



## The Biology of Soil Compaction

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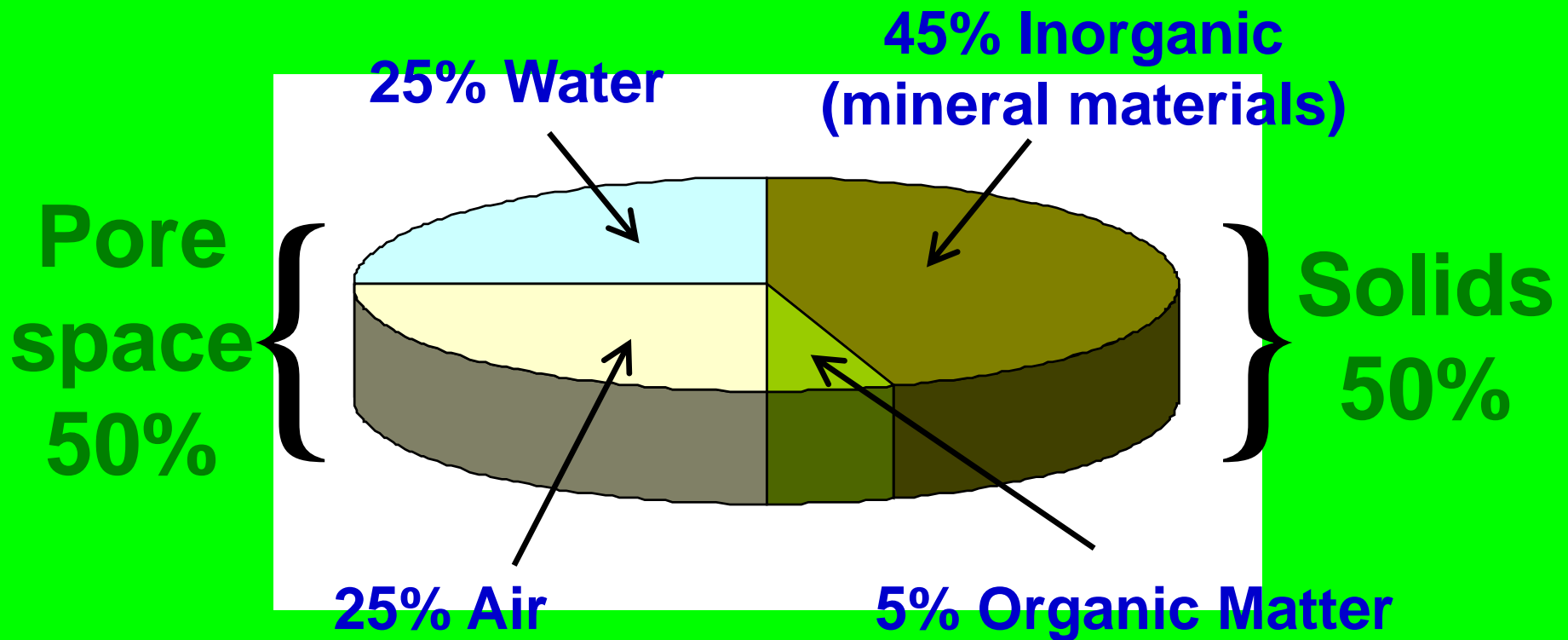
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# Ideal Soil Composition



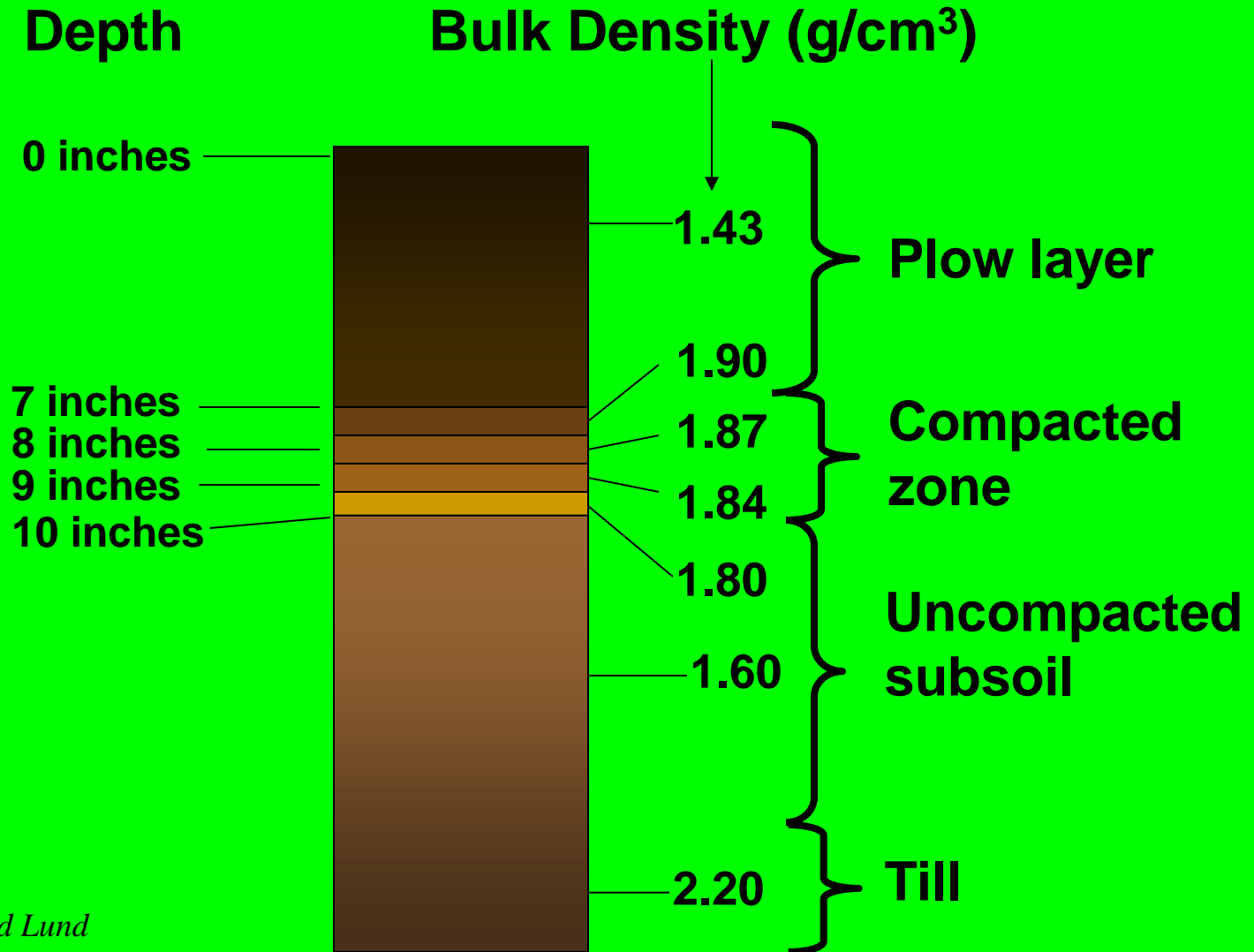
# Some Common Bulk Densities

- **Uncultivated/undisturbed woodlots**
    - 1.0 to 1.2 g/cm<sup>3</sup>
  - **Cultivated clay and silt loams**
    - 1.5 to 1.7 g/cm<sup>3</sup>
  - **Cultivated sandy loams**
    - 1.3 to 1.7 g/cm<sup>3</sup>
  - **Compacted glacial till**
    - 1.9 to 2.2 g/cm<sup>3</sup>
  - **Concrete**
    - 2.4 g/cm<sup>3</sup>
- 1.6 g/cm<sup>3</sup> = Root Limiting  
1.8 g/cm<sup>3</sup> = Roots Restricted

# Ideal Bulk Density by Soil Texture

Soil Texture	Ideal Bulk Density for Plant Growth (g/cm <sup>3</sup> )	Bulk Density that restricts Plant Growth (g/cm <sup>3</sup> )
Sandy	<1.60	>1.80
Silty	<1.40	>1.65
Clay	<1.10	>1.47

# Bulk Density and Compaction



# Soil Organic Matter Characteristics

\*Density of SOM: .6 g/cm<sup>3</sup> vs 1.45 g/cm<sup>3</sup> soil  
Bulk density = Mass (grams)/Volume (cm<sup>3</sup>)

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!

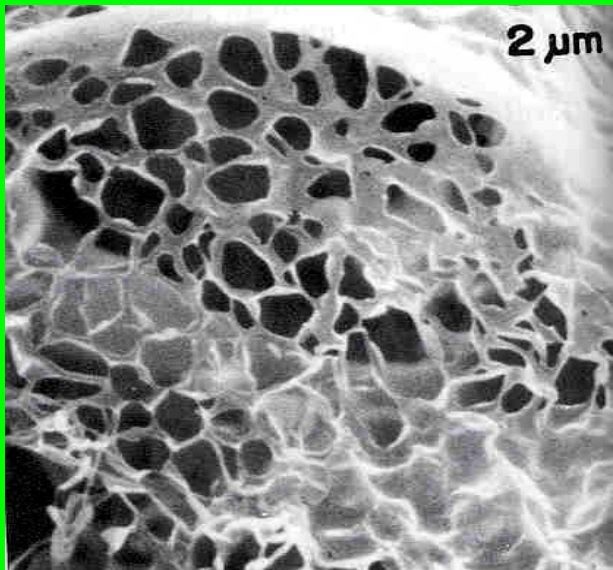
# Physical properties and nature of SOM

Color and shape ~ light to dark brown and amorphous

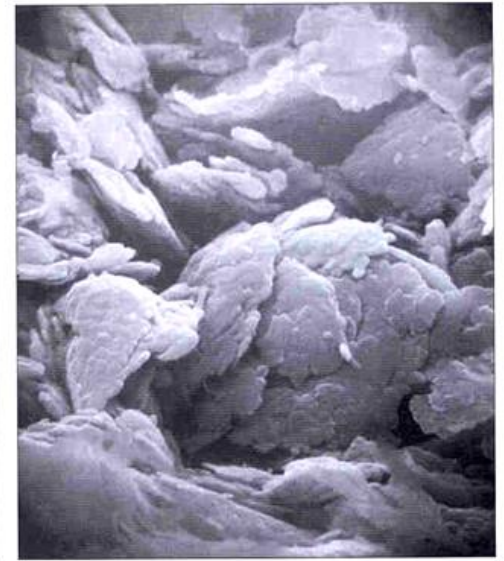
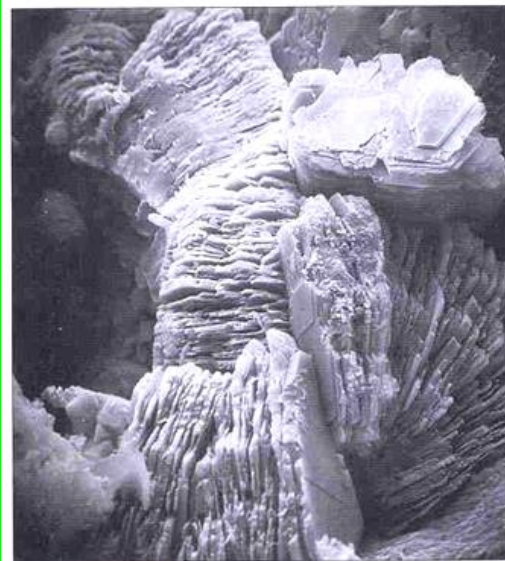
Size ~ Large to colloidal (0.1 - 2  $\mu\text{m}$ )

Surface area ~ Variable (20 – 800  $\text{m}^2 \text{g}^{-1}$ )

Adsorption ~ like sieve to hold cations, anions & water



Soil Organic Matter  
From Brady & Weil



Electron Microscope of Clay Particles

# Compacted Soil Characteristics

- \*Density 1.6 to 1.8 g/cm<sup>3</sup> vs 1.45 g/cm<sup>3</sup> 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.

