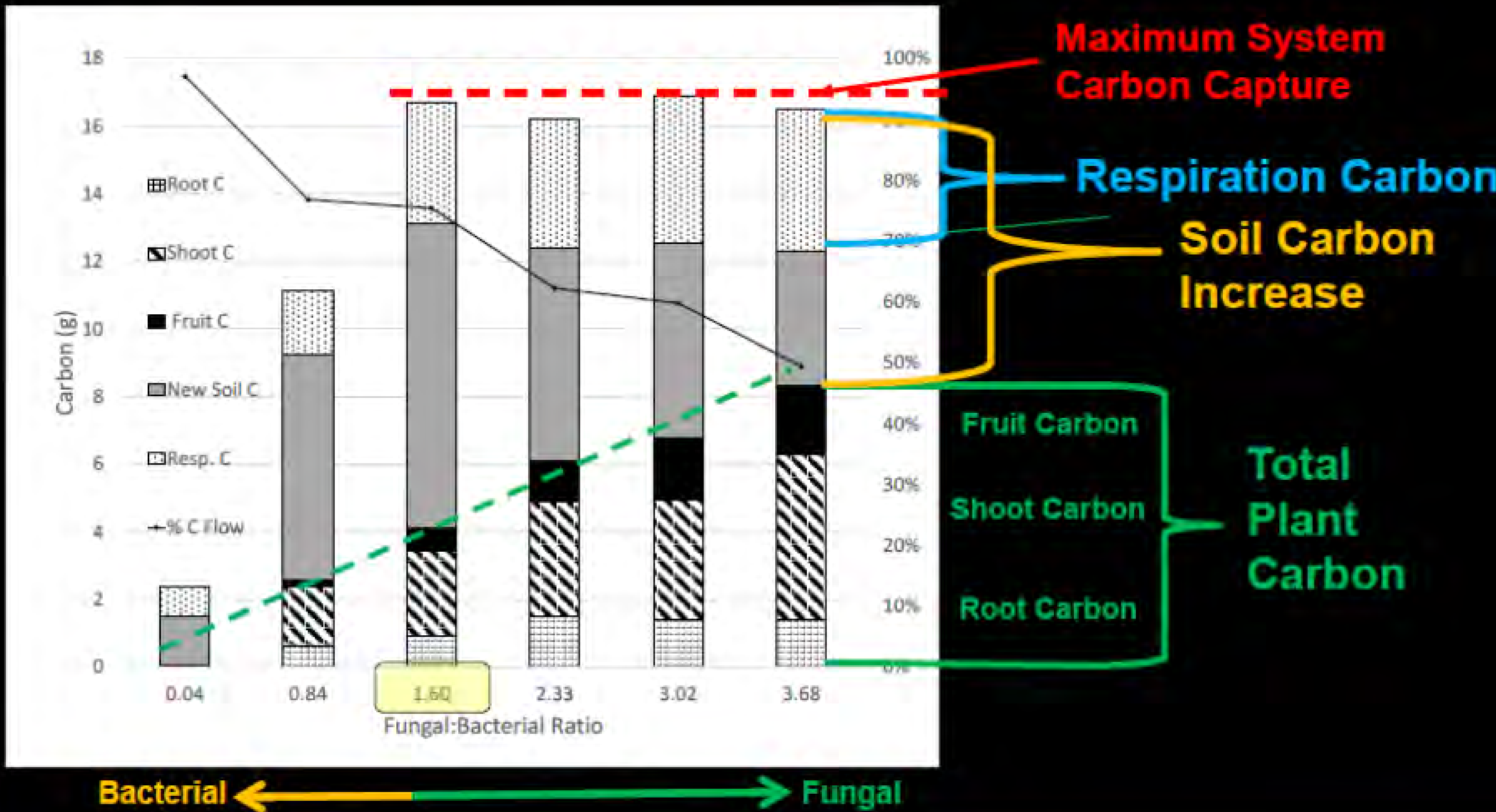
Fungi	0 µg	10 µg	250 µg	600 µg	800 µg	7000 µg
Bacteria	10 µg	100 µg	500 µg	600 µg	500 µg	700 µg



Harvested Crop
Ammonia Volatilization
Gaseous N losses
Soil Food Web
Additional N losses (runoff & erosion)
Soluble organic N
mineralization
Ammonification
(mineralization: aerobic & anaerobic)
NH4+
Ammonium
pH-dependent
NH3
Ammonia
Nitrification (mineralization: aerobic conditions)
Humus Formation
desorption
adsorption
NO2-
Nitrite
(plus H+)
NO3-
Nitrate
N2O
N2
NO
Denitrification
(low oxygen/anaerobic)
Soil Solution
CEC
(clay & humus)
Leaching


Macroaggregate
(2.0 – 5.0 mm dia.)
Water-Stable Soil Aggregate
Consisting of Clay, silt, humus, particulate organic matter, very fine sand, precipitated minerals.
White areas indicating presence of glomalin (Dr. Kris Nichols, USDA/ARS Mandan, ND)
Soil Solution
Soil Solution
Soil Solution
(the Soil Solution is held within the Macroaggregates & Microaggregates)
Dissolved Oxygen & Carbon Dioxide
O_2
Oxygen
(O_2 gas in macro pores)
O_2
CO_2
CO_2
Carbon Dioxide
(CO_2 gas in macro pores)
Root hair
Bacteria
Mycorrhizal hyphae
(Microorganisms are Sub-Aquatic Organisms)
Mineralization ⇄ Immobilization
Soluble Nutrients (e.g., OC, ON, OP, NH_4^+, NO_3^-, other: K^+, Ca_2^+, etc.)
Factors affecting Nutrient Cycling & Soil Health:
• Temperature
• Aeration
• Soil Moisture
• Soluble Organic Carbon
• C:N ratio
• Salinity

Carbon Partitioning vs. increasing F:B Ratio

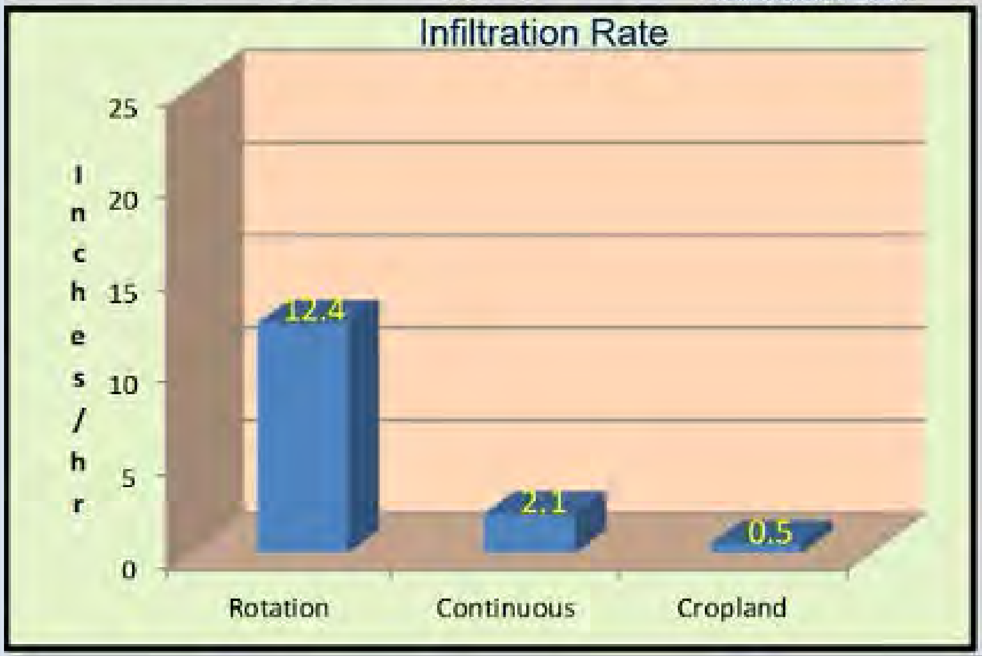


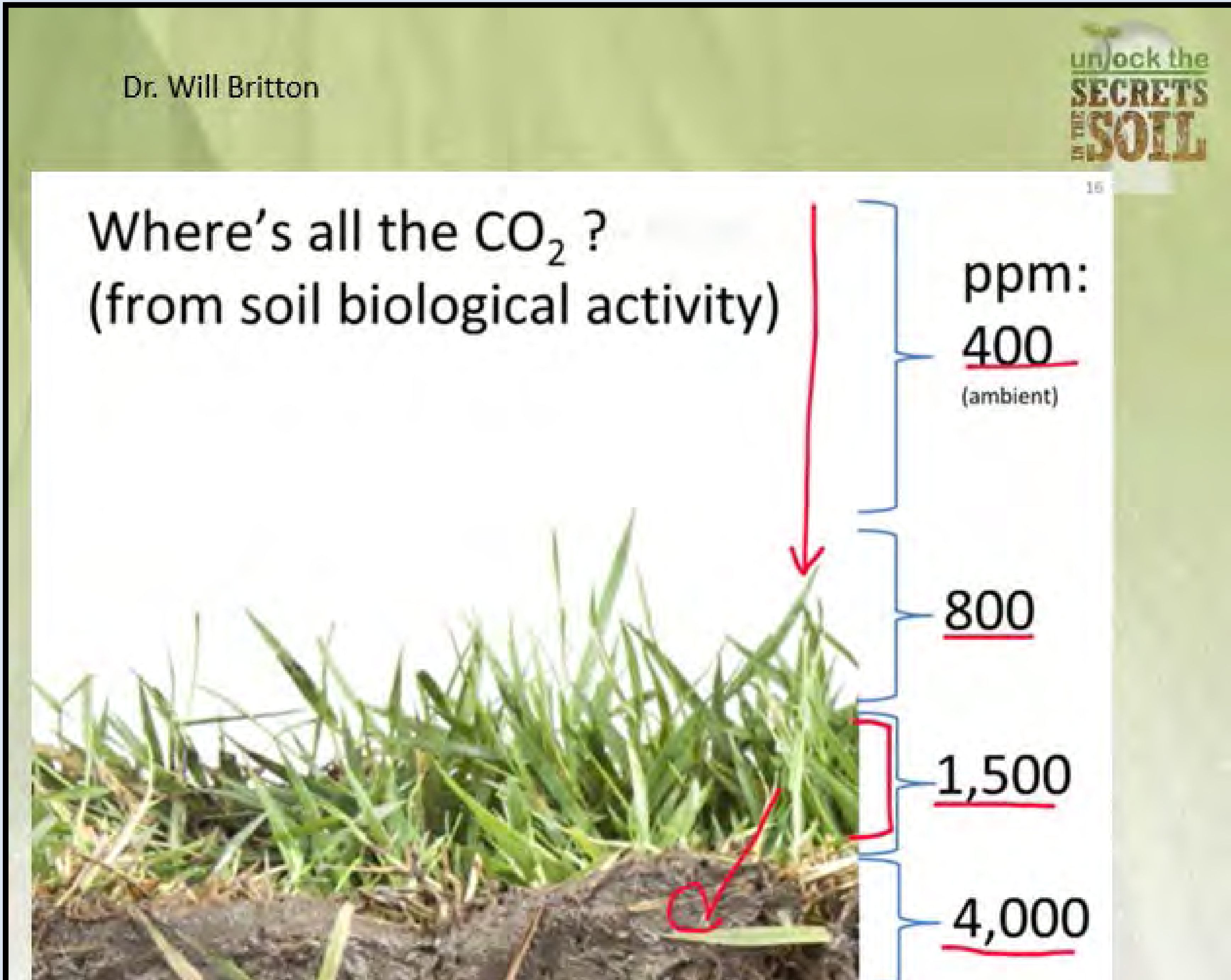
David C. Johnson- NMSU Institute for Sustainable Agricultural Research (ISAR)
davidcjohnson@nmsu.edu

