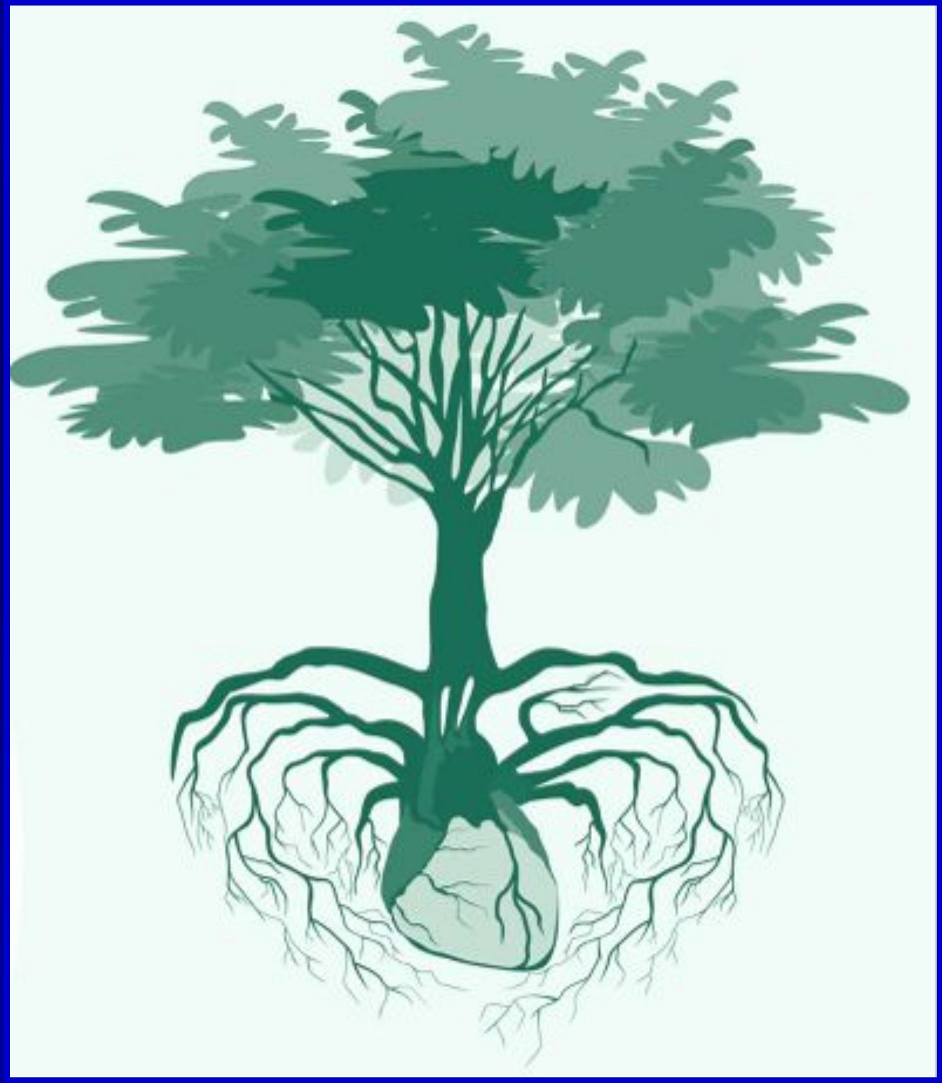
Managing Soil Biota for Economic and Environmental Sustainability

Civilized nations – Greek, Roman, British – were sustained by the primitive forests which anciently rotted where they stood. They survived as long as the soil is not exhausted.

Thoreau and Jared Diamond

Soil is the Heart of the System

- Connects above and below
- Ultimate recycler of C, N, O, P, etc.
- Drives physical, chemical, and biological processes
- Estimated value of soil services is $20 trillion globally per year – Pepper et al., 2009
- Estimated value of soil biota is $1.5 trillion globally per year (~$400/ac of arable land) - Dance, 2008




The Soil Livestock is a complex and diverse mix of species and represents the greatest concentration of biomass of anywhere on the planet.
Intraradical hyphae
Arbuscules

IF YOU BUILD IT, THEY WILL COME!

FOOD!!!!

HABTAT!!!

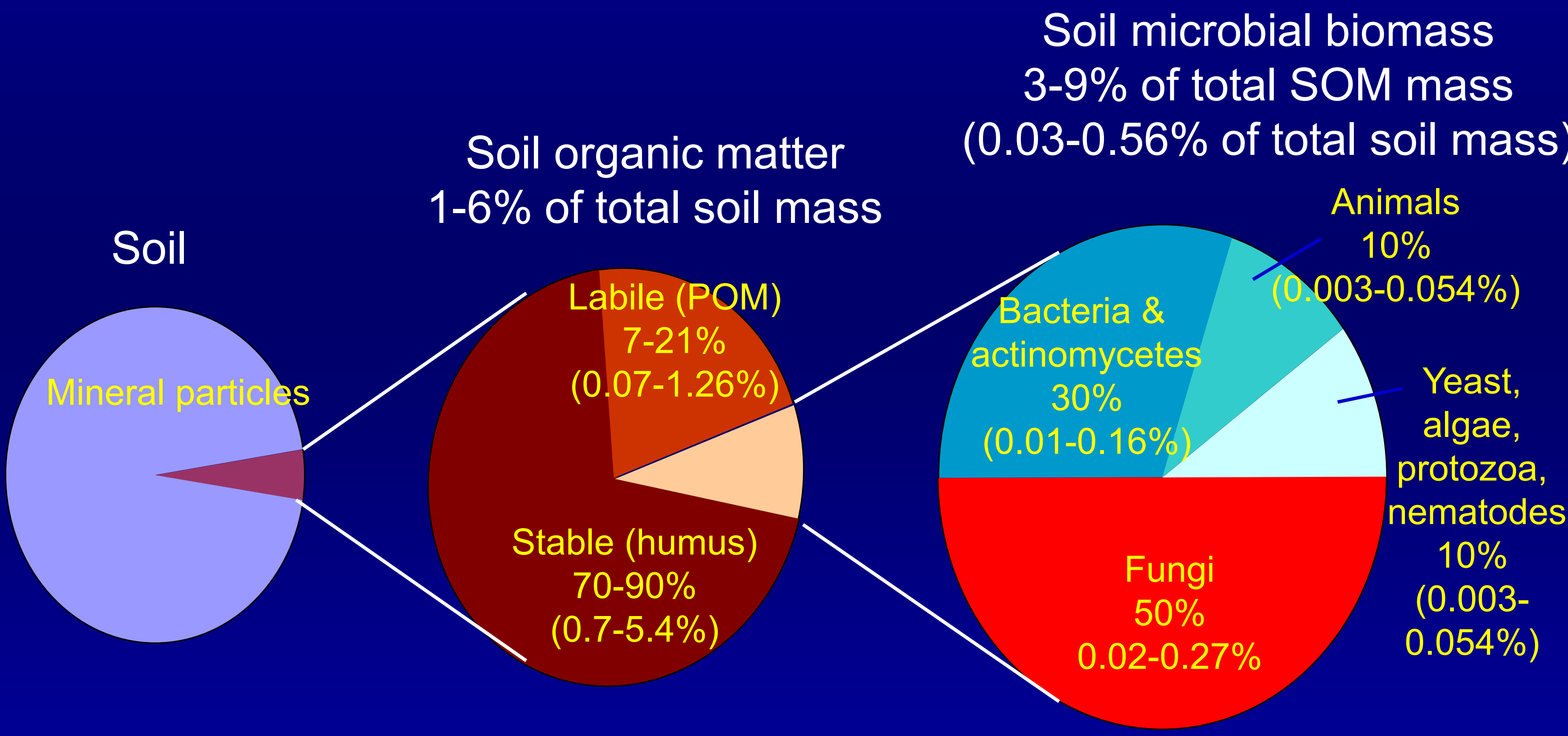

Soil is a universal, foundation resource for all agricultural industries. It is the engine room of productivity.

- Soil organic matter (SOM) is <6% of soil by weight but controls >90% of the function
- SOM is mostly negatively charged, but binds both cations and anions

Figure 2. Components that relate to nutrient availability in the soil-rhizosphere system.

- As soil organic matter increases from 1% to 3%, the available water holding capacity of the soil can double depending on soil texture(Hudson, 1994).
- SOM is equivalent to its own bulk volume while mineral soil is five time more dense than soil OM
- 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

Soil Organic Matter Composition



- Modified from Building Soils for Better Crops, Magdoff and van Es, 2000

Soil Carbon in the Rhizosphere

Increases\Improves:

1. biological activity – growth and diversity of microflora
2. water infiltration, holding capacity, quality, and efficiency of use
3. soil tilth and structure
4. natural fertility – nutrient cycling and storage and capacity to handle manure
5. cation exchange capacity
6. adsorption of pesticides

Decreases\Reduces:

1. soil erosion
2. soil compaction
3. air pollution

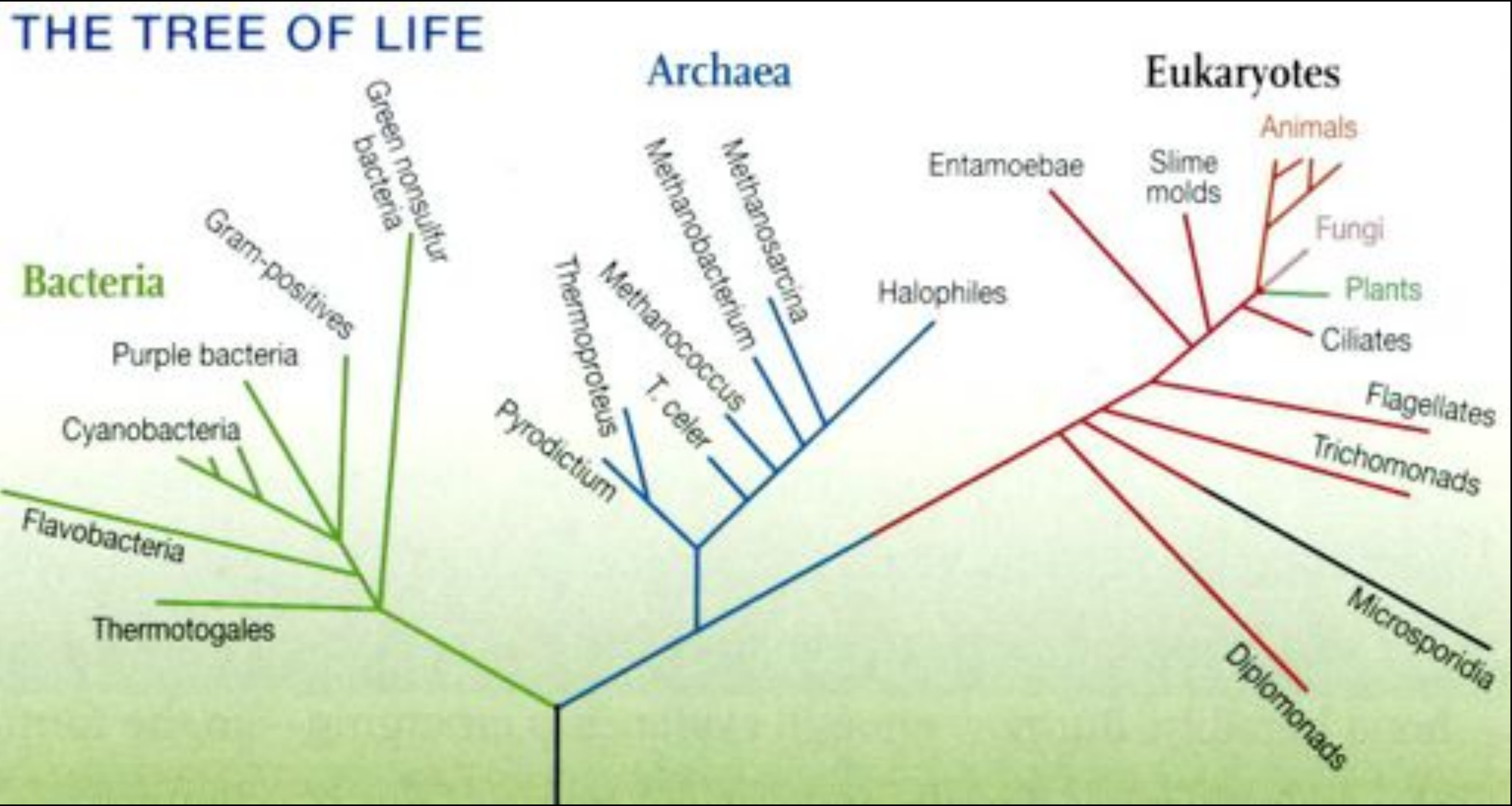
Carbon is the hub, each spoke is an environmental benefit which adds strength and support to the wheel to maintain environmental quality.

-Courtesy of Don Reicosky, ARS retired

Root of the problem is the root of the solution.

