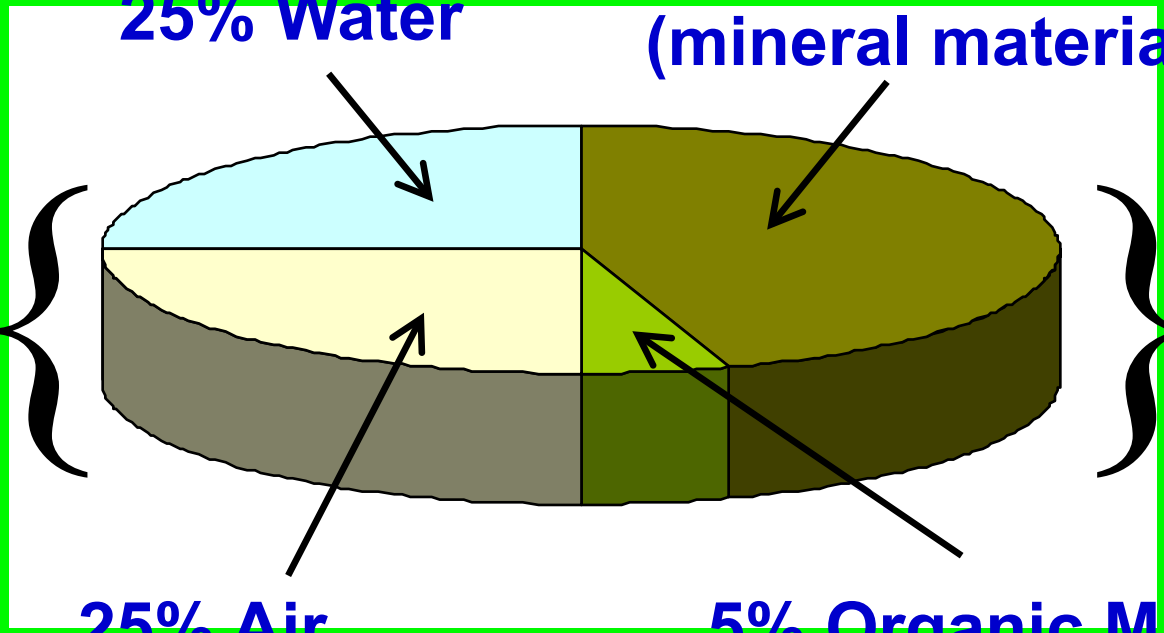
Soil Ecology, Nutrient Recycling, Improving Soil Structure

James J. Hoorman
hoorman.1@osu.edu
www.mccc.msu.edu

EMPOWERMENT THROUGH EDUCATION

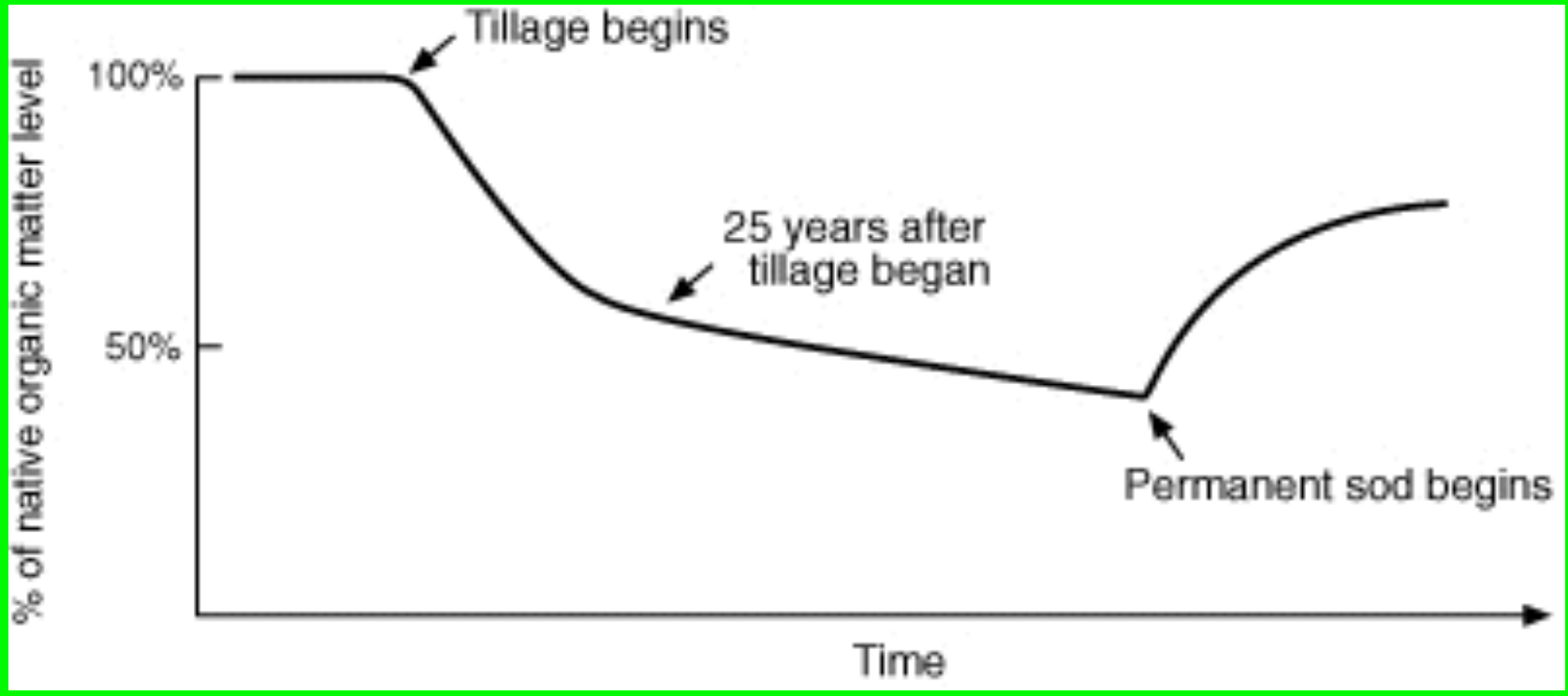
THE OHIO STATE UNIVERSITY EXTENSION

Ideal Soil Composition



SOM loss

Recent research



U of Minn

Nitrogen Losses in Corn

Corn has a high N requirement and is relatively inefficient, recovering only 30-50% of our annual fertilizer N input (Sims et al., 1995).
Why? We may have lost 50-70% of our SOM (Lal et al, 2004).

Most of the NO_3-N leaching occurs during the fall and early spring months when the soil is fallow in the typical corn-soybean rotation of the U.S. Midwest (Owens et al, 1995).

Making No-till Corn Work!

1)Why is adoption of No-till Corn so much lower? Expect 10-20% yield decrease.

2)What is missing? Takes 7-9 years continuous no-till before soil recovers. Takes 2-4 years if add a continuous cover crop? If manure is added, takes even less time.

Compare Conventional Tilled to Long-term No-till Soils

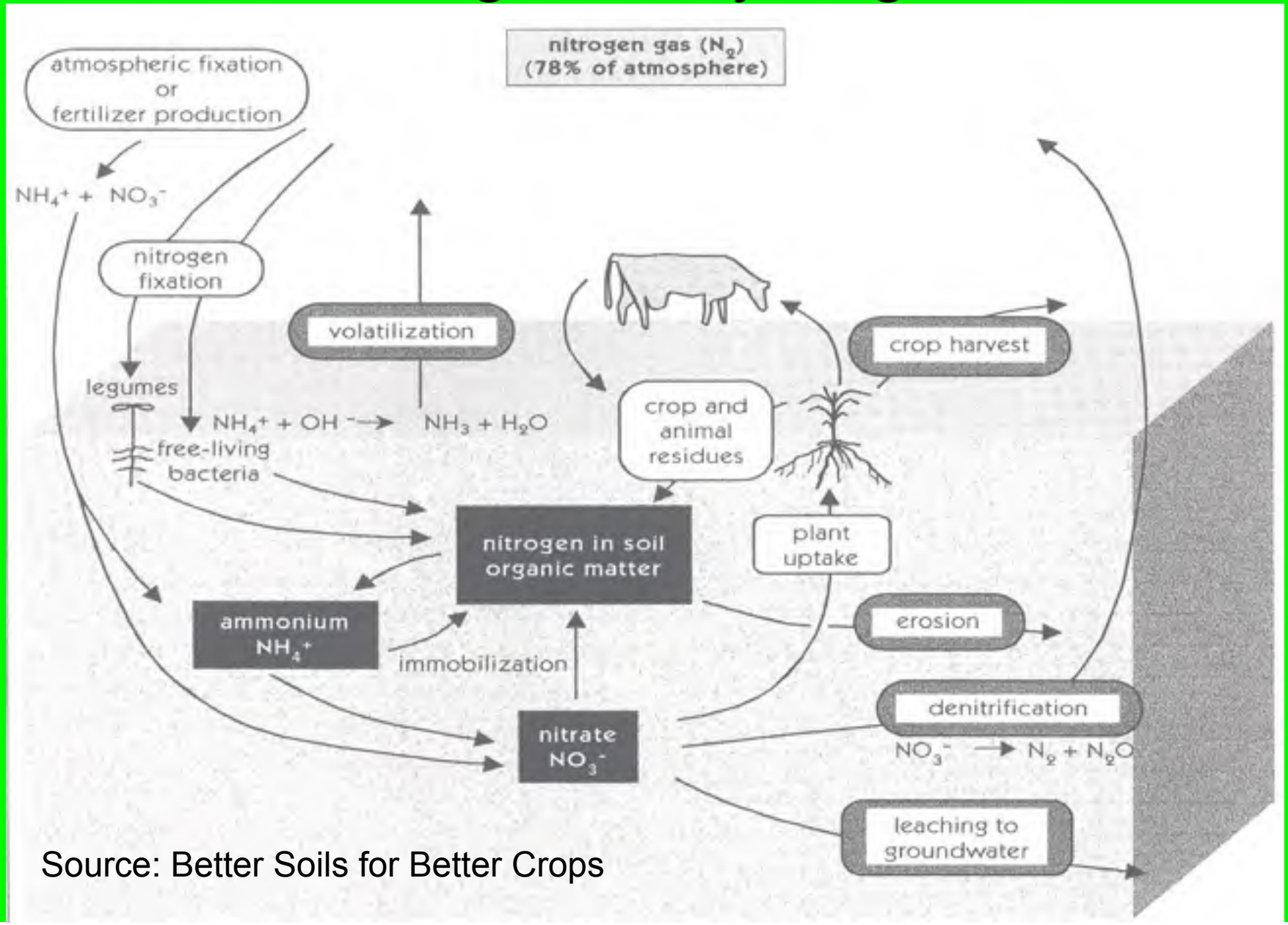
Conventional Soils	Long-term No-till Soils
1-3% organic matter	4-6% Organic matter
No residue on surface	High residue on surface
Plow Layer 8-10”	Macropores throughout soil profile
Microbial life dominated by bacteria	Microbial life composed of fungus and bacteria
“Hydroponic farmers”	

Soil Nitrogen Storage

Inorganic Forms: Fast Release
Nitrates ($N0_3$-) Ammonium Ion(NH_4+)
Available & Mobile (>10% in this form)

Organic Forms: Slow release (Proteins)
Stored in microbes, plants, crop residues, and SOM (<90% of Soil N in this form).

Nitrogen Recycling

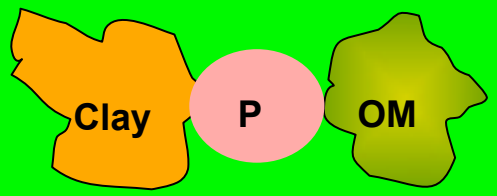


Source: Better Soils for Better Crops

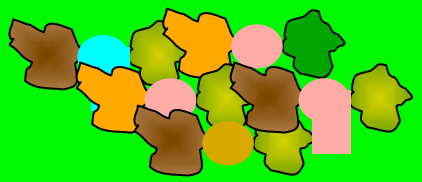
About 50-75% of the Available P in soil is organic.

P stabilizes the OM and forms a bridge to the clay.

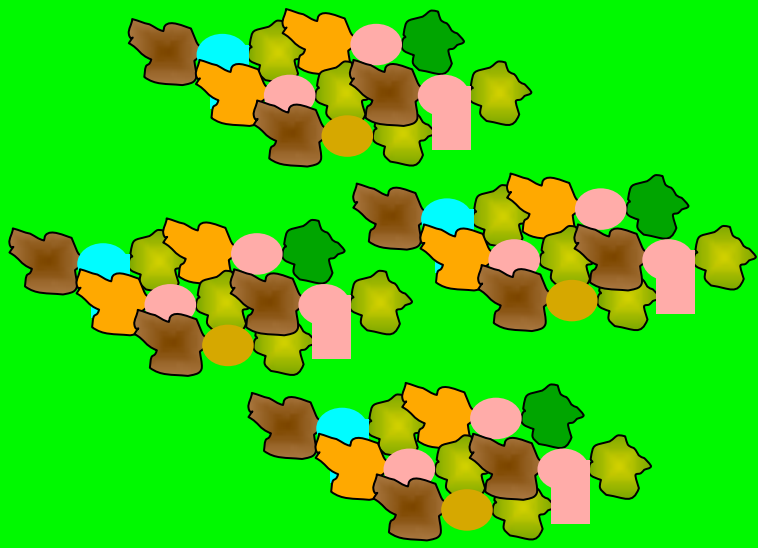
Our current P use efficiency is 50%.