New Mexico State University

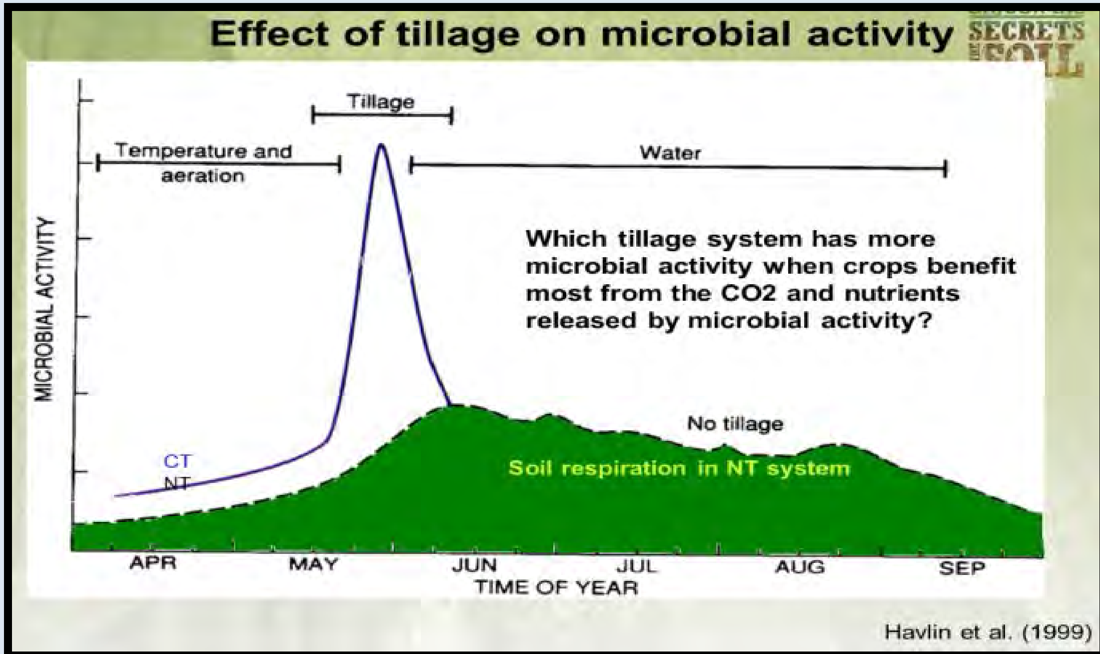
Stan Boltz and Jeff Hemingway SD

Hyde County
Glenham soil

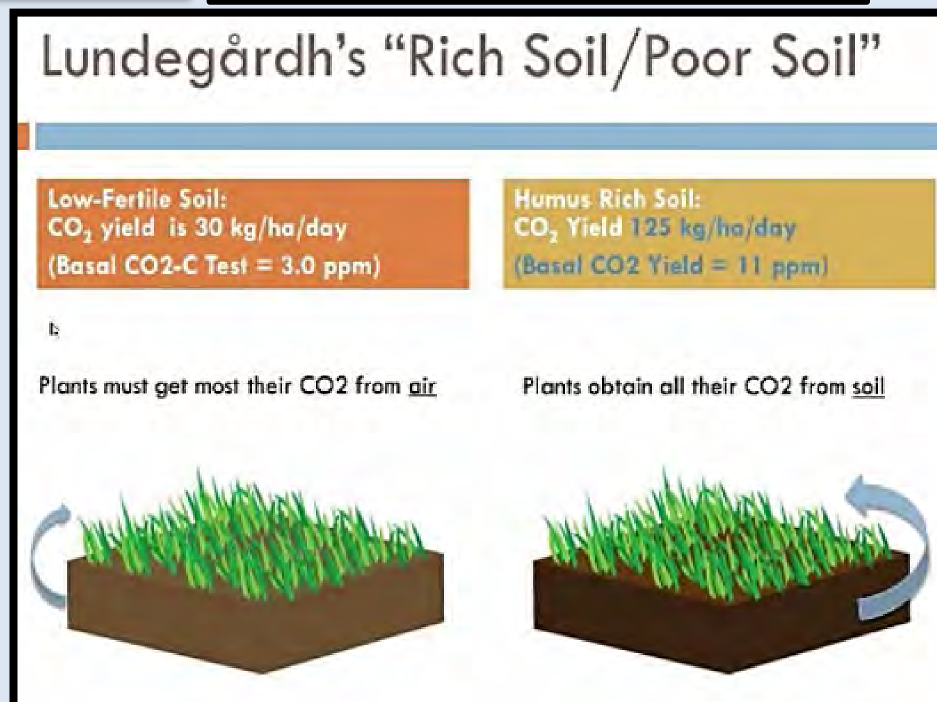


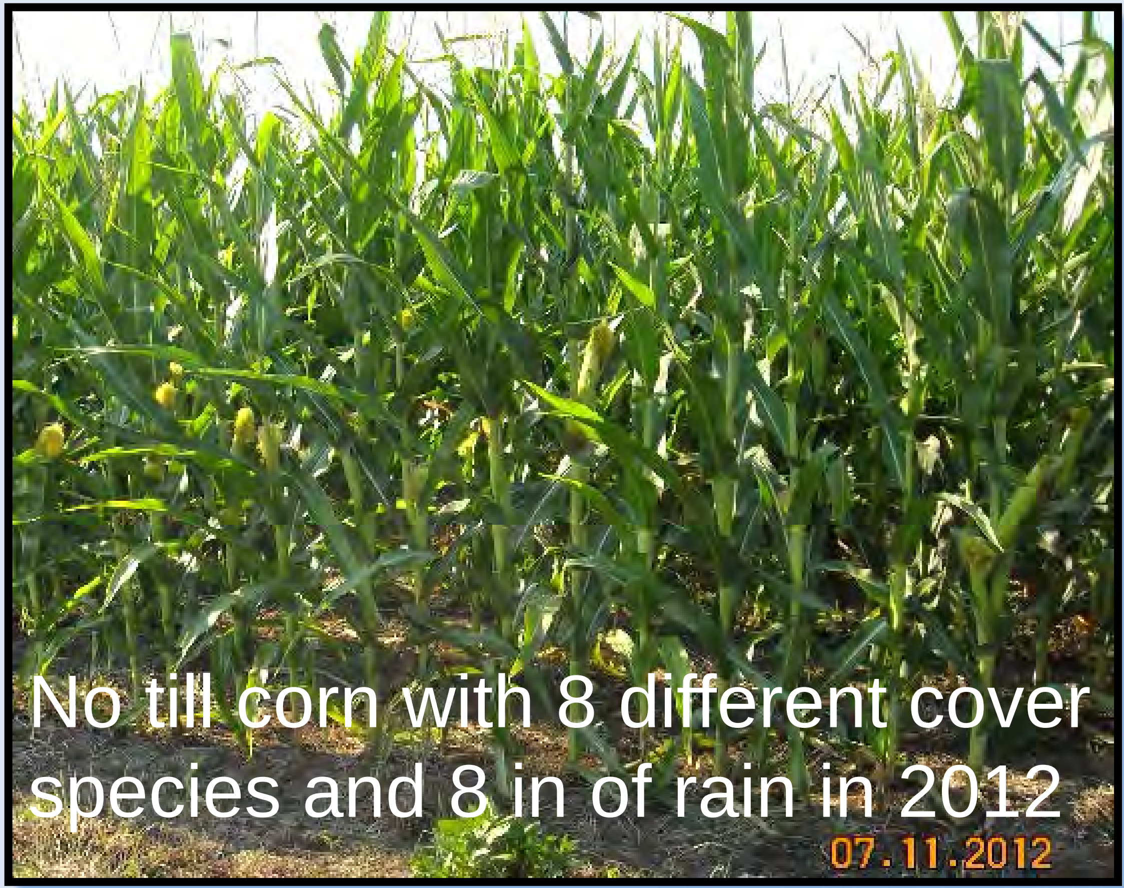


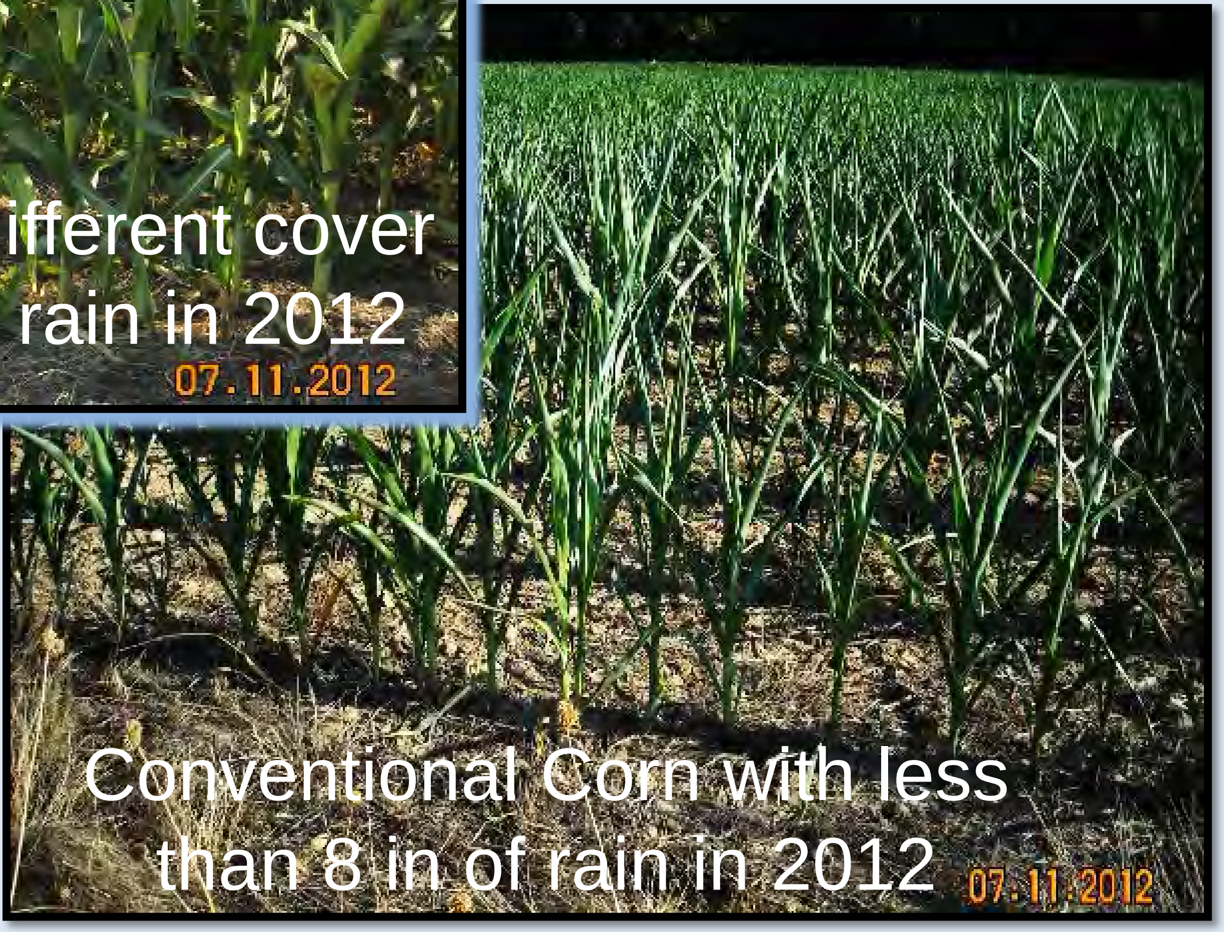
Dr. Will Britton
unlock the SECRETS IN THE SOIL
16
Where's all the CO_2 ?
(from soil biological activity)
ppm:
400
(ambient)
800
1,500
4,000



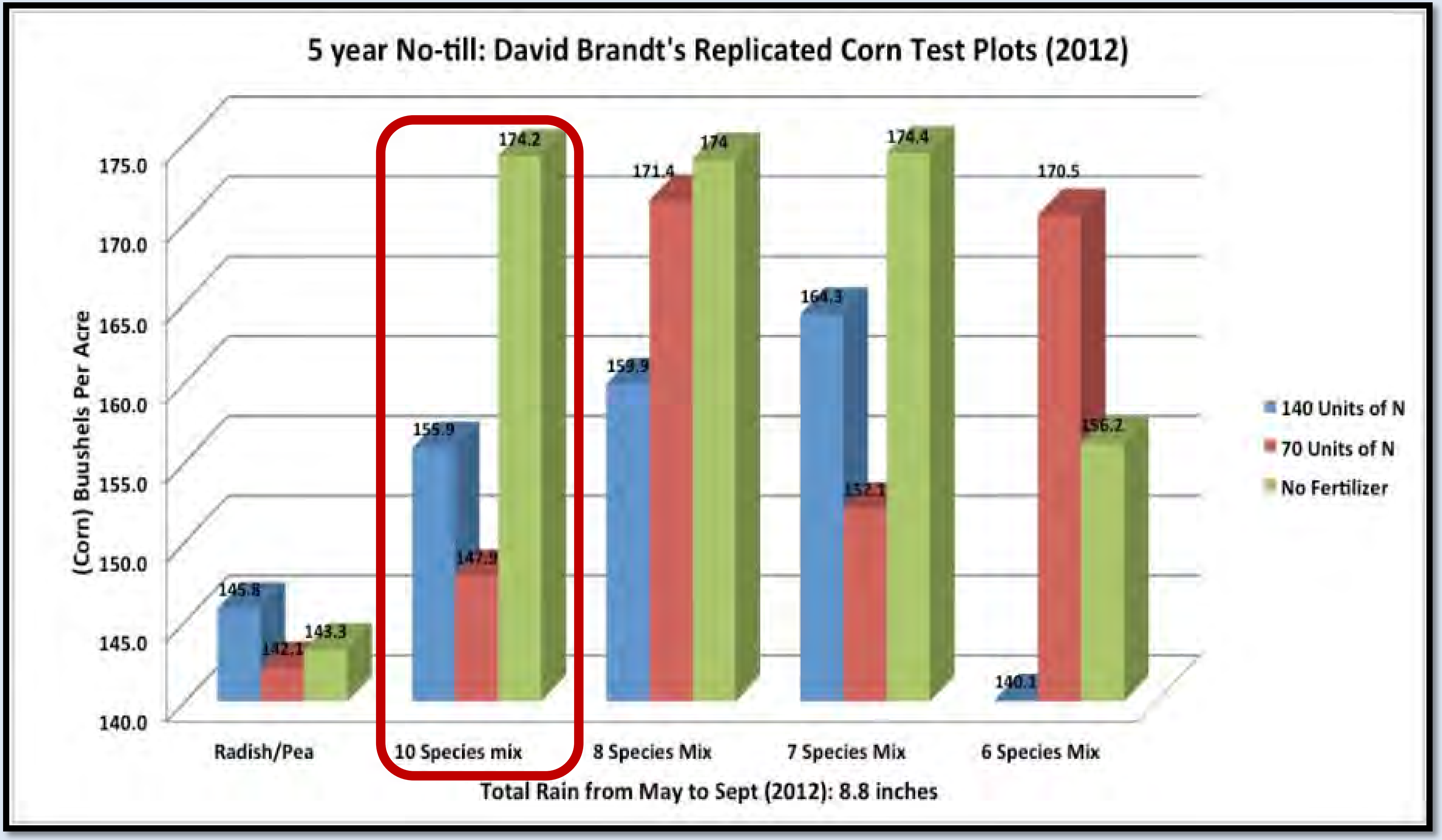
In a Humus Rich Soil, Plant obtain all their CO_2 from soil (We want to recycle all nutrients, including CO_2).




No till corn with 8 different cover species and 8 in of rain in 2012
07.11.2012


Conventional Corn with less than 8 in of rain in 2012
07.11.2012

1 Year of Data From 2012



2009- NT, peas, then cc mix, 2010- NT corn; board thought they could never get beyond 1/3 summer fallow
The Menoken Farm, Power of Crop Diversity, Both Sides were Planted into Last Year's Cover Crop Residue
Can we build soil health faster than we think? This was a degraded site!

What do these farmers and ranchers have in common?

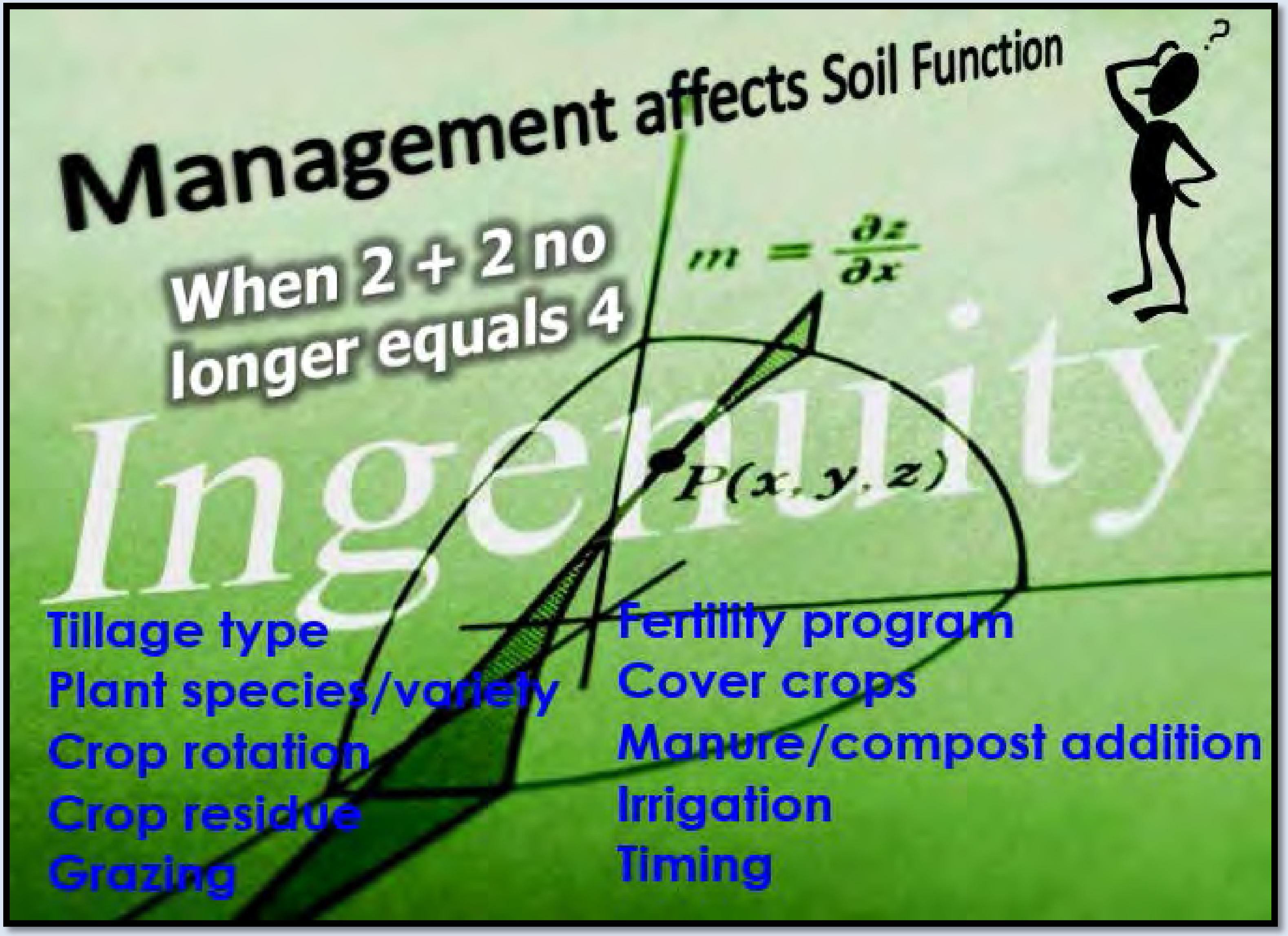
These farmers and ranchers farm and ranch in natures image!
What does this mean? Natural systems are always covered with diverse living plants, soils are never tilled (low physical disturbance), A living root is growing in the soil as long as possible. They have a different view of the soil. They understand that the soil is a living soil ecosystem.....a habitat for soil organisms.

Jonathan Cobb, Texas – implemented the use of no-till and cover crops. Integrated livestock back onto the farm.

Ray Styer (Reidsville, NC) Farms 155 acres. He has not used chemical fertilizer (nitrogen and phosphorous) in 16 years. Demonstration Soils come from his farm.