# Three Soil Compaction Factors

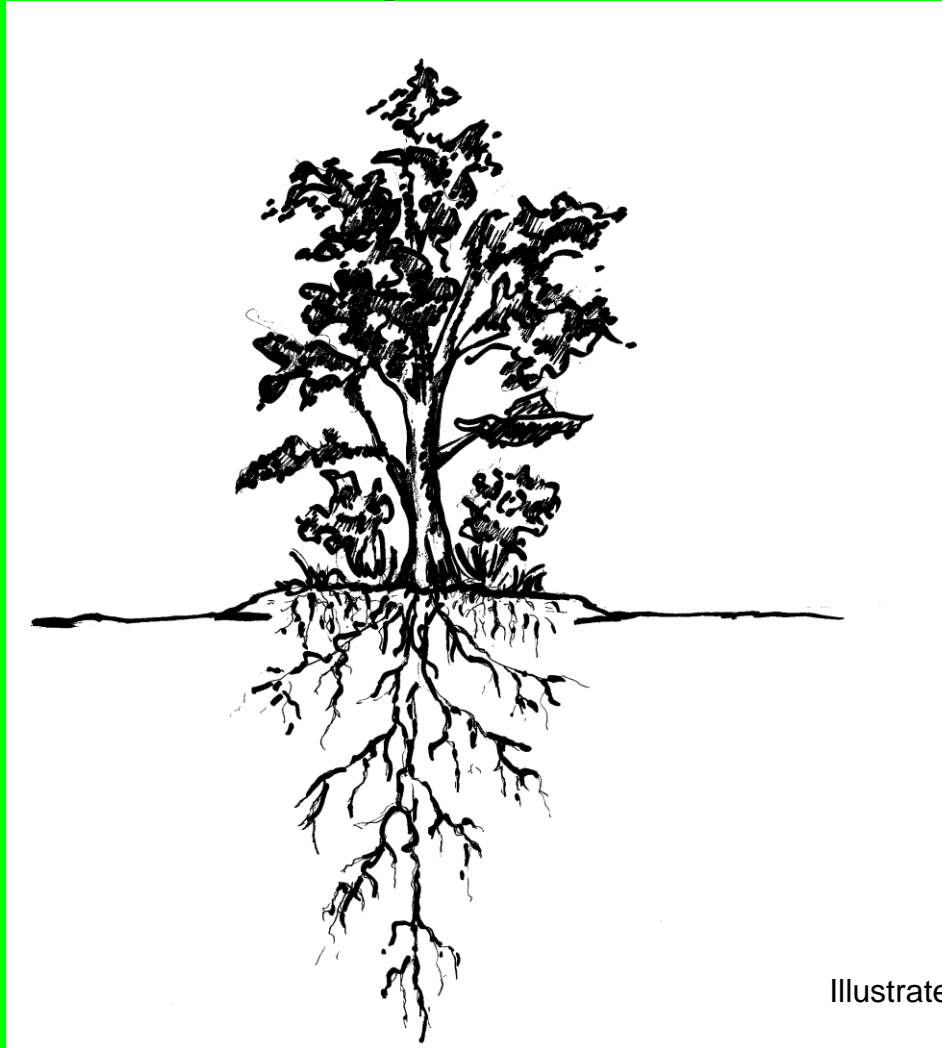
**1) Heavy Equipment (Weight)**

**2) Rain (Precipitation)**

**3) Gravity**

**What is a visual way to measure soil compaction?**

# Increased Water Storage Capacity Equals less Flooding



**1) 6-9 inch Elevation  
Difference**

**2) 50% Void Space  
Equals 3-4.5 inches  
of additional water  
storage capacity.**

Illustrated by Cheryl Bolinger-McKirnan & Jim Hoorman

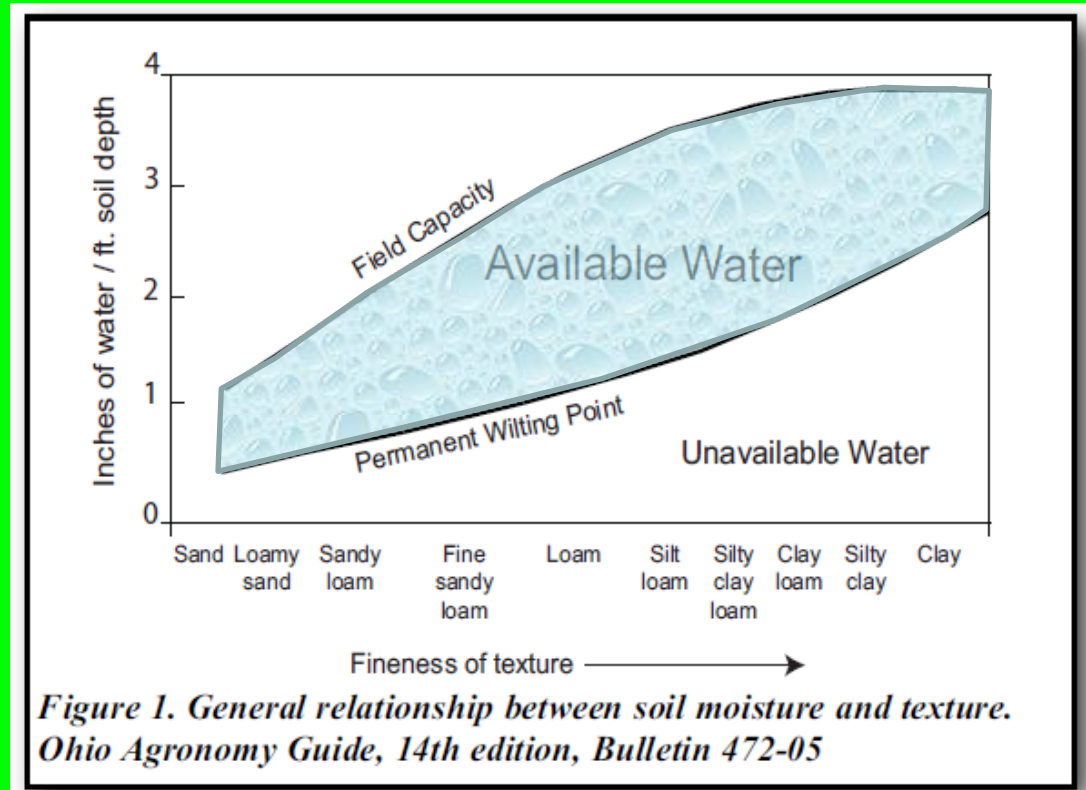
# SOM and Available Water Capacity Inches of Water/Per one foot of Soil

Berman Hudson Journal of Soil & Water Conservation 49(2) 189-194 March-April 1994

<b>Percent SOM</b>	<b>Sand</b>	<b>Silt Loam</b>	<b>Silt Clay Loam</b>
1	1.0	1.9	1.4
2	1.4	2.4	1.8
3	1.7	2.9	2.2
4	2.1	3.5	2.6
5	2.5	4.0	3.0

# Soil Inherent Properties

- Inherent Plant Available Water
  - Texture
  - Depth of Soil
  - Soil Layering
  - Presence of Rocks



Available water is largely an inherent soil property....

So what can we do?

# Soil Function- Provide Water to Plants

- Observations
  - Wilting & Stressed plants
- Weather?



- ❖ 200 bu Corn crop will need 22 inches of plant available water
  - Ohio receives 19 to 23 inches of water from April to September

Efficient Water Use Crucial! Are you capturing all your water with poor soil structure?

# Dynamic Properties: Infiltration

- If rainwater runs off field.... It is not available to the crop
  - Dynamic Soil Property greatly influenced by management

Tillage System	Water Infiltration Rate after 1 Hour (in/hour)
Plowed, disked, cultivated, bare surface	.26
No-tillage, bare surface	.11
No-tillage, 40% cover	.46
No-tillage, 80% cover	1.04

Source: Ohio Agronomy Guide: 12<sup>th</sup> Edition



- Residue cover prevents soil crusts

# Let's look at some common practices that have a negative impact on soil health and water quality

No soil structure, no infiltration



# Long Term No-Till vs. Rotational Tillage

Both Fields are a Corn/Soybean Rotation

These pictures are of a newly emerging corn crop

NoTill soybeans then StripTill Corn

NoTill Soybeans then Tilled corn

Same rain event on May 15  
 $\frac{3}{4}$ " less than  $\frac{1}{8}$  mile apart