Clay-P-OM

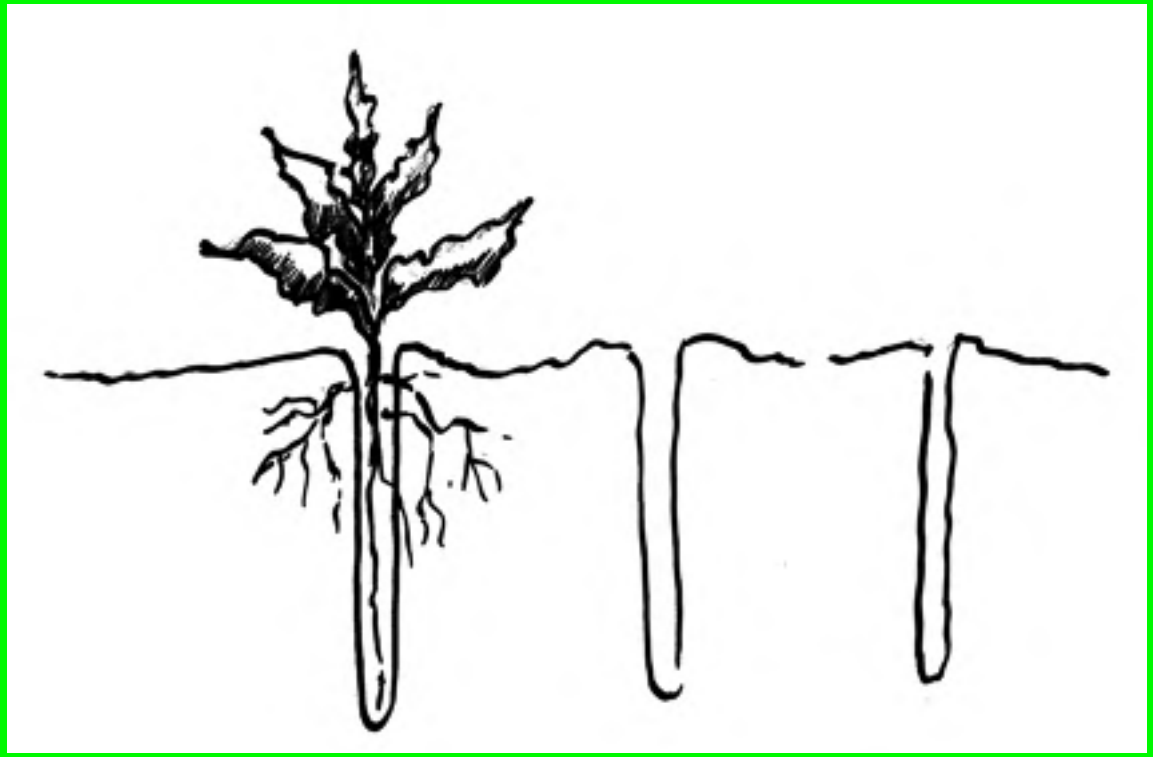


$(Clay\text{-}P\text{-}OM)_x$



$((Clay\text{-}P\text{-}OM)_x)_y$

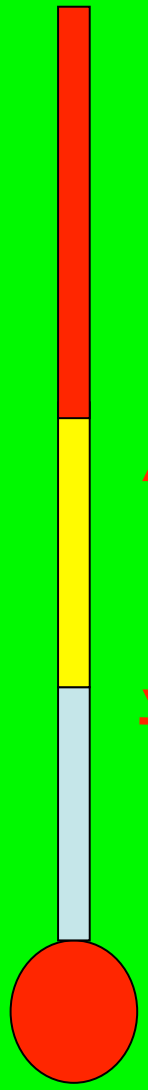
N0-TILL + COVER CROPS



Acts like biological valve to absorb N and P.
Keep the land green will keep the water clean!

Illustrated by Cheryl Bolinger-McKirnan & Jim Hoorman

When soil temperature reaches...



140 F — Soil bacteria die

130 F — 100% moisture is lost through evaporation and transpiration

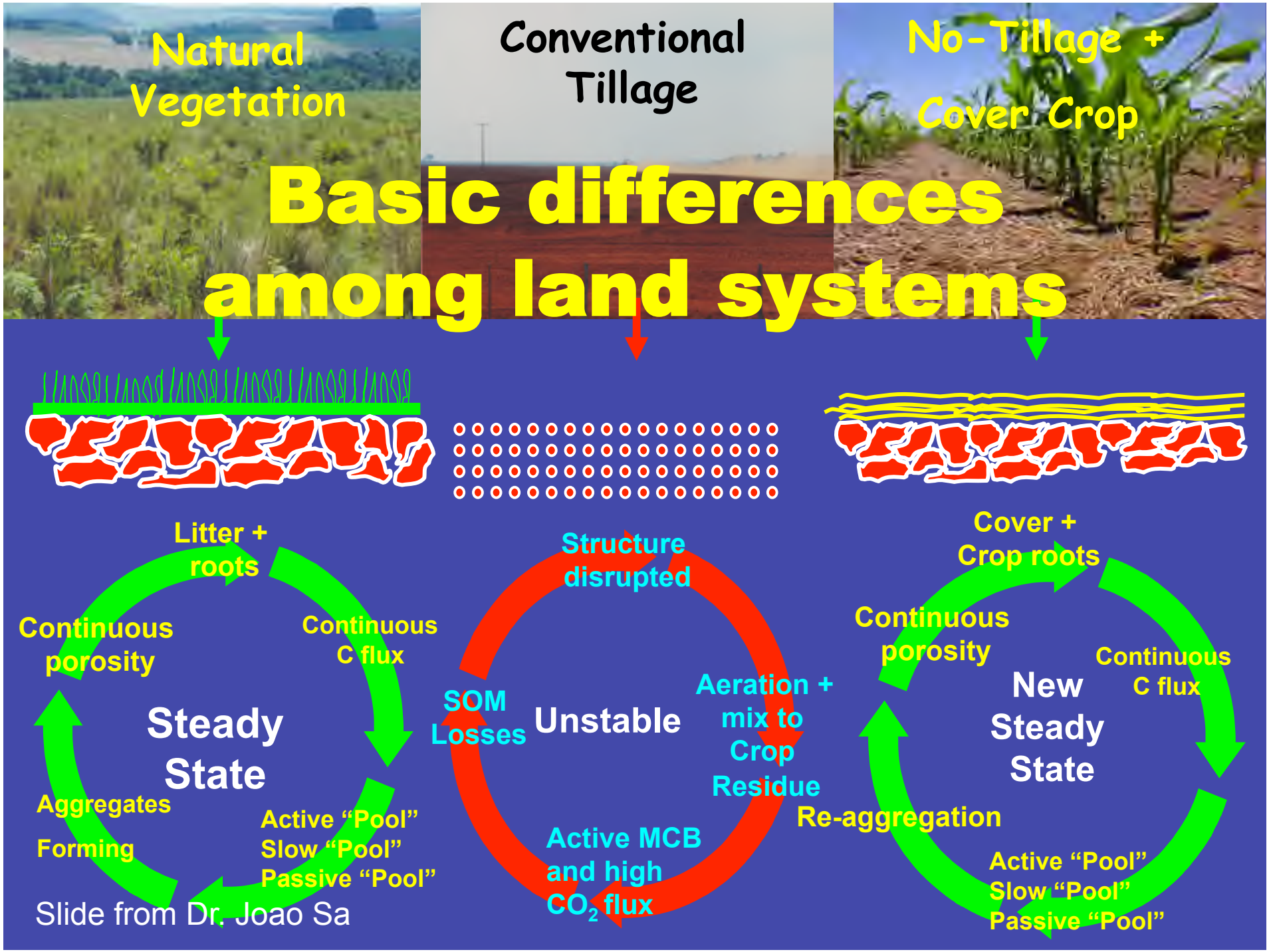
113 F — Some bacteria species start dying

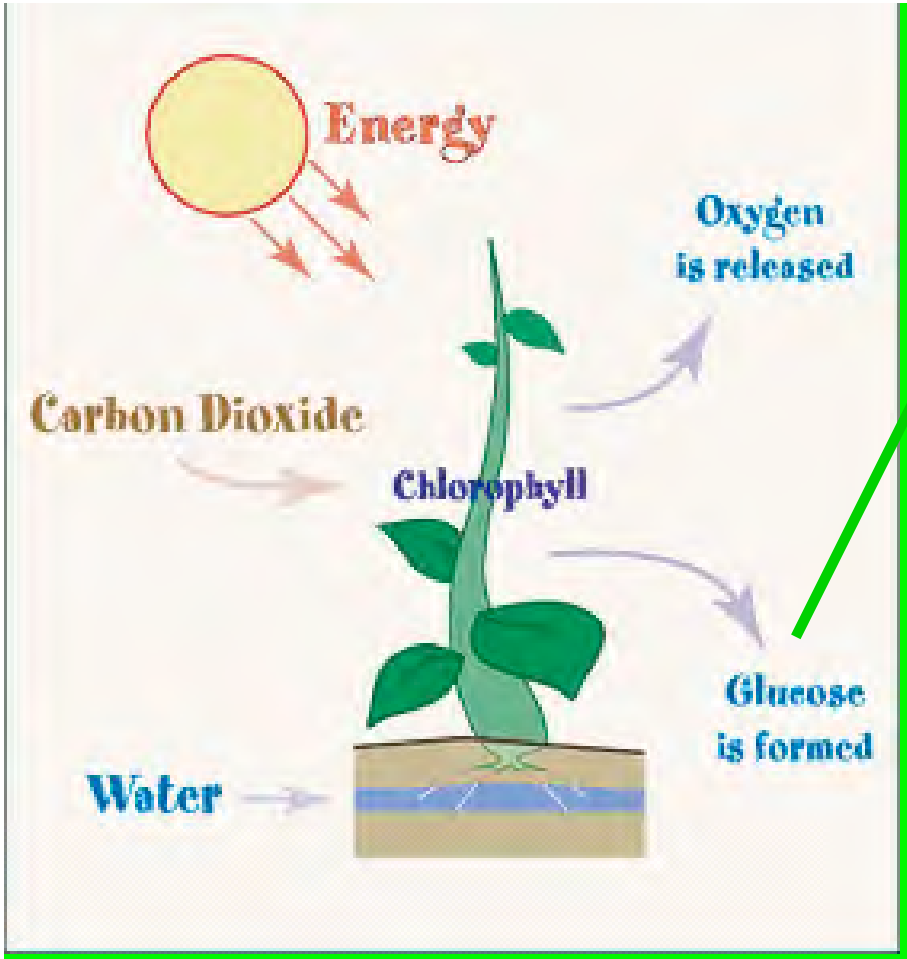
100 F — 15% of moisture is used for growth
85% moisture lost through evaporation and transpiration

95 F

70 F — 100% moisture is used for growth

J.J. McEntire, WUC, USDA SCS, Kernville TX, 3-58 4-R-12198. 1956


Natural Vegetation
Conventional Tillage
No-Tillage + Cover Crop
Basic differences among land systems
Litter + roots
Continuous porosity
Continuous C flux
Steady State
Aggregates Forming
Active "Pool"
Slow "Pool"
Passive "Pool"
Structure disrupted
SOM Losses
Unstable
Aeration + mix to Crop Residue
Active MCB and high CO_2 flux
Cover + Crop roots
Continuous porosity
Continuous C flux
New Steady State
Re-aggregation
Active "Pool"
Slow "Pool"
Passive "Pool"
Slide from Dr. Joao Sa



Glucose + Nutrients

Structural compounds

- Carbohydrates
- Amino acids/proteins
- Lipids (fat)
- Lignin

Non-structural compounds

- Enzymes
- Hormones
- Phenolics
- Vitamins

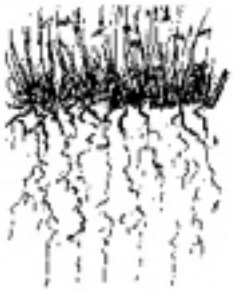
Carbon Storage
North to South

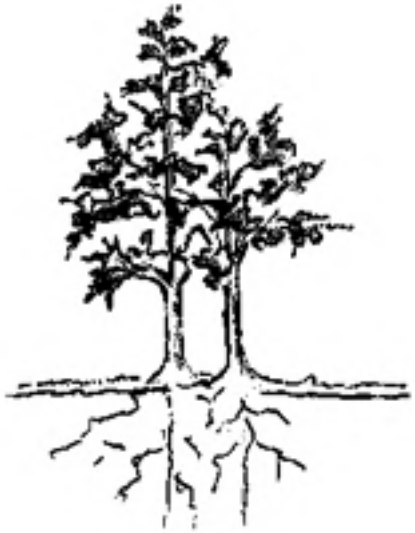
Arctic Tundra

Tropics

Carbon Storage
West to East

Prairie





Hardwood trees

100 g organic residues

Carbon dioxide

60-80 g

Energy + Nutrients

3-8 g Microorganism Polysaccharides	3-8 g Non-humic compounds	10-30 g Humic compounds
Living	Dead	Very Dead

SOM formula

$C_{349}H_{40}N_{26}O_{173}PS$

The storage of Nitrogen in the soil is related to Carbon!