Gabe Brown (Bismarck, ND) grows corn at a $1.51 a bushel. He has eliminated chemical fertilizer (nitrogen and phosphorous) on his 2000 acres of crop land and he ranches 4000 acres. He has reduced his herbicide usage by 75 percent and has reduced his fuel usage by 66 percent.

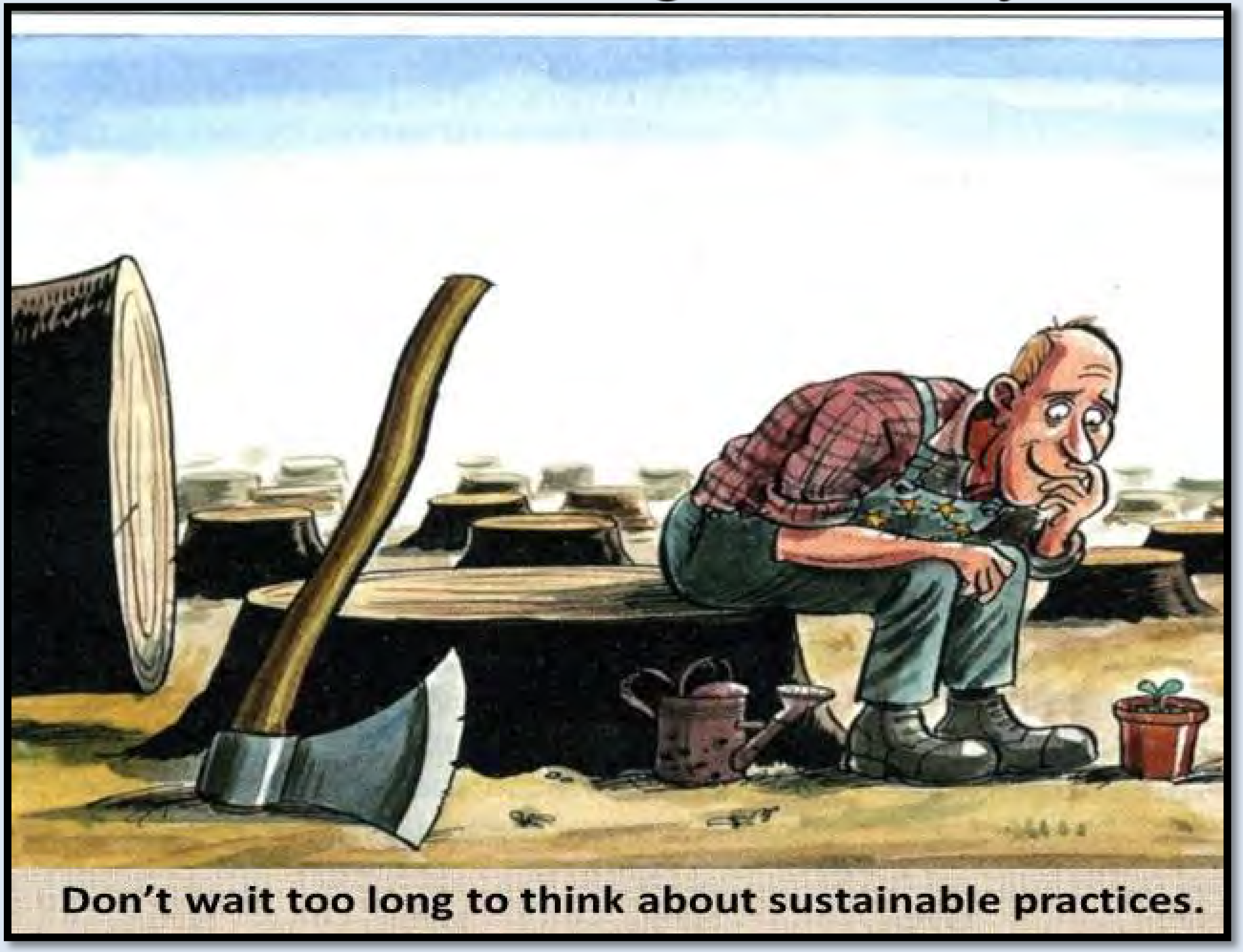
Dave Brandt: (OUR HOST) Corn-Soybean-Wheat farmer from Carroll, OH has been using no-till and cover crops since the 1970's, had been using a split row planter to seed a row of tillage radish and a legume, has incorporated multi-species cover crops into his system in the last few years.



The biological approach is still an important practice for those who use chemical fertilizers and intensive tilling. As described previously, the addition of biology to the system prevents loss of added nutrients, reducing the amount of chemical fertilizer needed each year.

Movement of biology in the soil also improves texture, reducing the need to till soil and the fuel costs related to these practices.

Soil Health Management Systems



Soil Health Management Systems – **managing cropland to enhance the Soil's Health – use of conservation practices/agronomic practices to improve the capacity of the soil to function – to provide vital ecosystem functions – It is more of a Proactive Approach rather than a Reactive Approach to farming problems**. Use of Cover Crops plays an integral role in creation of soil structure which leads to greater water holding capacity and not to mention nutrient cycling (along with addition of Nitrogen from legumes and added Phosphorus from Mycorrhizal Fungi).

We have made our soil "leaky"

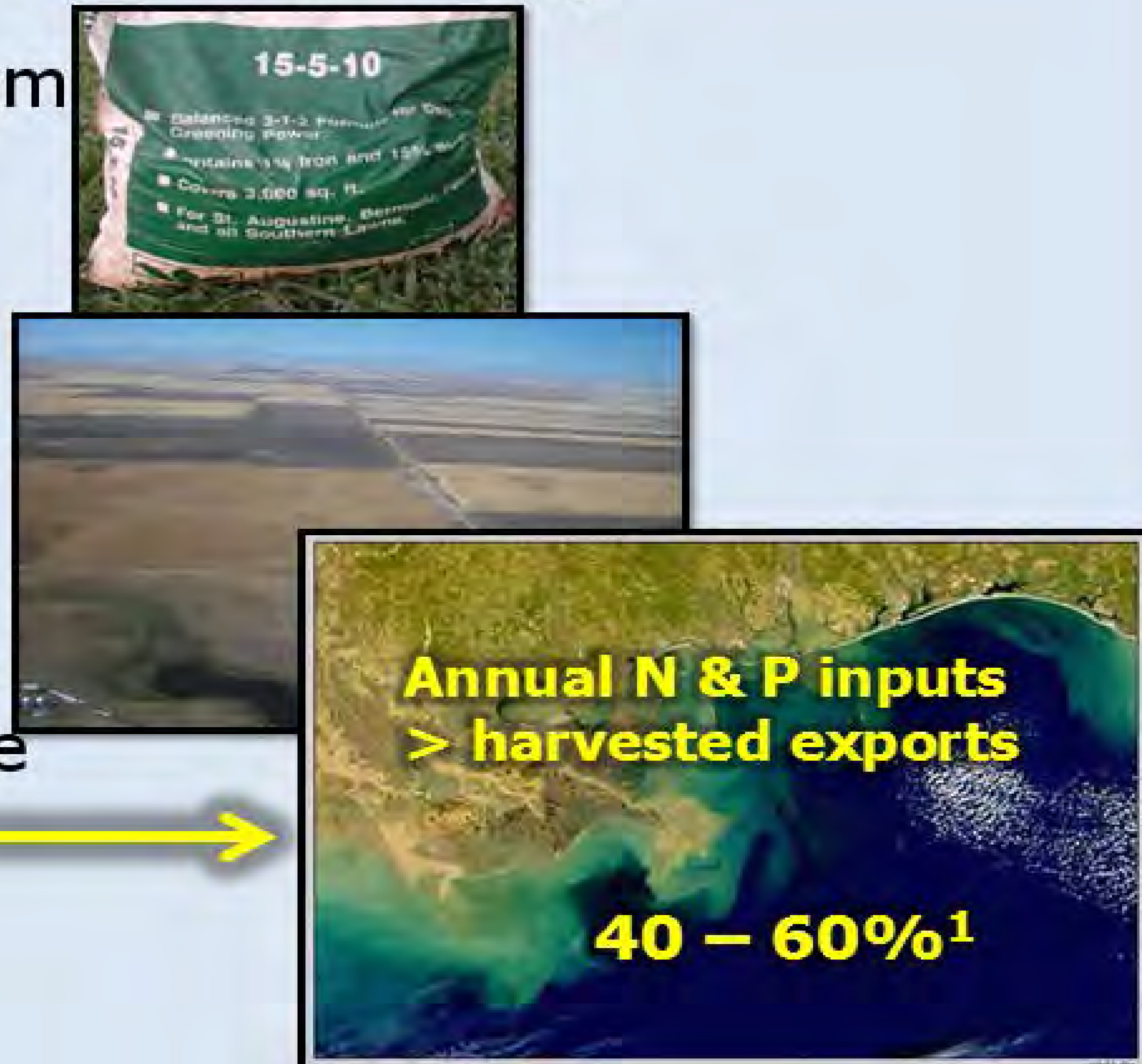
Chemistry paradigm

↓

Simplified cropping system

↓

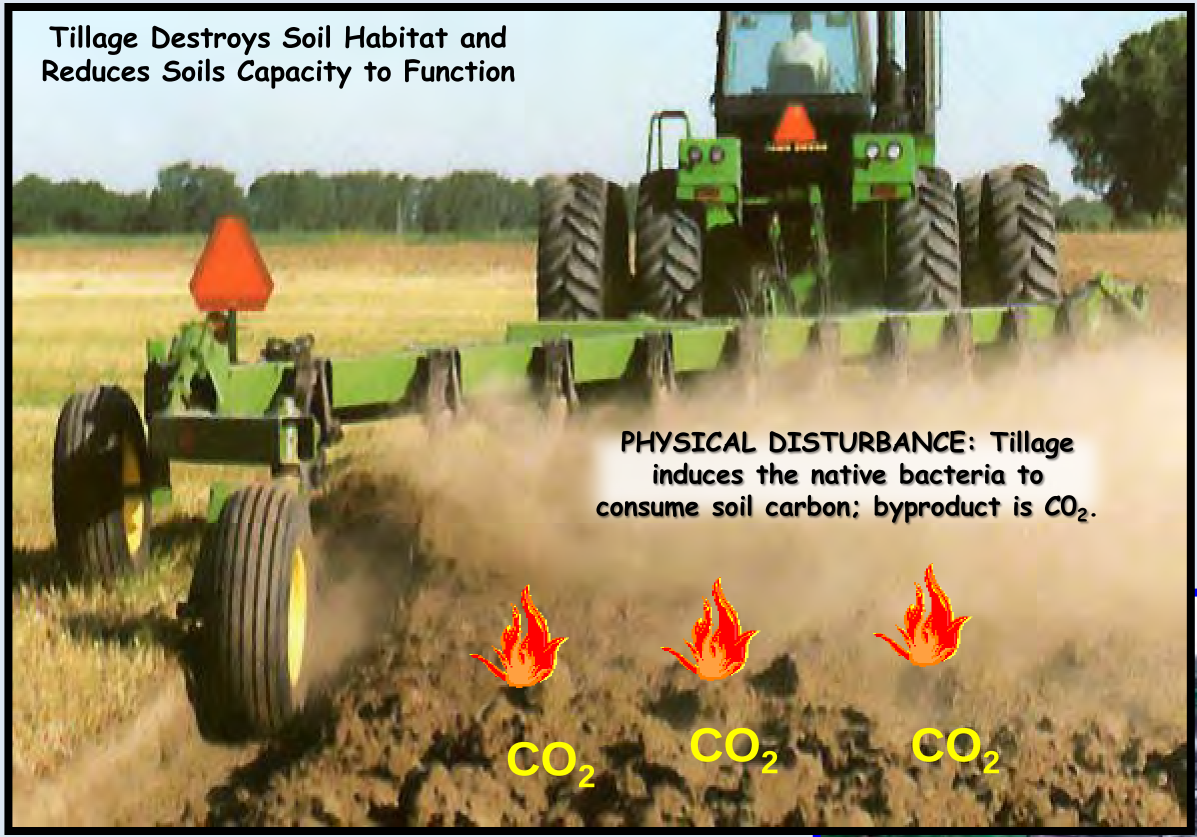
Maximize nutrient saturation in space & time →



Any guesses to how much we're losing in nutrients? After 30 years of concentrated effort. . .inputs consistently exceed harvested exports by 40-60%!!! >>>> substantial losses.

1- (Bolland and Gilkes, 1998; David and Gentry, 2000; Galloway and Cowling, 2002; Van der Molen et al., 1998).

Image: http://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1086025423&topicorder=6&maxto=20&minto=1


Tillage Destroys Soil Habitat and Reduces Soils Capacity to Function
PHYSICAL DISTURBANCE: Tillage induces the native bacteria to consume soil carbon; byproduct is CO_2.
CO_2
CO_2
CO_2


Agricultural soils do not have a water erosion/runoff problem, they have a water infiltration problem.


No Till
Conventional Till
Ray the Soil Guy

No. 1 Environmental Enemy in Production Agriculture

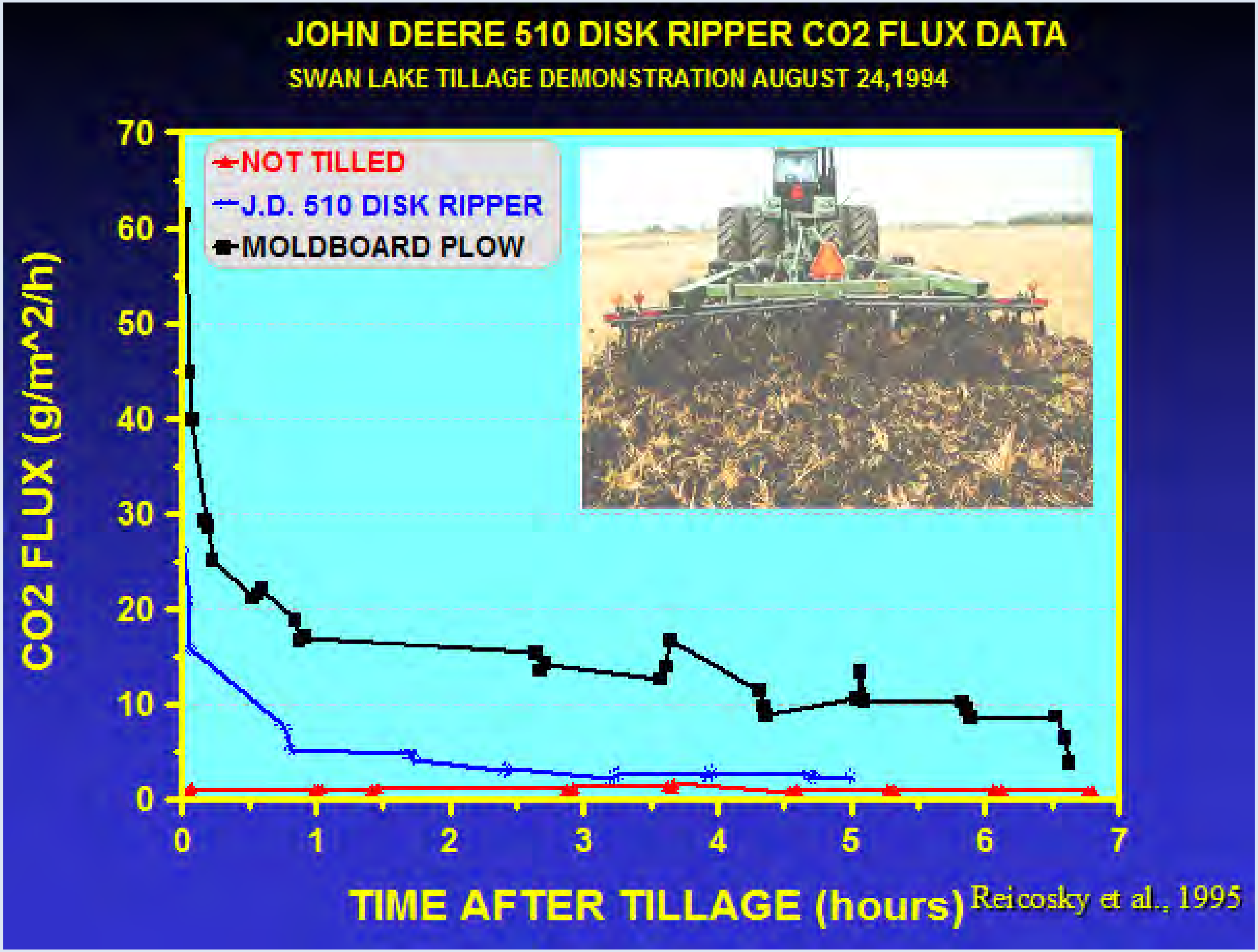
Tillage-induced Carbon Dioxide Loss


Native Soil Root Zone


Cultivated Soil Root Zone

Understands Soil Function !