The Rhizosphere is the area:

- **Immediately surrounding [0.5-1 inches (1-2.5 cm)] the plant roots**
- **Of highest biological activity due to the high concentration of photosynthetically-derived carbon (approx. 70%) – Juma, 1993**
- **Of some of the greatest impact on soil structure**
- **Of the majority of the nutrient cycling activity**
- **Most impacted by aboveground management**



Huge Diversity of the "Unseen Majority"

Biology of the Soil

- Soil is organic (i.e. living)
- Billions of different organisms from millions of species
- Total weight of living organisms in the top six inches of an acre of soil can range from 5,000 to 20,000 pounds.
- Soil from one spot may house a very different community from soil just a yard (meter) away, because of water or nutrient variations or soil physical properties.

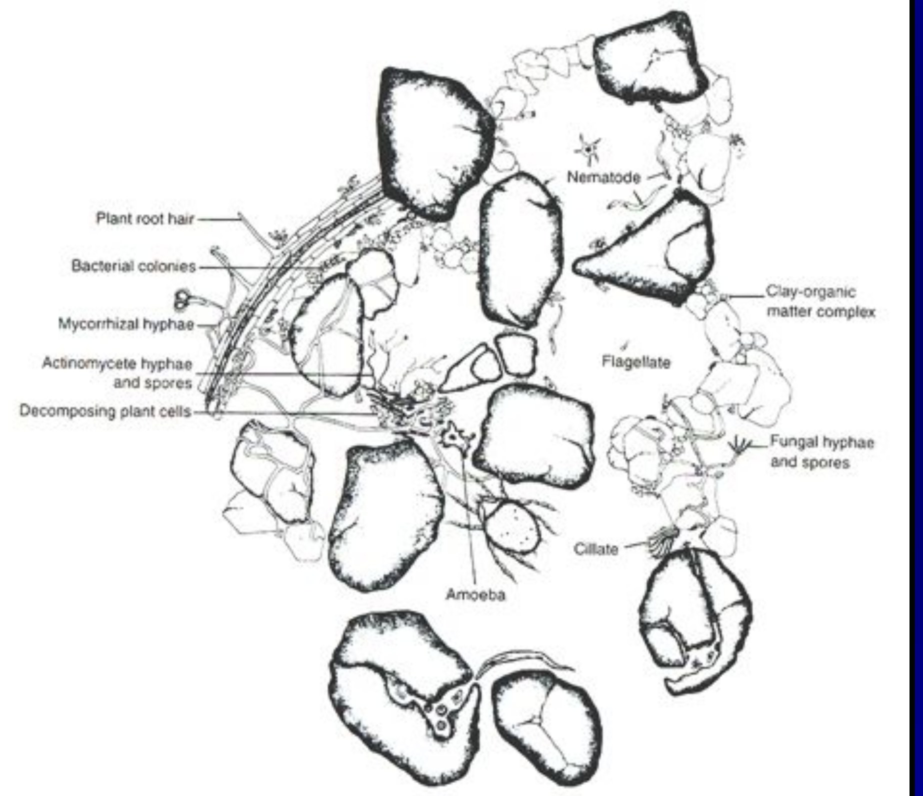
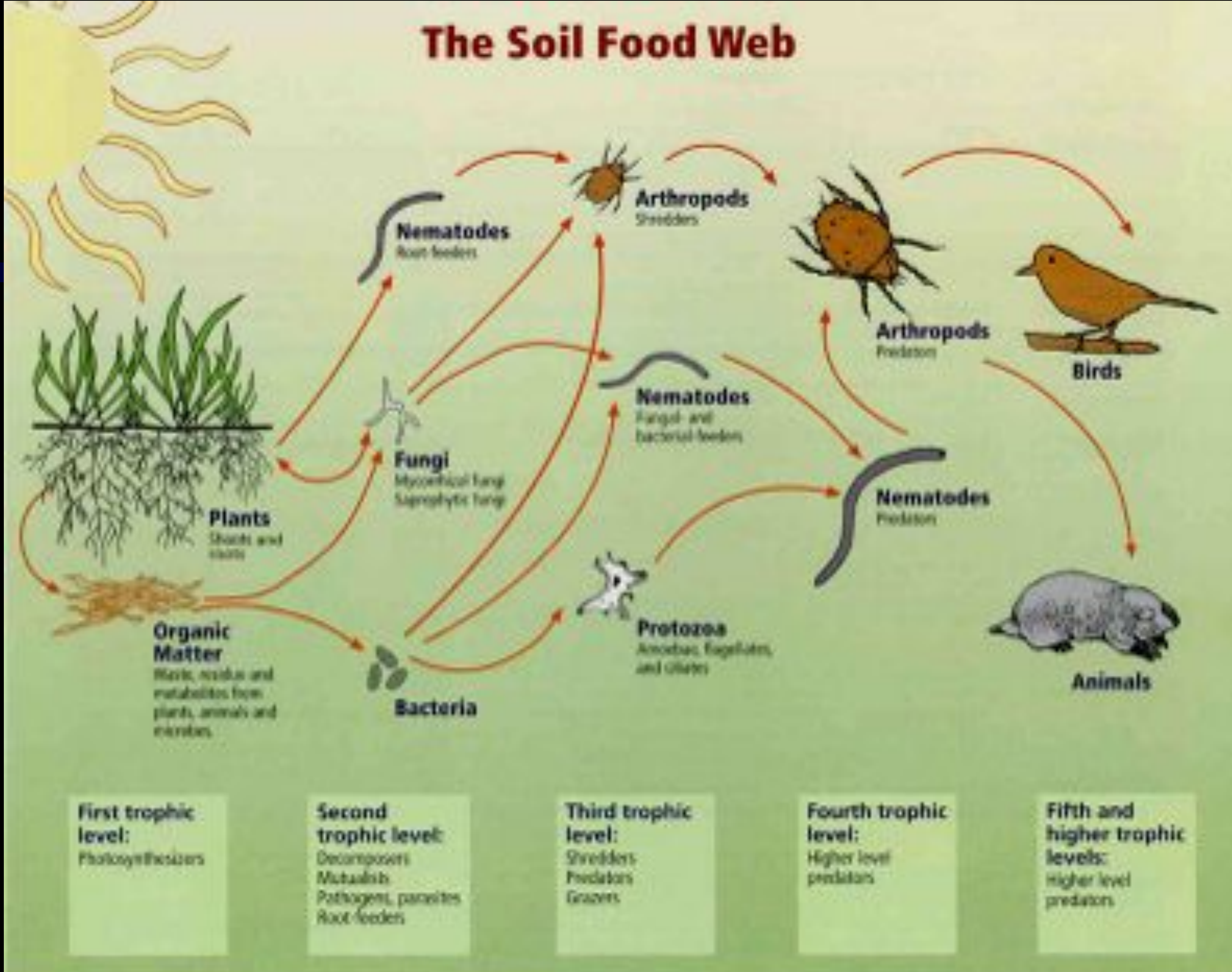


FIGURE 5.2 Diagrammatic representation of a plant root and associated biota approximately 1 cm^2 of a surface grassland horizon associated with a plant root. (Adapted from S. Rose and T. Elliott, personal communication.)



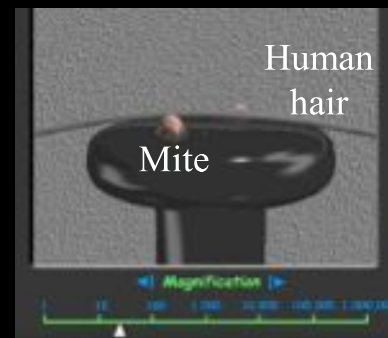
Relationships between soil food web, plants, organic matter, and birds and mammals
Image courtesy of USDA Natural Resources Conservation Service
http://soils.usda.gov/sqi/soil_quality/soil_biology/soil_food_web.html.

Size Classification (by body width)

Micro

Meso

Macro & Mega



Bacteria

Actinomycetes

Fungi

Nematodes

Protozoa

Microarthropods

(Mites)

(Springtails)

Earthworms

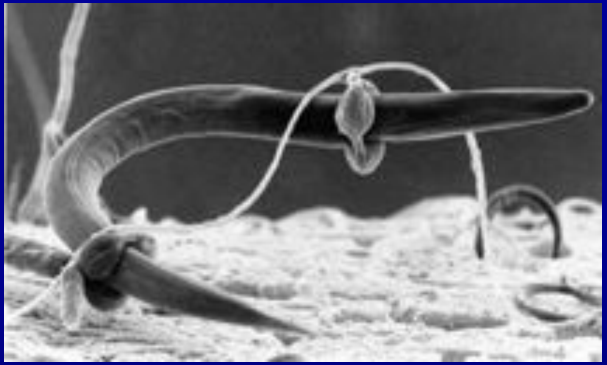
Bacteria on a needle

100 um
1/200 in

2 mm
1/10 in

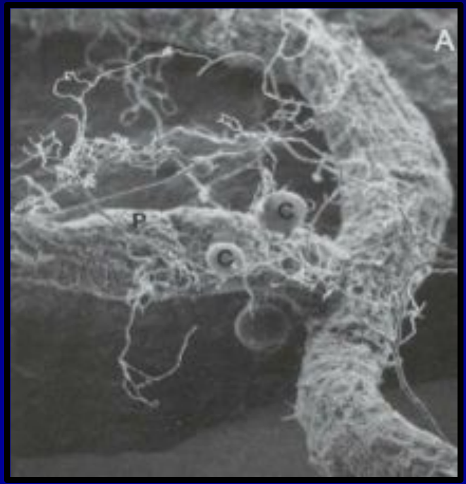
Body Width

- Swift et al., 1979
http://cellsalive.com/howbig.htm
http://mrbarlow.files.wordpress.com/2008/10/bacteria-on-a-pin.jpg