Schulten and Schnitzer (1997)

Value of Soil Organic Matter

Assumptions: 2,000,000 pounds soil in top 6 inches
1% organic matter = 20,000#

Nutrients:

Nitrogen:	1000# * $0.50/#N	=	$500
Phosphorous:	100# * $0.45/#P	=	$ 45
Potassium:	100# * $0.42/#K	=	$ 42
Sulfur:	100# * $0.50/#S	=	$ 50
Carbon: 10,000# or 5 ton	* $2/Ton	=	$ 10

Value of 1% SOM Nutrients/Acre = $647

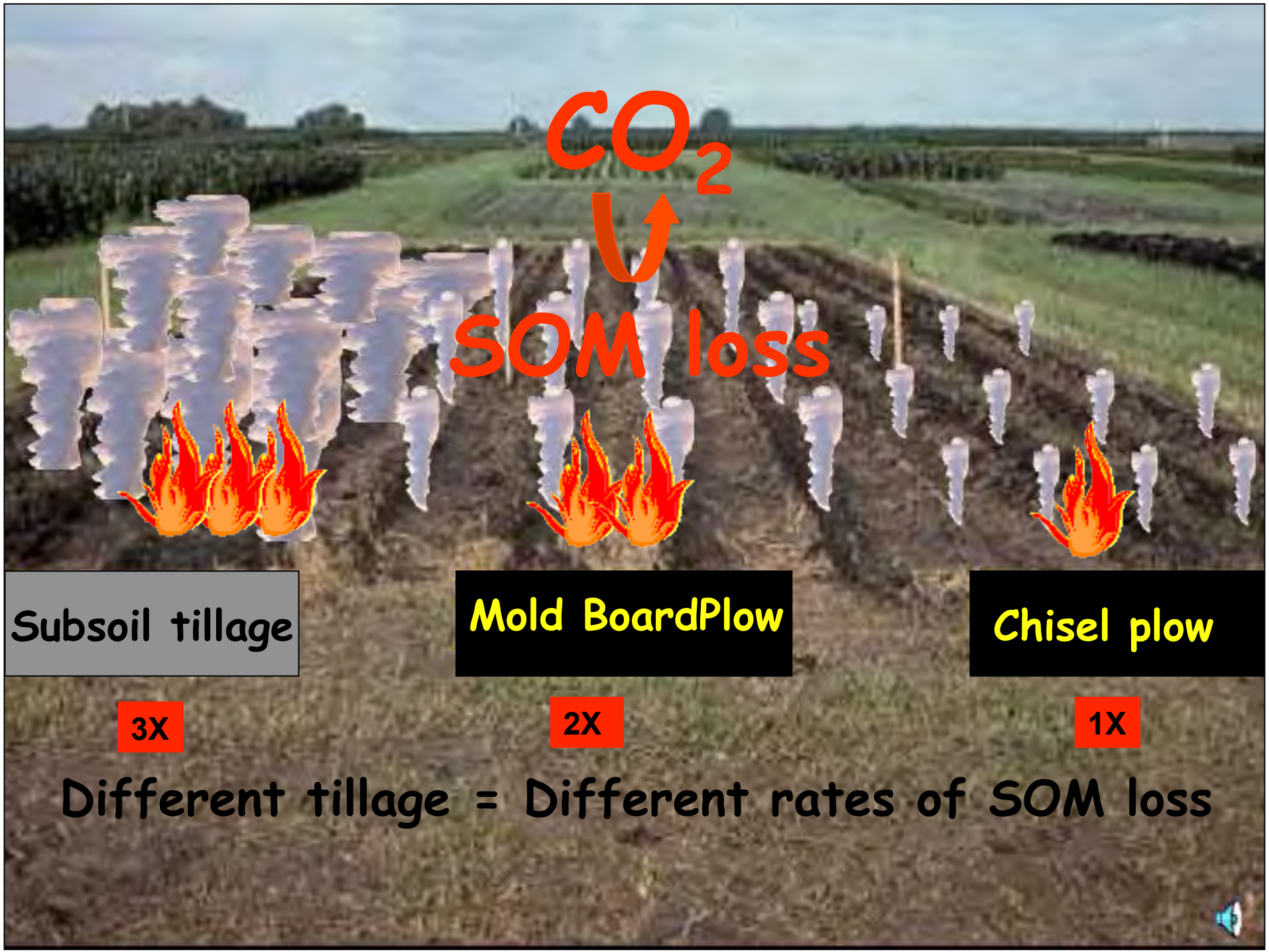
Jim Kinsella/Terry Taylor (2006)
Jim Hoorman (2009-2011)

Conventional agriculture is related to **soil**, air and water quality degradation

1.2 billion ton CO_2/y i.e. 570 M ton SOM loss

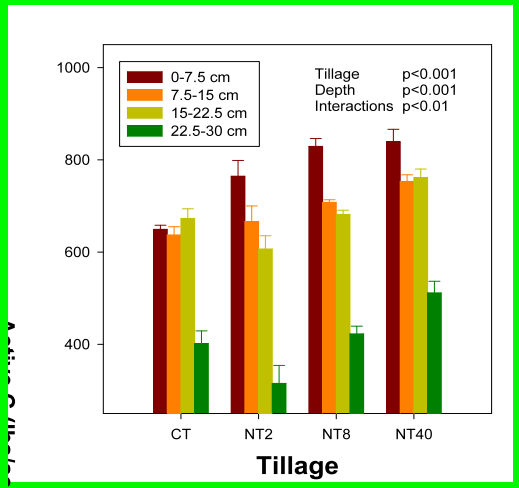
A 1% loss of SOM= 1000 lbs N/ac

Loss of SOM as CO_2


CO_2
SOM loss
Subsoil tillage
Mold BoardPlow
Chisel plow
3X
2X
1X
Different tillage = Different rates of SOM loss

Holding SOM (C) by no-till and crop rotation

All the atmospheric CO_2 ~ only 40% of the soil's C holding capacity (Wallace 1984)


1000
800
600
400
0-7.5 cm
7.5-15 cm
15-22.5 cm
22.5-30 cm
Tillage p<0.001
Depth p<0.001
Interactions p<0.01
CT
NT2
NT8
NT40
Tillage

Relative amount of microbes in soil

Amount of organism in 100 to 200 g of soil

Relative amount of microbes in handful of soil

Bacteria **up to 50 billion**

Actinomycetes **up to 2 billion**

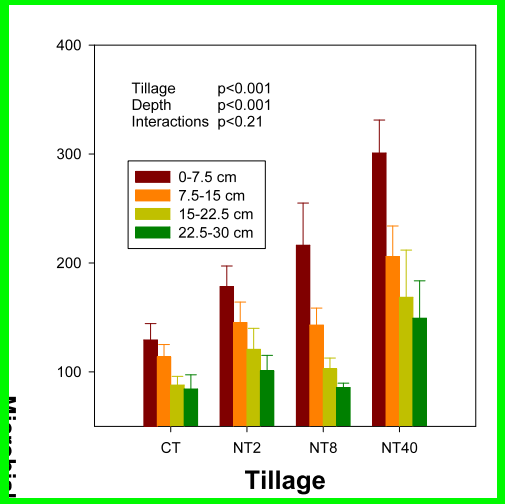
Fungus **up to 100 million**

Protozoa **up to 50 million**

Nematodes **10,000**

Arthropodes **1000**

Earthworm **0 to 2**


400
300
200
100
Tillage p<0.001
Depth p<0.001
Interactions p<0.21
0-7.5 cm
7.5-15 cm
15-22.5 cm
22.5-30 cm
CT
NT2
NT8
NT40
Tillage