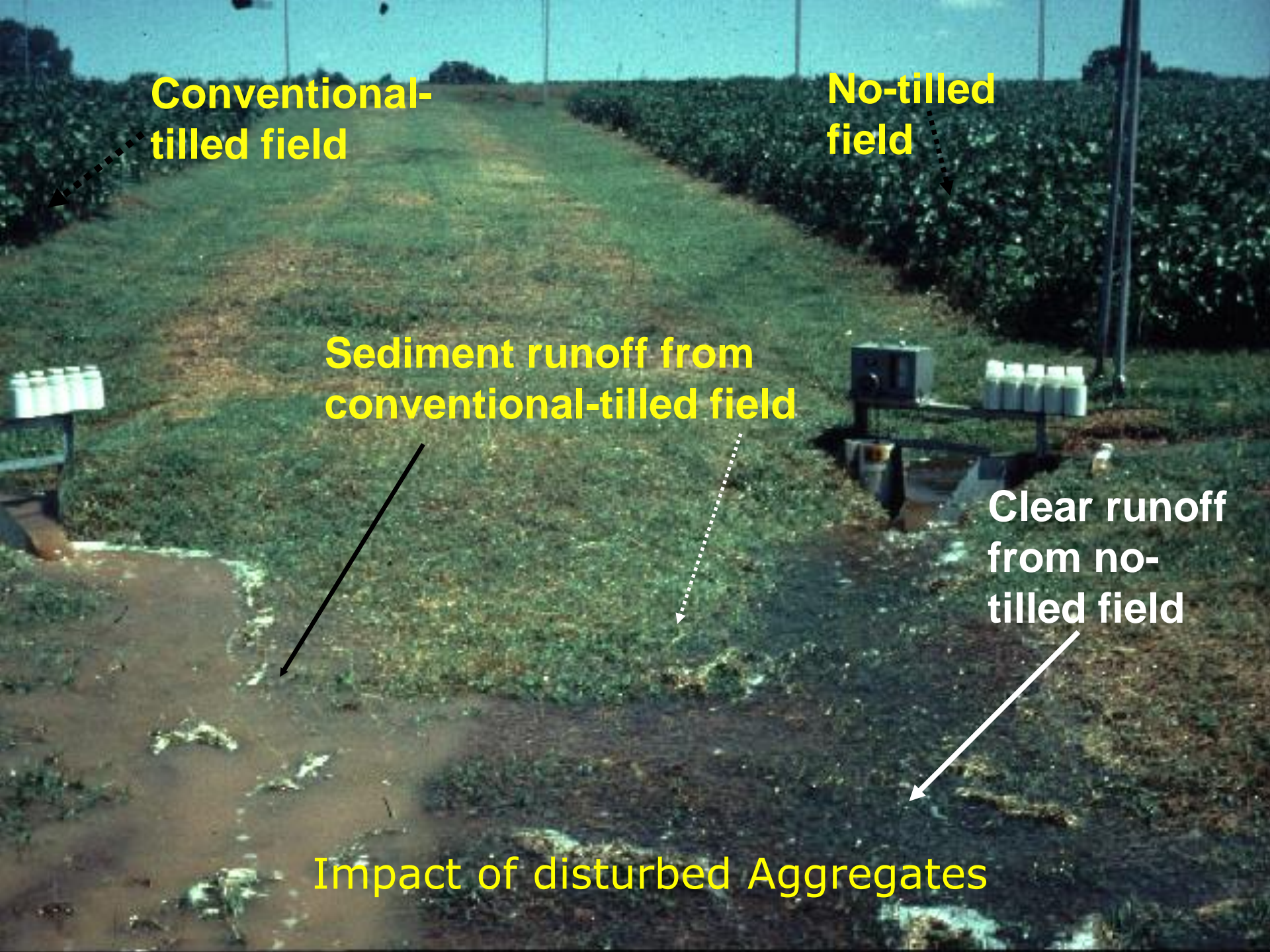
**Conventional-tilled field**

**No-tilled field**

**Sediment runoff from conventional-tilled field**

**Clear runoff from no-tilled field**

**Impact of disturbed Aggregates**



# Saving Nutrients in the Soil

...is related to the speed of Water!

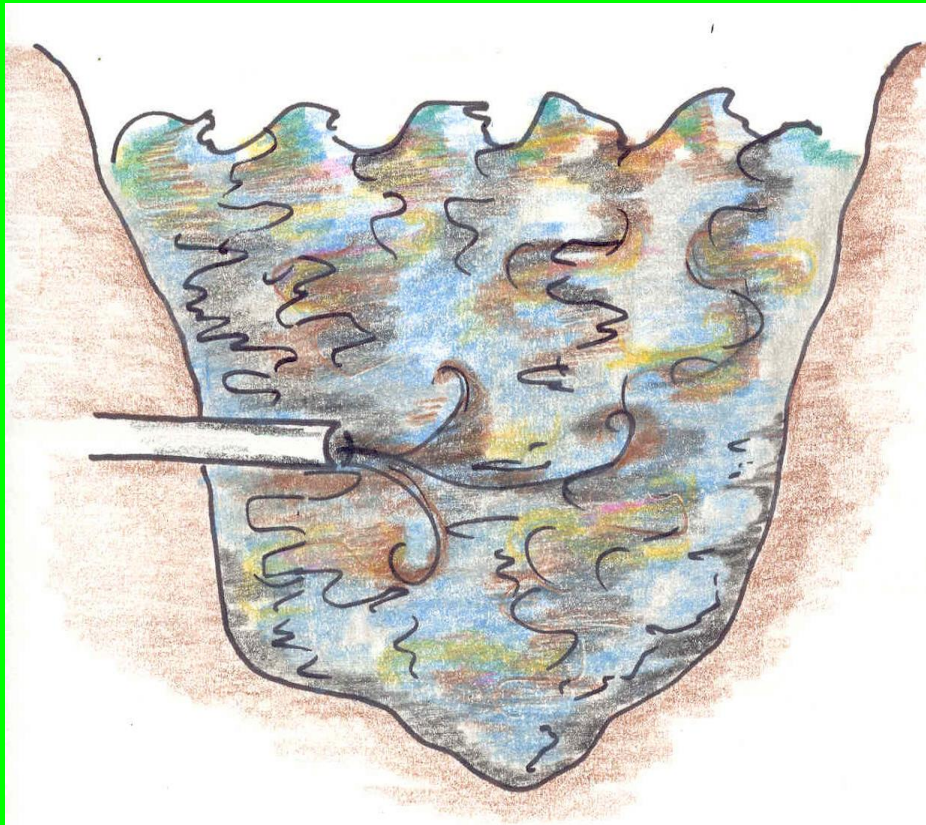
If the velocity of water is doubled how many more nutrients travel in a stream with the water?

$2^6 = 64$  times more nutrients lost!

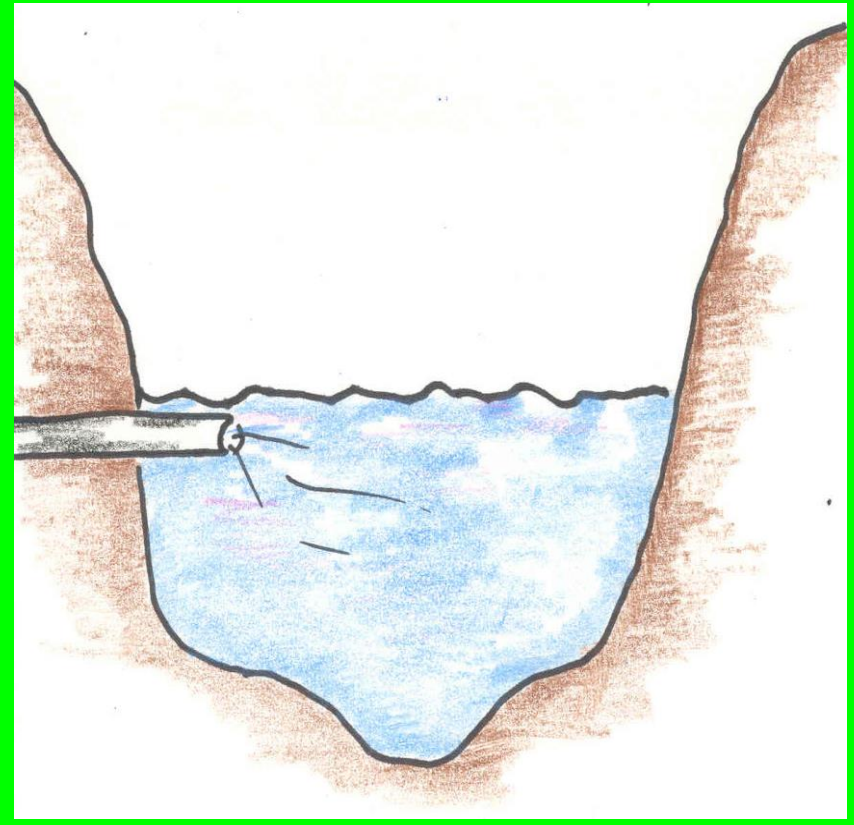
1	to	2 mph	64x
2	to	4 mph	128x
4	to	8 mph	256x
8	to	16 mph	512x
16	to	32 mph	1,024x

# Agricultural Flooding

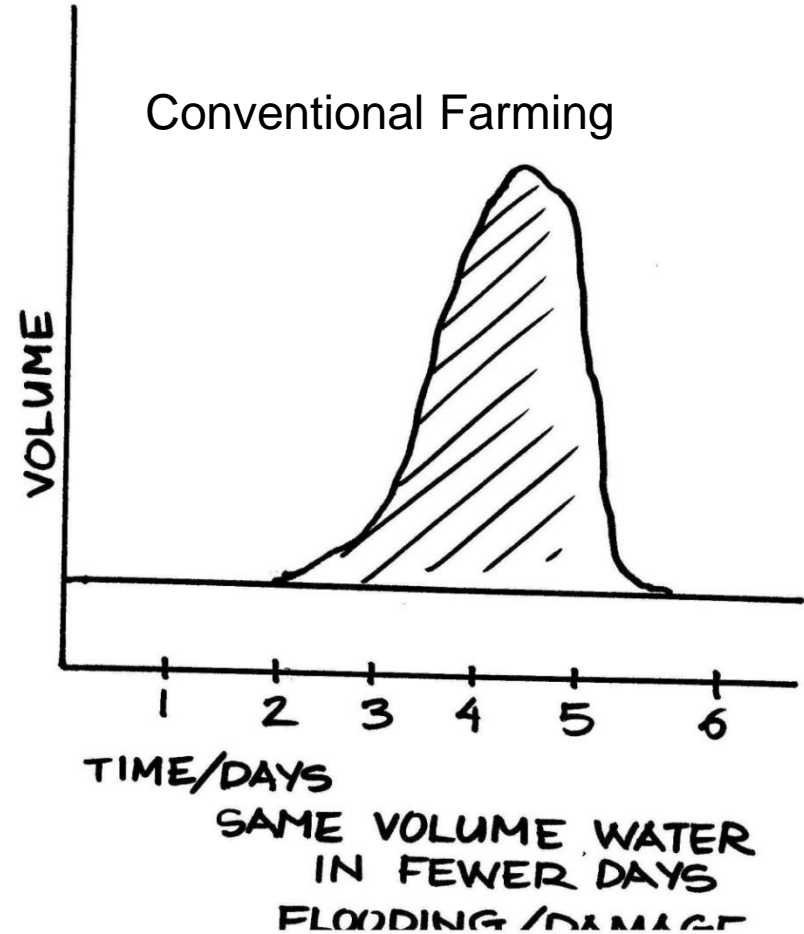
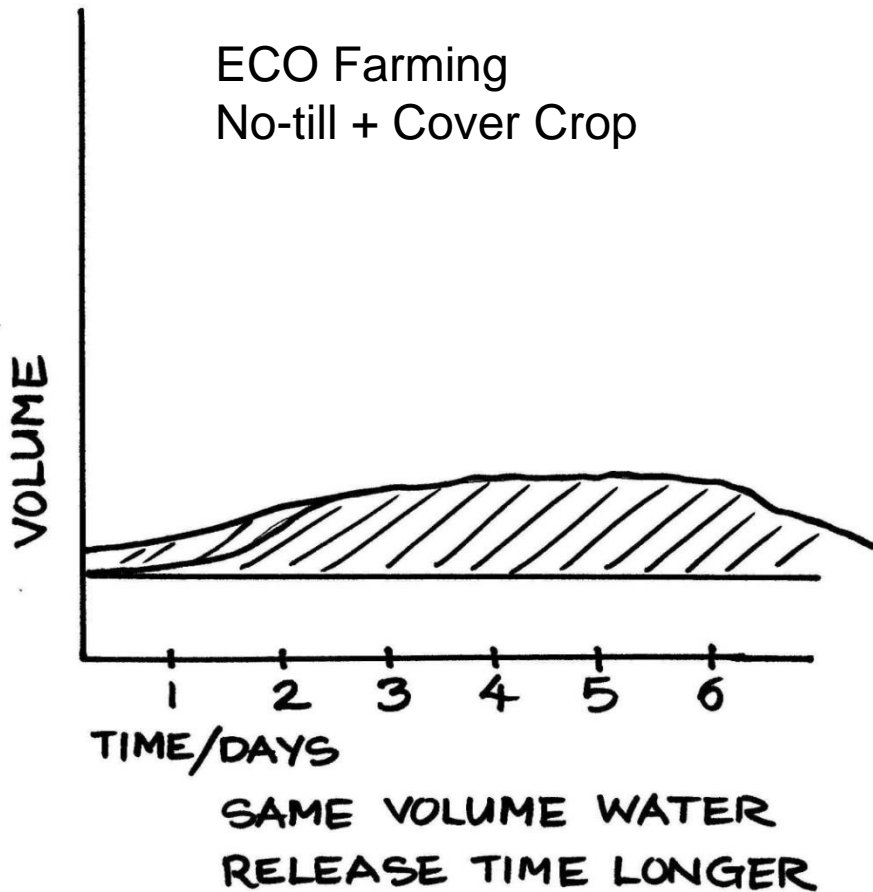
Conventional Tillage