Soil Biota

- Predator and Prey
- Pathogens
- Mutualists\Beneficials
- Commensalists



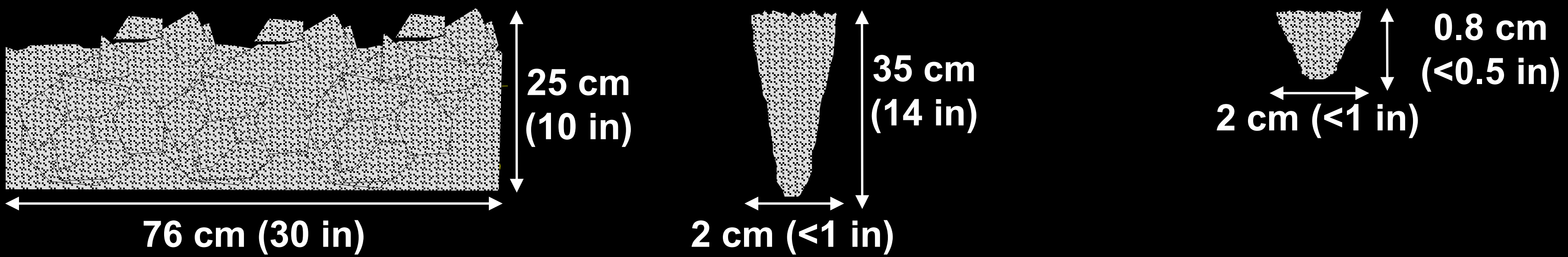
When 2 + 2 no longer equals 4

Tillage type
Plant species/variety
Crop rotation
Crop residue
Grazing

Fertility program
Cover crops
Manure/compost addition
Irrigation
Timing

Management affects combine

Tillage



Moldboard Plow | **Subsoil Shank** | **No Knife No Till Drill**

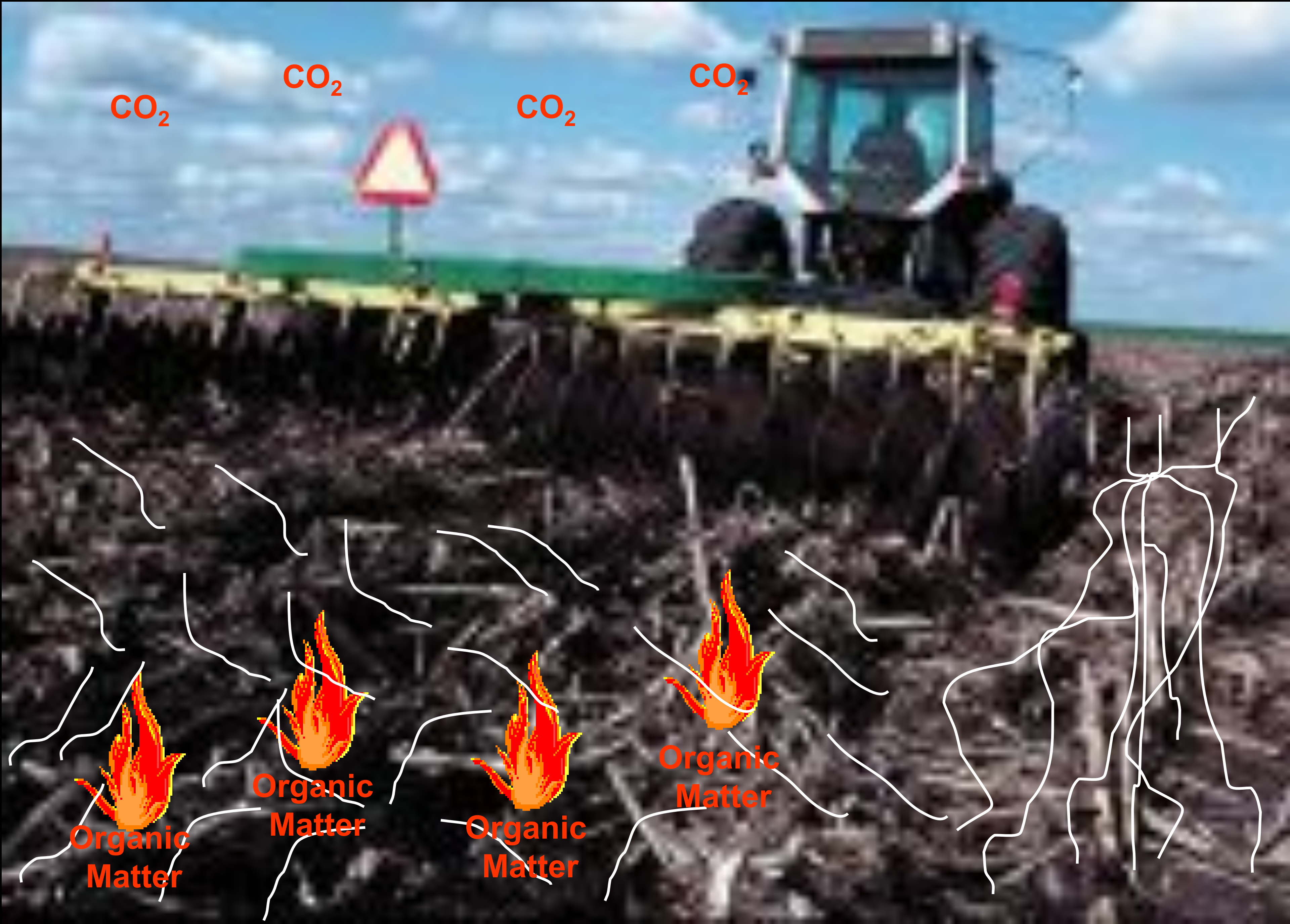
Tillage Induced Decomposition

TABLE 3

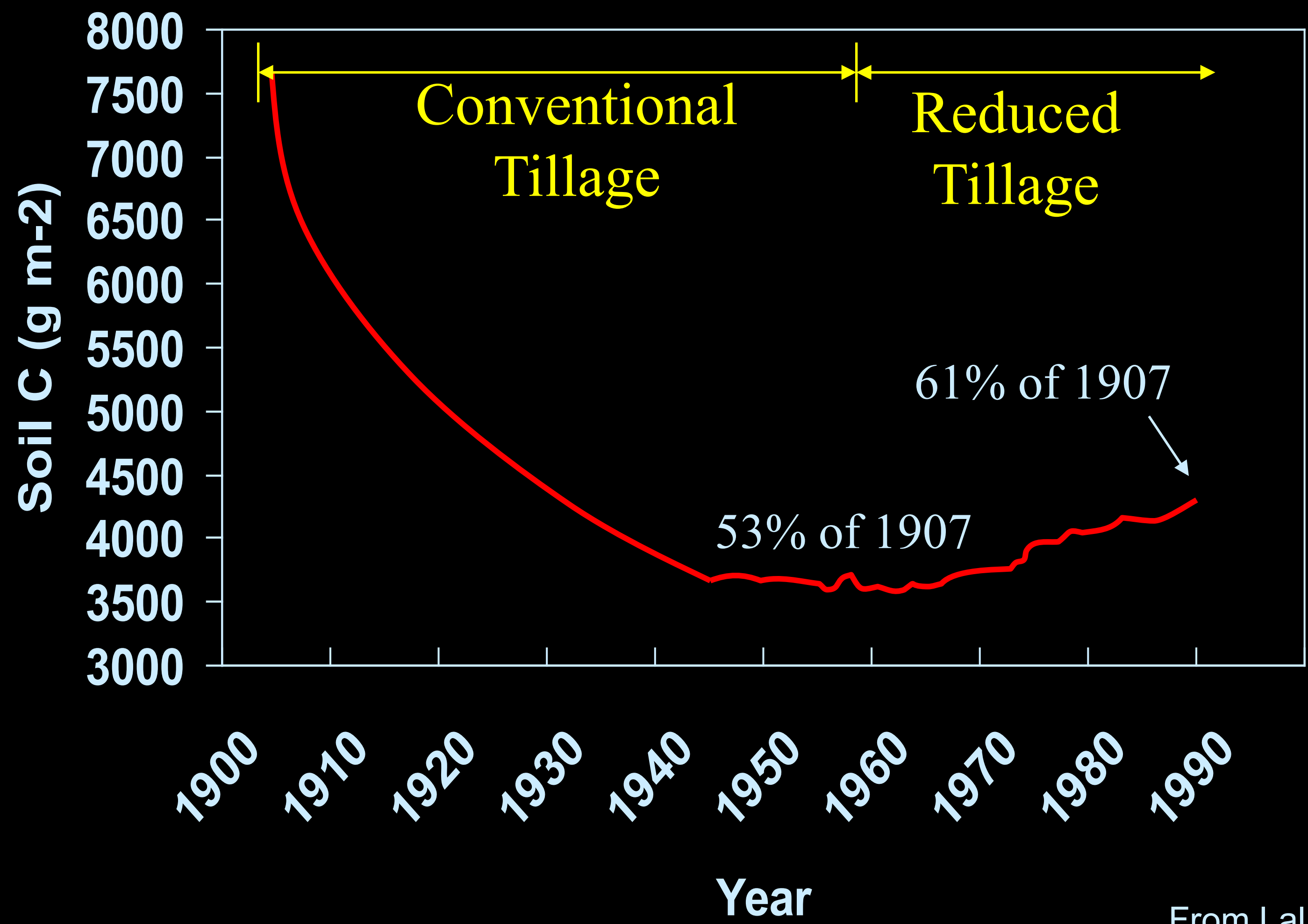
Tillage induced flush of decomposition of organic matter

Type of tillage	Organic matter lost in 19 days (kg/ha)
Mouldboard plough + disc harrow (2x)	4 300
Mouldboard plough	2 230
Disc harrow	1 840
Chisel plough	1 720
Direct seeding	860

Source: Glanz, 1995


CO_2
CO_2
CO_2
CO_2
Organic Matter
Organic Matter
Organic Matter
Organic Matter

Historic Loss of Soil Carbon



From Lal et al., 1998

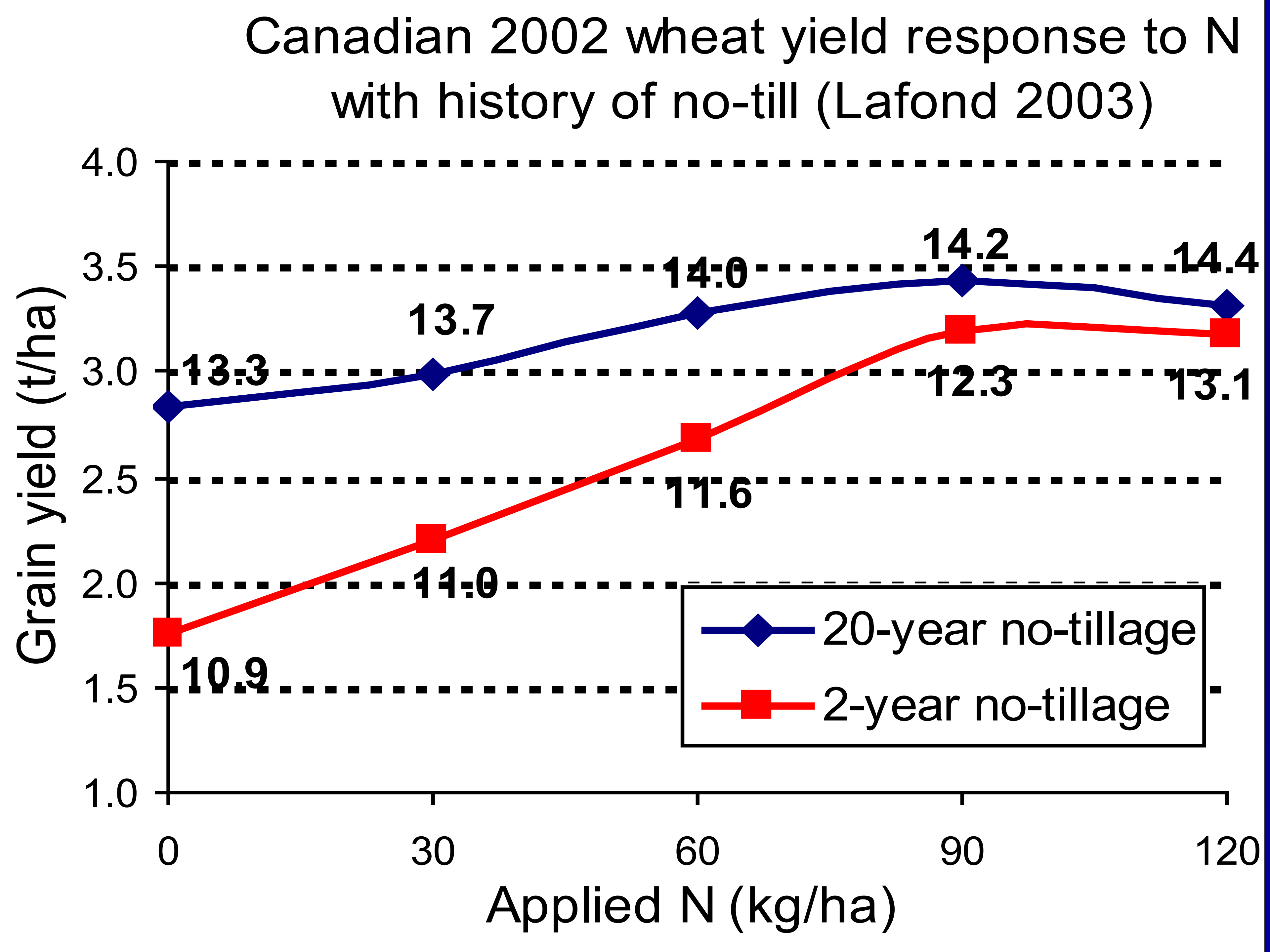
CONVENTIONAL TILLAGE (plow + disk)			CONSERVATION TILLAGE (no-till)
% OM	depth(in)	% OM	
	0		
3	0.5	11	
3	1	8	
3	2	6	
3	4	3	
3	6	2	
1	8	1	
0.5	10	0.5	

CONVENTIONAL TILLAGE (plow + disk)

- BARE SURFACE CRUST FORMING
- COMPLETE MIXING OF SOIL AND RESIDUE
- SECONDARY TILLAGE PAN
- MOLDBOARD PLOW PAN

CONSERVATION TILLAGE (no-till)

- CROP RESIDUE ON SOIL SURFACE
- IMPROVED SOIL PROPERTIES NEAR SURFACE
- MACROPORES AND WORM HOLES, PORE CONTINUITY



Canadian 2002 wheat yield response to N with history of no-till (Lafond 2003)
Grain yield (t/ha)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0
30
60
90
120
Applied N (kg/ha)
13.3
13.7
14.0
14.2
14.4
10.9
11.0
11.6
12.3
13.1
20-year no-tillage
2-year no-tillage

Biological tillage by soil fauna has to replace "iron tillage"!

– Rolf Derpsch

How much residue goes to SOM?

A 90 bushel sorghum crop yields about 5000 pounds of crop residue. One-half of this residue is carbon.

1/2 of 5000 = 2500

How much residue goes to SOM?

If 2/3 of this carbon is consumed by microorganism and exhaled as CO_2, it leaves about 840 pounds of organic material to be converted into SOM, but most of this is tied up in the bodies of soil organisms.

1/3 of 2500 = 840

Crop Residue Treasure or Trash?