Conventional tillage system

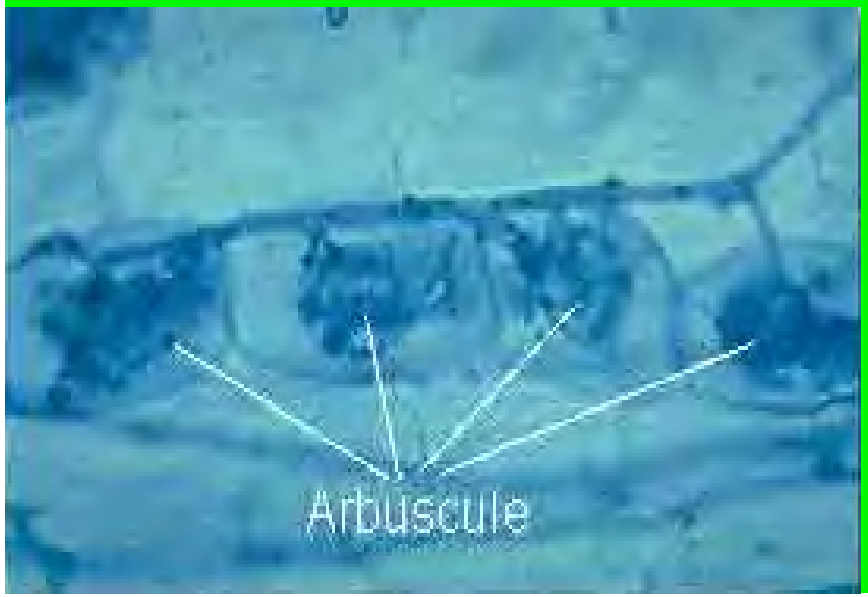
Bacteria-dominated

Bacteria have 20-30% C-use efficiency

Prefer Aerobic Conditions

E. coli bacteria, like the one shown here, can be enlisted to produce an antimalarial drug.

Fungi-dominated



In No-till system

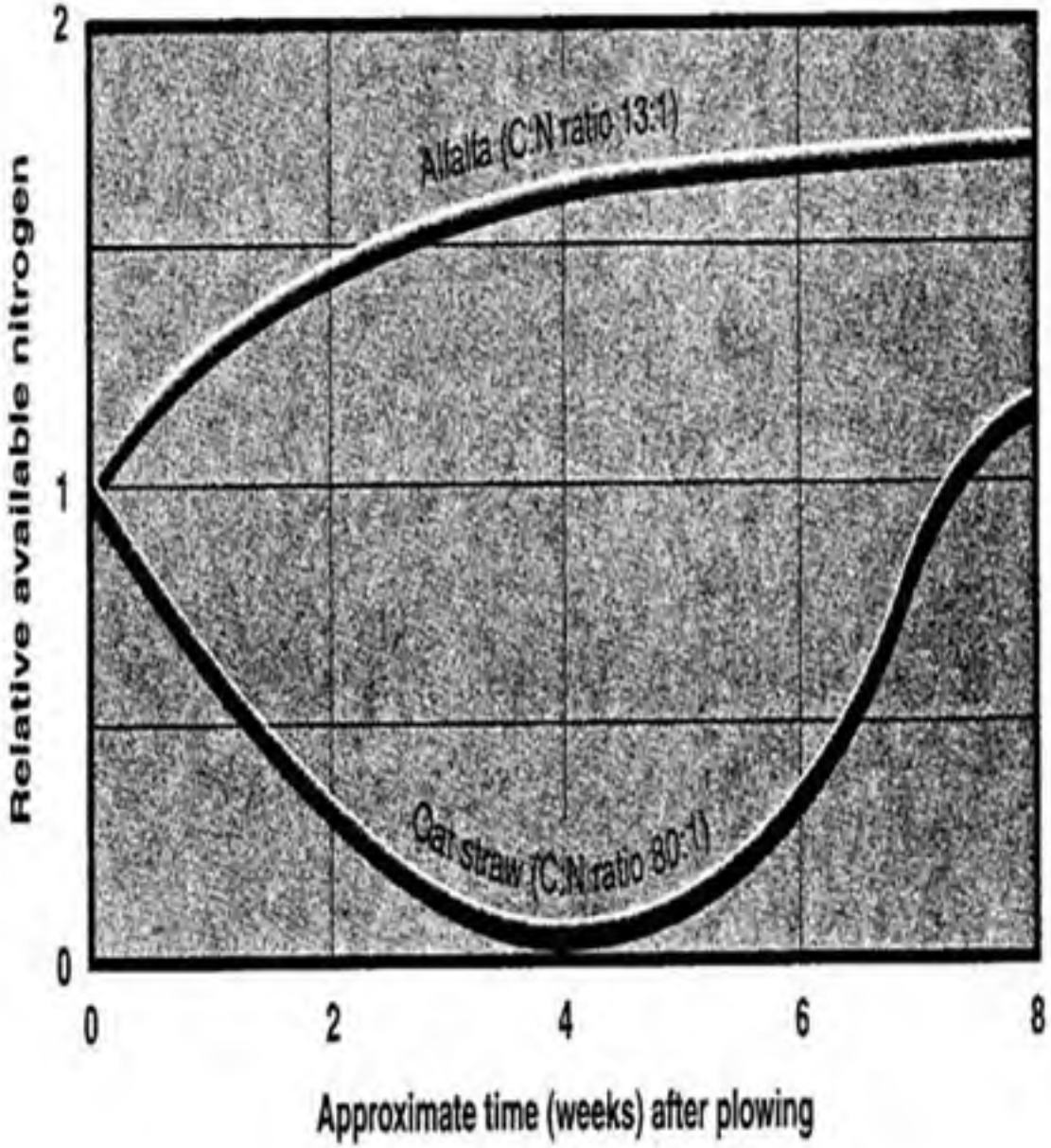
Nematode and fungal relationship

Fungi has 40-55% C-use efficiency

Obligate aerobes & Heterotrophs

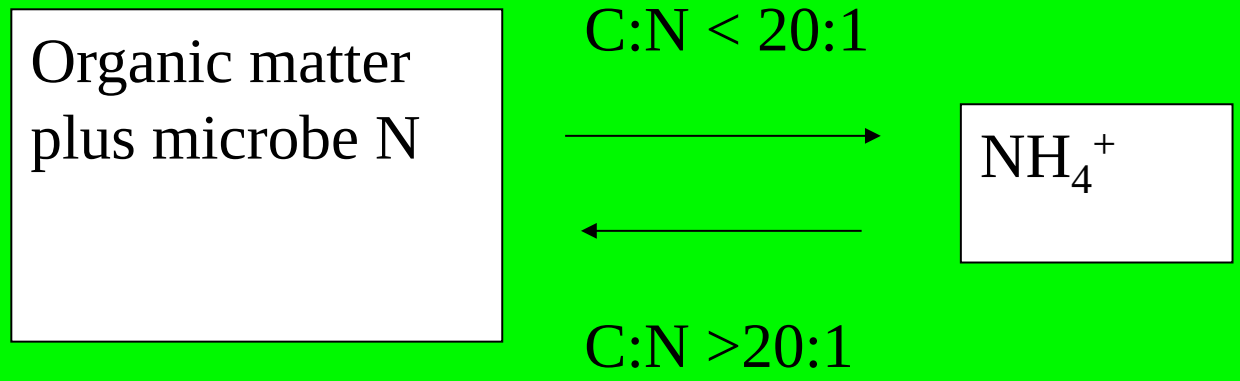
Alfalfa
Low C:N
Ratio C:N = 13:1

Oat Straw
High C:N
Ratio C:N = 80:1

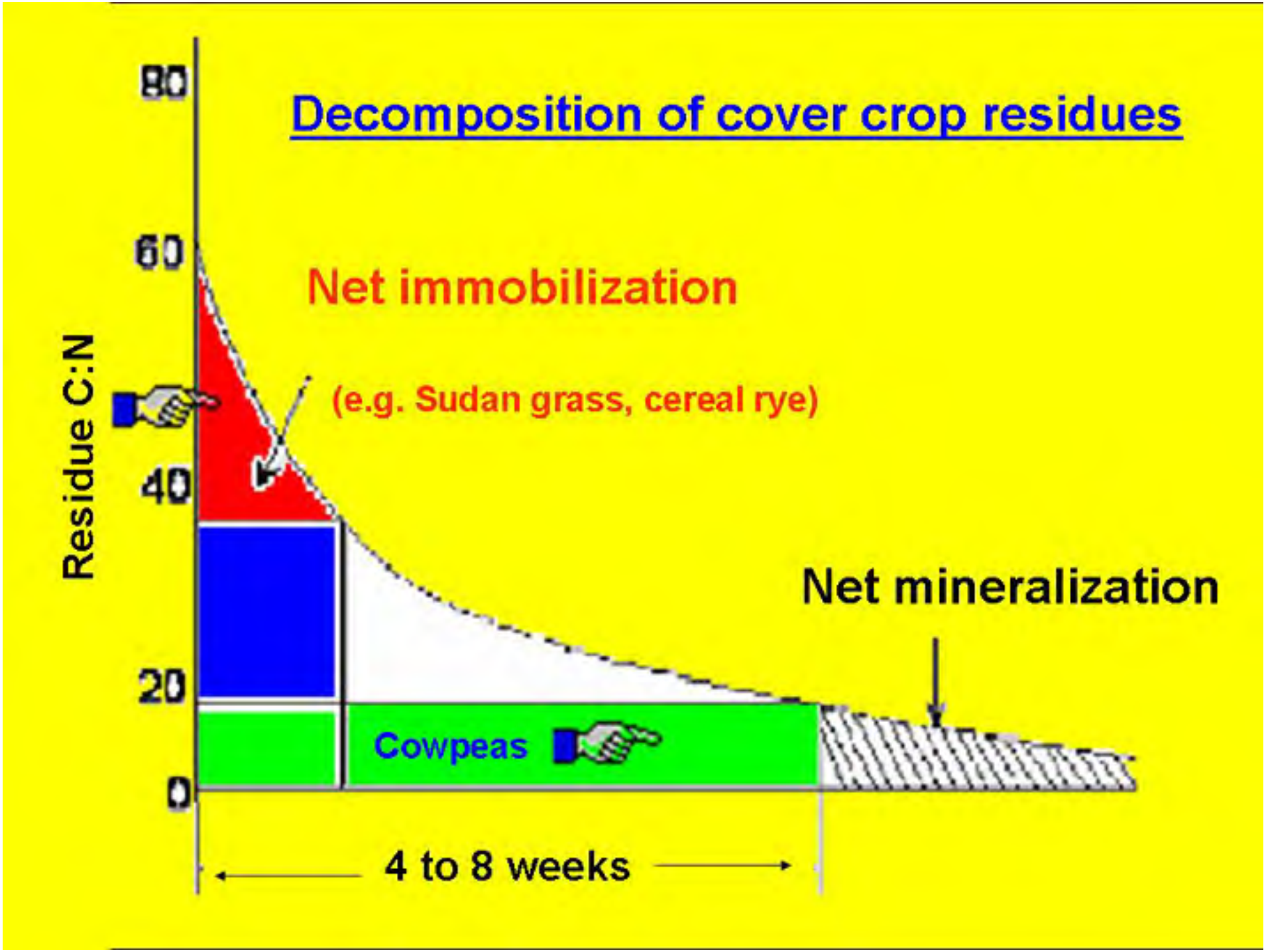


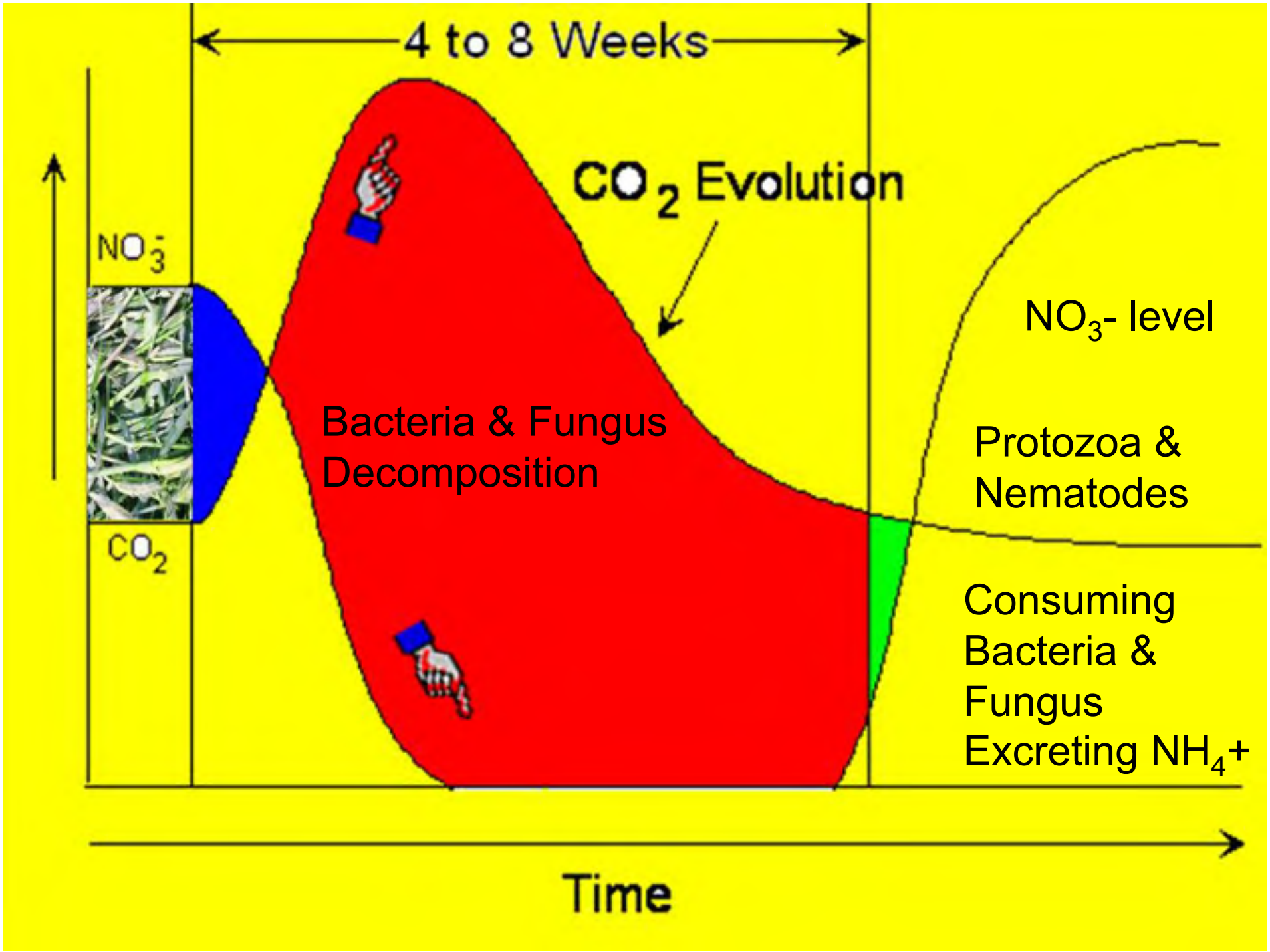
C:N Ratio of Organic Matter

As a rule of thumb:
At C:N >20:1, NH_4^+ is immobilized (tied up)
At C:N < 20:1, NH_4^+ is mineralized (released)



Typical C:N Ratio in soil is 10-12


Decomposition of cover crop residues
Residue C:N
80
60
40
20
0
Net immobilization
(e.g. Sudan grass, cereal rye)
Net mineralization
Cowpeas
4 to 8 weeks


4 to 8 Weeks
CO_2 Evolution
NO_3^-
CO_2
Bacteria & Fungus Decomposition
NO_3- level
Protozoa & Nematodes
Consuming Bacteria & Fungus Excreting NH_4+
Time

Carbon to Nitrogen ratio of Microbes
Bacteria: 5:1 (20% Nitrogen)
Fungus: 10:1 (10%Nitrogen)

More nitrogen less carbon in Bacteria than in Fungus

Reproduction Phase
Bacteria: 30 minutes Fungus: ??
Protozoa: 6 hours Nematodes: 2 years

Where are the microbes located? 1,000 to 2,000 times more located next to the roots.