ECO Farming

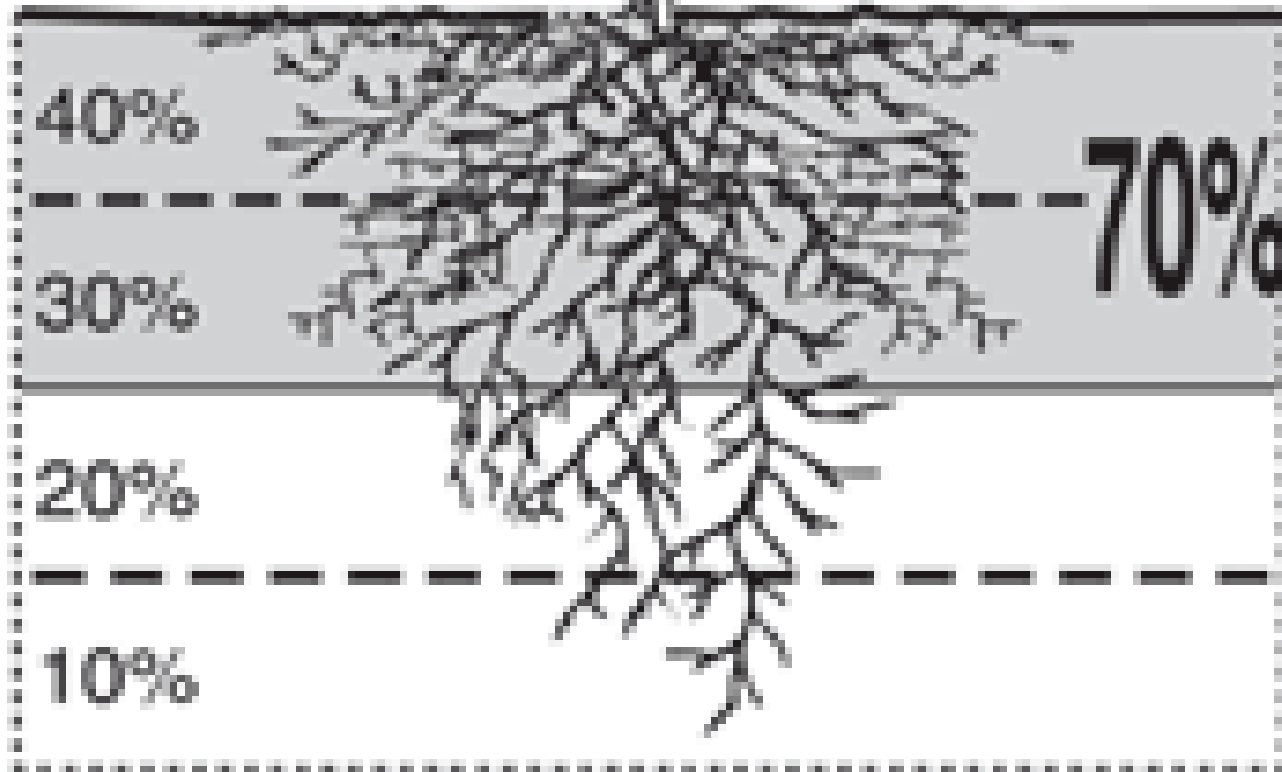


# Flooding Hydrographs



# Water Uptake

Water Uptake



Top Half of Roots

# For Hot Dry Summers??

- For Corn Production:

75 degrees Fahrenheit – 1 Inch water/week

85 degrees Fahrenheit – 2 inch water/week

95 degrees Fahrenheit – 4 inch water/week

Water requirements double for every 10 degree increase in temperature!

Heat and drought linked together quickly increase yield losses.

By Elwynn Taylor, Iowa Ag. Climatologist



# Dynamic Properties: Rooting Volume

- Soil Structure:  
Arrangement of Soil Particles
  - Root Development
  - Water Infiltration

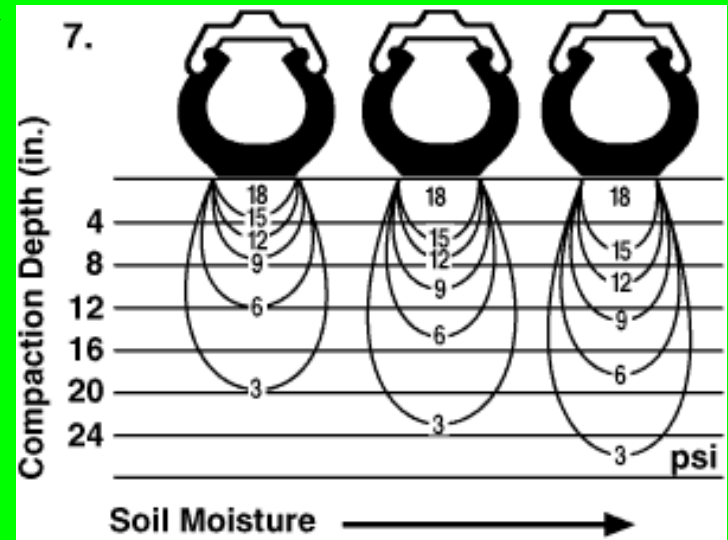


## DYNAMIC PROPERTY!

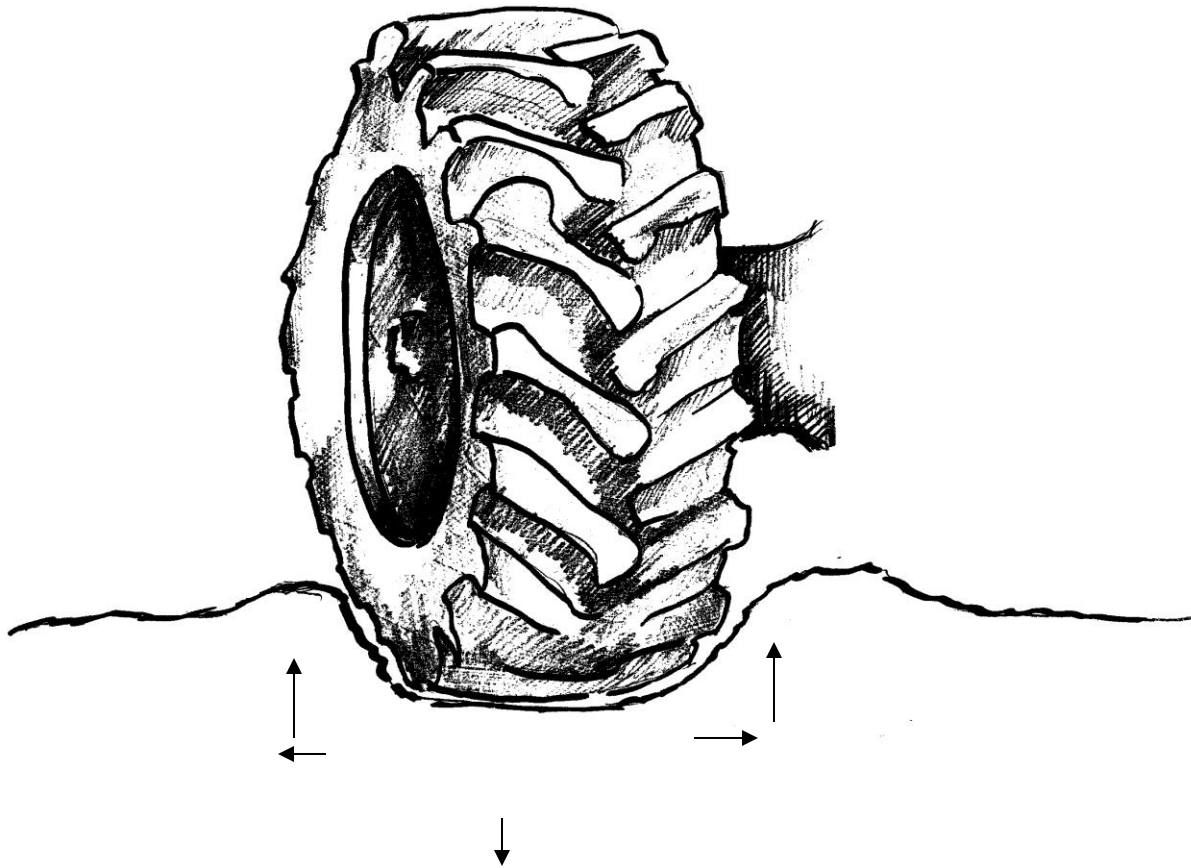
- Soil Compaction: The absence of soil aggregation & pore space
  - Compaction can reduce yields up to 60%.
  - Compaction has been shown to persist up to 9 years

# Increasing Root Volume

- Increase Aggregation & Aggregate Stability
  - Promote Biological Activity
  - Increase Organic Matter
  - NoTill
- Prevent Soil Compaction
  - Stay off wet soils!
  - Controlled/managed traffic
    - 80% of soil compaction from wheel traffic occurs on the first pass of a tire.