- **Treasure**
  - **Erosion control**
  - **Nutrients**
  - **Organic matter and soil quality**
  - **Soil moisture conservation**
  - **Weed control**
- **Trash**
  - **Seeding issues**
  - **Crop issues**

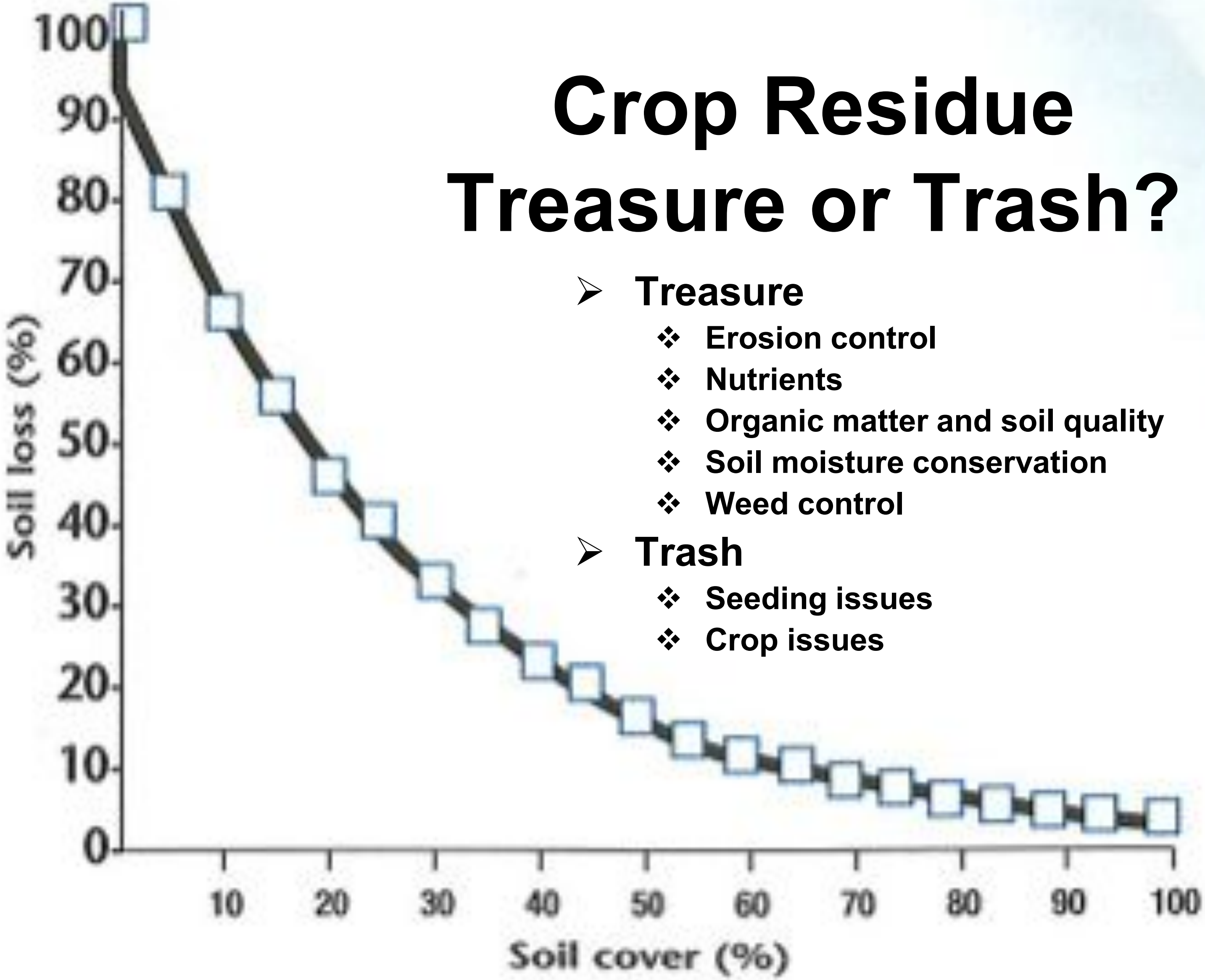
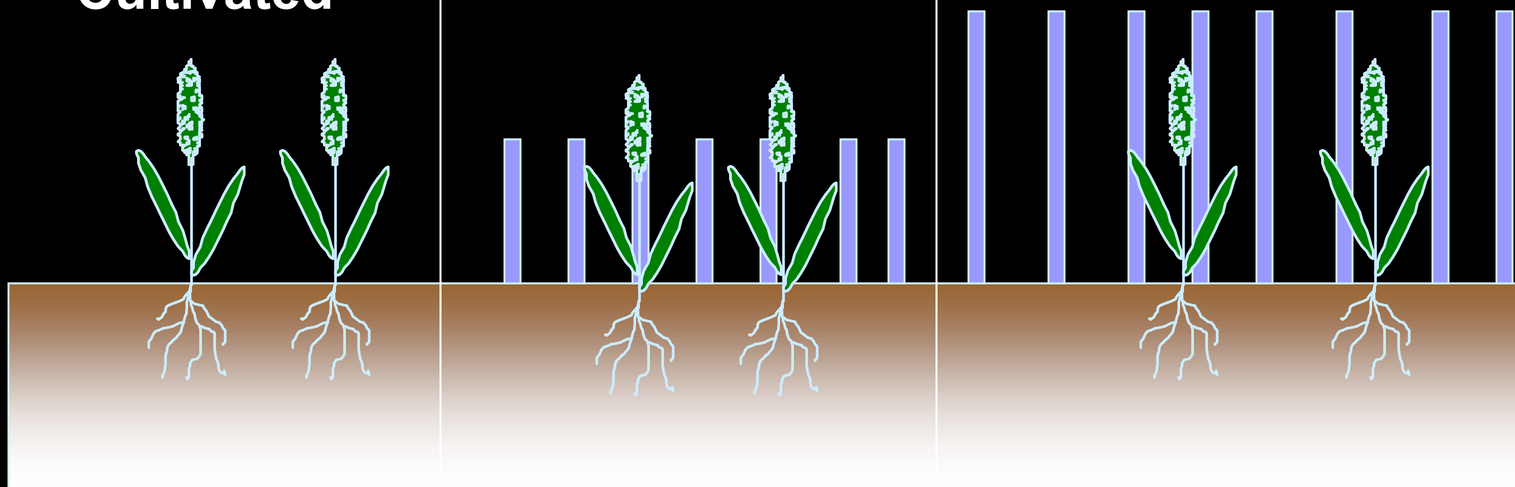


FIGURE 6. Residue cover – relative soil loss relationship. With 30% residue cover, soil loss is reduced 70%.

No Till and Residue Management Combine to Produce Stubble which Impacts Evaporation



Ground Level Effects

	Cultivated	6-8" Stubble	12-14" Stubble
Wind:	100%	85%	32%
Evap. Demand:	100%	95%	70%

- Cutforth and McConkey, 1995

Stubble Height Effects on Yield (bu/ac) & WUE (kg/ha/mm)

	Stubble Height After Seeding					
	Cultivated		6-8"		12-14"	
Crop	Yld	WUE	Yld	WUE	Yld	WUE
Wheat	33.5	7.5	36.0	7.9	38.0	8.4
Pea	35.7	11.3	37.1	11.5	37.7	12.0
Lentil	19.1	5.6	19.8	6.3	23.0	7.2
Chickpea	22.3	6.3	24.4	7.7	25.3	7.2
Canola	27.4	5.1	29.9	5.5	32.6	6.0

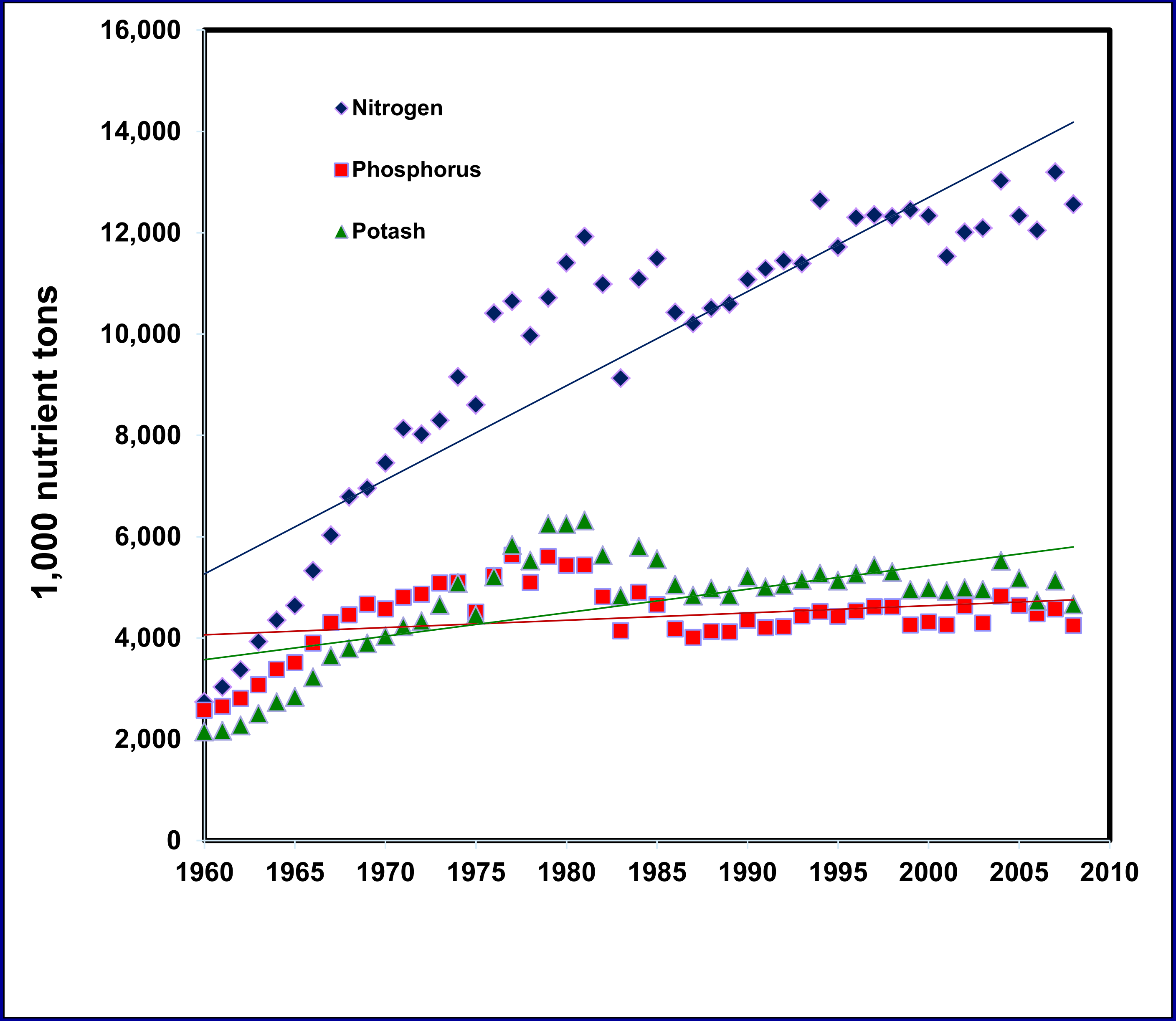
Brown Ranch after 13 inches of rainfall in 24 hr period

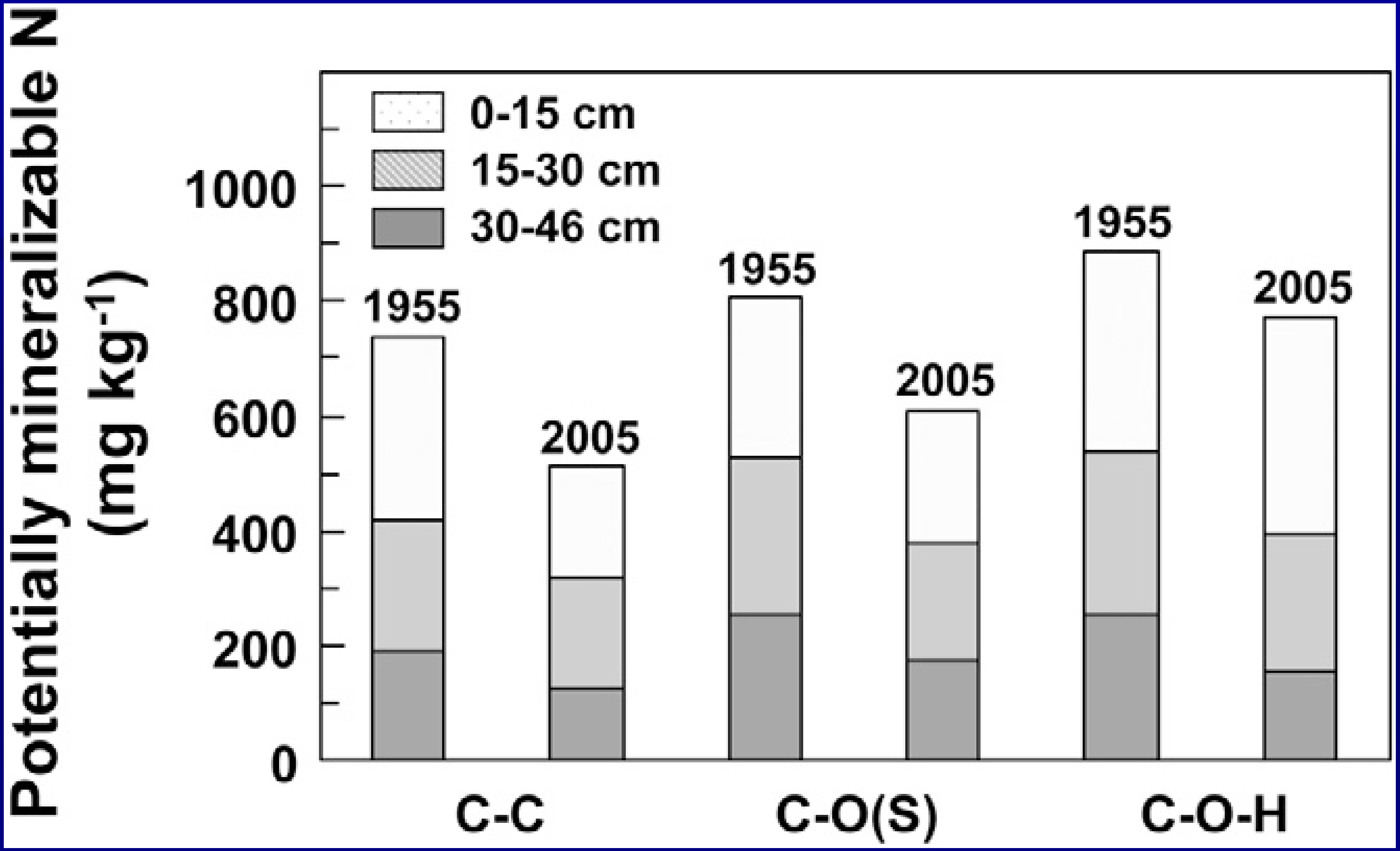
Plant Diversity

Crop	C:N Ratio
Cereals	80:1 – 100:1
Corn	60:1
Peas	25:1 – 30:1
Soil OM	10:1 – 12:1