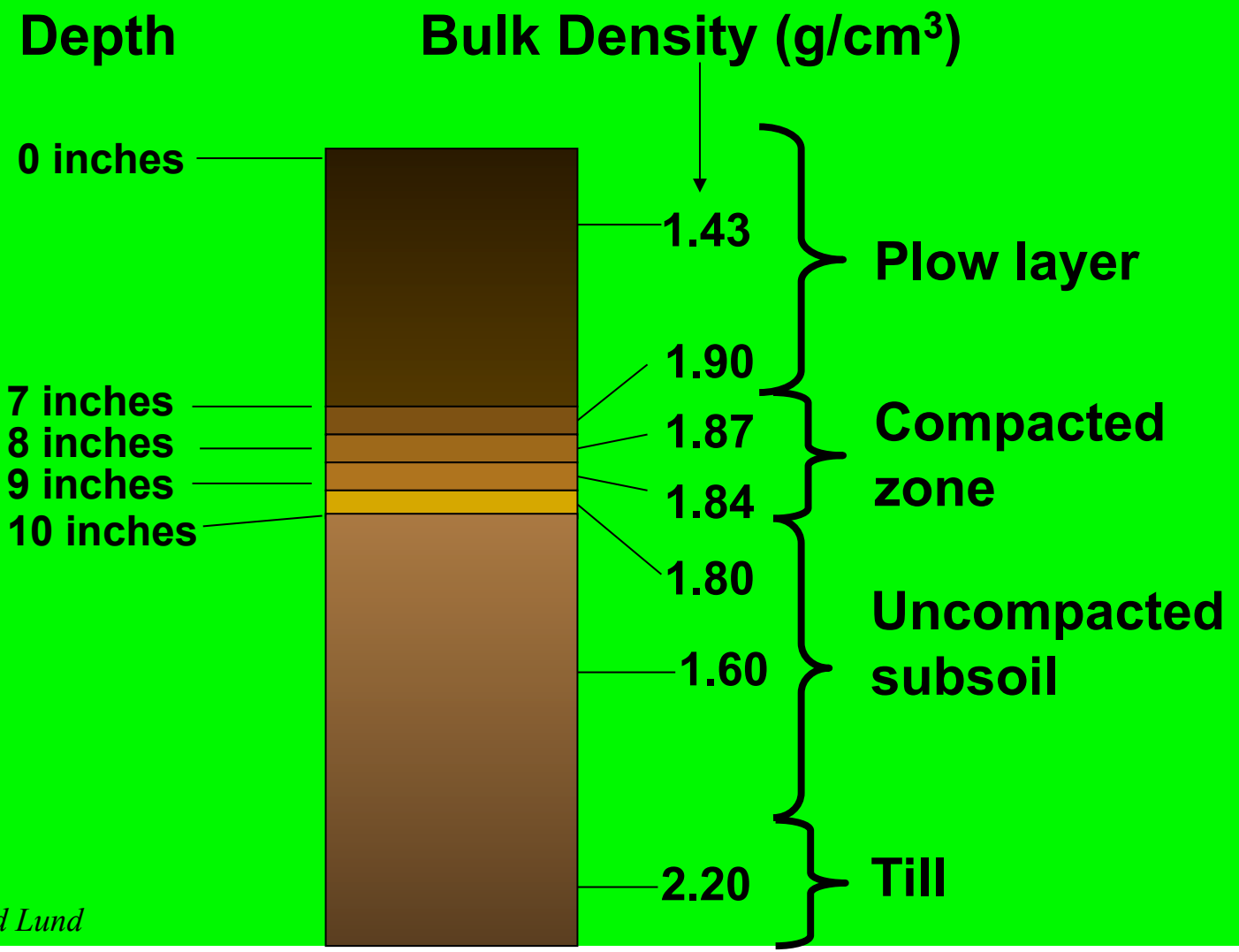
Rhizosphere

Living roots release many types of organic materials into the rhizosphere within 50 µm of the surface of the root.

Some Common Bulk Densities

- **Uncultivated/undisturbed woodlots**
  - **1.0 to 1.2 g/cm^3**
- **Cultivated clay and silt loams**
  - **1.5 to 1.7 g/cm^3**
- **Cultivated sandy loams**
  - **1.3 to 1.7 g/cm^3**
- **Compacted glacial till**
  - **1.9 to 2.2 g/cm^3**
- **Concrete**
  - **2.4 g/cm^3**

Bulk Density and Compaction



Data from Camp and Lund

Soil Organic Matter Characteristics

*Density of SOM: .6 g/cm^3 vs 1.45 g/cm^3 soil

Bulk density =Mass (grams)/Volume (cm^3)

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

*Every Pound SOM holds 18-20# of Water!

*SOM acts like a Sponge!

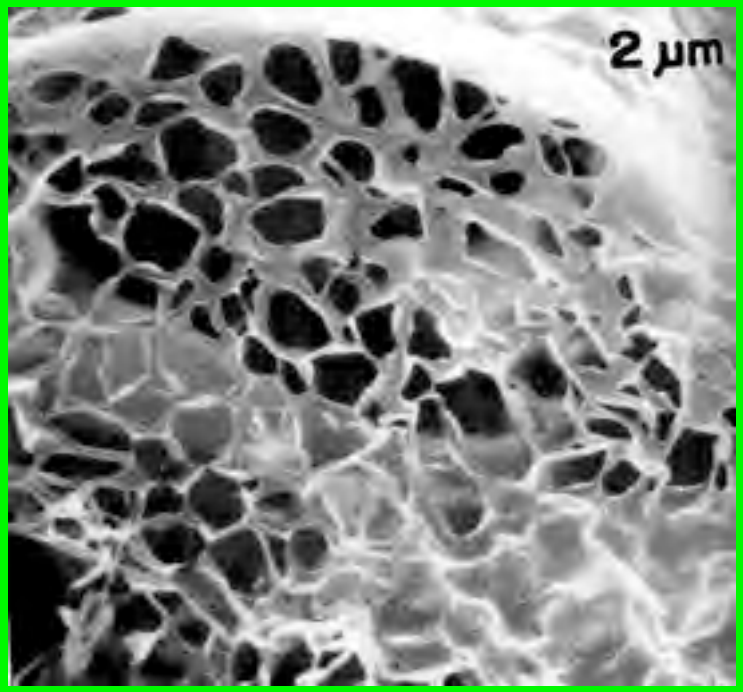
Physical properties and nature of SOM

Color and shape ~ light to dark brown and amorphous

Size ~ Large to colloidal (0.1 - 2 μm)

Surface area ~ Variable (20 – 800 m2 g-1)

Adsorption ~ like sieve to hold cations, anions & water



Compacted Soil Characteristics

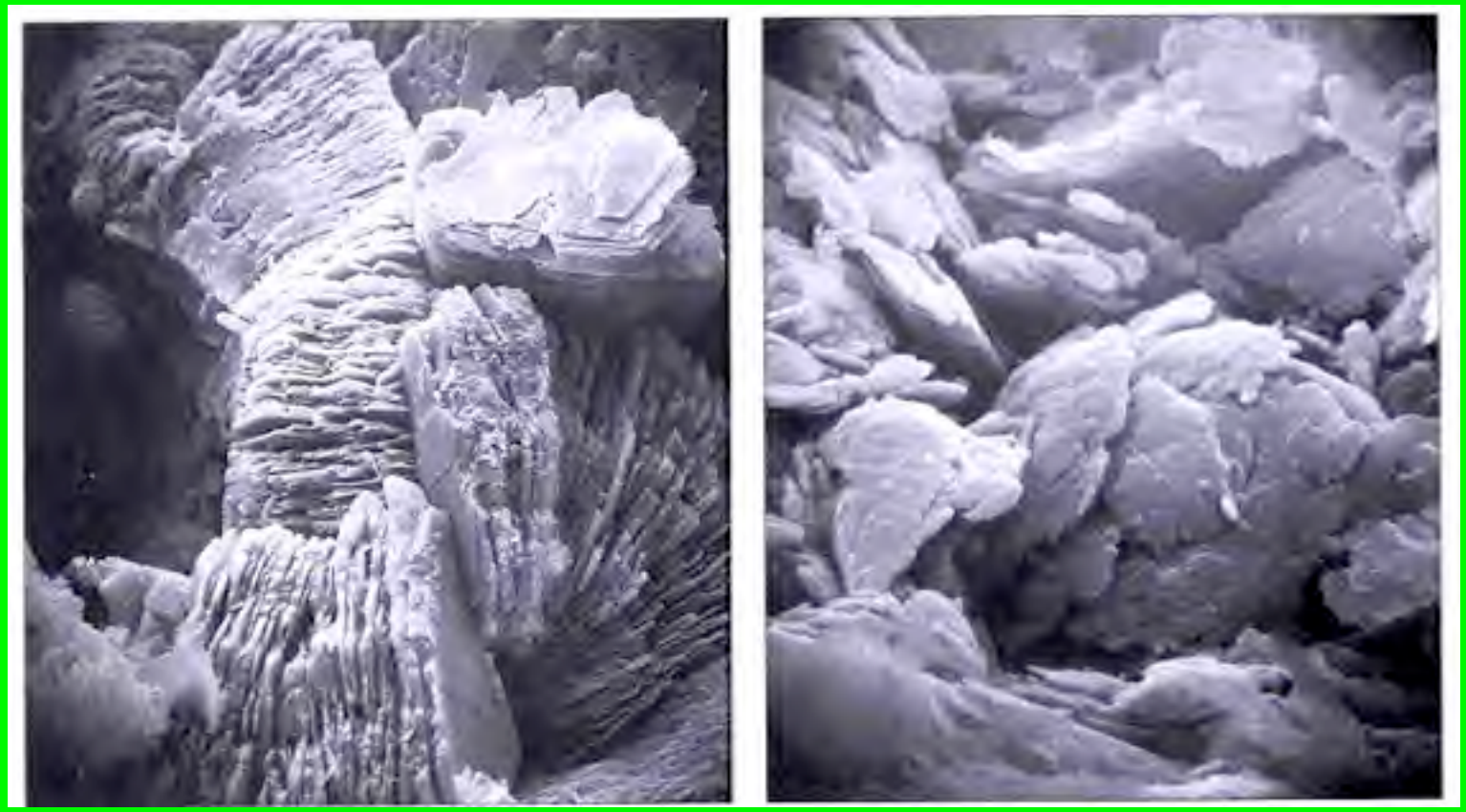
*Density 1.6 to 1.75 g/cm^3 vs 1.45 g/cm^3 regular soil.

*Compacted soil has higher density than regular soil so it has less space for air and water storage.

*Dense soils acts like a road or pavement!

Result in Flash floods!

*Dense soils have less microbes/biological life.



Electron microscopy of clay minerals

Three Soil Compaction Factors

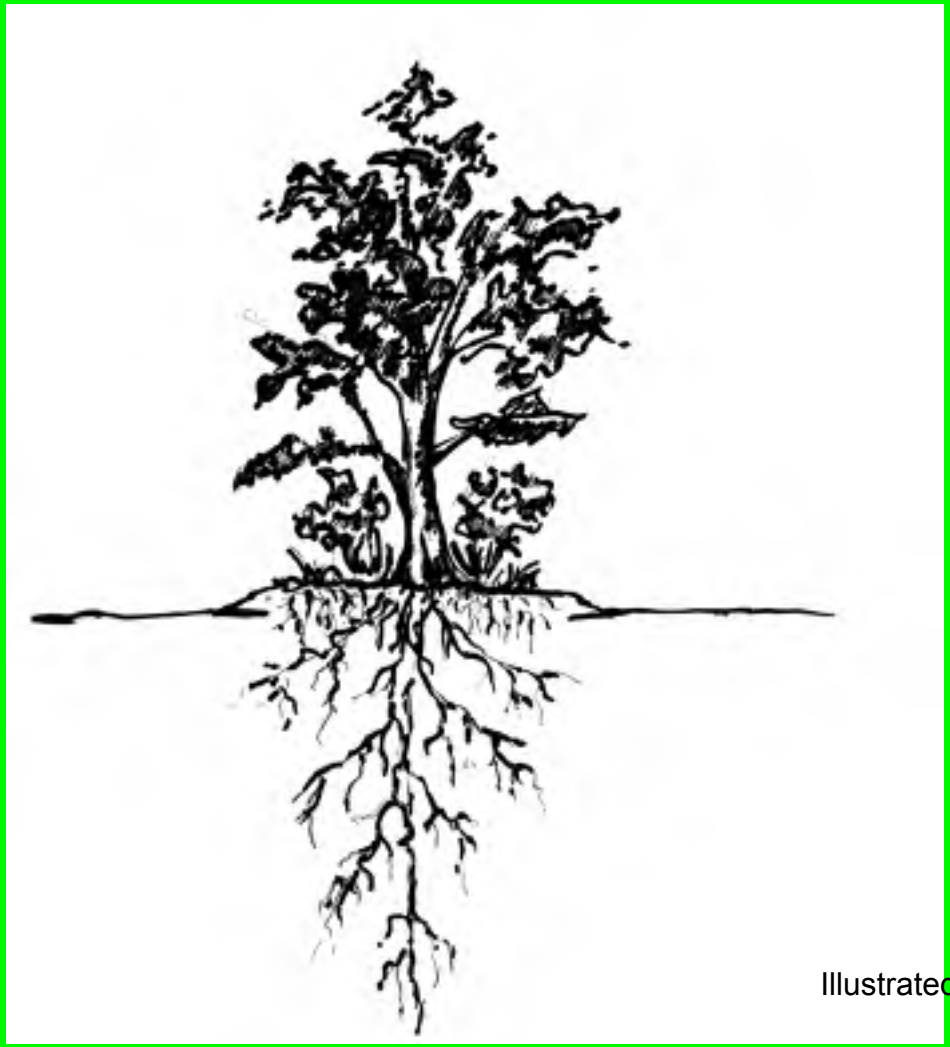
1) Heavy Equipment (Weight)

2) Rain (Precipitation)

3) Gravity

What is a visual way to measure soil compaction?