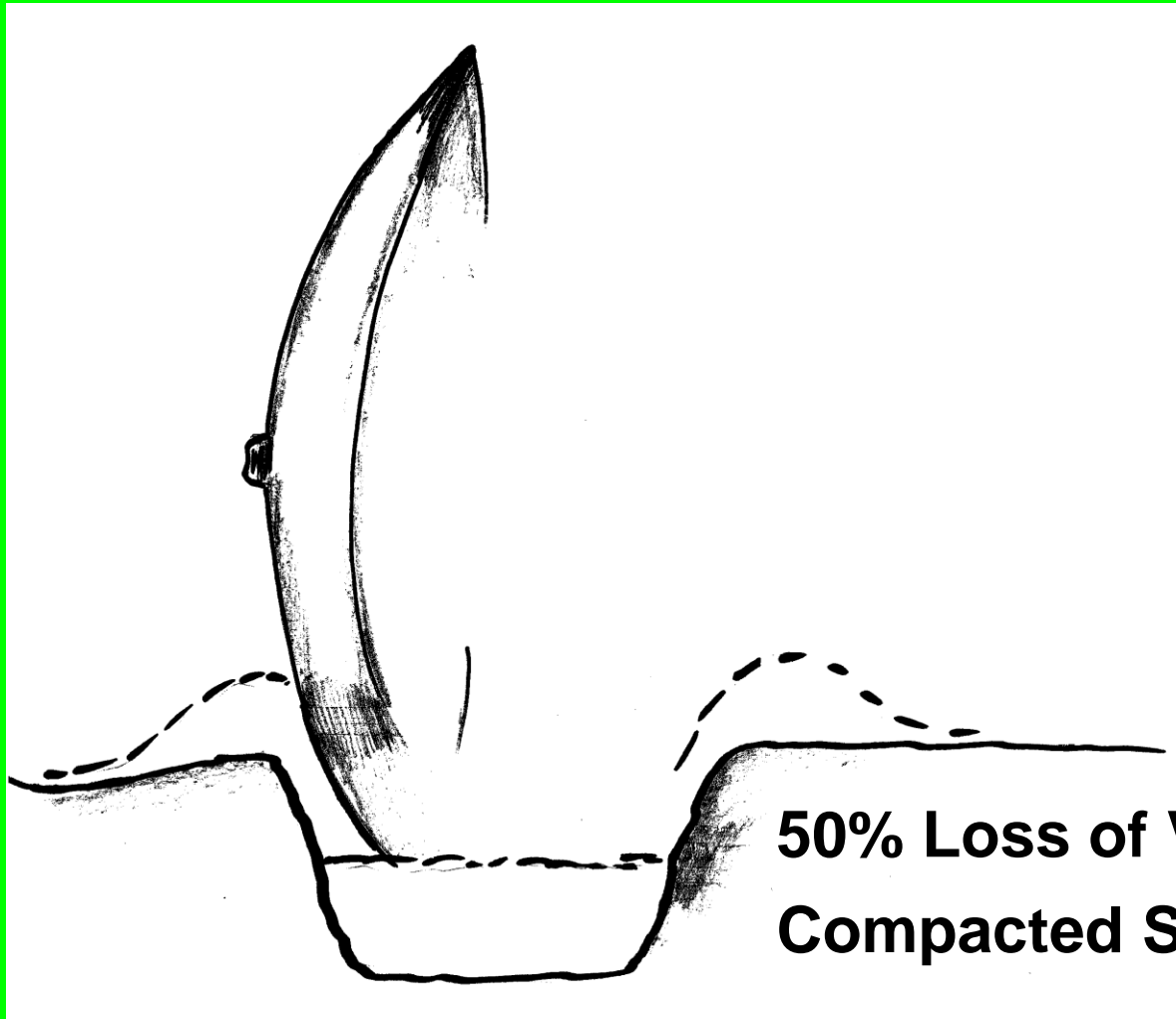


# Tire Rut Soil Compaction



Illustrated by Cheryl Bolinger-McKirnan & Jim Hoorman

# Loss of Void Space





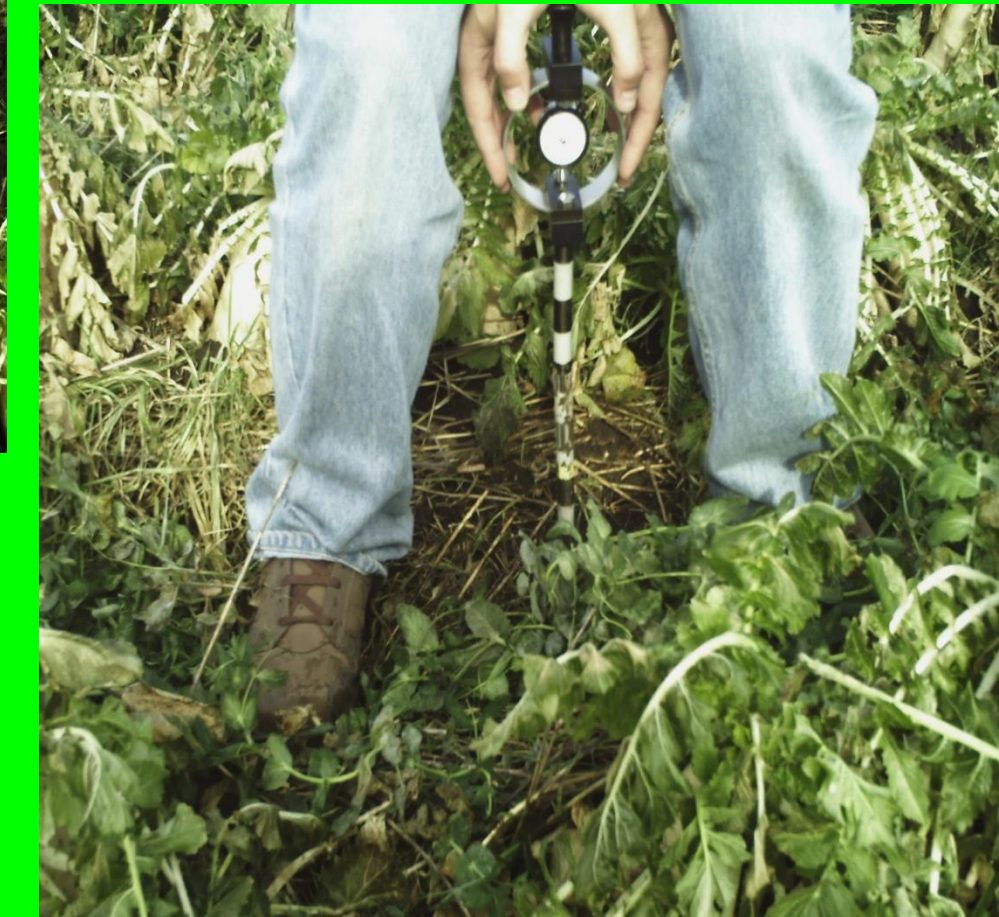
**Roots expanding the soil**



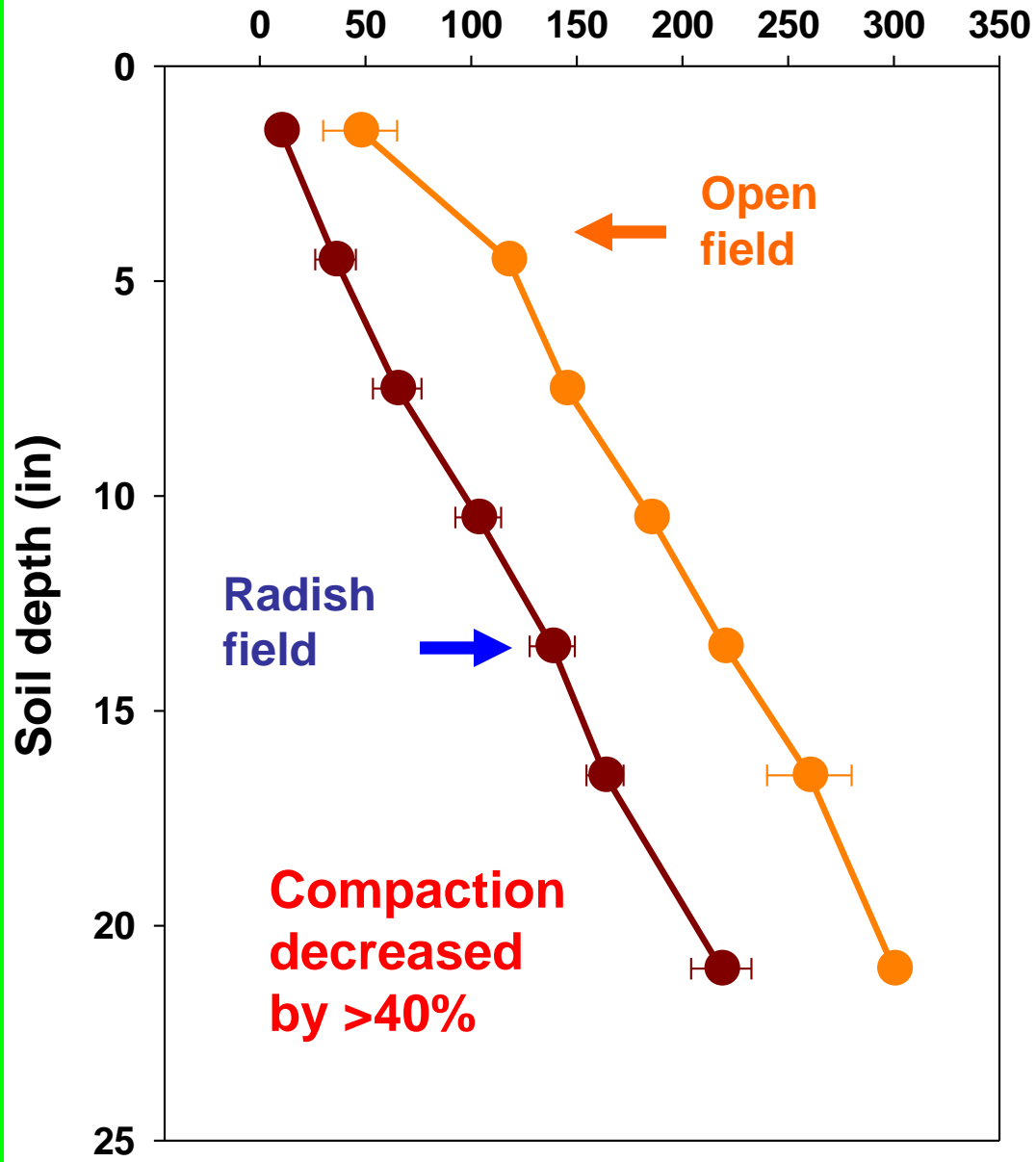
**Roots reducing  
soil compaction**



## Measuring soil compaction

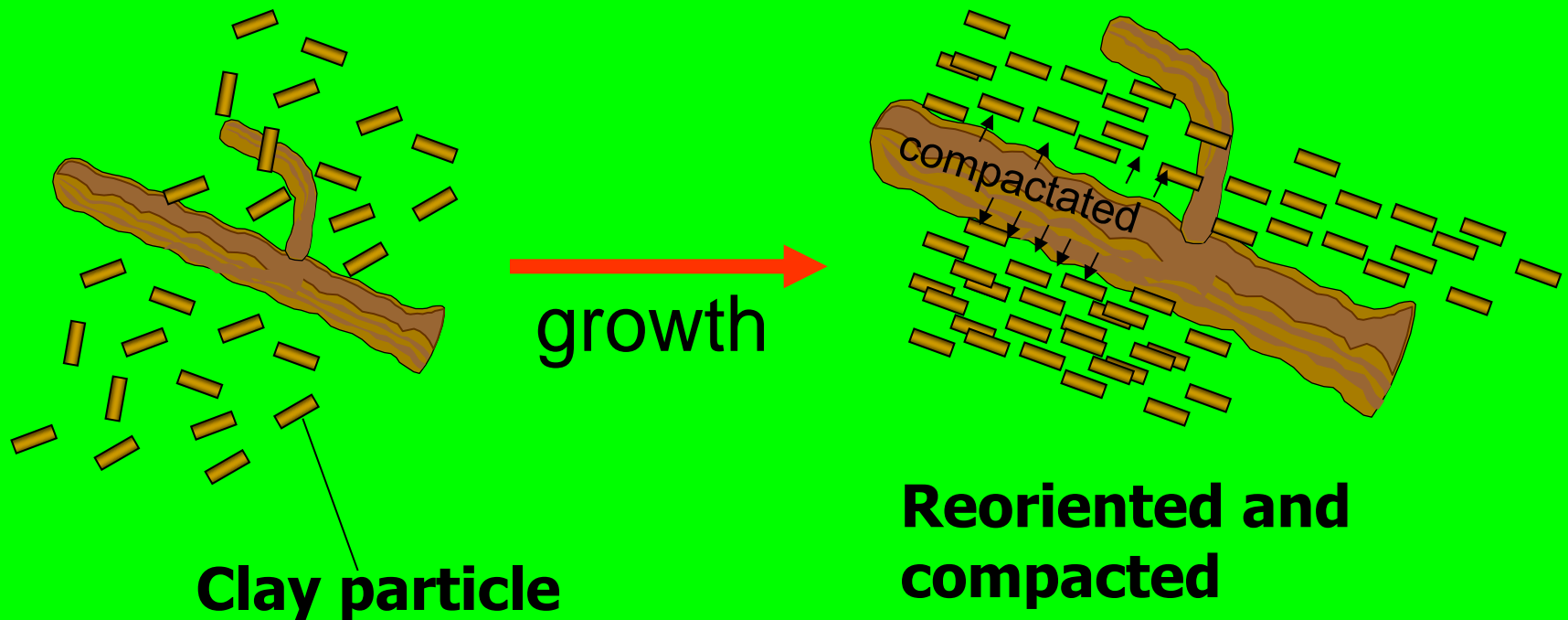


# Penetration resistance (lbs/in<sup>2</sup>)



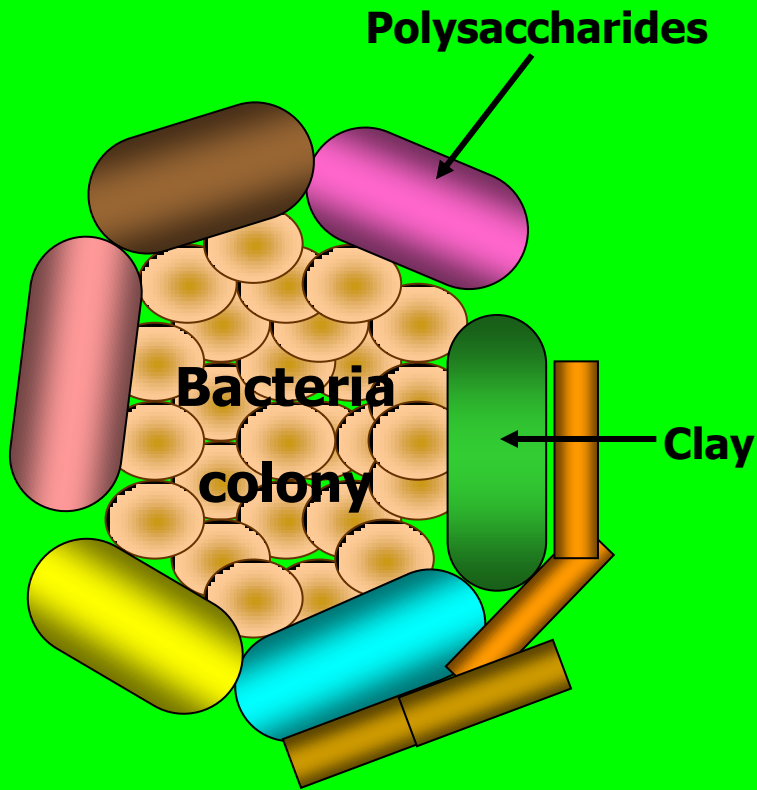