Does Not Understand Soil Function!



Work completed by Dr. Reicosky Soil Scientist, USDA ARS NC Soil Conservation Research Lab Morris MN

Work shows the release of CO_2 within 7 hours after tillage was done

- Plowing had a high initial flux and the rapid decline to a higher value than NT or conservation tillage tool
- Conservation tillage tool has high initial flux that approaches the NT treatment.
- No-till is very low near the zero line

Carbon degradation leads to nutrient problems.

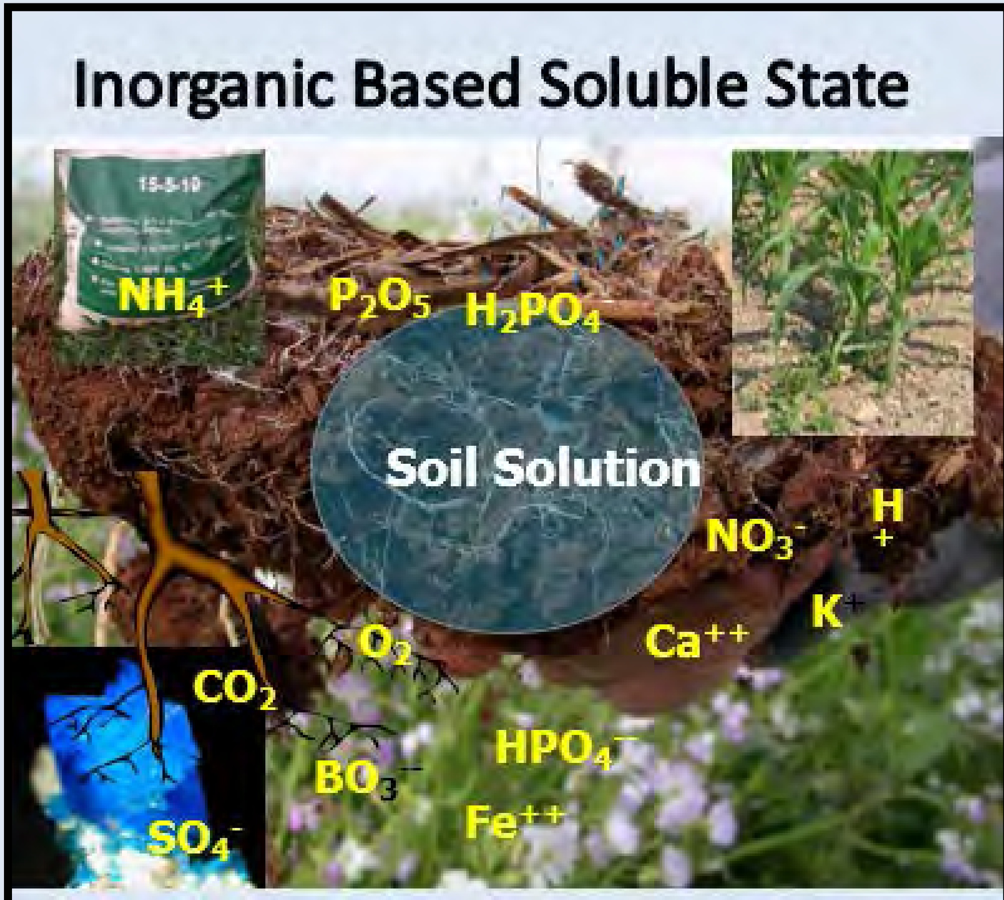
P. DIEDERICH/NYT/REDUX/EYEVINE

Phosphate is mined to produce fertilizers for crops, but phosphorus leaching into water supplies is an environmental hazard.

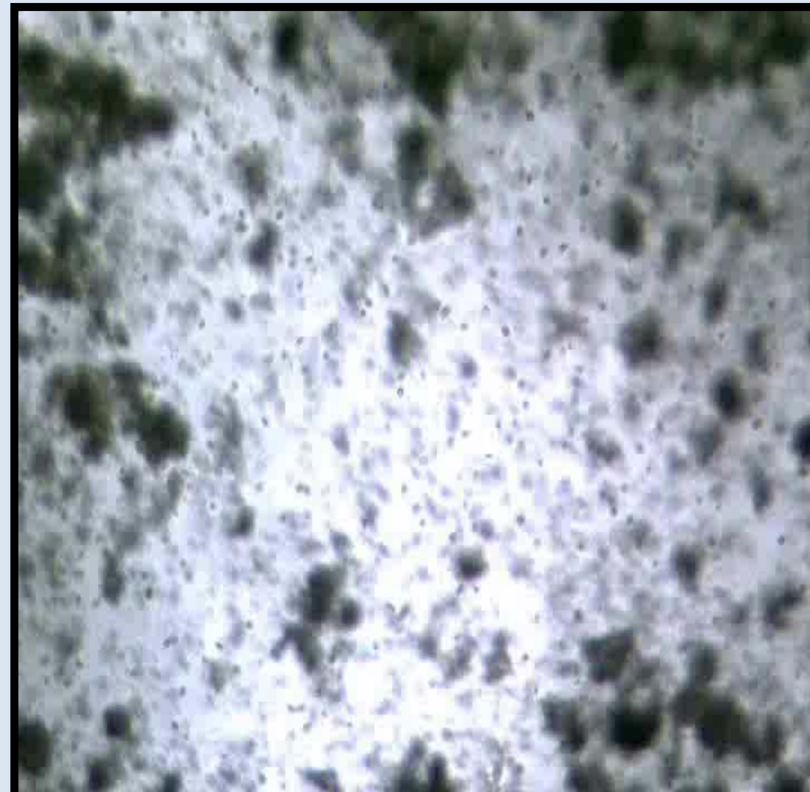
A broken biogeochemical cycle

Excess phosphorus is polluting our environment while, ironically, mineable resources of this essential nutrient are limited. **James Elser** and **Elena Bennett** argue that recycling programmes are urgently needed.

P- also issues with- possible future shortage, yet there is an excess in the Mississippi?



Ecologically Based

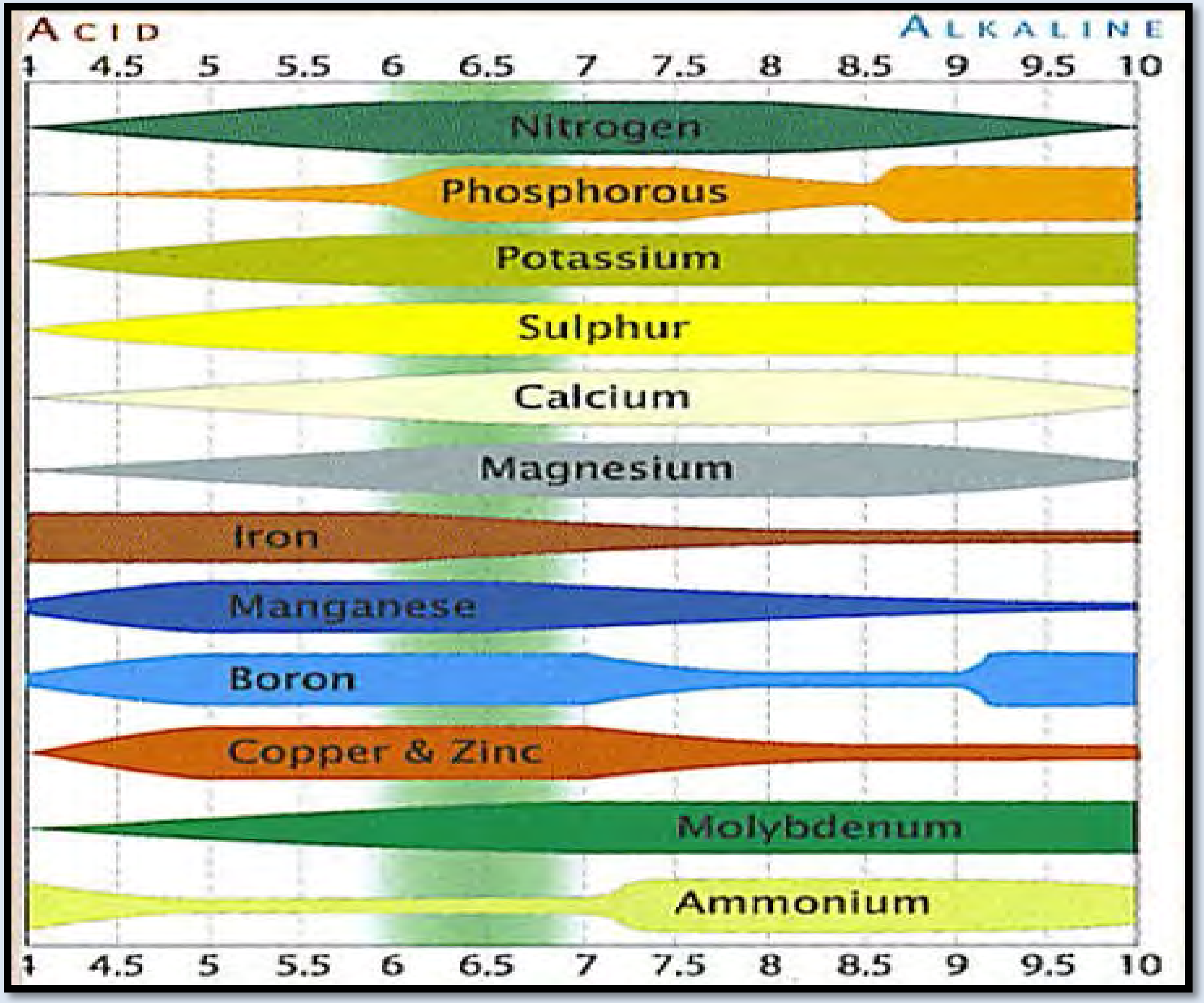


- 40 to 60 % N and P Loss Cassmen 2002
- Bare fallows 4-8 months
- Decoupled C,N,P cycle

- Organic-mineral pools
- Microbially plant mediated process
- Strategic use of variable nutrients sources

Soil the black box: There are many things that interact with soil solution.
Plants absorb nutrients from soil solution and extrude H+, OH- and HCO3-.
Soils exchange cations with soil solution. Minerals release nutrients into soil solution.
OM releases nutrients to soil solution through mineralization.
Roots both living and dead exchange CO_2 & O_2 with soil solution.
Nutrients can be added to soil solution by artificial fertilizer and rain water.

The soil is NOT a chemistry set or the black box.



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

Beneficial organisms in soil are very important for nutrient retention and prevention of leaching.

Plants also provide microbes with the source of energy (food in the form of sugars, proteins and carbohydrates) to perform chelation. These energy/ foods are provided in the plant roots, on leaves, and all plant surfaces.

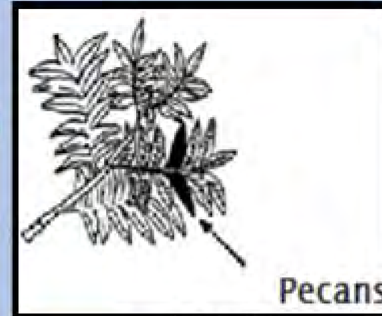
Chelated forms of nutrients are immediately available for plant uptake. Nutrient additions can be reduced in a biological system because nutrients are not lost as a result of leaching, and the nutrient cycling process is more efficient than in inorganic, saltbased systems. – Everything occurs around the root!

Rollins Ph.D., Carole Ann; Ph.D. Carole Ann Rollins; Ph.D. Elaine Ingham (2006-05-01). Adding Biology for Soil and Hydroponic Systems (Kindle Locations 278-280). Environment Celebration Institute. Kindle Edition.

Nutrient Management: Irrigation Water, Soil & Plant Tissue Analysis for Pecan)

Pecan Plant Tissue Analysis:

- N = 2.66% Optimum: Sufficiency Range: 2.49 – 2.8%
- P = 0.12% Optimum: Sufficiency Range: 0.11 – 0.3%
- K = 0.95% Optimum: Sufficiency Range: 0.74 - 1.25%
- S = 0.22% Optimum: Sufficiency Range: 0.19 - 0.4%
- Ca = 1.21% Optimum: Sufficiency Range: 0.89 – 1.5%
- Mg = 0.31% Optimum: Sufficiency Range: 0.29 - 0.6%
- Zn = 58.22 ppm Optimum: Sufficiency Range: 49 – 100 ppm
- Fe = 135 ppm Optimum: Sufficiency Range: 49 – 300 ppm
- Mn = 58.1 ppm Low: Sufficiency Range: 99 - 800 ppm
- Cu = 5.8 ppm Low: Sufficiency Range: 9 – 30 ppm
- B = 105.4 ppm High: Sufficiency Range: 29 – 45 ppm
- Na = 0.02% Optimum: Sufficiency Range: 0 – 0.1%



- Sample at Midseason
- Sample midshoot leaflets/leaves
- Sample #: 25 – 60

Soil Analysis:

- Organic Matter = 0.6% (Low)
- Nitrogen Mineralized = 12.0 lbs./ac.
- Nitrate-N = 8.55 lbs./ac. (Low)
- Phosphorus = 5.0 ppm (Low)
- Potassium = 122.0 ppm (Low)
- Sulfate-S = 20.7 ppm (Adequate)
- Calcium = 2,948.0 ppm (High)
- Magnesium = 187.0 ppm (Low)
- Zn = 0.4 ppm (Low)
- Iron = 4.6 ppm (Low)
- Mn = 4.2 ppm (Low)
- Cu = 0.6 ppm (Adequate)
- B = 0.4 ppm (Low)
- Sodium = 2.6% of total CEC (good)

Irrigation is by micro-sprinkler and subsurface drip (These fields were previously flood irrigated).

Water Quality Analysis Pounds per Acre:

- Nitrate-N = 12.2
- Potassium = 89.5
- Sulfate-S = 490.0
- Calcium = 591.0
- Magnesium = 146.2
- Sodium = 592.0
- Chloride = 783.0
- Bicarbonate = 1,911.4
- Carbonate = 26.1
- Iron = 9.3
- Mn = 0.22
- B = 1.31

Total Salts = 5,640.2

Dysfunctional Soil

Solution is **NOT** to pile on more inputs, or wait for the next "silver bullet" technology (RR crops, 2,4-D res. crops, slow release N)- there are almost always unintended consequences to this approach. **Herb. Resistant weeds-** coming your way if you don't have them yet. Remember sitting in a seminar at Cornell (early 2000s)- speaker wasn't worried about HR weeds- says they take a long time to develop.

We need to change how we think about the soil!

Instead enhance ecosystem function – Carbon Cycle, Soil Food Web, Water Cycle and Nutrient Cycle.

Leaky Soils

- Soil ecosystem is overwhelmed
  - Cannot process or store added nutrients
  - Is dependent on chronic additions of fertilizer
  - "Fertilizer treadmill"
- **A problem of carbon (C)**
  - **Microbial assimilation of N and P is C limited**
  - **C, N & P cycles have become decoupled**
  - **Increased biomass, but not C**

C, P, & N cycles are disconnected- in nature they are connected. The microbial community (carbon) is what mediates/processes P & N- cycling, makes them available to plants. We thought we could bypass the microbes! We can, but it costs!

Ironic that we're spending money on fertilizer efficiency products when a healthy, functioning soil is the most efficient system out there!