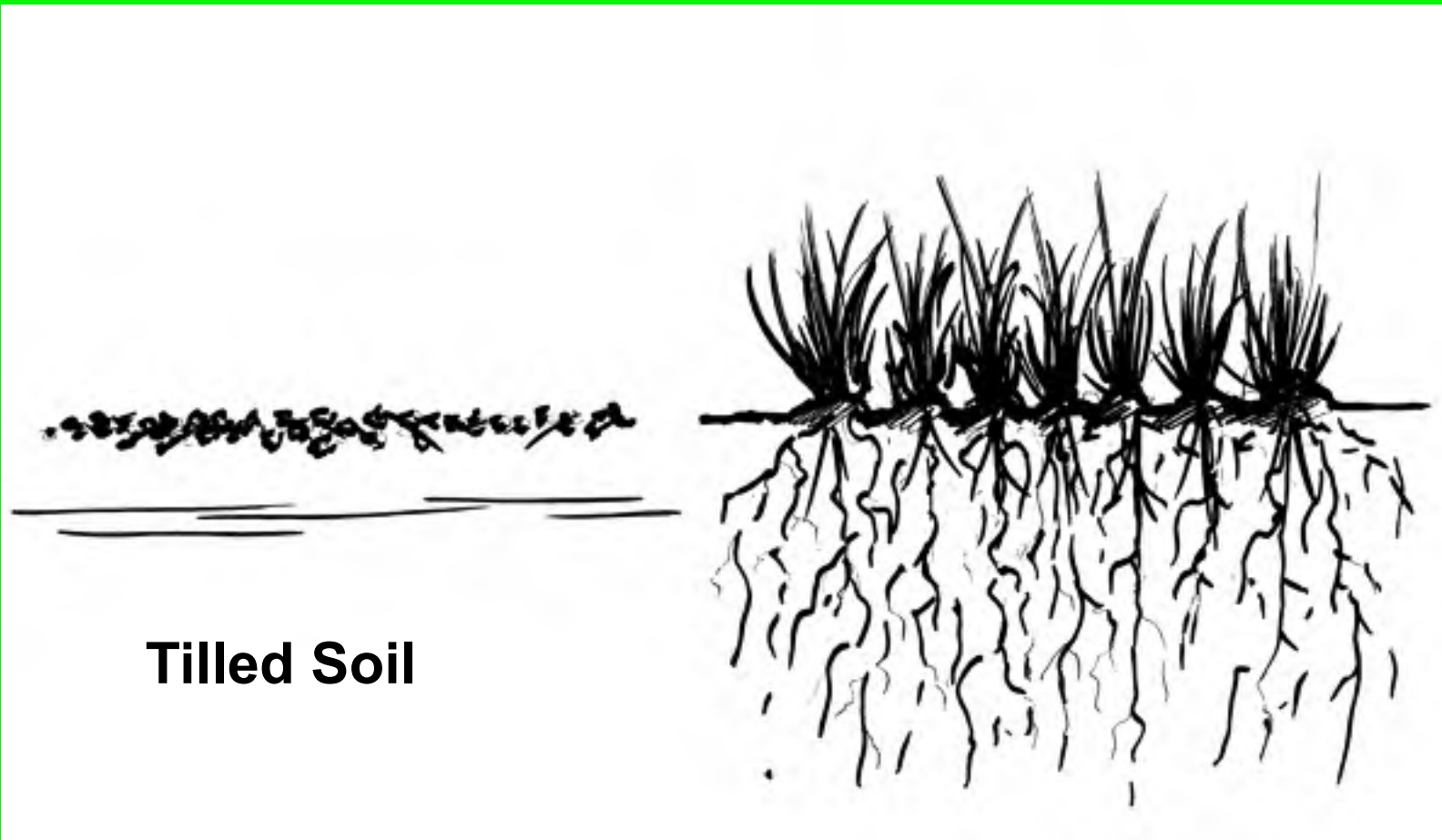
Elevation Difference Between Fence Row and Field



6-9 inch Difference

Illustrated by Cheryl Bolinger-McKirnan & Jim Hoorman

Compacted vs Vegetated Soil



Tilled Soil

Plants slow down water runoff, increase water infiltration

Illustrated by Cheryl Bolinger-McKirnan & Jim Hoorman

Water Holding Capacity of Soil

How Much water can a bare soil hold? 1.7 inches

How much water can a soil with pasture or grass hold? 4.2-4.5 inches

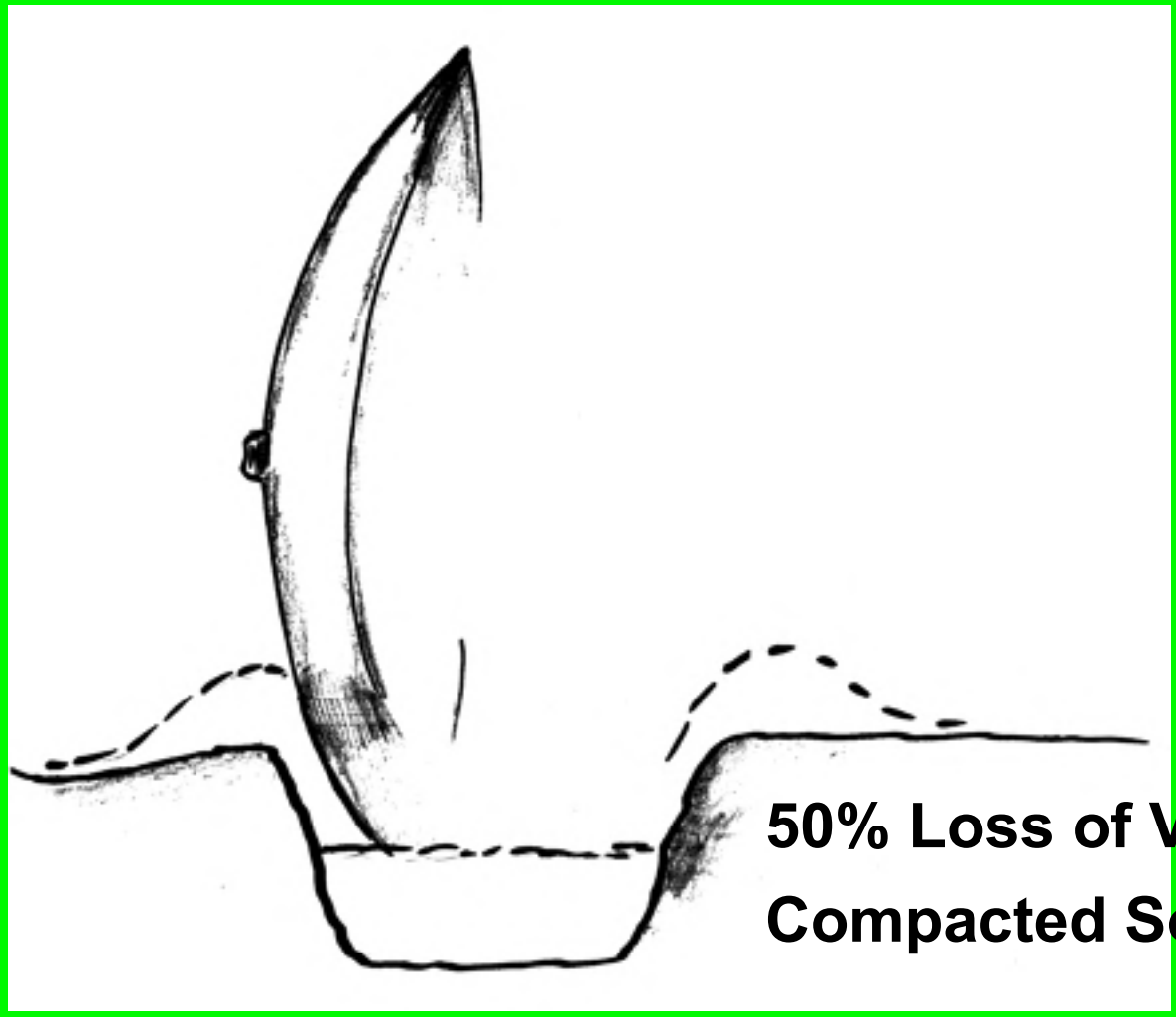
Every 1% SOM holds about 1 acre inch of water.

Why? (Source USDA-NRCS website)