# Roots and fungi hyphae

Fine roots go through the soil pores and drying the soil and compress clay particles to form the aggregates that will be stabilized by polysaccharides excreted by microorganisms (Allison, 1968)



# Microaggregates formation

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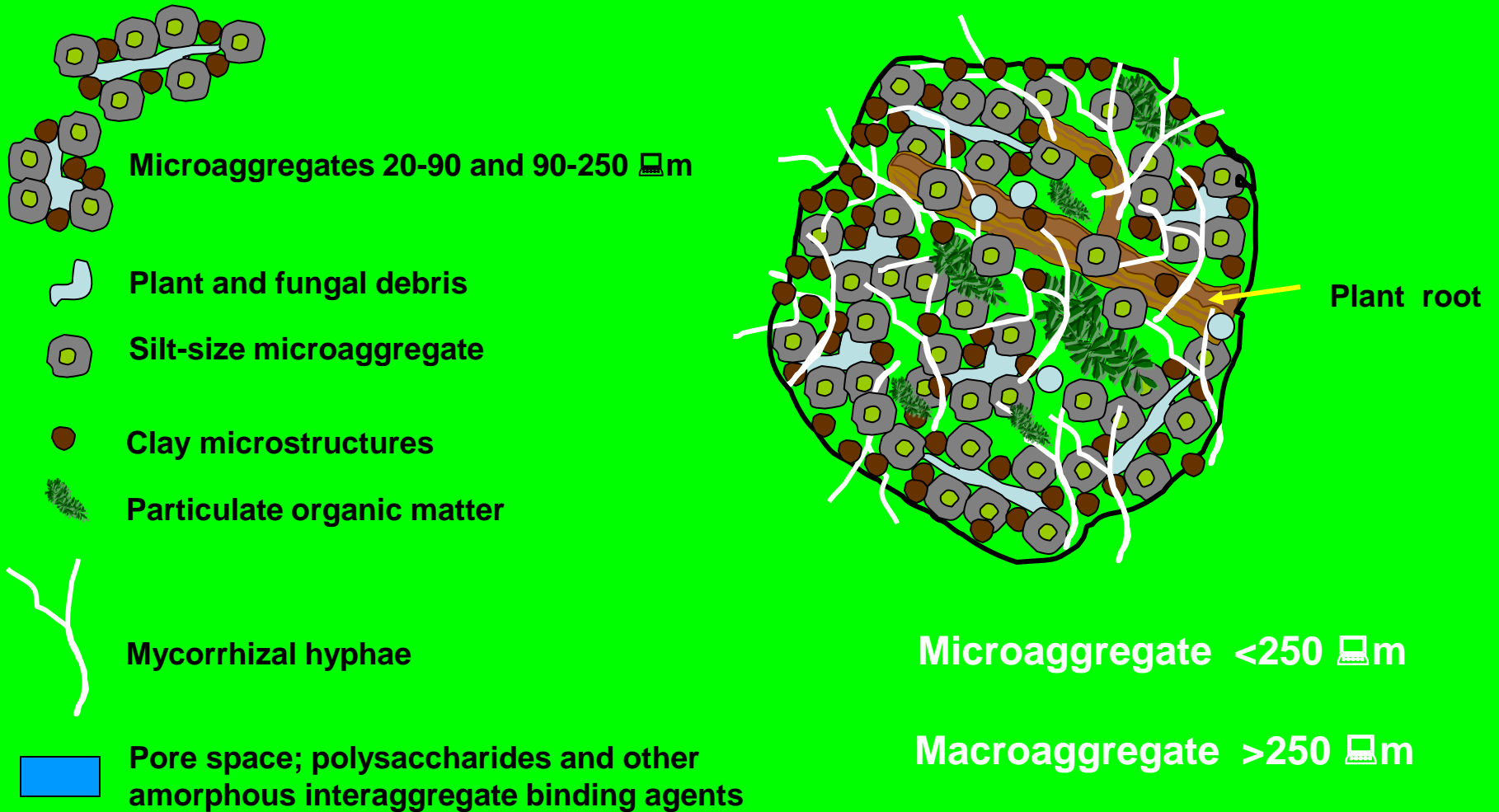


**Foster, 1983** - cells and bacteria colonies are enclosed in polysaccharides capsules, aligned by clay particles, forming an aggregate.