Fertilizer Impact

Fig.2. The two wheat plants on the left were grown with perennial grasses in a Pasture Crop treatment while the wheat plant on the right was grown in adjacent bare soil, amended with 100kg/ha DAP.

The application of large quantities of inorganic N—such as found in urea, MAP, DAP etc.—inhibits the activities of both associative diazotrophs (nitrogen fixers) and mycorrhizal fungi (phosphorus). Long-term use of these products results in a decline in soil structure, decline in soil carbon—and ironically, a decline in soil nitrogen (Khan et al 2007, Mulvaney et al 2009).

Phosphorus inhibits the production of strigolactones – these are plant hormones that promote root growth and elongation.

Where diverse summer cover crops are being grown to support soil microbial communities, it is advisable to reduce N use, but this must be done slowly, to provide time for free-living N-fixing bacteria to re-establish. There is no need for synthetic N in the cover crop provided a variety of broadleaved plants, including legumes, are present.

Remember freeliving N-fixing bacteria and mycorrhizal fungi (needed for N transfer to plants) have only one energy source—liquid carbon from an actively growing green plant.

At the same time as you are weaning your soil off synthetic N you must also be maintaining as much diverse year-round living groundcover as possible.

Adding fertilizer is like. . .

Getting pizza delivered for 365 days, all on 1 day!. You're happy for 1, 2, 3 days, but. . . there will be waste!

Predicting when plants will need N, P, K etc. is about impossible.

Healthy soil has a "second by second" delivery system. But soil the foodweb knows.

Mulvaney- i) soil N not accounted for, ii) fert. form, placement, timing- hard to synchronize w/soil and crop N dynamics

Paradigm Shifts

- Prior to 1940s/1950s- Ecological paradigm
  - Fertilizer seen as a *supplemental* nutrient source
  - Understand & manage soil biology
  - Maintain SOM
  - Plant diversity
    - Legumes part of rotations- clover in 19th century
  - Long-term experimentation
  - Integrated crop-livestock systems

Drinkwater, L.E. & S.S. Snapp. 2007. Nutrients in Agroecosystems: Rethinking the management paradigm. Advances in Agronomy. 92:163-186.

"A Plant that Changed the World: the rise and fall of clover 1000-2000" (Thorkild Kjaergaard, Landscape Research, vol. 28, No. 1, 41-49, 2003) – **clover made it possible to feed growing populations by providing N to grain crops.**

Joel Salatin- "Normal farms have animals."

Agricultural Year Book – "Soils and Men" – 1938 – Lots of discussion of how biology influences the chemical and physical aspects of the soil.

The basic difference between ecological systems and chemical systems is that ecological (organic/biological) systems require carbon (meaning sugars, proteins, etc.) , that's processed by organisms, while inorganic (chemical) systems attempt to provide all the nutrients needed in inorganic forms. Eventually, chemical systems flounder – mainly because no single species of plant can provide or sustain needed carbon/nutrients to maintain soil function. Many times our monoculture cropping systems become Carbon limited –

How are we doing?

- Conclusions
  - “. . .little consistent progress. . .in reducing. . .nitrate since 1980.”
  - “. . .[nitrate] concentration. . .increasing in some parts of the basin.”
- ***28 years of no progress, despite conservation efforts?***

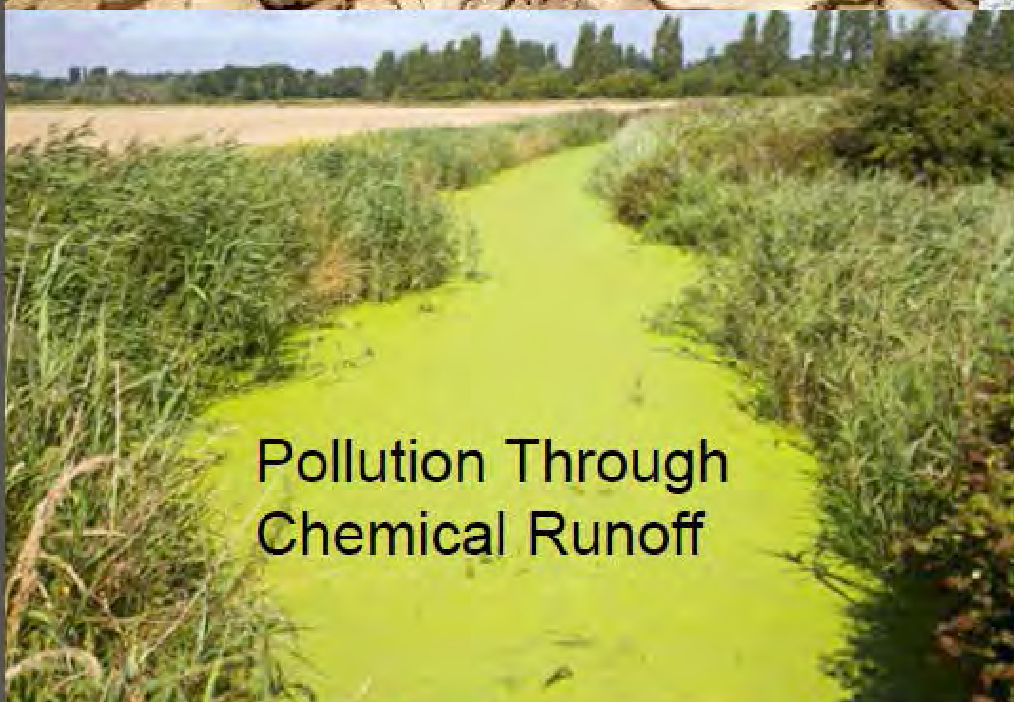
Recently, this research was cited by Sen. Tom Harkin at a 2012 Farm Bill hearing where (former) Chief Dave White testified.

Sprague, et al 2011

Environmental Problems

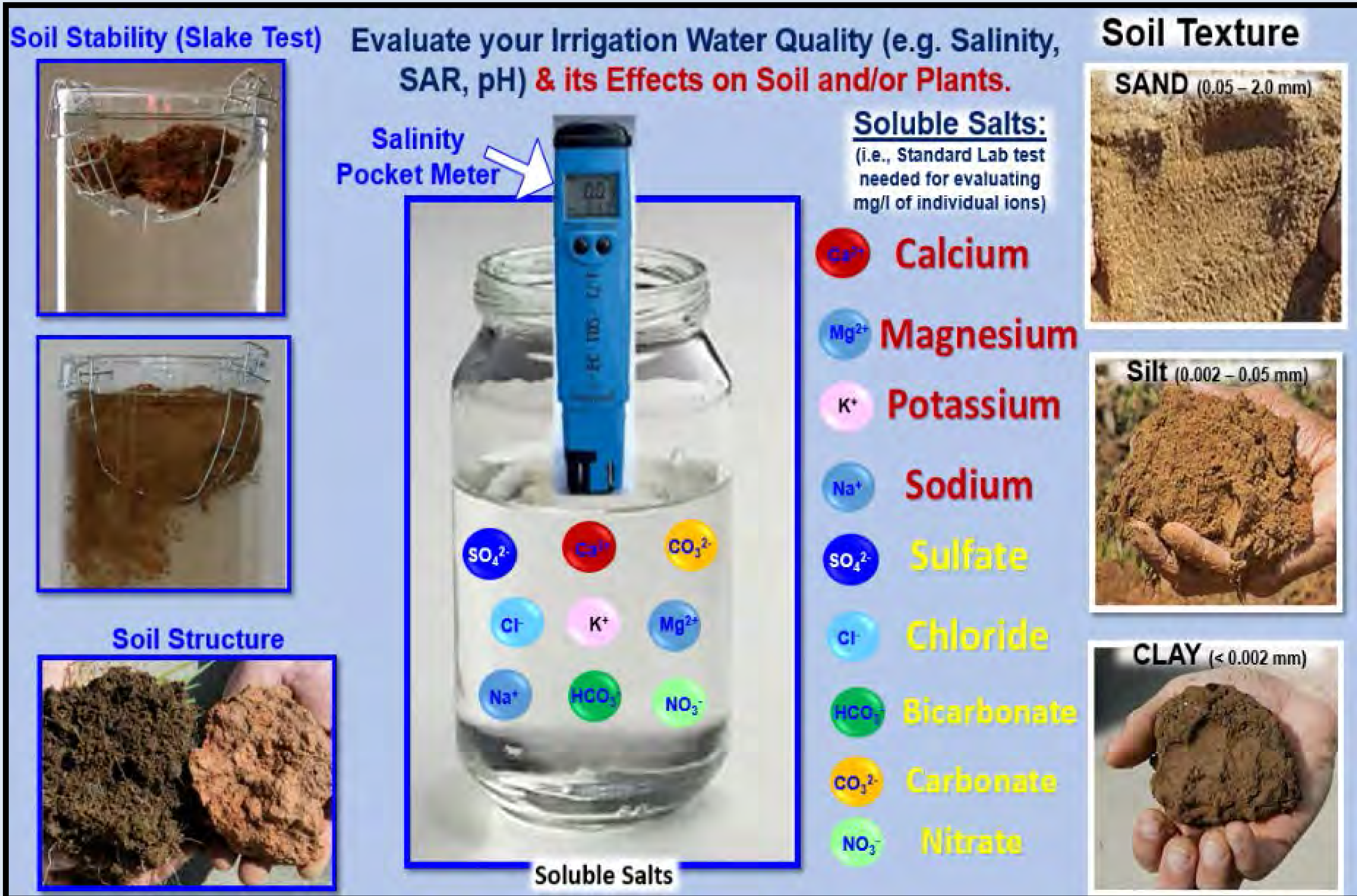
- *Nitrate in the Mississippi River and Its Tributaries, 1980 to 2008: Are We Making Progress?**
  - Changes in nitrate concentration, 1980 - 2008

Sprague et al 2011 (Environmental Science & Technology)



David C. Johnson- NMSU Institute for Sustainable Agricultural Research (ISAR)
davidcjohnson@nmsu.edu

New Mexico State University


Soil Stability (Slake Test)
Evaluate your Irrigation Water Quality (e.g. Salinity, SAR, pH) & its Effects on Soil and/or Plants.
Soil Texture
SAND (0.05 – 2.0 mm)
Salinity Pocket Meter
Soluble Salts:
(i.e., Standard Lab test needed for evaluating mg/l of individual ions)
Ca^{2+} Calcium
Mg^{2+} Magnesium
K^+ Potassium
Na^+ Sodium
SO_4^{2-} Sulfate
Cl^- Chloride
HCO_3^- Bicarbonate
CO_3^{2-} Carbonate
NO_3^- Nitrate
Silt (0.002 – 0.05 mm)
CLAY (< 0.002 mm)
Soil Structure
SO_4^{2-}
Ca^{2+}
CO_3^{2-}
Cl^-
K^+
Mg^{2+}
Na^+
HCO_3^-
NO_3^-
Soluble Salts

Paradigm Shifts

- After 1940s/1950s- Chemistry paradigm
  - Only need fertilizer to support high yields
    - No need for diverse rotations
    - No need for adding organic amendments
  - Short-term experimentation
  - Focus on soluble inorganic N and P
    - P, nitrate tests
  - Biological to chemical

Drinkwater, L.E. & S.S. Snapp. 2007. Nutrients in agriculture: Rethinking the management paradigm. Advances in Agronomy. 92:163-186.

Low cost synthetic fertilizers made diverse farming “unnecessary” and made specialized farming more economically attractive (but ecologically simple- which nature will try to fix! – why we get weeds).

We lost crop diversity and animals!

Soil Biology changed within these cropping systems (Govt. crop subsides/**insurance** subsidies and policy have not helped- encourages corn, soybeans, cotton – continuous monocultures) **Nutrient recycling became biologically unnecessary b/c of 1909- Haber-Bosch process = cheap fertilizer**. However, now we are realizing that lack of micronutrients and carbon leads to reduced yields – not about just the application of NPK.

What has this paradigm shift done for us?

- Costs- $
- N Efficiency
- Environmental problems

Ideas have consequences! What you think/believe (about soil/nature) will determine your actions.

The Chemical paradigm, Increases Costs – Decreases N Efficiency – Increases Environmental Problems.

Soil Health Paradigm - Reduced Costs – Enhanced N Efficiency – Prevents Environmental problems.

Soil Microorganisms and Higher Plants (Krasil’nikov)

- **Soil fertility is determined by biological factors, mainly by microorganisms. The development of life in soil endows it with the property of fertility.**
- **Soil is created by microorganisms.**
- **Cannot divorce soil biology from fertility.**
- **"Were this life dead or stopped, the former soil would become an object of geology" (Vi'lyams, 1950, p 204).**

Soviet scientists knew that the soil provides nutrients- “The principal property of soil fertility is determined by biological factors, mainly by microorganisms.”

Agricultural Year Book – “Soils and Men” – 1938 – Lots of discussion of how biology influences the chemical and physical aspects of the soil.

This was published in 1958. Lots of our soils are objects of geology, propped up by inputs.
http://www.soilandhealth.org/01aglibrary/010112Krasil/010112krasil.intro.html

Without microbes you’ve got moon dust. Can’t do anything about the geology.

Impacts of Synthetic N on Soil

- **Current paradigm:**
  - Add N to compensate for N taken out in crop.
  - Nutrient budgets (NRCS 590 standard, most land grant universities)
  - Synthetic N builds up soil C and N reserves- maintains soil fertility
  - Soil N does not decline when fertilizer supplies more N than crop takes out

Does a crop receive most of its' nutrients directly from fertilizer? NO.

Microbes get most of it first, then plants get it.

About 30% can also be lost- leaching, runoff, etc. Fertilizer is about 30-40% efficient.

Impacts of Synthetic N on Soil

- ***Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production***
  - **Mulvaney et al 2009, Journal of Environmental Quality.**

Title! See also: "The Myth of Nitrogen Fertilization for Soil Carbon Sequestration," Khan, S.A., Mulvaney, T.R., and Boast, C.W. Journal of Environmental Quality 36:1821 – 1832 (2007).

Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production
R. L. Mulvaney,* S. A. Khan, and T. R. Ellsworth University of Illinois

The degradation of soil C and N resources necessarily increases reliance on synthetic N fertilization (e.g., Singh et al., 1998), but given the value of organic matter for improving the chemical, physical, and microbial properties of soil, this strategy cannot be expected to maintain current levels of productivity (Cassman et al., 2003; Tong et al., 2003).

Overwhelmingly, **the evidence is diametrically opposed to the buildup concept** and instead corroborates a view elaborated long ago by White (1927) and Albrecht (1938) that fertilizer N depletes soil organic matter by promoting microbial C utilization and N mineralization. An inexorable conclusion can be drawn: The scientific basis for input-intensive cereal production is seriously flawed.

The long-term consequences of continued reliance on current production practices will be a decline in soil productivity that increases the need for synthetic N fertilization, threatens food security, and exacerbates environmental degradation.

Conclusions:

- **“. . .excessive N fertilization has a detrimental impact on FNUE [fertilizer N uptake efficiency] and does not promote soil N storage.”**
- continued reliance on current production practices will be a decline in soil productivity that increases the need for synthetic N fertilization

Mulvaney, et al 2009

Fertilizer treadmill. Soil N declined in fertilized Morrow plots, NOT increased.