Tire Rut Compaction

Illustrated by Cheryl Bolinger-McKirnan & Jim Hoorman

Loss of Void Space



50% Loss of Void Space

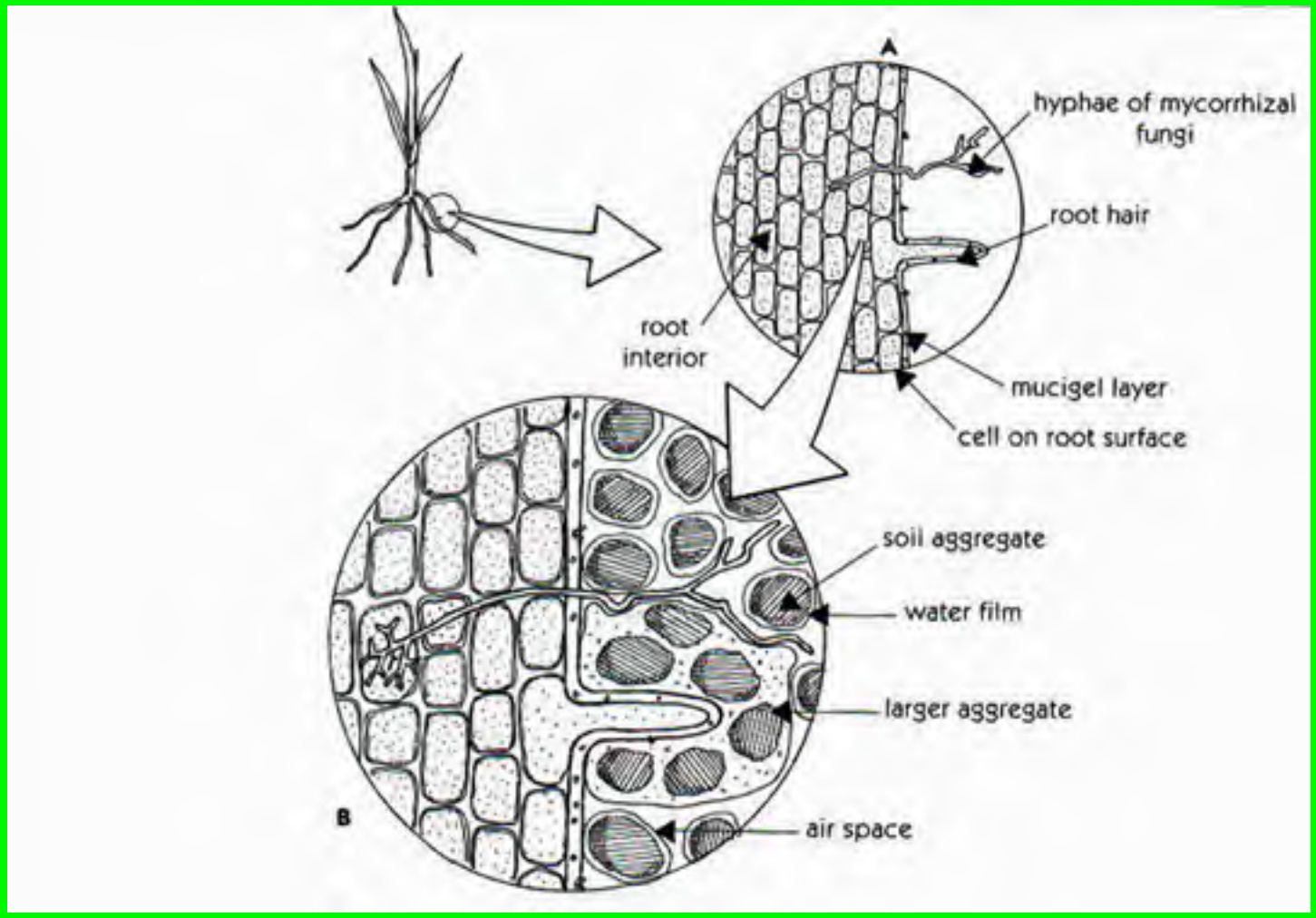
Compacted Soil- 50%

Illustrated by Cheryl Bolinger-McKirnan & Jim Hoorman

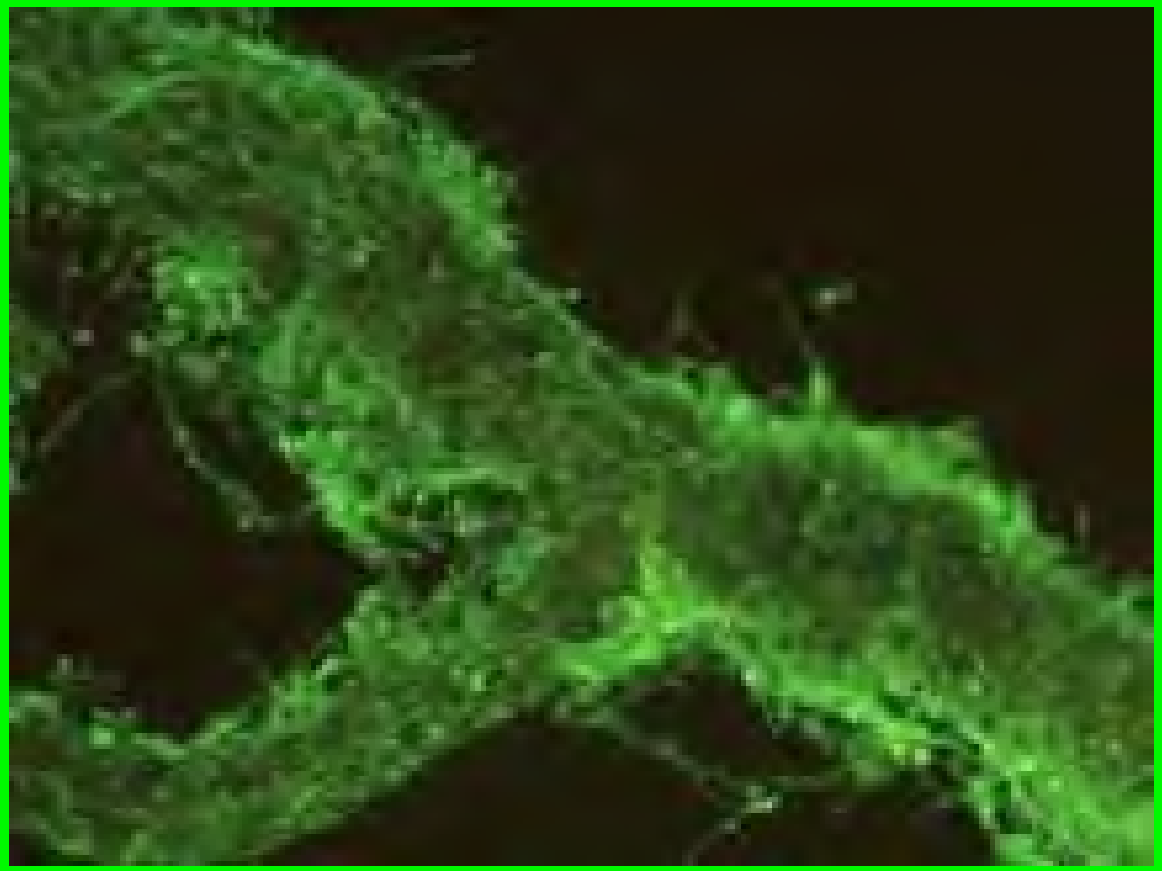
Roots expanding the soil

Roots reducing
soil compaction

Mycorrhizal Fungus

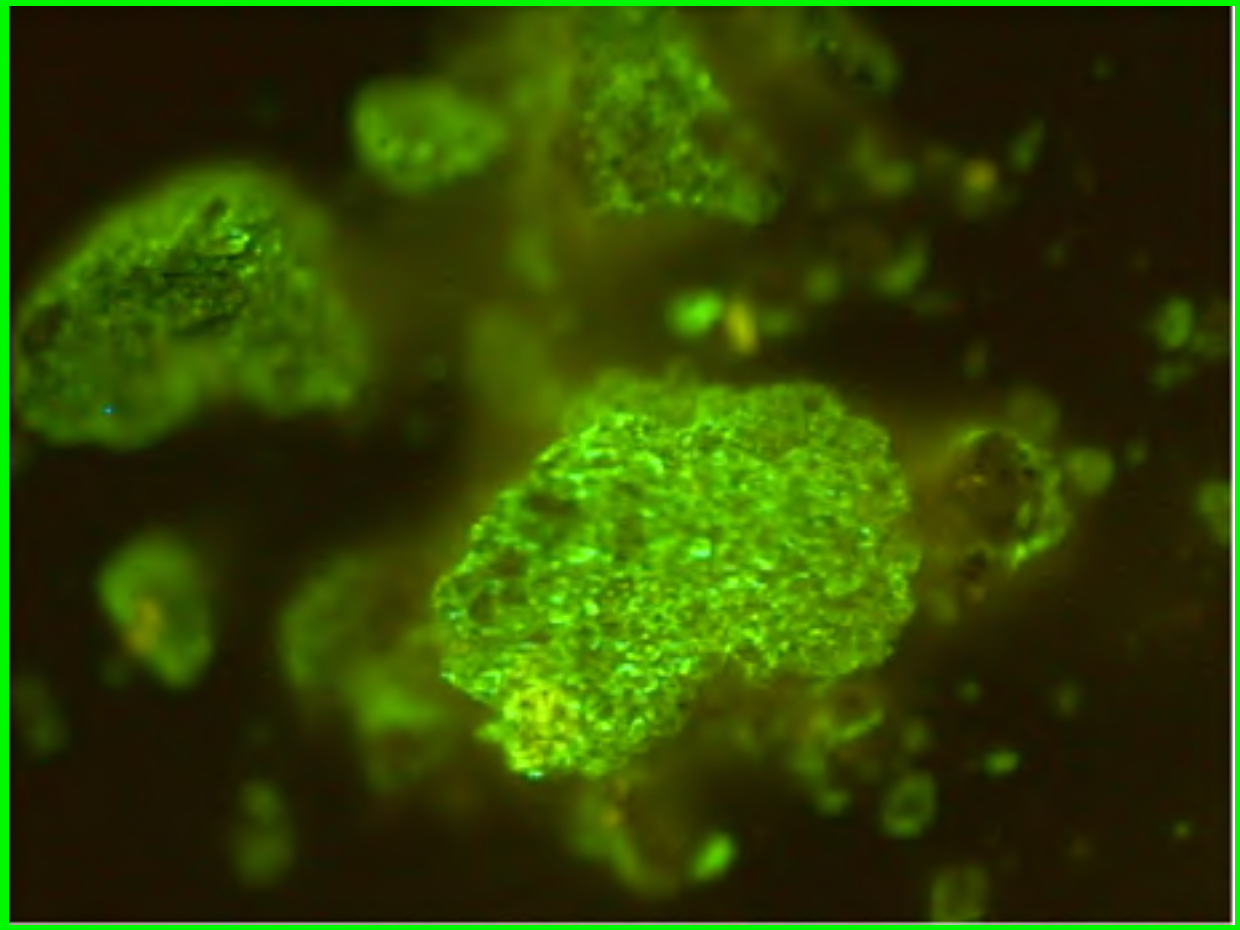


Source: Better Soils for Better Crops



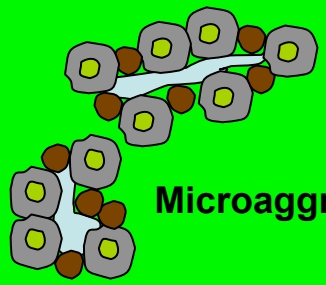
Sticky substance, glomalin, surrounding root heavily infected with mycorrhizal fungi. Fungi help roots explore up to 20% of the soil volume. A root by itself can only explore 1% of the soil volume. Photo by Sara Wright.

Mycorrhizal Fungus



Sticky substance, glomalin, surrounding soil aggregates, water soluble. Photo by Sara Wright.

Microaggregates-macroaggregates model



Microaggregates 20-90 and 90-250 μm

Plant and fungal debris

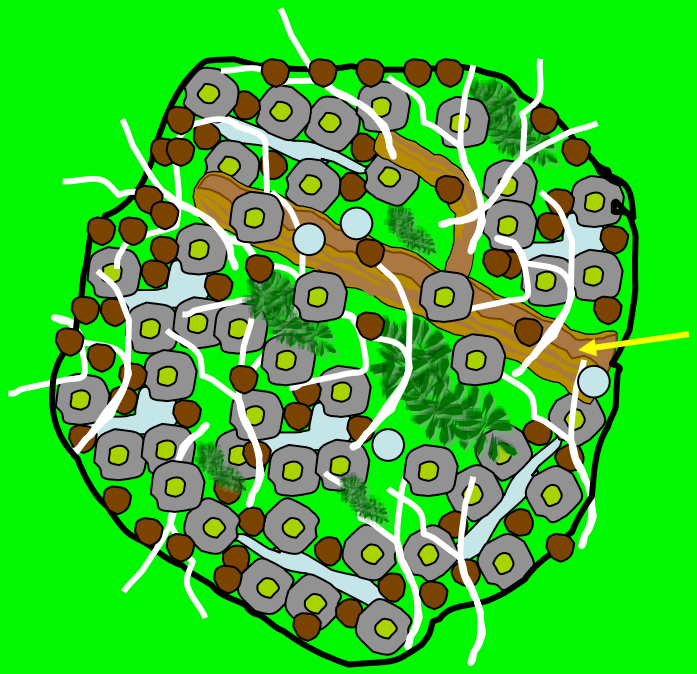
Silt-size microaggregate

Clay microstructures

Particulate organic matter

Mycorrhizal hyphae

Pore space; polysaccharides and other amorphous interaggregate binding agents



Plant root

Microaggregate <250 μm

Macroaggregate >250 μm

Adapted from Jastrow and Miller, 1997

Slide from Dr. Charles Rice Presentation – Argentine and Dr. Joao Sa

© 1999 M.Mikha

Building Soil Structure is like Building a House

Architecture	Mother Nature
Carpenter	Plants
Foundation/Cement	Sand Silt Clay (K^+, Ca^{++})
Frame for House	Roots
Nails/Lag Screws	Humus & P
Braces	N & S
Insulation/Glue	Polysaccharides
Roof	Surface Residues