- Hartman - 1999

Fertilizer use in the U.S. from 1960-2008, NASS



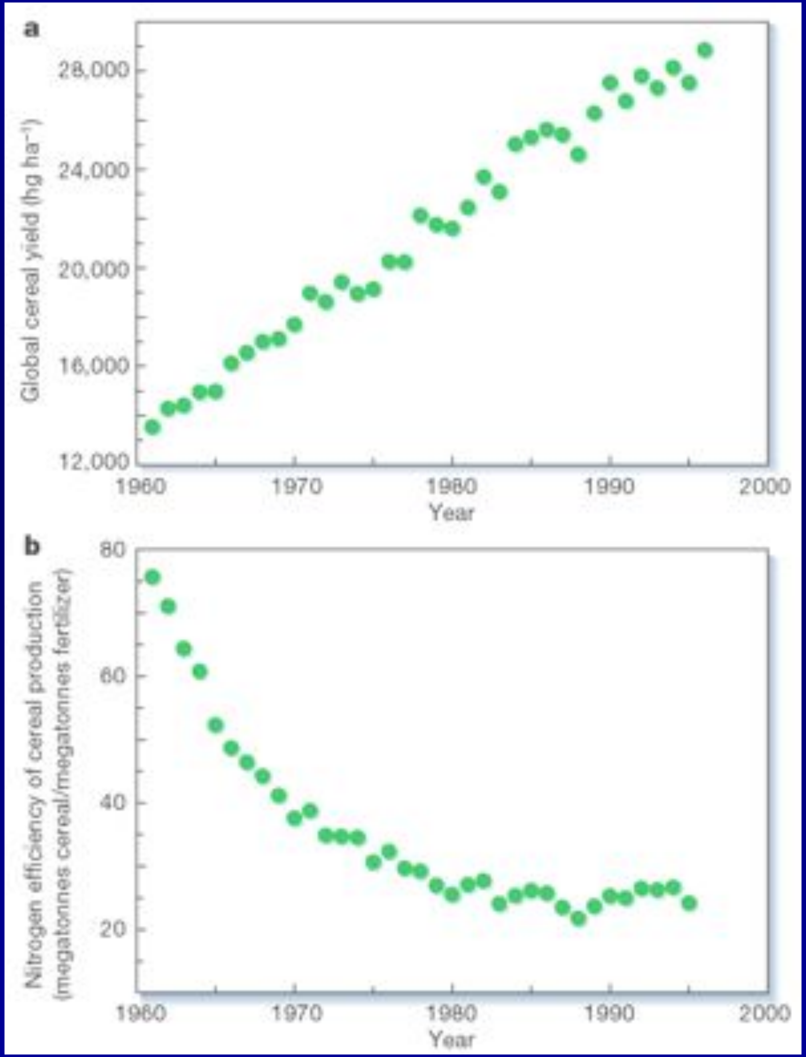


Potentially mineralizable soil N before and after 51 yr of nitrogen–phosphorus–potassium fertilization of previously unfertilized Morrow Plots cropped to continuous corn [C-C]; a corn-oats (1876–1966) followed by corn-soybean (since 1967) rotation [C-O(S)], or a corn-oats-alfalfa hay rotation [C-O-H]. Fertilizer N was applied as urea to corn (168 [1955–1966] or 224 [since 1967] kg N ha−1) and oats (28 kg N ha−1).

- Mulvaney et al., 2009

Fertility Management

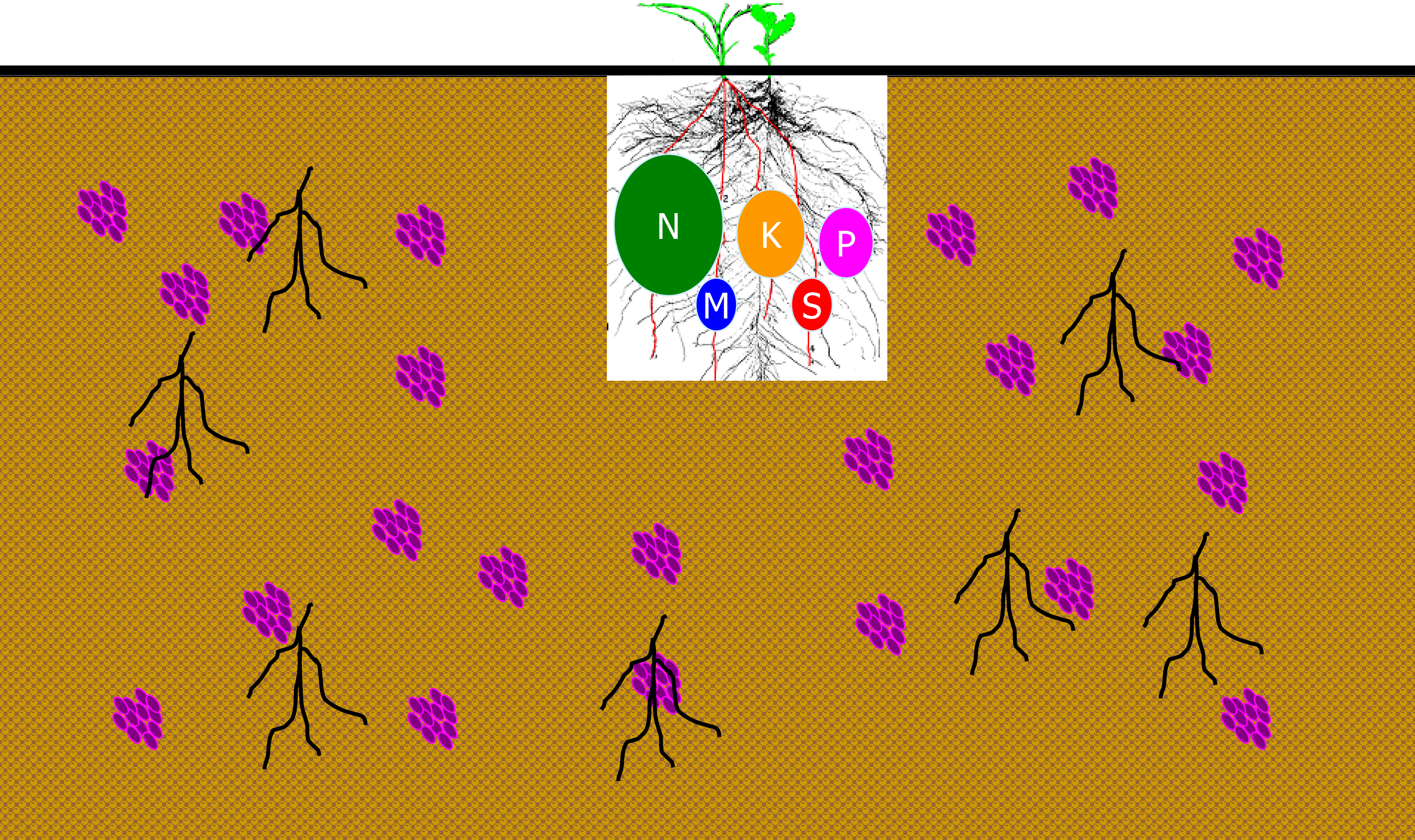
- Too little fertility
  - Plant available – synthetic vs. biologic
  - 30-50% of nitrogen fertilizer is used by the plant
  - 30% of phosphorus is used by the plant
  - Fertility and water
- Too much fertility
  - Availability, timing, water, and pH