**40 to 60%** of the soil microbial biomass associated with microaggregates

**90%** of the bacteria linked to clay

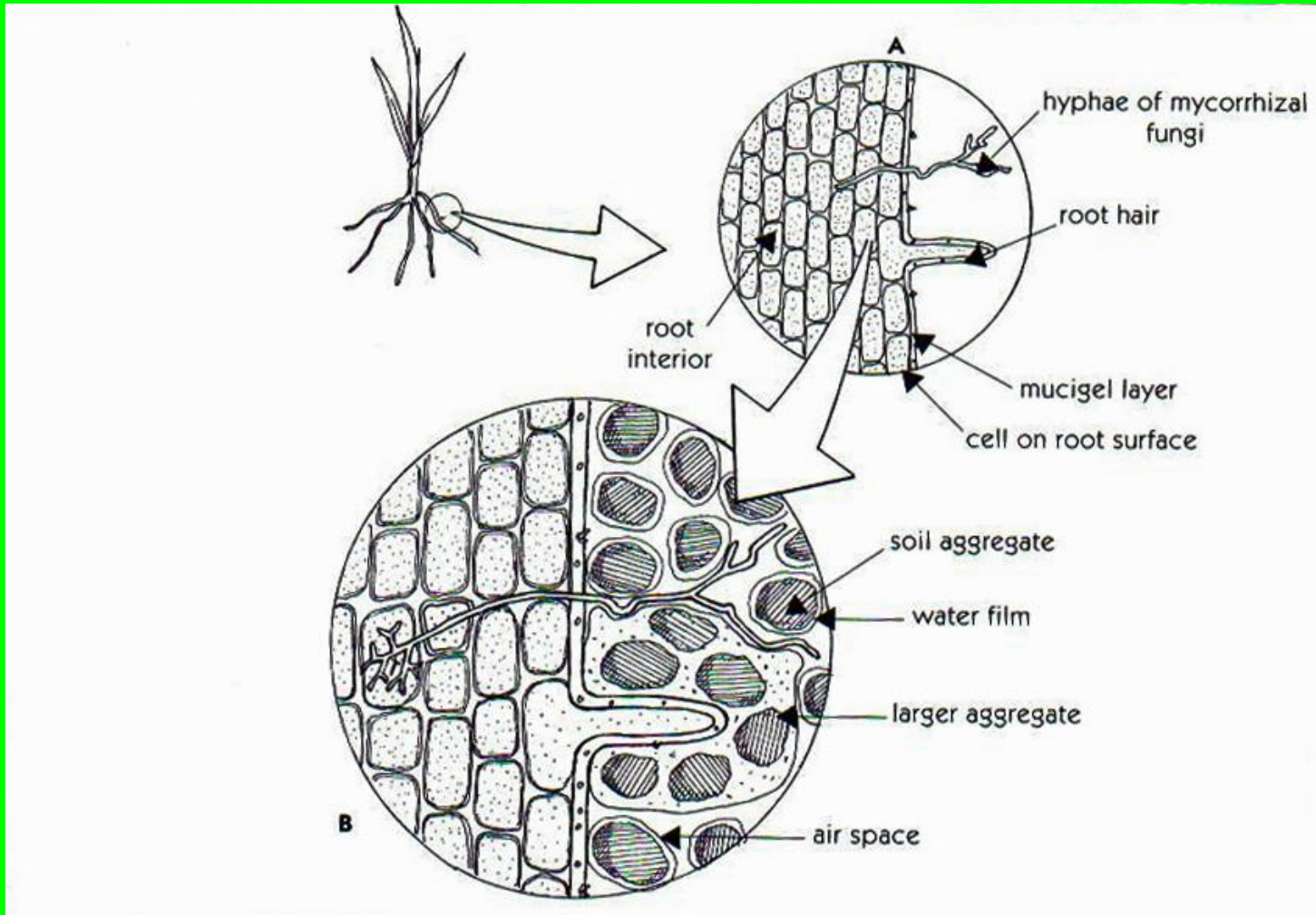
# Microaggregates-macroaggregates model



Adapted from Jastrow and Miller, 1997

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

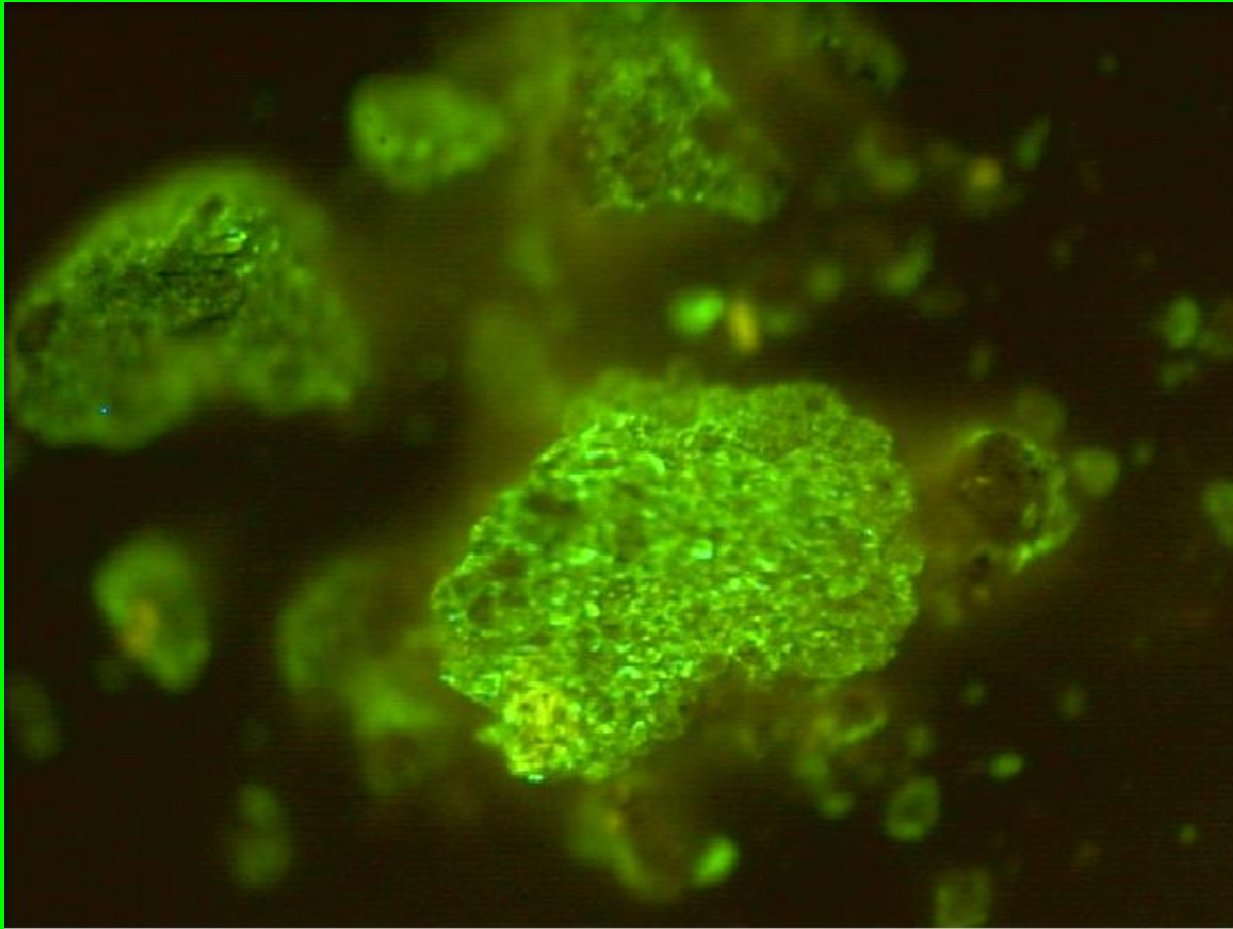
# Mycorrhizal Fungus



# Mycorrhizal Fungus & Roots



Fungus equals white or yellow filaments, roots are light brown to tan in color.