Building Soil is Like Building a House

Roof-Surface Residue

Insulation/glue-Glomalin-G

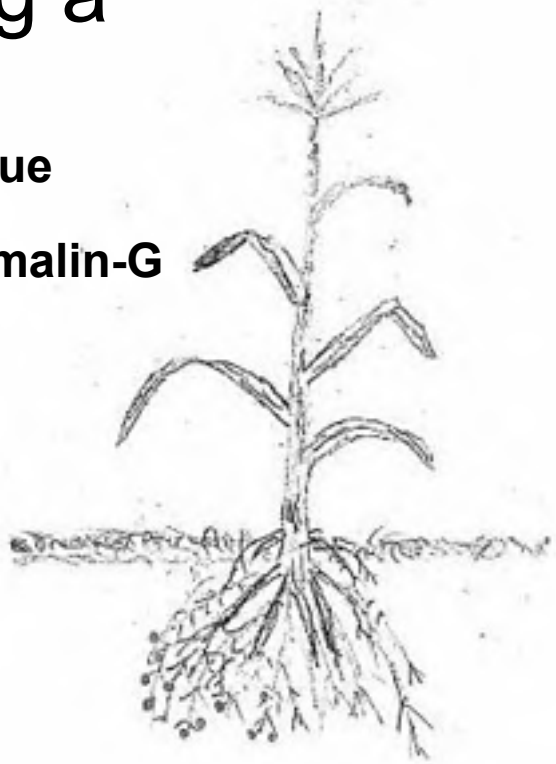
Nails – Humus-OM

Lag Screw - P

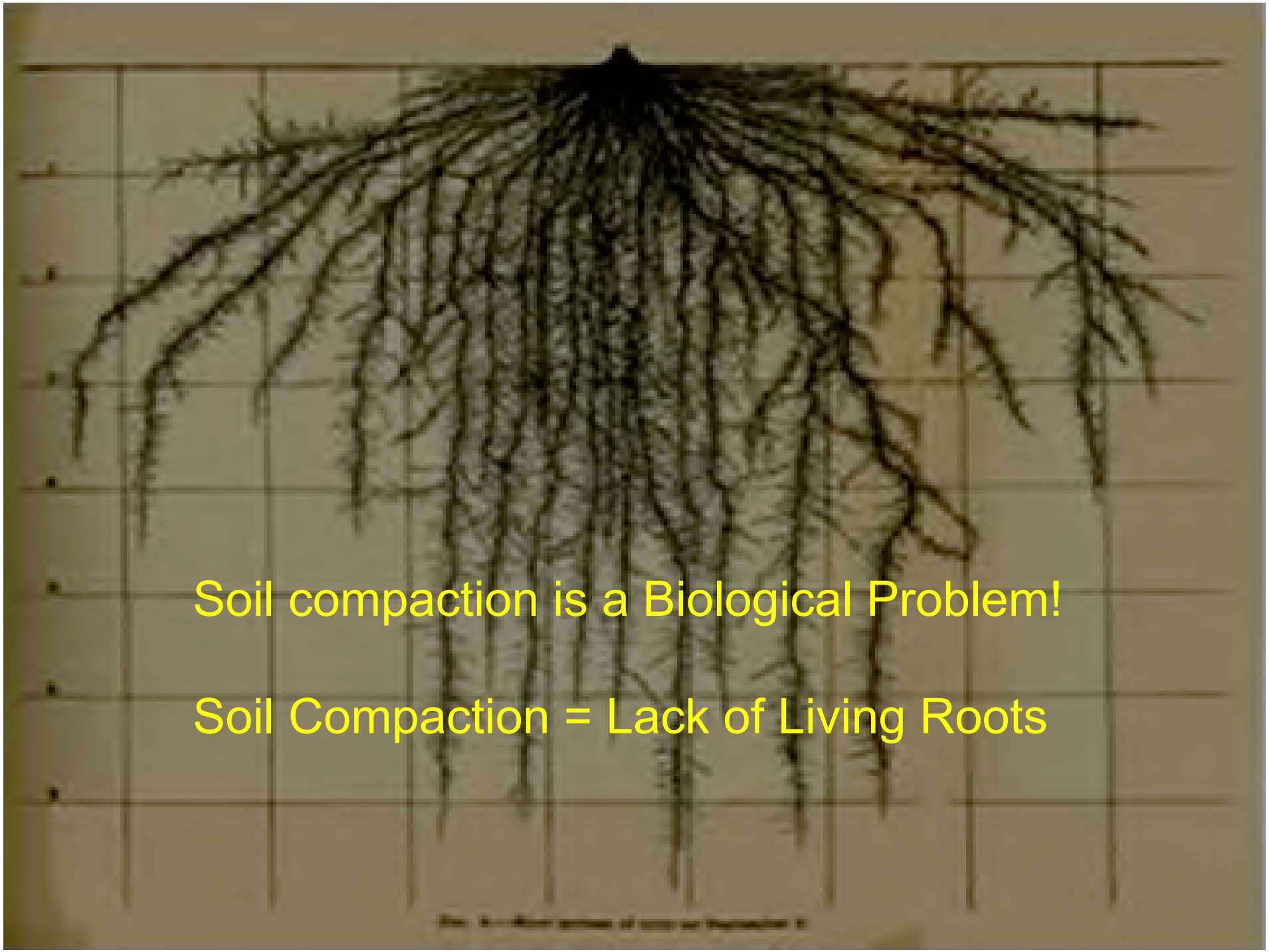
Braces – N & S

Wood – Roots - OM

Foundation-Clay-C



Macroaggregate


Soil compaction is a Biological Problem!
Soil Compaction = Lack of Living Roots

Oxygen and Carbon Dioxide

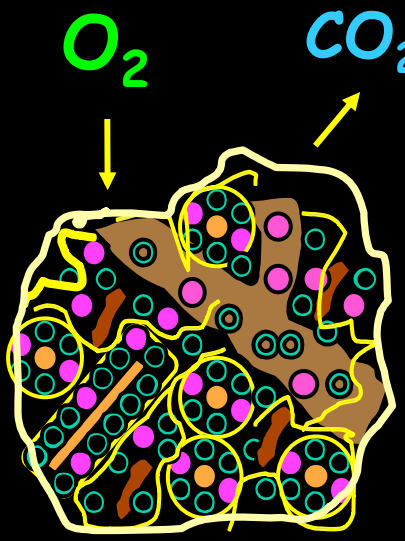
Carbon dioxide (CO_2) is heavier than O_2

CO_2 and O_2 are inversely related in the soil.
If one increases the other decreases.

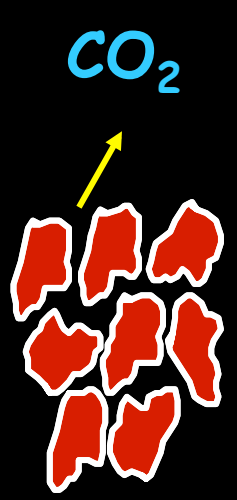
Too much O_2 in the soil causes CO_2 to be lost from the soil to the atmosphere.

Roots act like a **Biological Valve** to control O_2.

Oxidation and release CO_2



disruption



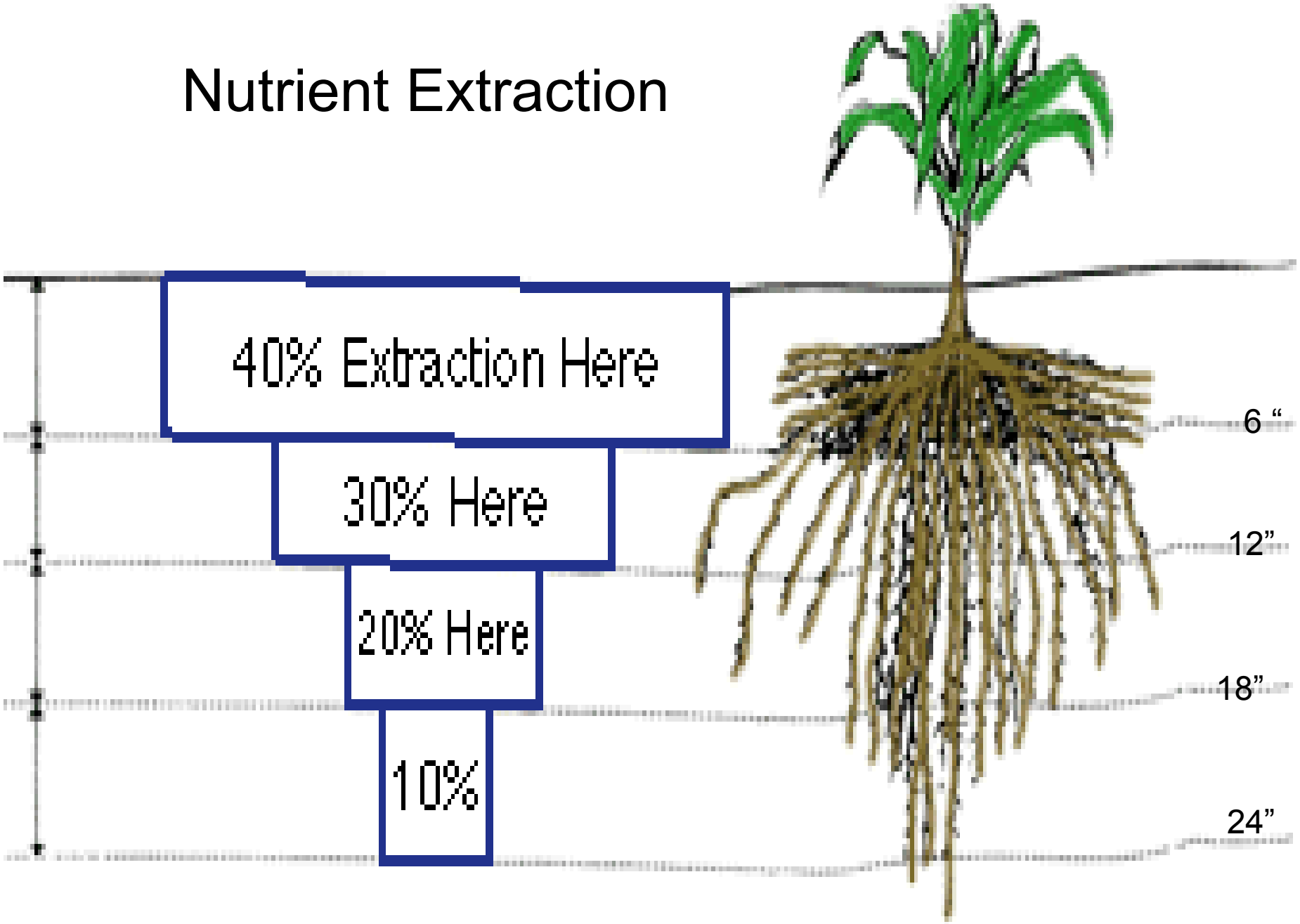
Cold No-till Soils

- Probably due to Compaction.
- Compacted soil hold moisture and heat (cold).

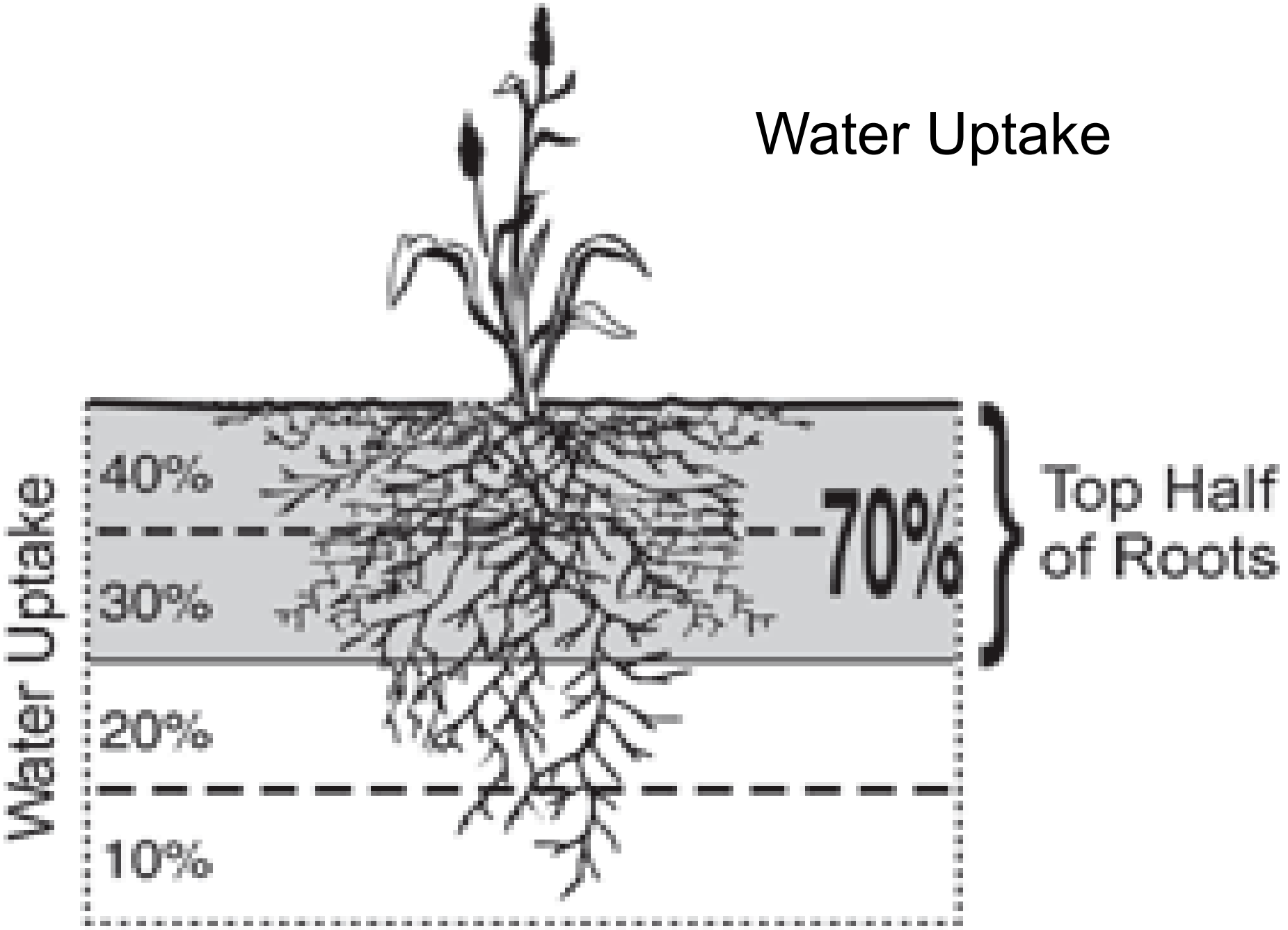
No-till with a Cover Crop

- Aerated soils warm up faster
- Black residue absorbs heat
- Thick residue at surface has biological activity and gives off heat.

Nutrient Extraction



Water Uptake



Saving Nutrients in the Soil

…is related to the speed of Water!

If the velocity of water is doubled how many more nutrients travel in a stream with the water?

2^6 = 64 times more nutrients lost!

1	to	2 mph	64x
2	to	4 mph	128x
4	to	8 mph	256x
8	to	16 mph	512x
16	to	32 mph	1,024x

Summary

- Organic Matter and Microbes influence Nutrient Recycling and Soil Compaction.
- Active Living Roots and Microbes work together to Improve Soil Structure.

- Cover Crops and No-till are the Solution!

Soil Ecology, Nutrient Recycling, Improving Soil Structure

James J. Hoorman
hoorman.1@osu.edu
www.mccc.msu.edu

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