Conclusions:

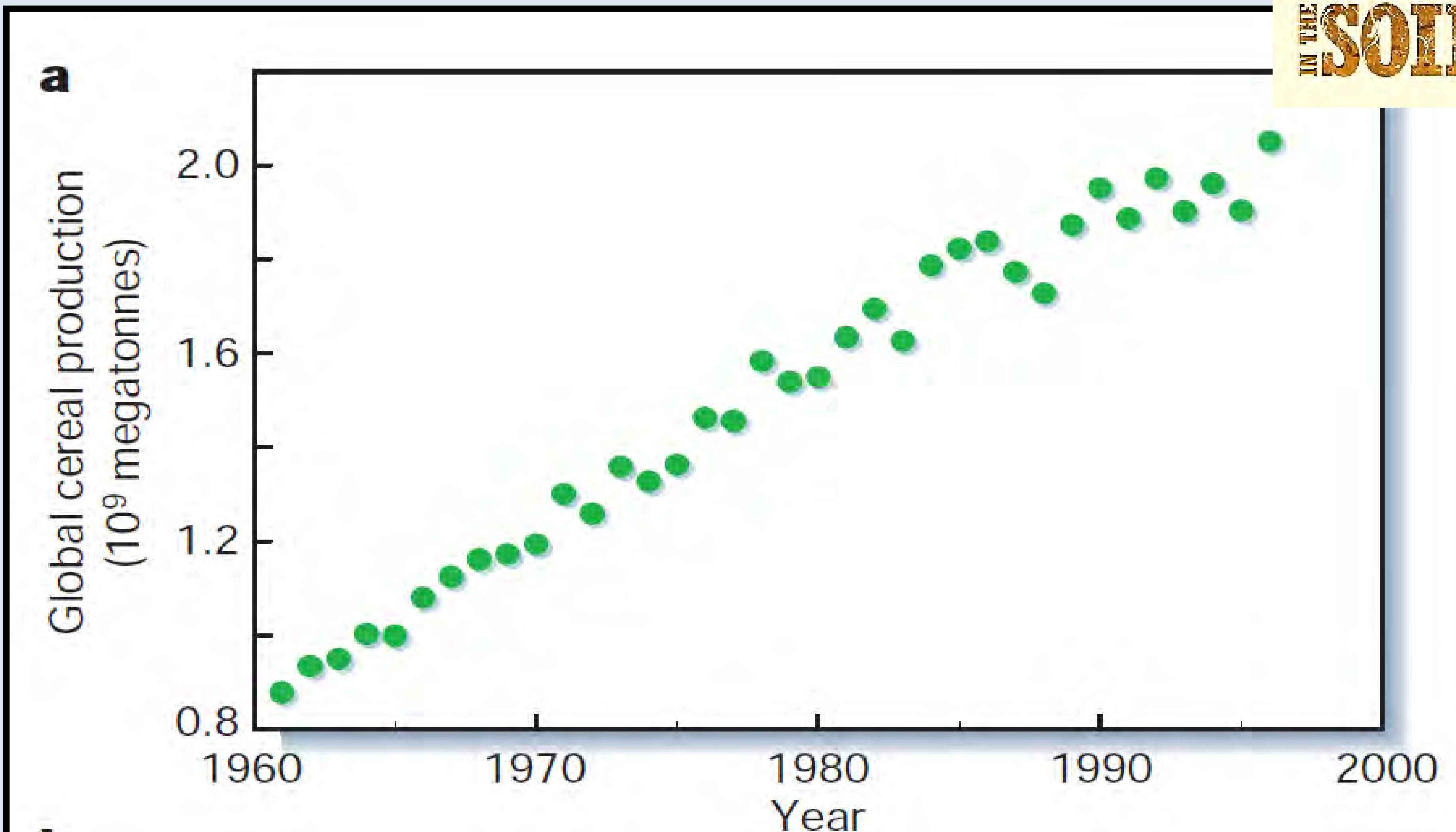
- "Overwhelmingly, the evidence is diametrically opposed to the buildup concept and instead corroborates a view elaborated **long ago by White (1927) and Albrecht (1938) that fertilizer N depletes soil organic matter by promoting microbial C utilization and N mineralization**."

Mulvaney, et al 2009

Notice the cited authors/dates- this was some time ago that this was understood!

We are stoking the fire by adding N- fert. N enhances soil microbes in using C from crop residues or OM = microbial oxidation of residue C and native SOC. Messing with the C:N balance.

Cereal production has doubled

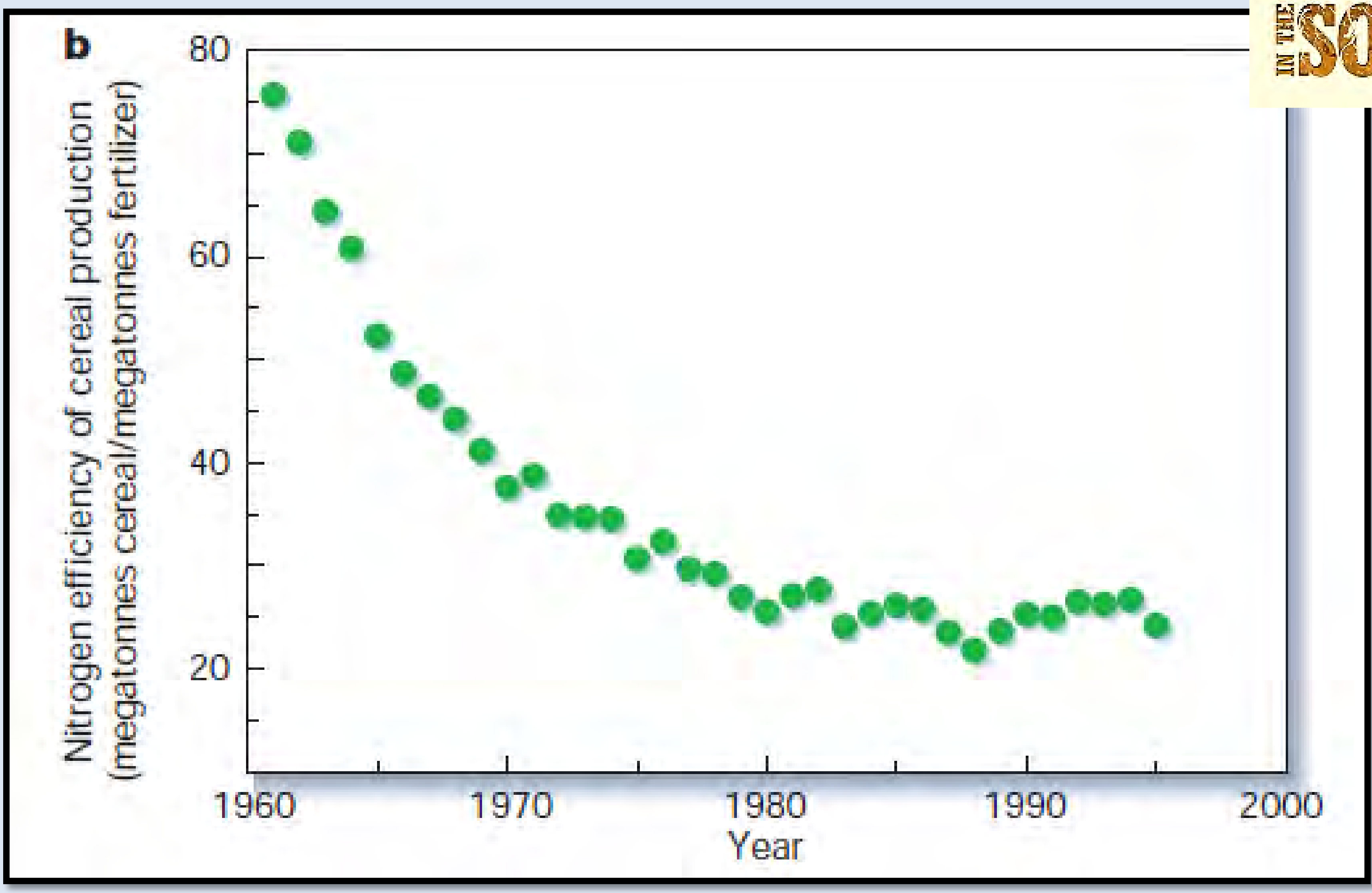


Tilman et al, 2002

But at what cost? N inputs increased to get these yields. **What have those inputs done to the soil?**

Agriculture sustainability and intensive production practices, Nature, vol 418, 8 August 2002

However- N efficiency decreasing



Global numbers. Annual global cereal production divided by annual global application of nitrogen fertilizer.

Tilman et al, 2002

- **Diminishing returns**
  - **66% global decrease in N efficiency**
- **Resource concerns with higher N & P use**
- **<u>What are we doing to the soil?</u>**

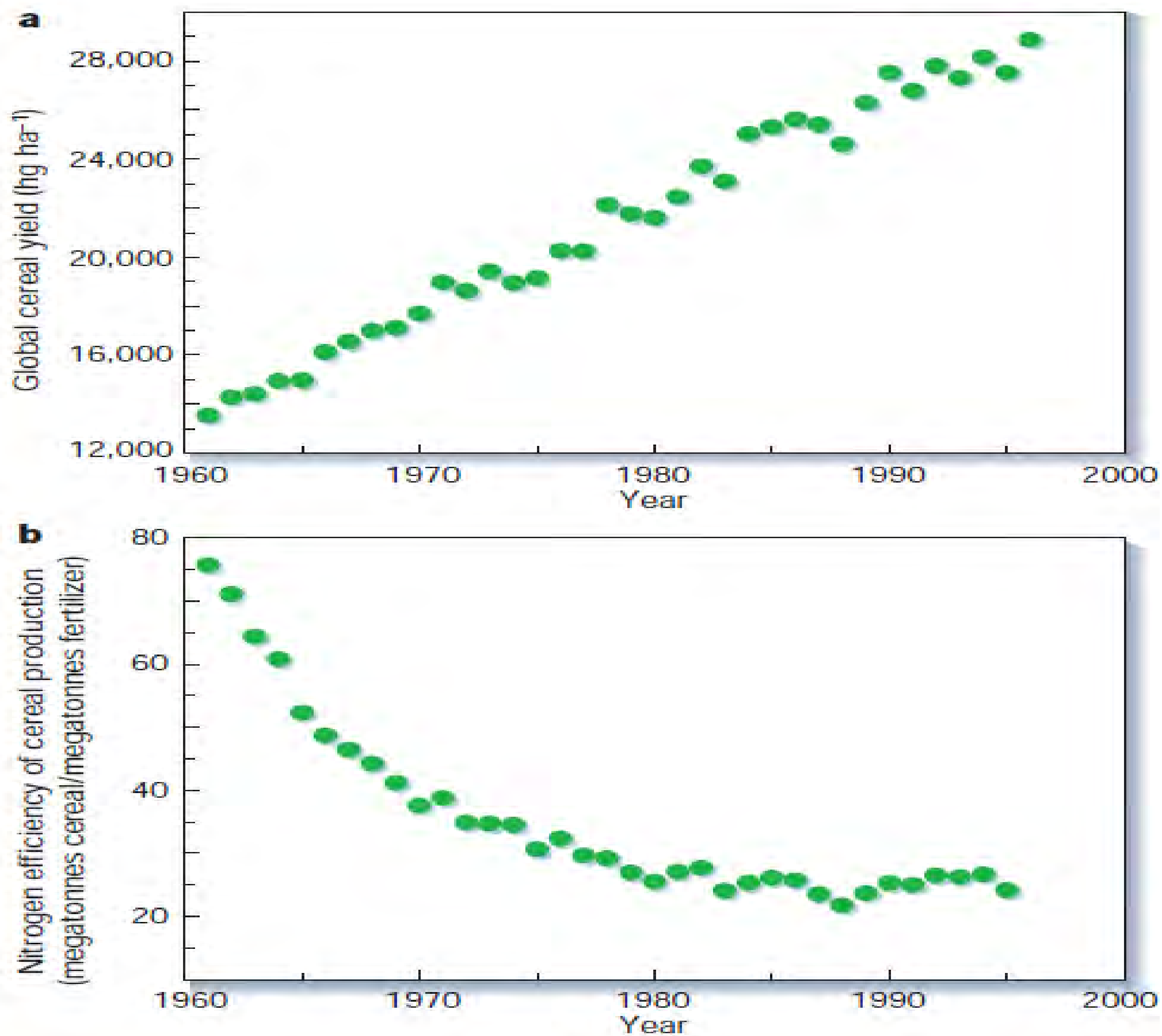


Figure 2 Diminishing returns of fertilizer application imply that further applications may not be as effective at increasing yields. **a**, Trends in average global cereal yields; **b**, trends in the nitrogen-fertilization efficiency of crop production (annual global cereal production divided by annual global application of nitrogen fertilizer)[2].

Tilman et al, 2002

Annual global cereal production divided by annual global application of nitrogen fertilizer.

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

Fertilizer Nitrogen applied Kg/ha (pounds/ac) 	Corn Grain Yield Mg/ha (Bu/ac)	Total N in corn plant Kg/ha (pounds/ac)	Fertilizer derived N in Corn Kg/ha (pounds/ acre)	Soil-derived N in corn, in Kg/ha (pounds/ acre)	Fertilizer-derived N in corn as percent of total N in corn %	Fertilizer-derived N in corn as percent of N applied % 
50 (45)	3.9 (62)	85 (77)	28 (25)	60 (54)	33	56
100 (90)	4.6 (73)	146 (131)	55 (50)	91 (81)	38	55
200 (180)	5.5 (88)	157 (141)	86 (78)	71 (63)	55	43

The majority of inorganic commercial fertilizers are utilized by the soil microbes before it is recycled to the plants.

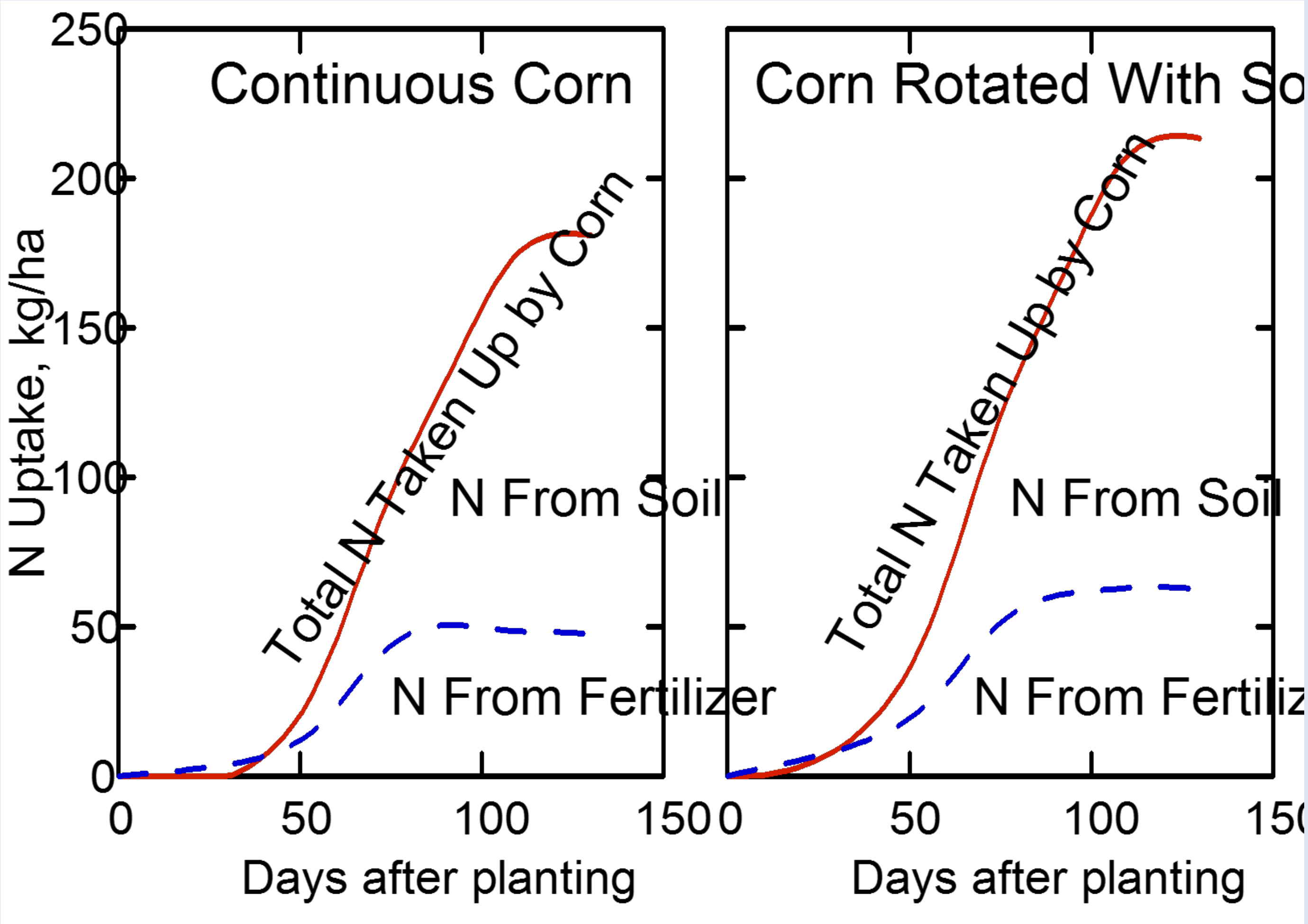
Fertilizer derived N only represents 33% to 55% of the N in a corn plant.