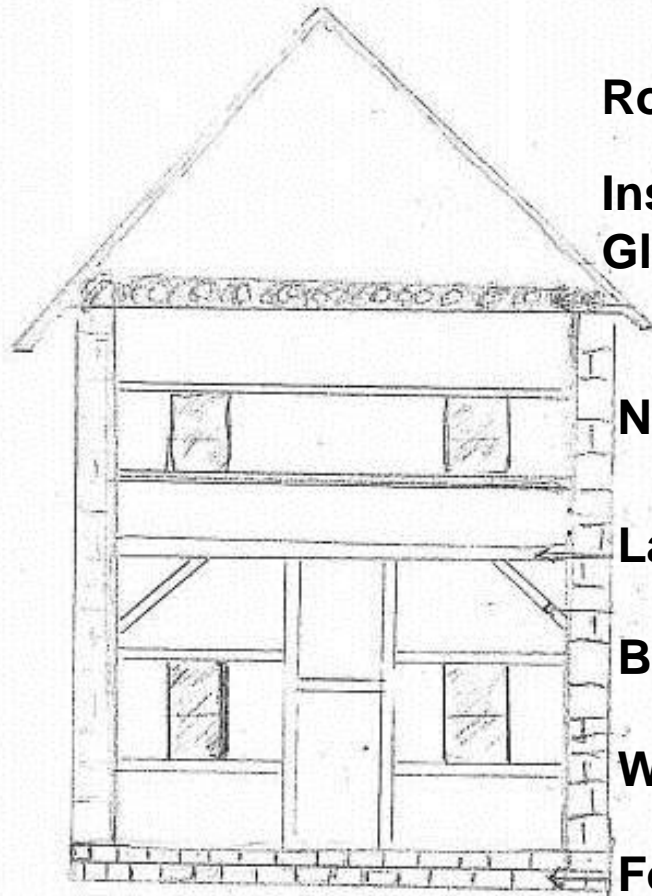


**Sticky substance, glomalin, surrounding soil aggregates, water soluble. Photo by Sara Wright.**

# 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
House wrap	Glomalin
Roof	Surface Residues

# Building Soil is Like Building a House



**Roof-Subsurface Residue**

**Insulation/glue/House wrap-  
Glomalin-G**

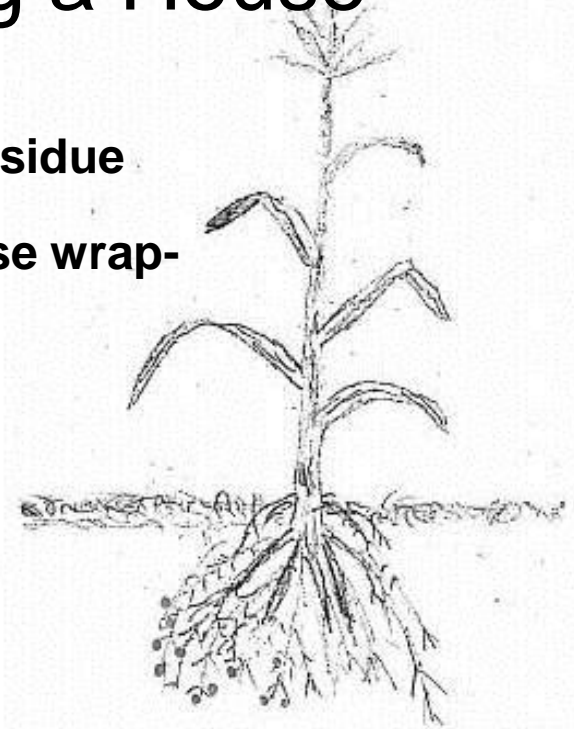
**Nails – Humus-OM**

**Lag Screw - P**

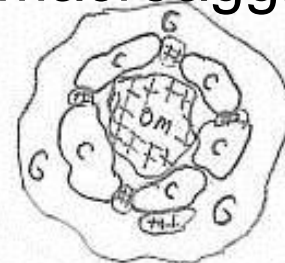
**Braces – N & S**

**Wood – Roots - OM**

**Foundation-Clay-C**



**Macroaggregate**



# Oxygen and Carbon Dioxide

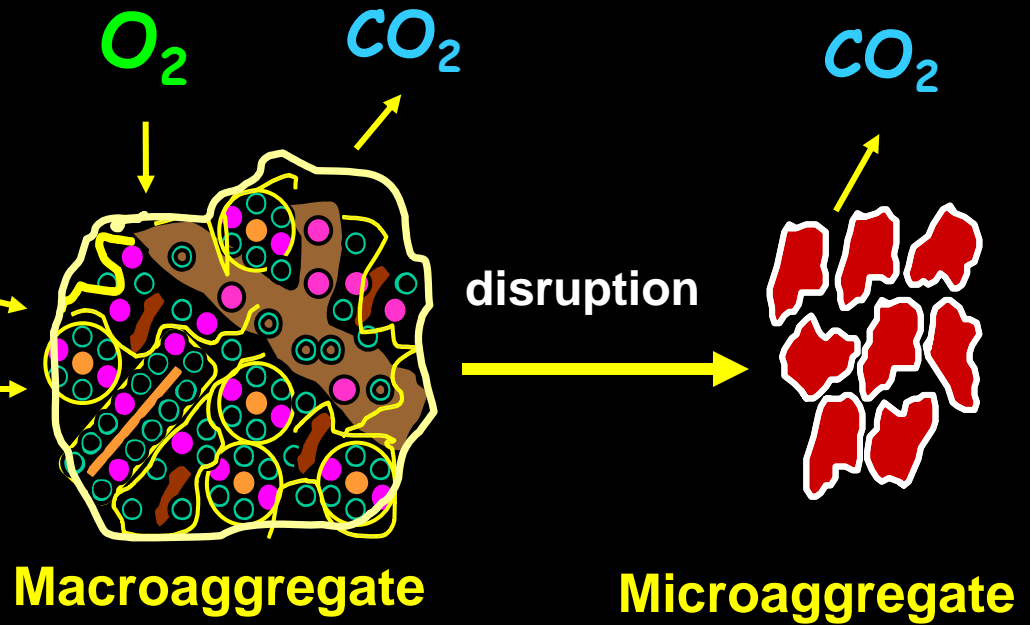
Carbon dioxide ( $\text{CO}_2$ ) is heavier than  $\text{O}_2$

$\text{CO}_2$  and  $\text{O}_2$  are inversely related in the soil.  
If one increases the other decreases.

Too much  $\text{O}_2$  in the soil causes  $\text{CO}_2$  to be lost from the soil to the atmosphere.

Roots act like a **Biological Valve** to control  $\text{O}_2$ .

# Oxidation and release CO<sub>2</sub>



# 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.

# Why do our Soils Compact?

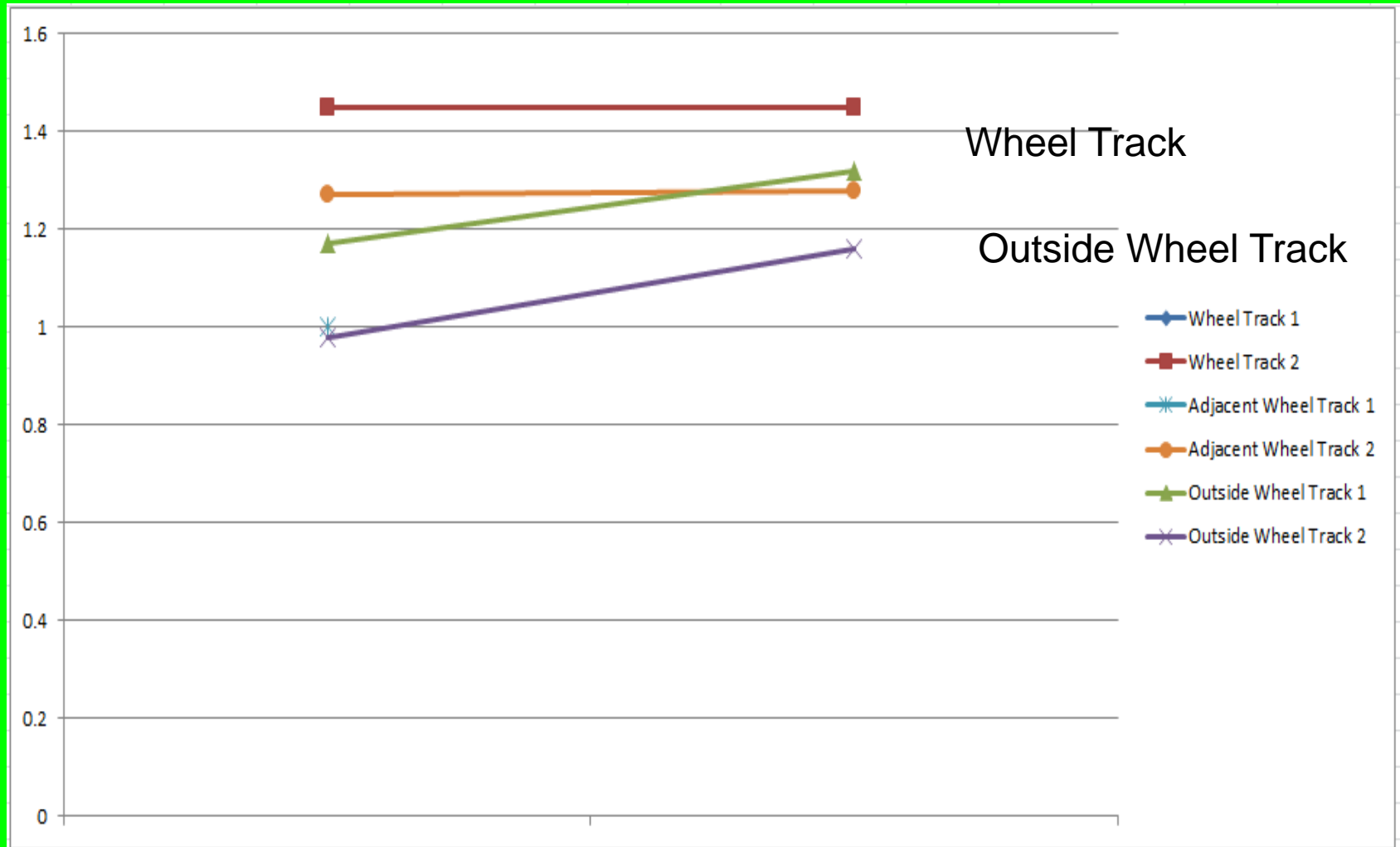
- Look at your Crop Rotation
  - Drilled Soybeans have poor root system
  - Corn has thick roots limited by plow layer
- What percentage of time do we have live roots?  
Corn-Soybean rotation  $4/12$  months =  $1/3$  of time
- Does No-till have more Live Roots than Conventional tillage? NO
- What is missing in No-till? Live Roots



Soil compaction is a Biological Problem!

Soil Compaction is related to a lack of Living Roots in the soil profile.

# Controlled Traffic Data



# Ideal Bulk Density by Soil Texture

Soil Texture	Ideal Bulk Density for Plant Growth (g/cm <sup>3</sup> )	Bulk Density that restricts Plant Growth (g/cm <sup>3</sup> )
Sandy	<1.60	>1.80
Silty	<1.40	>1.65
Clay	<1.10	>1.47

Data from Ohio OARDC test station shows that on Hoytville clay soil (39% clay) that controlled traffic reduced the bulk density outside the wheel tracks while increasing the bulk density inside the wheel track. Soil compaction can persist for at least 9 years and reduce yields by 60% with severe soil compaction. Australia research shows a 10 to 40% increase in crop yields with controlled traffic (Robinson).

# Subsoiling and Compaction



# Subsoiling Yield Gains (Losses)

- Conventional tillage with subsoiling
  - Corn Yield gain 1-3 bu or 3%
  - Soybean Yield Gain 2-5 bu or 10%
- No-till and subsoiling
  - Corn Yield loss 1-3 bu or 3%
  - Soybean Yield loss 2-5 bu or 10%

# Subsoiling vs. Cover Crops

**What can a subsoiler do?**

**Immediate change in soil structure, 18 inches deep**

**Increase infiltration**

**Leaves soil susceptible to compaction later**

# Subsoiling vs. Cover Crops

What can cover crops do?

Slow change in soil structure, 3 ft deep or deeper.

Increase infiltration, over time

Protect soil from erosion

Add nutrients and organic matter

Fit into a continuous no-till system

Help protect against soil compaction

# Soil Resistance to Compaction Ranked

- Continuous No-till, controlled traffic, cover crop
- Continuous No-till with growing cover crop
- Continuous No-till, heavy residue, no cover crop
- Continuous No-till, light residue or bare ground
- Intermittent No-till
- Shallow tillage (Aer-Way, Phoenix harrow...)
- Strip-till
- Subsoiled, wide spaced shanks
- Moldboard or chisel plow, finely tilled seedbed
- Subsoiled, deep ripped, full surface tillage

# Best Cover Crops to Fight Soil Compaction?

- Grasses: Fibrous Roots  
Sorghum Sudan > Annual Rye > Cereal Rye/Oats
- Brassicas: Large Taproot (Fine root hairs)  
Oilseed Radish > Turnips (Shallow rooted)
- Legumes: Large Root Network  
H. Vetch > Cowpeas > Red Clover > Winter peas
- For Surface Compaction? For Deep Compaction?  
Buckwheat > Phacelia                      Sunflowers

# Summary

- Soil Compaction is related to the Biology of the Soil & How the Soil was Managed.
- Organic Matter and Microbes influence Soil Compaction.
- Cold No-till Soils result from Soil Compaction and poor Soil Structure.
- Active Living Roots and Microbes work together to Improve Soil Structure.
- Equals No-till plus Cover Crops or a new system called ECO Farming!



## **The Biology of Soil Compaction**

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