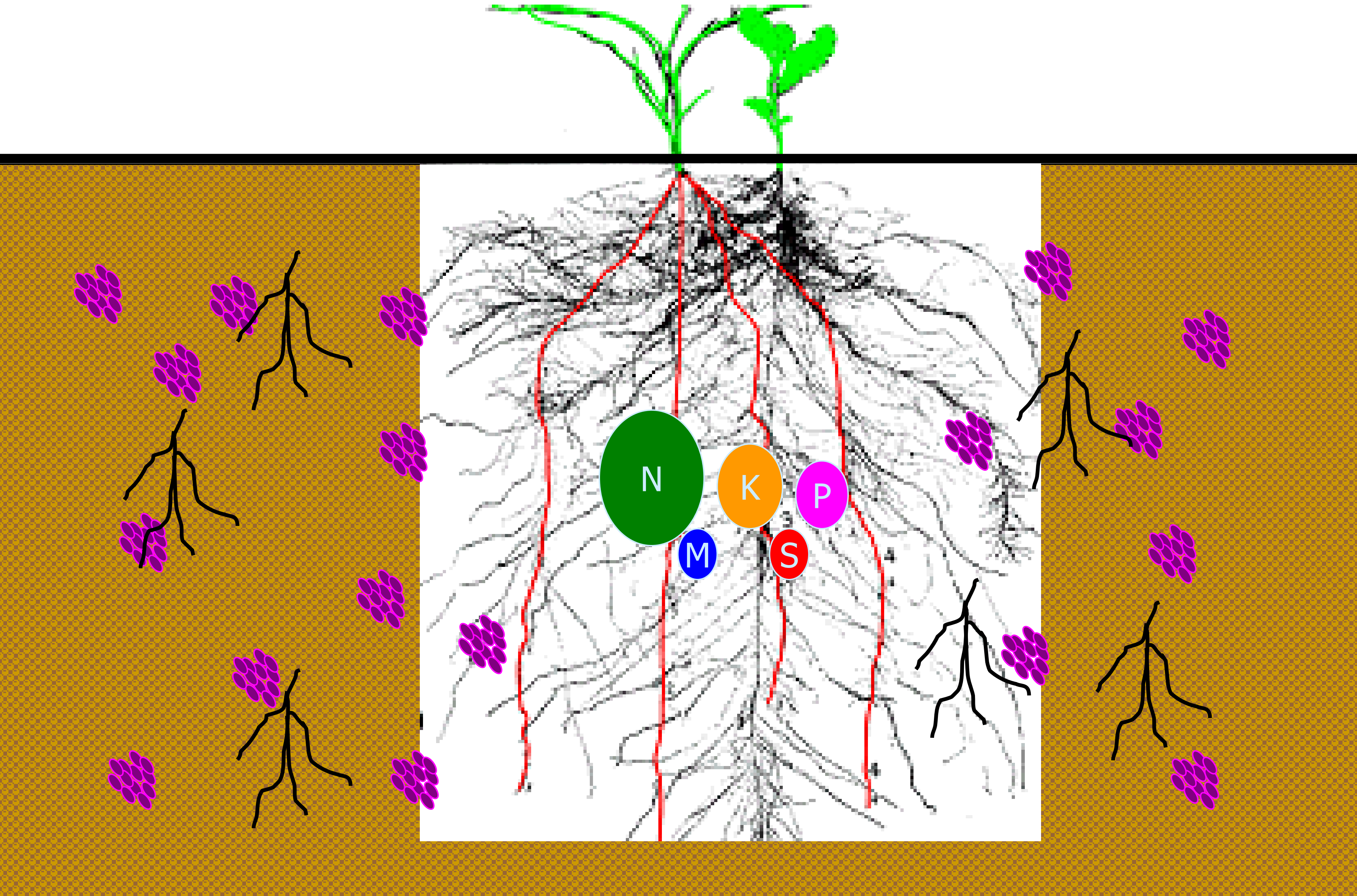
- Tilman et al., 2002

Add Fertilizer – The Big Buffet Drives Food Availability

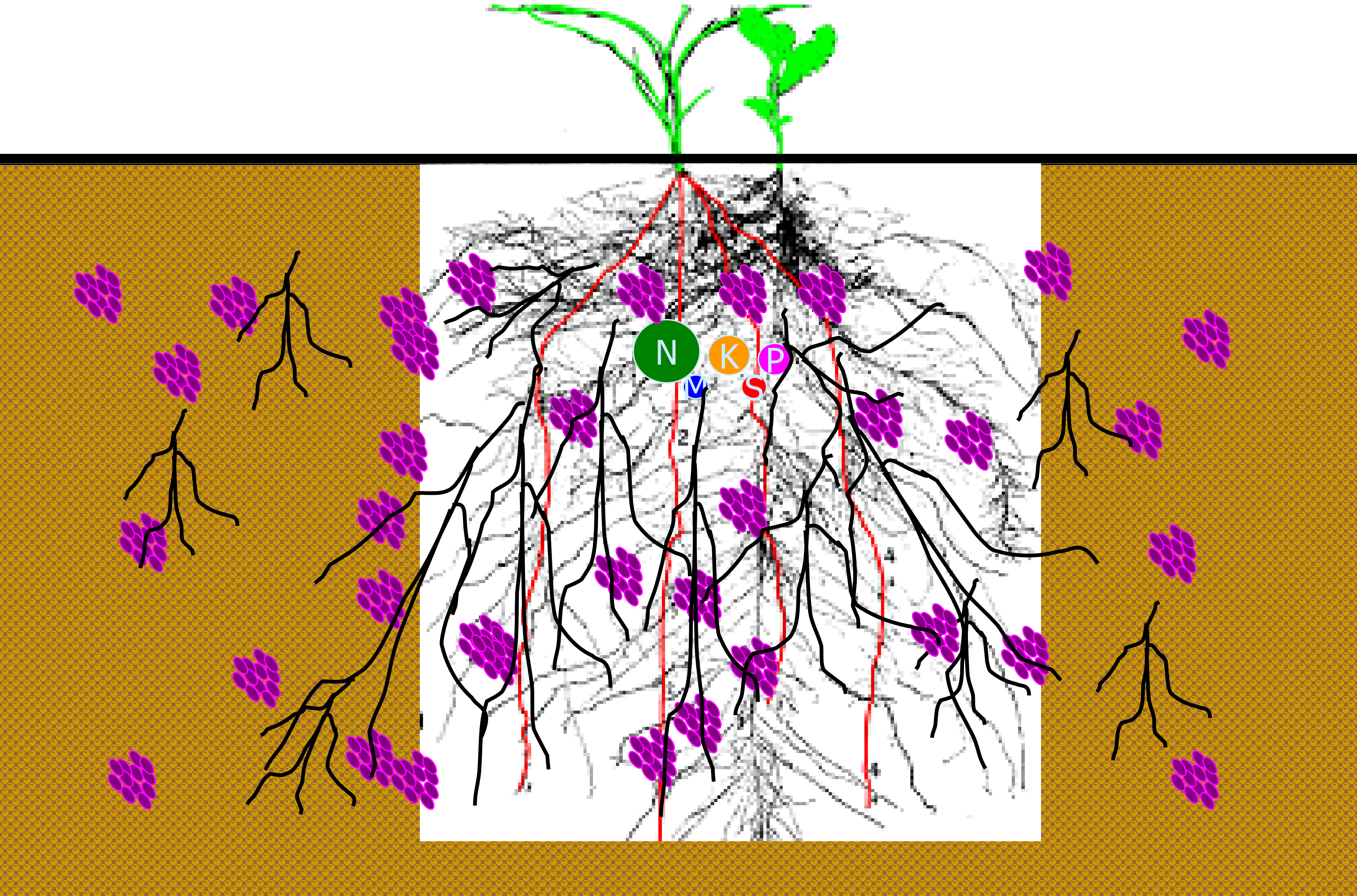
The Big Buffet Drives Organisms Away



Need a Bigger Buffet


N
K
P
M
S

Tap into the natural fertility of soils



Cropping Systems and Soil Carbon Sequestration

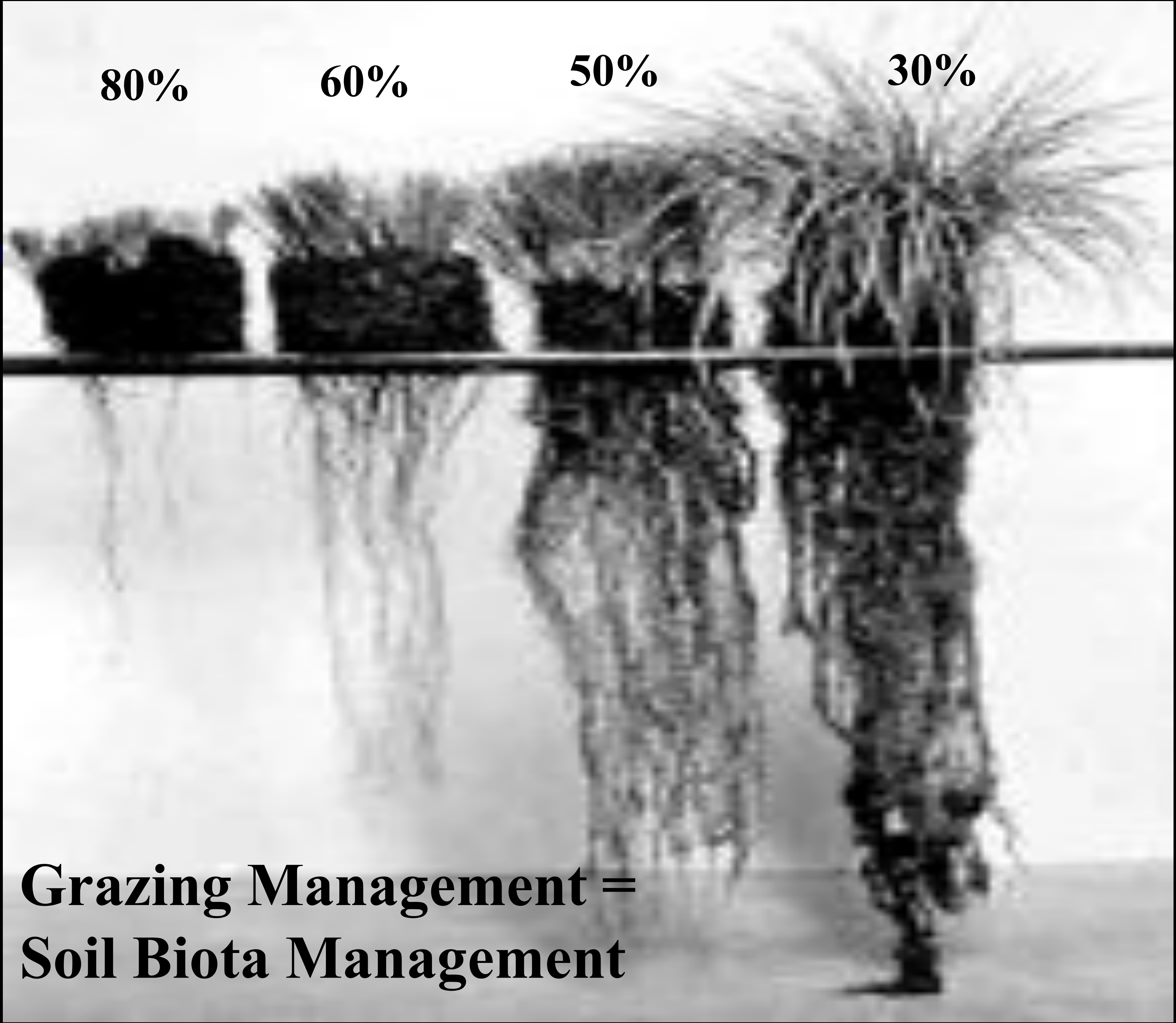
Long-term Cropping System Study

USDA-ARS, Mandan, ND, 1983-1996

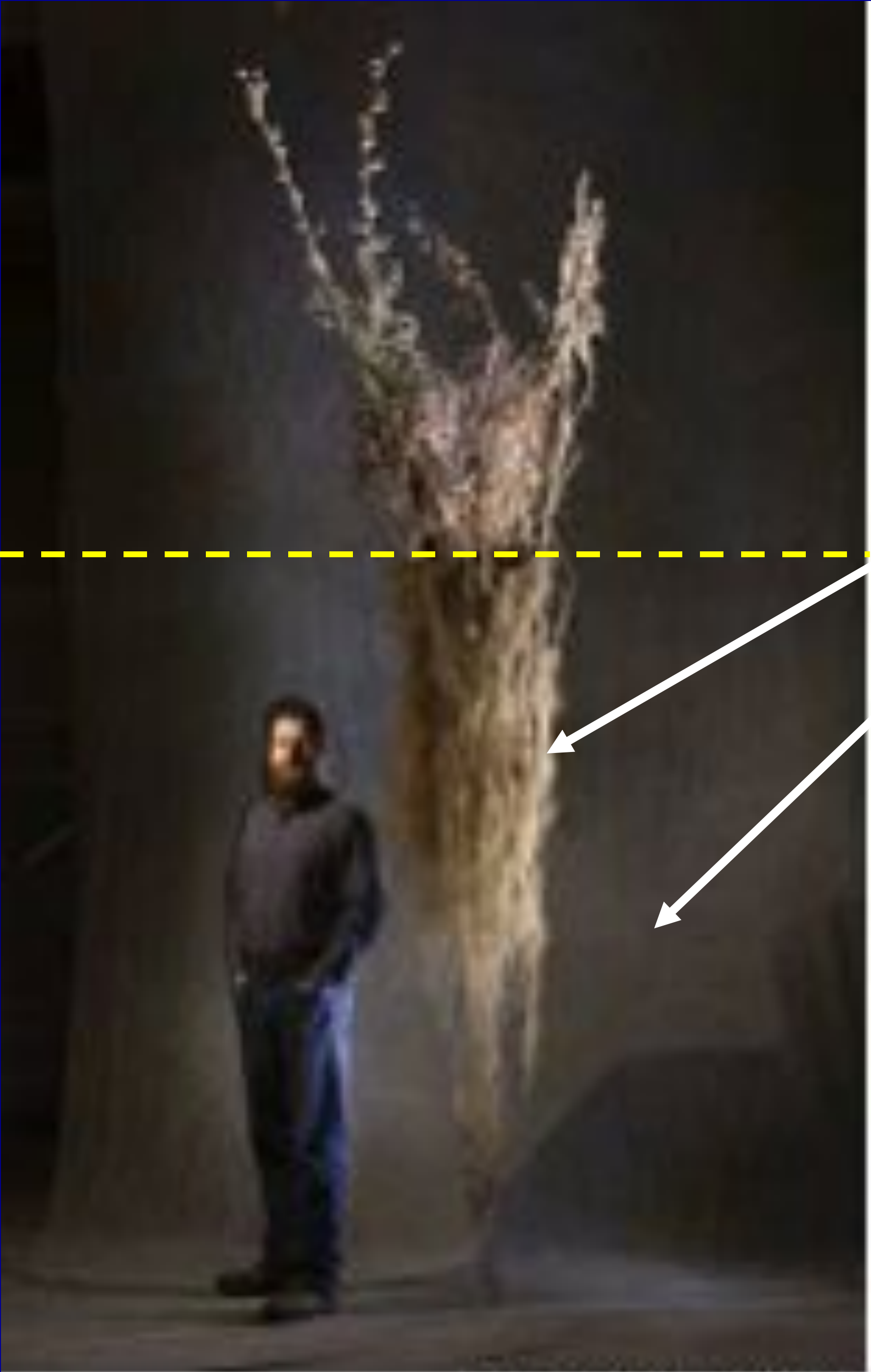
Results for 0-6" depth

	- - - - - ton C ac^{-1} yr^{-1} - - - - -		
Cropping System	**CT**	**MT**	**NT**
SW-F	- 0.12	- 0.07	-0.14
SW-WW-SF	- 0.06	0.01	0.10

From Halvorson et al. (2002)


80%
60%
50%
30%
Grazing Management =
Soil Biota Management

Micro herd: Ultra High Stock Density- with tall grass and long root



Photograph by Jim Richardson

Twice the number of microbes near the root system than outside the root system

Gail Fuller Emporia, KS
Corn crop with companion mix – white clover, pantain, turnip, crimson clover, cosmos, and marigold - planted May 7, 2011 with 2.25” rain on it

Gail Fuller, Emporia, KS,

Corn planted May 7 with companion crops seeded day before corn, same field as above, one hot week later with air temps. Of 100 when pics taken, Corn with companion crops no more stressed than corn without