Where does the rest of the N come from? The soil organic matter and the soil microbes. Most of the organic nitrogen comes available later in the growing season as soil temperatures increase and rainfall occurs. So if we can increase our SOM and our soil microbial life, we can increase our soil nutrient efficiency.

What about P? Source of Nitrogen in Corn in North Carolina on an Enon Sandy Loam Soil Fertilized with Three Rates Nitrogen as NH+4-NO-3 (tagged Isotope 15 N))

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

Even where normal rates of fertilizer are used, soil organic matter and rotation residues are the main source of N taken up by corn.



From Omay, et al. 1998. SSSAJ 62:1596-1603

Corn Sample Protein Analysis

No Fertilize 9.1% Protein

Half Rate Fertilizer 8.6% protein

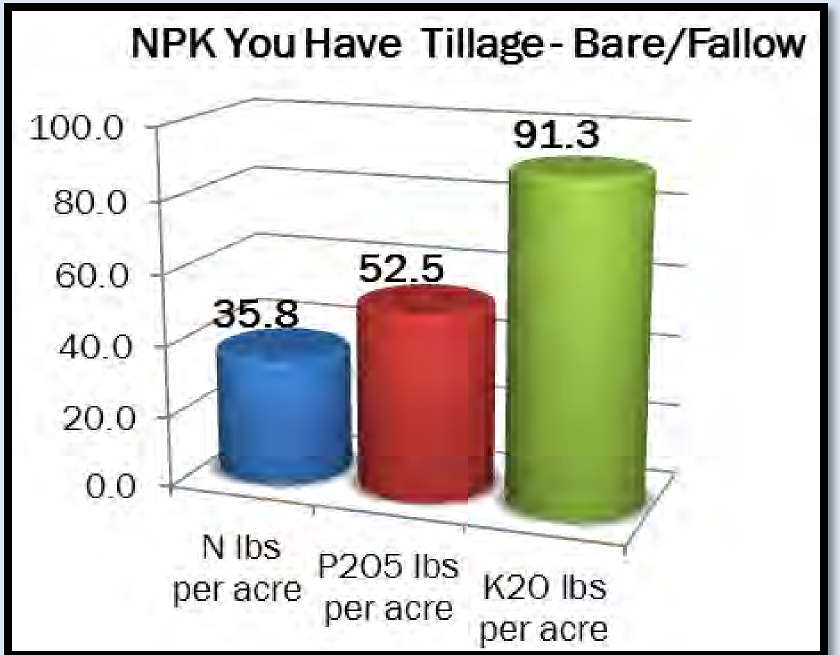
With Fertilizer 7.5% protein

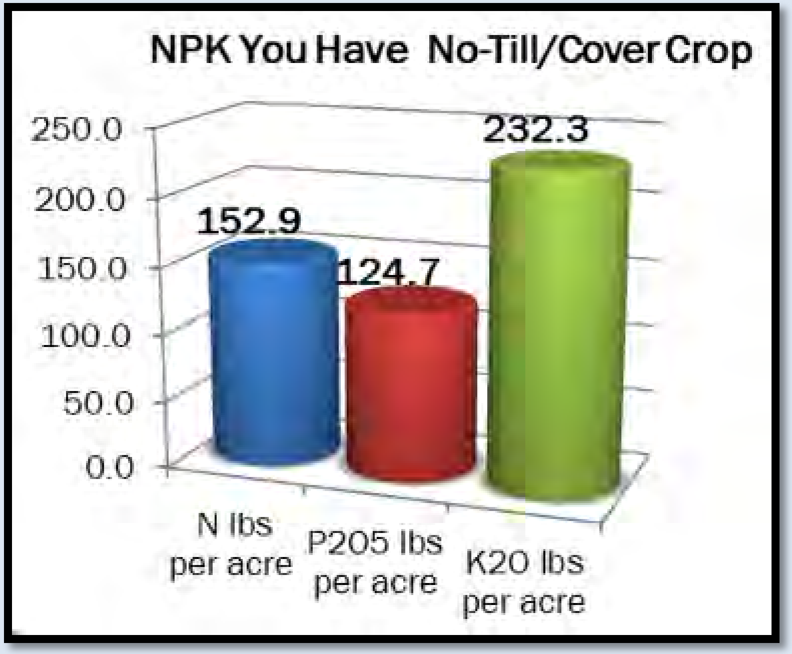
9.1 protein means increasing value of grain by 27 cents= $27/100 bu. of corn…example..100,000 bu. X 0.27= $27,000 dollars….another pickup truck

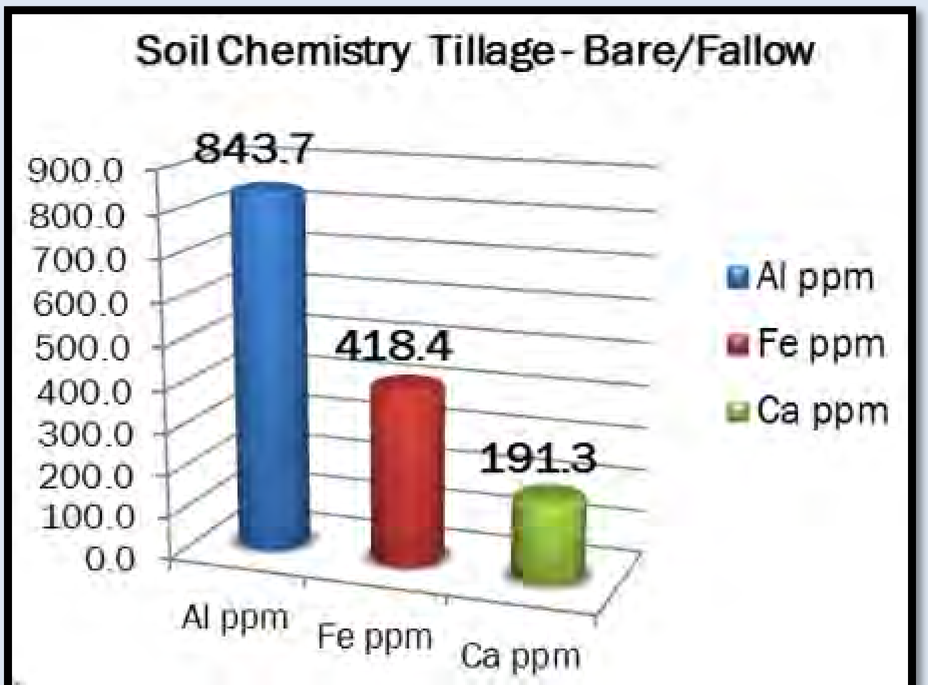
Note higher Protein content where cover crops/no fertilizer was used?

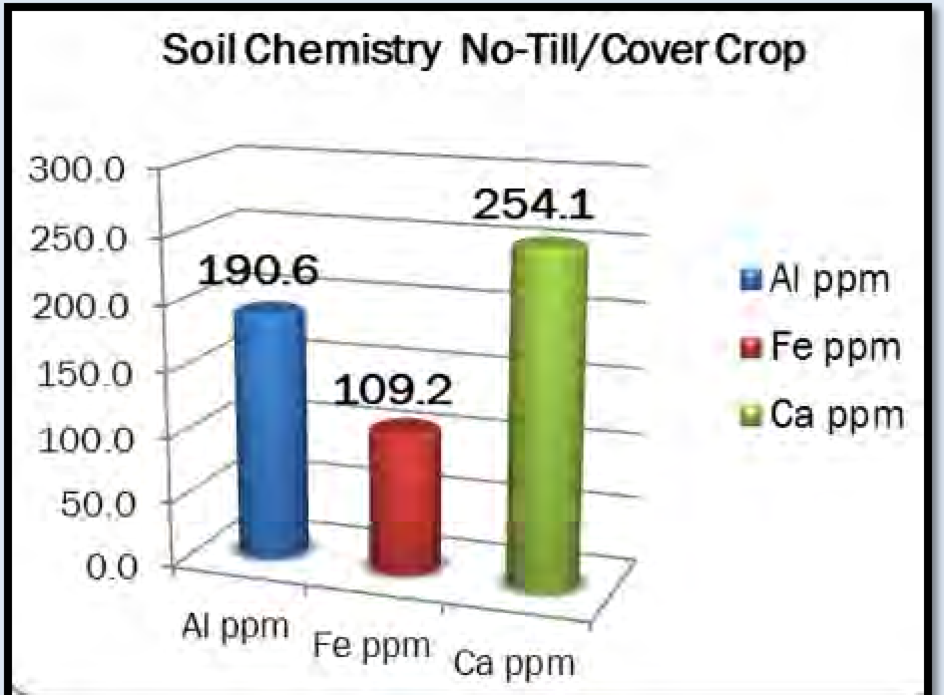
Note higher Protein content where cover crops/ half rate fertilizer used?

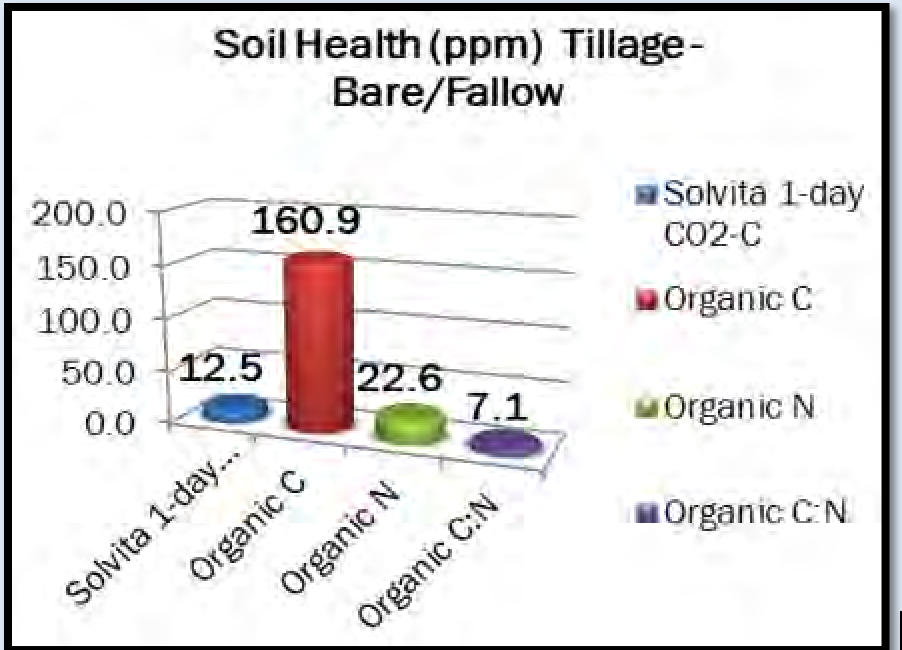
As you transition into cover crops – system goes from being dominated by inorganic nitrogen to pools where organic nitrogen is enhanced – along with diversity and biology.


NPK You Have Tillage - Bare/Fallow
100.0
80.0
60.0
40.0
20.0
0.0
35.8
52.5
91.3
N lbs per acre
P2O5 lbs per acre
K2O lbs per acre

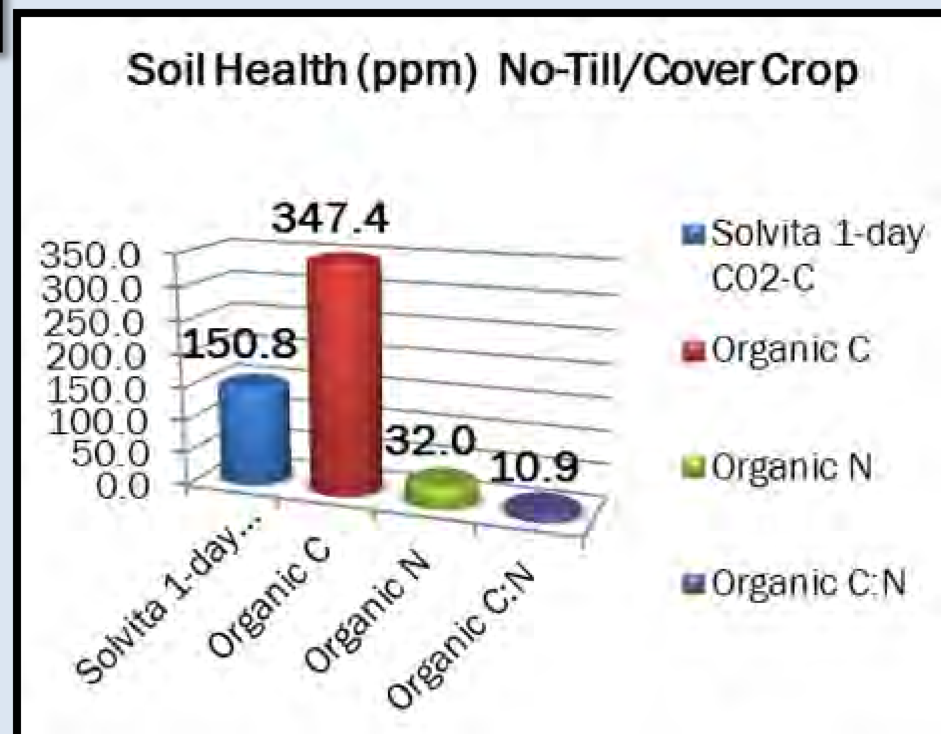

NPK You Have No-Till/Cover Crop
250.0
200.0
150.0
100.0
50.0
0.0
152.9
124.7
232.3
N lbs per acre
P2O5 lbs per acre
K2O lbs per acre


Soil Chemistry Tillage - Bare/Fallow
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
843.7
418.4
191.3
Al ppm
Fe ppm
Ca ppm
Al ppm
Fe ppm
Ca ppm

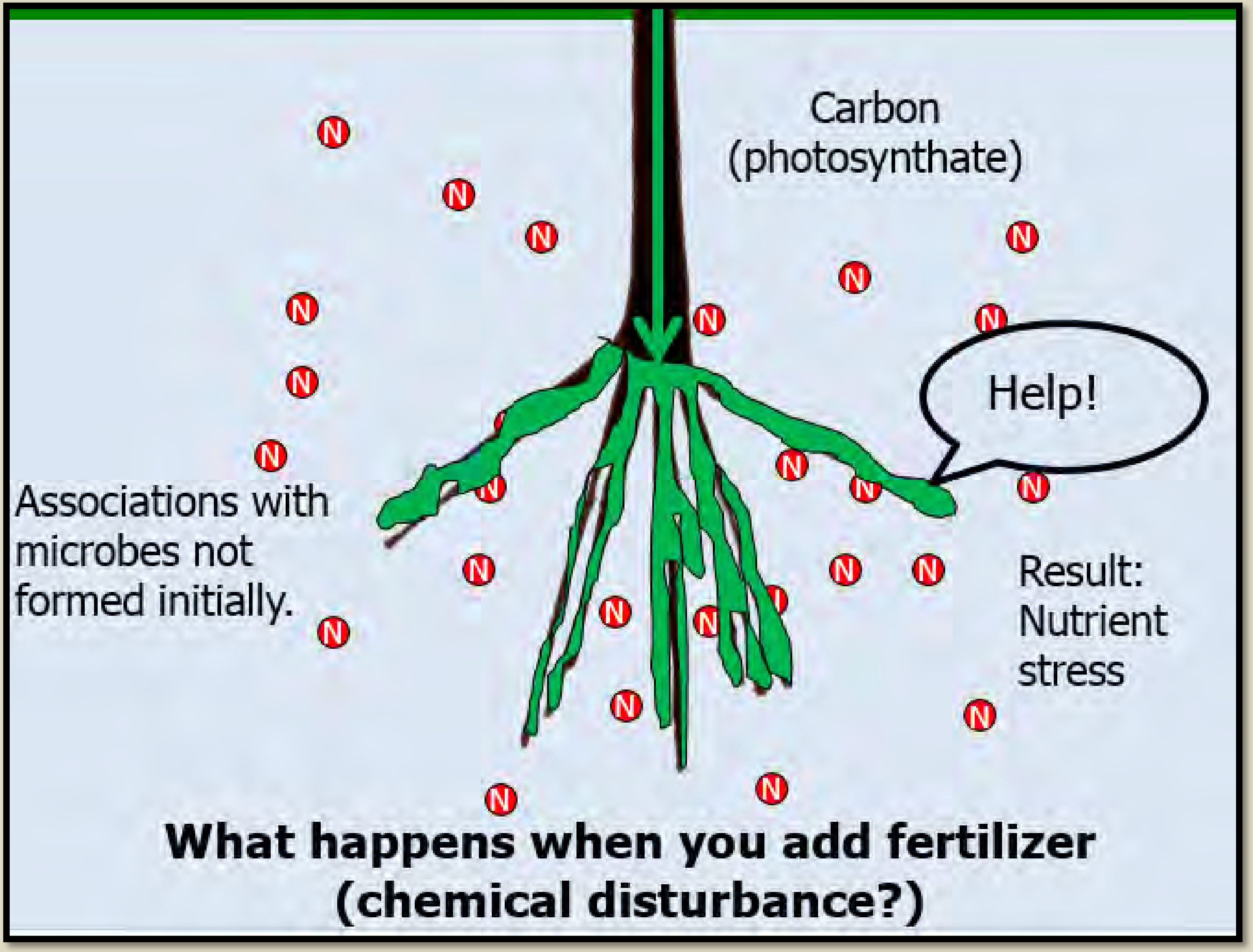

Soil Chemistry No-Till/Cover Crop
300.0
250.0
200.0
150.0
100.0
50.0
0.0
190.6
109.2
254.1
Al ppm
Fe ppm
Ca ppm
Al ppm
Fe ppm
Ca ppm