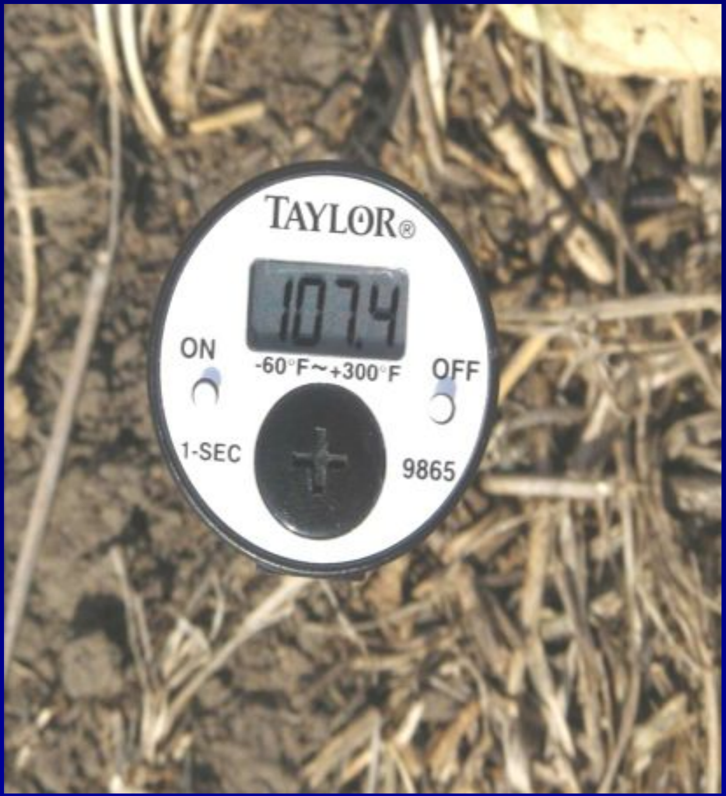

06.30.2011

Cover Crop Enhancement, 2006

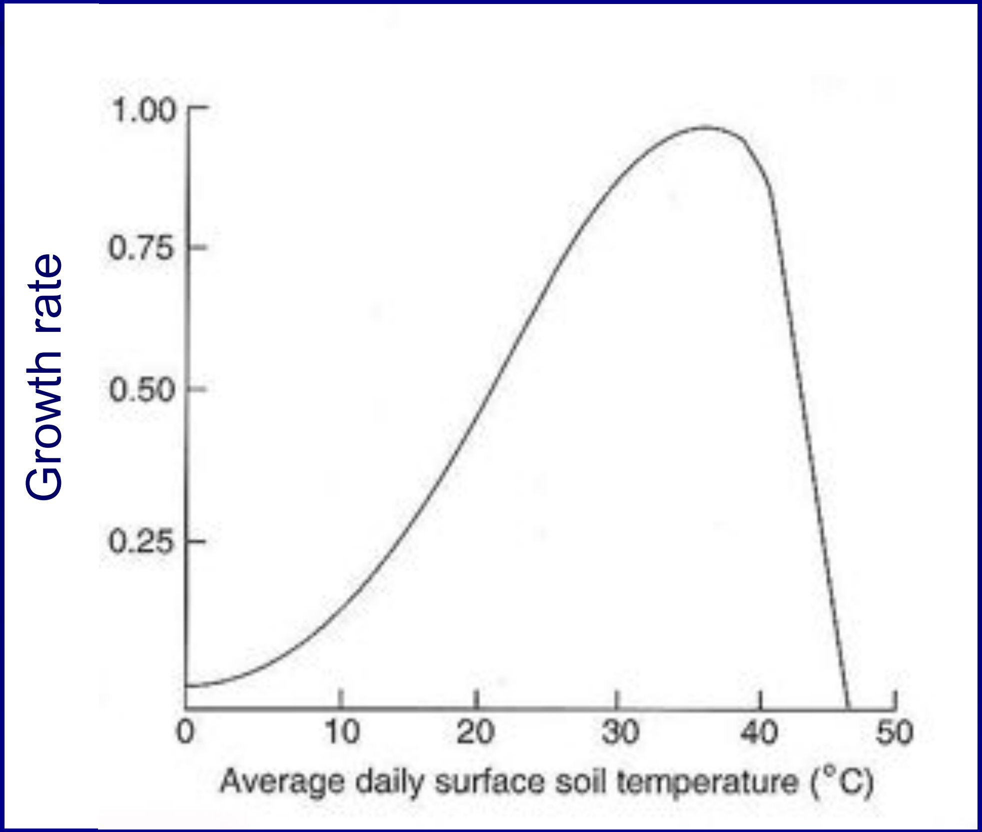
Soil Cover Impacts Soil Temperature which Impacts Biological Growth

Living Plant (i.e. Cover Crop)

Some Crop Residue No Till System



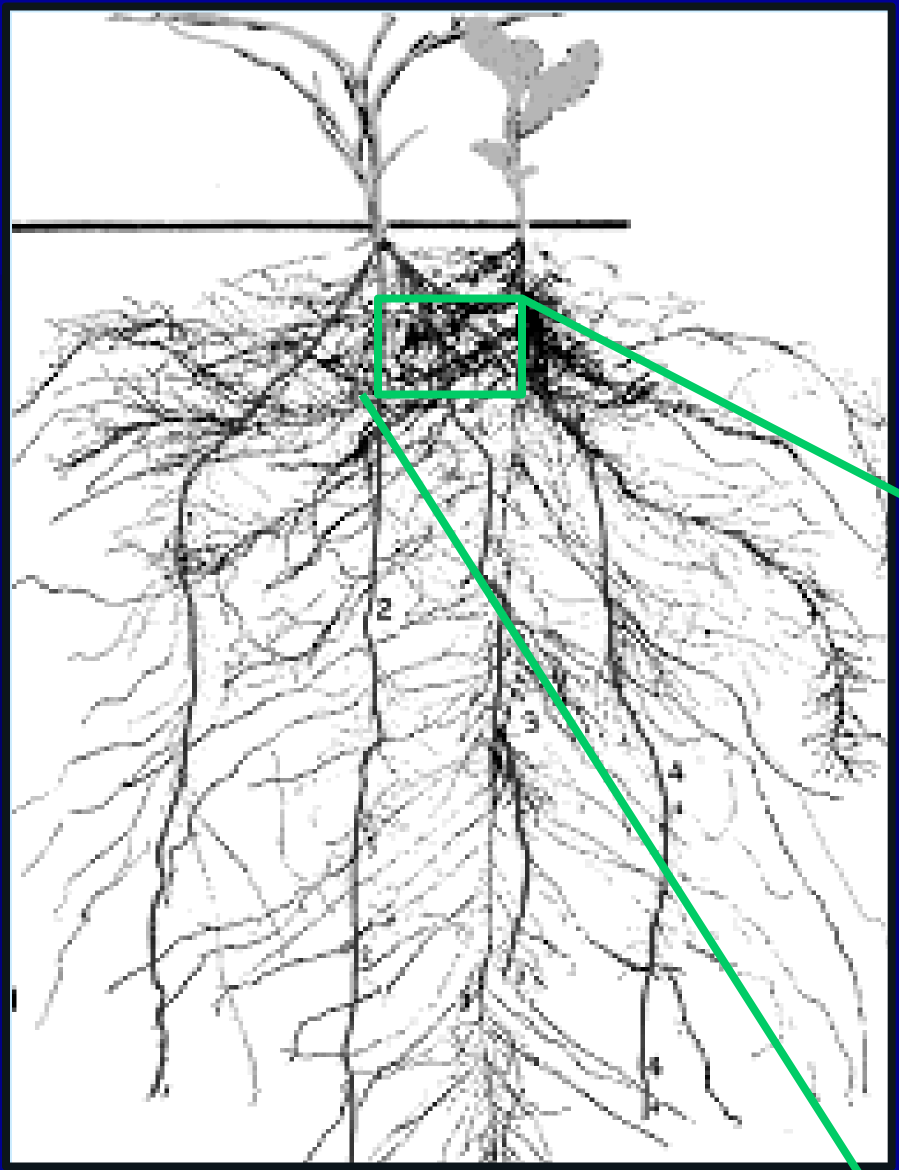
Microbial Growth Curve



Any time soil temperatures, even in microclimates, are above freezing microbial activity will occur. Optimum microbial growth occurs at about 28-45°C (about 80-110°F), but can slow dramatically between 40-48°C (100-115°F.)

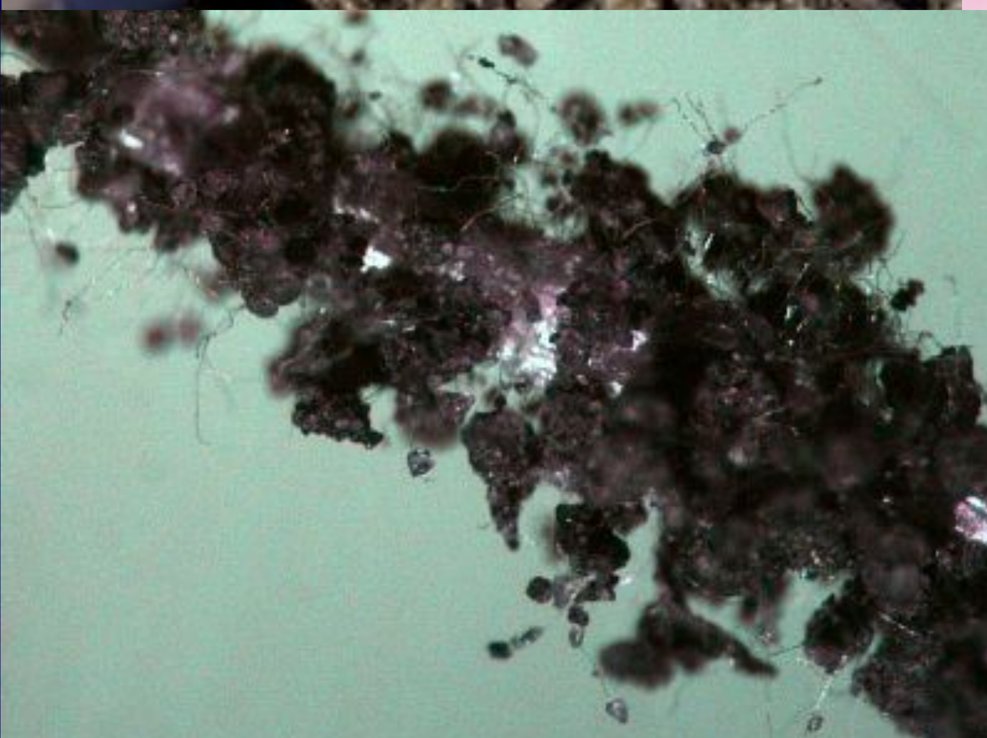
Using Cover Crops to Improve Internal Cycling of N

- Inorganic soil N immobilized on-site in growing plant biomass
  - prevents loss from leaching, denitrification, volatilization
- Augmented by N-fixation (leguminous cc)
- Organic form in dead biomass slows release of N and reduces loss as organic N mineralized to ammonium
- Ammonium oxidized to nitrate (nitrification, autotrophic microbes – Nitrobacter, Nitrosomonas, Archea)



Interplant transfer, primarily N from biological N fixation and P, via mycorrhizal fungal hyphae.

Soil Architecture – Soil Aggregates Food and Habitat

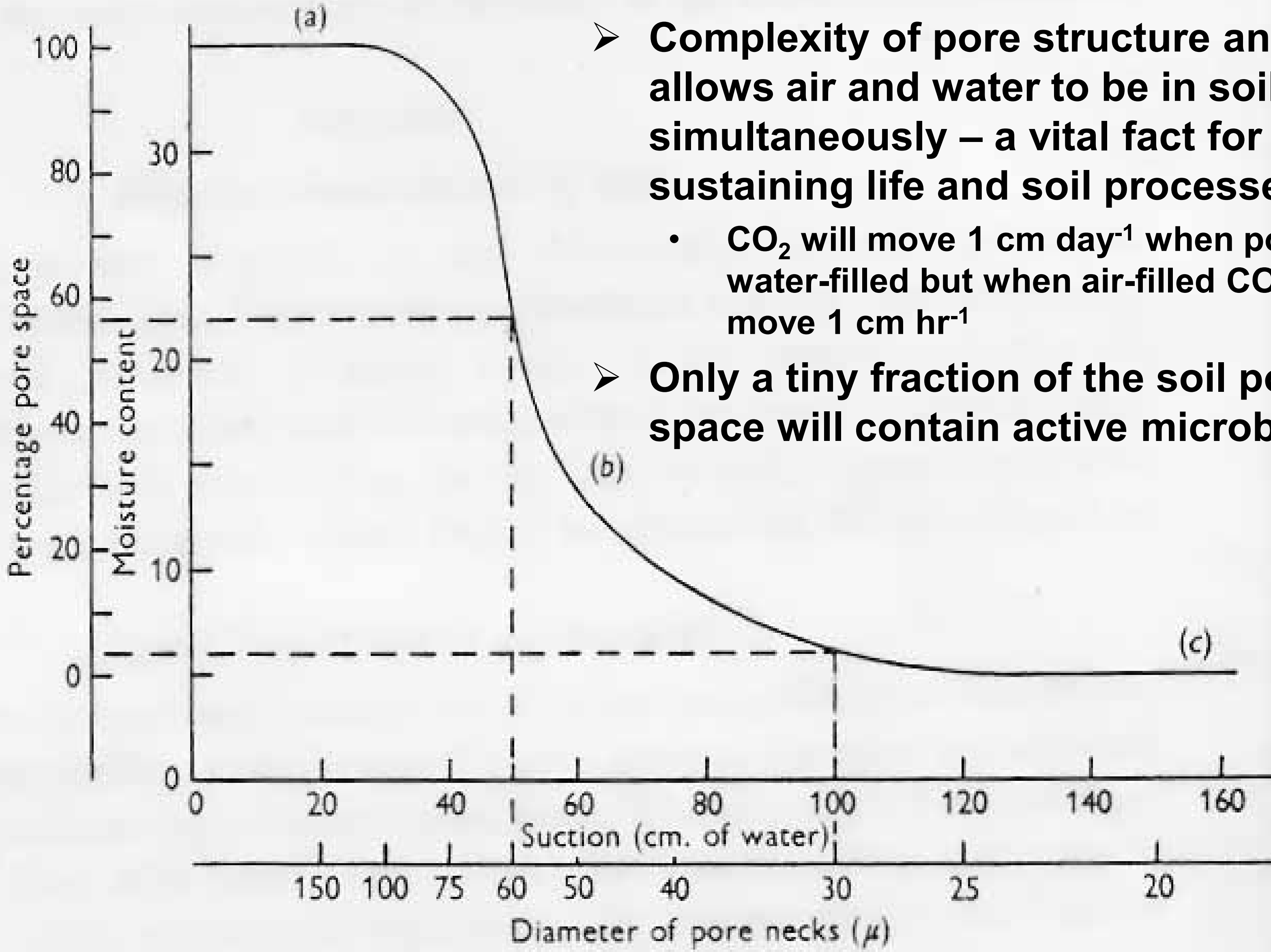


(12.5X magnification)

Compaction Impacts on Root Growth

In poorly aggregated soil, or where zones of compaction exist due to poor aggregation, roots will grow where there is no compaction (left) or will bend to avoid compacted zones (above).