Soil Health (ppm) Tillage - Bare/Fallow
200.0
150.0
100.0
50.0
0.0
160.9
12.5
22.6
7.1
Solvita 1-day...
Organic C
Organic N
Organic C:N
Solvita 1-day CO2-C
Organic C
Organic N
Organic C:N



Soil Health (ppm) No-Till/Cover Crop
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
347.4
150.8
32.0
10.9
Solvita 1-day...
Organic C
Organic N
Organic C:N
Solvita 1-day CO2-C
Organic C
Organic N
Organic C:N



Adding fertilizer preempts this process. Plants won't give up energy if they don't have to. What does the plant do when the fertilizer is gone?

Once fertilizer is gone, plant needs to form associations- takes C at the time you want C to go to forming seed = nutrient stress

Proven Yield Method

- 5 assumptions:
  1) Crop gets most of its' N from fertilizer, not the soil
  2) All fields need fertilization
  3) Fertilizer efficiency should be constant
  4) Higher yields require more N
  5) Whole field N management adequate
- Wrong!
  - "Forget What You've Learned About Applied Nitrogen Rates" (No-Till Farmer)

Forget What You've Learned About Applied Nitrogen Rates, Ron Perszewski
http://www.no-tillfarmer.com/pages/Feature-Article-Archives.php

Yield-based recommendations in common use for corn production during the past three decades rely on the premise that fertilization, rather than indigenous soil N availability, is the major source for crop uptake.

Premise that crop gets most of it's N from fertilizer is inconsistent with evidence from ^{15}N-tracer investigations.

Plant uptake is generally more extensive for soil than fertilizer N when corn is grown to maturity with typical or even excessive fertilization (e.g., IAEA, 1970; Chichester and Smith, 1978; Bigeriego et al., 1979; Gerwing et al., 1979; Olson, 1980; Kitur et al., 1984; Blackmer and Sanchez, 1988; Timmons and Cruse, 1990; Balabane and Balesdent, 1992; Reddy and Reddy, 1993; Torbert et al., 1993; Jokela and Randall, 1997; Tran et al., 1997; Omay et al., 1998; Stevens et al., 2005).

the uptake of fertilizer nitrogen increased as the rate of fertilizer increased. However, even at 240 pounds per acre of fertilizer, at the end of the growing season the crop had still taken up more of its nitrogen from the soil than from the fertilizer.

How Plants Repel Insects: Observation of Monarchs; Brix and Nutrient Dense Plants

Oscar Morand – Focus was in Science and he immersed himself in permaculture – spent time with Geoff Lawton – noted permaculture specialist.

The beds, two plants each, looked pretty similar, but on bed 1 the monarchs were a lot less numerous and the amount of leaves still on the plants was far greater than on the plants on bed 2.

And the most surprising fact was that even if it was 2 pm, even if the conditions were exactly the same than the “excited” monarchs of bed 2, **these “bed 1” monarchs were mostly dormant, and a few were moving very slowly.** I even tried to poke one on the antenna (peace upon him) and almost no reaction. As a good scientist I needed a reference point, so I went to poke a “bed 2” monarch and there the reaction was huge: the monarch moved all around and I could feel how annoying it must have been.

How Plants Repel Insects: Observation of Monarchs; Brix and Nutrient Dense Plants

Another observation was their manure. And yes, I did spend some time observing very closely the output generated by our monarch friends, and again I got two different results between bed n°1 and bed n°2.

On bed n°2 the manure looked almost the same color as the stem of the swan plant: a light green color. But after looking at the monarchs' packets of fertilizers on bed n°1, it was different. The color was a lot darker: a dark green.

How Plants Repel Insects: Observation of Monarchs;

Brix and Nutrient Dense Plants

The refractometer is a tool which measures the refractive index of a liquid. When light rays shine through the liquid they strike the carbohydrates, salt and other molecules depending upon the type of calibration used.

When the light rays strike the molecules, they bend or refract. The greater the calibrated molecular concentration of the liquid in question, the greater the refraction. (1)

And the molecular concentration of the plant is:
... the concentration of sugars, vitamins, amino acids, proteins, hormones, and other solids dissolved within the juice of the plant which is measured in **BRIX (ratio of the mass of dissolved solids to water).**(2)

The Brix unit that the refractometer gives is basically the mineral content of the plant; thus, the higher the refraction, the higher the mineral content, the higher the nutrient-density of the plant.

BRIX of the swan plants were as follows:

- **12 for the swan plant on bed n°2, the bed with the excited caterpillars**
- **18 for the swan plant on bed n°1, the bed with the dormant caterpillars**

How Plants Repel Insects: Observation of Monarchs, Brix and Nutrient Dense Plants

The higher the nutrient density of a plant, the higher the nutrition of it, the higher the amount of minerals per caterpillar's mouthful; thus, the higher the mineral concentration of the monarch manures and, therefore, the darker the poo.

why the monarchs were more attracted by the plants on bed n°2 — the plants that have the lower BRIX reading, of 12. Nature allows the most adaptable to survive and the less adaptable to be devoured.

It will always first recycle the less functional, allowing the most adaptable and healthiest forms of life to perpetuate themselves.

Dr. Philip Callahan of the University of Florida, a USDA entomologist, explains that insect antennae are actually like small semiconductors, and, as they are coated with wax, are also paramagnetic structures. They receive various wavelengths in the infrared spectrum. Once the information is received, the insect's brain determines whether the frequencies correspond to a mate, food, water

If a plant is in perfect or near perfect health (mineral balance), it will vibrate at a given composite frequency. If there happens to be a mineral deficiency, it will vibrate at a slightly different composite frequency.

How Plants Repel Insects: Observation of Monarchs; Brix and Nutrient Dense Plants

If a plant is in perfect or near perfect health (mineral balance), it will vibrate at a given composite frequency. If there happens to be a mineral deficiency, it will vibrate at a slightly different composite frequency. **If there is a serious deficiency or several deficiencies that make that plant unfit for animal or human consumption, it will vibrate at a significantly different frequency that the insects know as food, hence an insect infestation**

The insects are able to sense, to capture the vibrations of their environment and process it to determine if it is food or not. Now we understand why there were more monarchs on the plants of bed n°2 than on those of bed n°1. The plants of n°2, with a BRIX reading of 12, have a lower composite vibrational frequency than the plants of n°1. **Not only that, but I suppose that the BRIX of bed n°1's plants are high enough to not be considered as proper food by the insects.**

Use of Compost Teas

Field 7 – onions with Conventional fertilizer and herbicide application

Field 12
Reduced herbicide rate
Three compost teas applied.
2X prior to seeding and 1X post seeding.

Ian Smith, Mooreville, Tasmania

Can we reduce Weed Pressure by manipulating the biology in the soil – Yes.

This is an example where conventional onions (fertilizer/herbicide) were compared to Onions grown with reduced herbicide but three compost teas were applied – 2x prior to seeding and 1x post seeding.


Field 7 Onions with Conventional fertilizer and
herbicide applications, planted same date as Field 12


Close-up showing clean seedbed. Field 12

Overall view of Field 12 - low weed pressure

Field 12 one spray run not treated with compost tea.(Can you spot the difference?)

Have you seen cropland in the 1st Stage of Ecological Succession?

You are growing Cotton which is a later successional plant in a ecosystem that is in the 1st stage of Ecological Succession.

Conditions are more apt to grow weeds than the desired crop.

Pigweed:
For Pigweed to be in that ecosystem, it has to be in the 1st stage of ecological succession. Pigweed grows very fast, produces lots of biomass and seed – however, **pigweed needs both chemical / Mechanical injury to break dormancy – what you see here in this slide is the environment / ecosystem for pigweed to be there – no Carbon, high nitrate, and tillage / disturbance is occurring in that system on a continual basis – Fix the true problem and not just the symptom**. This is valid for all we do when enhancing Soil Health.

I hope that I have proven to you how important it is to understand how the soil functions -

Ecology & Weeds

- What is a weed?
- What selects for weeds?
- Relationship of soil biology to weeds
- **Weeds- nature's first responders**
  - Effort to restore balance- nature's soil restorers
    - Provide quick cover- first step to regenerating a broken system
    - We fight this process with herbicides

How were weeds defined to you?

What is a weed?

- Any plant out of place
- Plant you don't want
- What is the real definition of a weed?

Weeds occupy a niche in ecological succession. They have a purpose!

What selects for weeds?

- Disturbed soil
- Pulse of nitrates- high concentrations for short times, no nitrate for short time
- Forcing the system to grow 1 thing- simple cropping systems
- GE cropping systems

What is a weed?

- Consider the ecology!
- Bare soil ➔ bacterial ➔ fast growing plants with lots of seeds
  - Short time- seed to seed
  - **Need high levels of NO_3**

- Change the biology- change the plant community

Soil is trying to get covered & add carbon.

Outline

- History- paradigm shifts
- Current issues with nutrient management
- N cycle, soil biology and nutrient cycling
- Ecology and “weeds”
- Farming ecologically & working with producers

Change the way you think about soil.

There are two types of Systems for growing plants:

1)Organic / Biological – Ecological Paradigm

1) Inorganic / Synthetic – Chemical Paradigm

Challenges - Summary

- Increasing demand for commodities
- Increased use of inputs- e.g. synthetic N
- More N required to get same yield- efficiency declining- “Fertilizer treadmill”
- Soil resource being degraded, leaky
- Environmental impacts>>more regulation?

How do we fix this?

How do we get beyond this? Monoculture, soil w/ no roots in the ground means microbes are not being fed, tillage destroys their habitat, less water is going in.

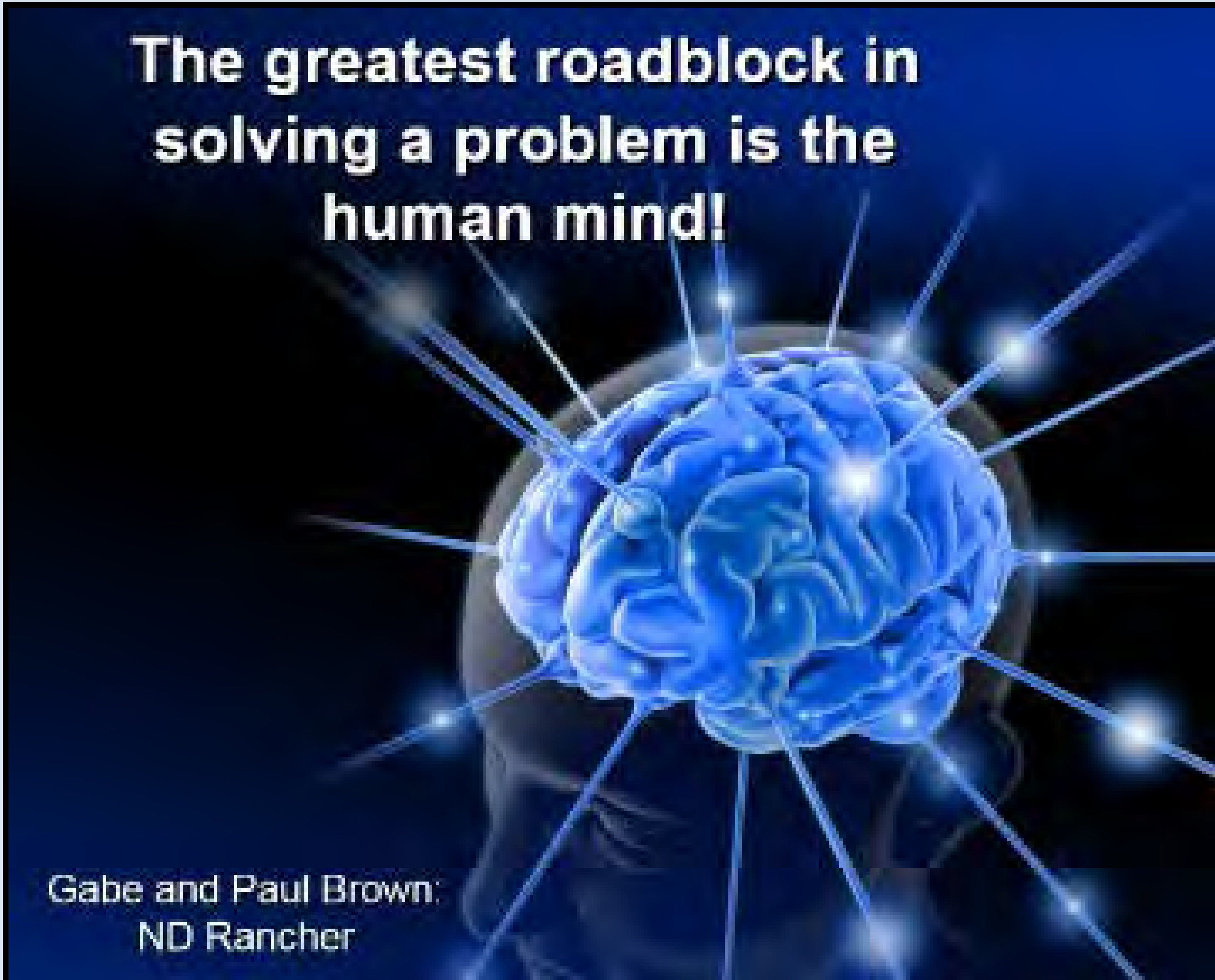
What's the Solution?

- **Primarily a <u>mindset</u> change**
  - **How the soil is viewed- is it a chemistry set, or a living system?**
  - **FOCUS: SOIL HEALTH**
- Paradigm changes are difficult!
- **Secondary: Technology/management**
  - **Cover crops, diversity, no-till, etc.**
- **Fix the carbon cycle**

Paradigm Shifts

- Paradigm shift #1 Stop treating the symptoms of dysfunctional soil; solve the problem of dysfunctional soil.
- Paradigm shift #2 Restoring soil function can be accomplished without going broke.
  - **Apply basic principles of ecology to create quality habitat.**
  - There is no waste in Nature.
- Paradigm shift #3 Conservation practices do not restore soil health, understanding soil function restores soil health.

Erosion, T; e.g. paying for NT conversion w/
EQIP $$$ w/out understanding soil health


The greatest roadblock in solving a problem is the human mind!
Gabe and Paul Brown: ND Rancher

Questions?