Porosity and Soil Biology



- Complexity of pore structure and size allows air and water to be in soil simultaneously – a vital fact for sustaining life and soil processes
  - CO_2 will move 1 cm day^{-1} when pores are water-filled but when air-filled CO_2 will move 1 cm hr^{-1}
- Only a tiny fraction of the soil pore space will contain active microbes

Water Management

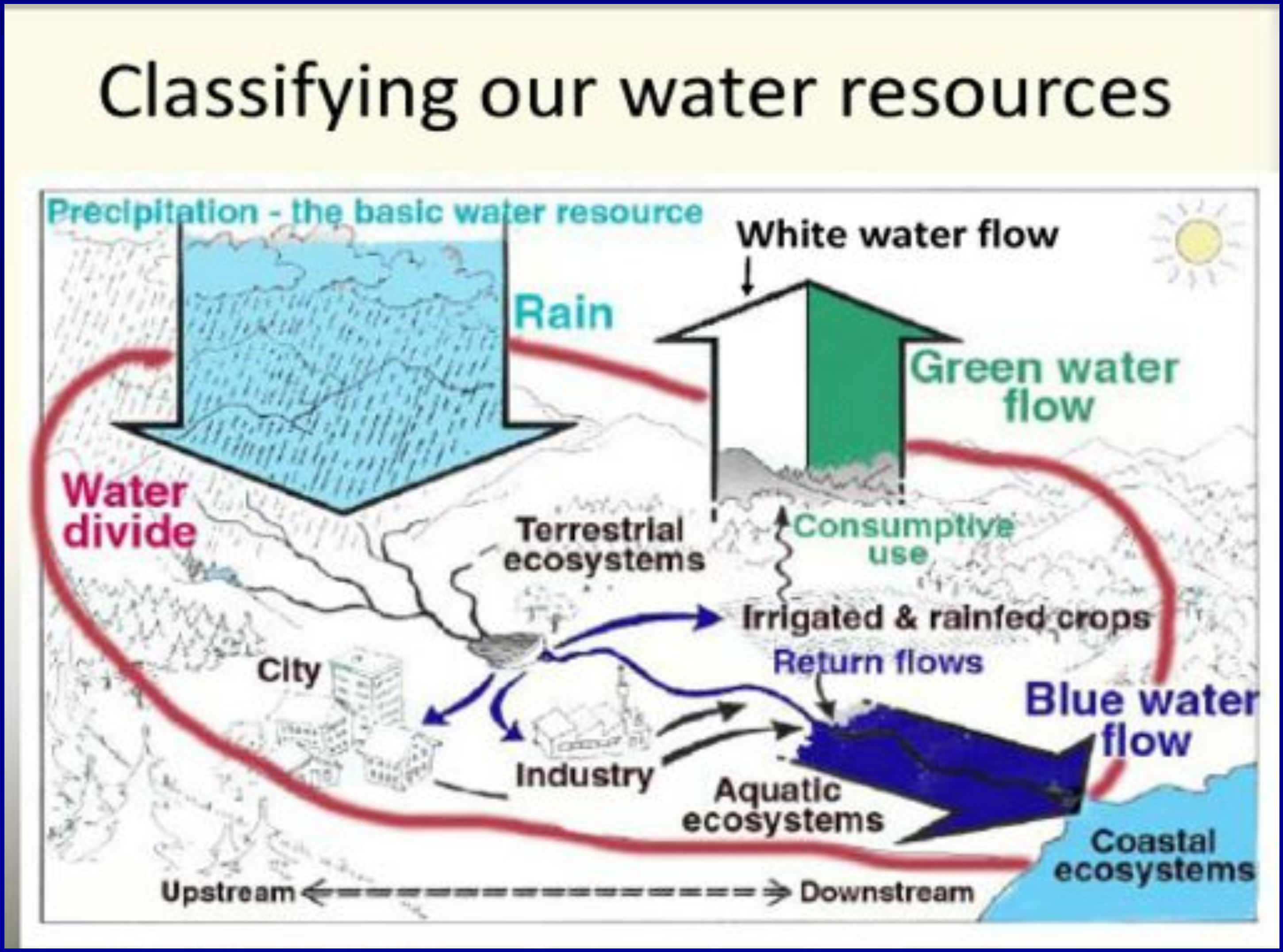
- The Drought Myth - a case of plant hunger rather than thirst - unfertilized corn required 26,000 gallons of water per bushel yielded 4X less than a fertilized field receiving only 5,600 gallons of water per bushel. – W.A. Albrecht, 2000

- A mix of seven cover crop species yielded almost 3 times the yield of single crop species on 7 in of soil moisture. Soil moisture with no cover crop approximately the same as with cover crop. Field with manure and no commercial fertilizer yielded the same as a fertilized field and plant tissues tested sufficient or high for N, P, K, and S – North Dakota

- 45% greater porosity increases infiltration rate by 167% for the first inch and 650% for the second inch - Karlen et al., 1998

- Loose soil has a slower rate of drying compared to packed soil, because the water films are discontinuous and moisture is not readily conducted to the surface.

But where do we get the water to grow the cover crop ?
We often don't have enough for our cash crop!



Water Infiltration

Conventional

Undisturbed

Erosion

Reduced

Conventional

No-till

Why are aggregates important?

❖ Improve Soil Structure

✓ Porosity

- Root penetration
- Aeration
- Water infiltration
- Water holding capacity

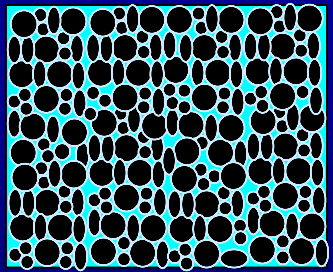
✓ Erosion control

❖ Improve Nutrient Cycling

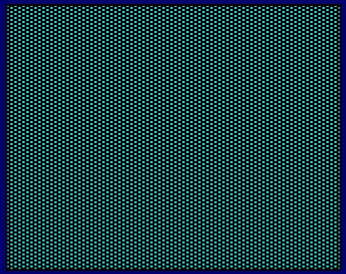
✓ Provides a protected habitat

✓ Provides food

✓ Protects soil organic matter (i.e. carbon) from rapid decomposition



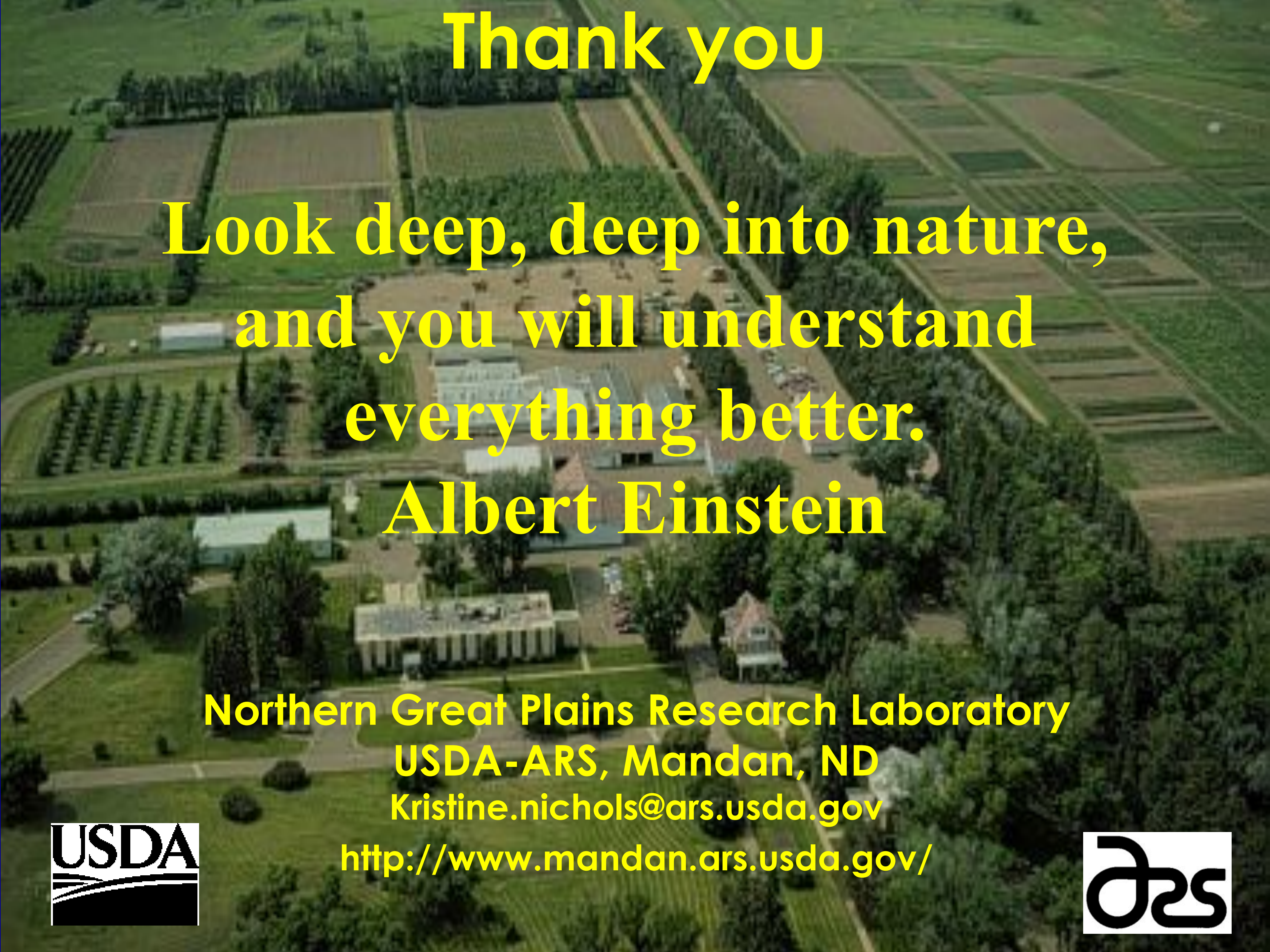
Water-filled well aggregated soil above and not well aggregated soil below.



Soil Aggregate stability

Management vs. Getting the Job Done

- New GREEN REVOLUTION is a BROWN (SOIL) REVOLUTION
- Utilize resources most efficiently
  - Increase soil biological activity
- Doesn’t mean working harder but working smarter!
- Designing for what you don’t have!
  - Pest management
  - Specific C/N ratios (residue management)
  - Soil armor – leaf size, placement, and strength
  - Efficient use of water and nutrient resources



Thank you

Look deep, deep into nature, and you will understand everything better.

Albert Einstein

Northern Great Plains Research Laboratory
USDA-ARS, Mandan, ND
Kristine.nichols@ars.usda.gov
http://www.mandan.ars.usda.gov/


(SQ – 18) Soil Organic Matter & Organic Carbon Gains and Losses Guide
Harvest (tons/ac.)
Cash Crop/Major Crop
(Crop Rotations; tons/ac.)
Carbon Dioxide (CO_2) & Heat Energy loss
Plant Organic Compounds: sugars, starches, simple proteins, crude proteins, hemicelluloses, cellulose, fats, waxes, lignins, etc.
Soil Food Web
Compost (tons/ac.)
Slow Decomposition
Root Exudates
Grazed (tons/ac.)
Crop Residues (tons/ac.)
Oxygen (O_2)
Decomposition
Rhizosphere
(Photos: Soil Biology Primer)
Manure (tons/ac.)
Decomposition
Root Exudates
Cover Crops (Legume & None-Legume mixtures; tons/ac.)
Soil Moisture & pH
Carbon Dioxide (CO_2) & Heat Energy loss
NOTE: The Crop Residues Carbon:Nitrogen (C:N) ratio strongly influences the rate of decomposition.
Humification: The process involved in the decomposition of organic matter and leading to the formation of humus
Soil Humus: Active Pool
Humification
Soil Humus: Slow Pool
Humification
Soil Humus: Passive Pool
Humification
Microbial action can transfer organic carbon from one Pool to another.
Soil Humus (Humic & Nonhumic substances): That more or less stable fraction of the soil organic matter remaining after the major portions of added plant and animal residues have decomposed. Usually it is dark in color. About 20-30% of humus in soils consists of nonhumic substances (e.g., polysaccharides). These substances are less complex & less resistant to microbial attack than those of the humic group. Some of these nonhumic substances are microbially modified plant compounds, while others are compounds synthesized by soil microbes as by-products of decomposition. Humic Substances include Humin (highly condensed, complexed with clay), Humic acids and Fulvic acids. All three groups of humic subtances are relatively stable in soils.
rudy garcia 2009