Science and Biology of Soil Health

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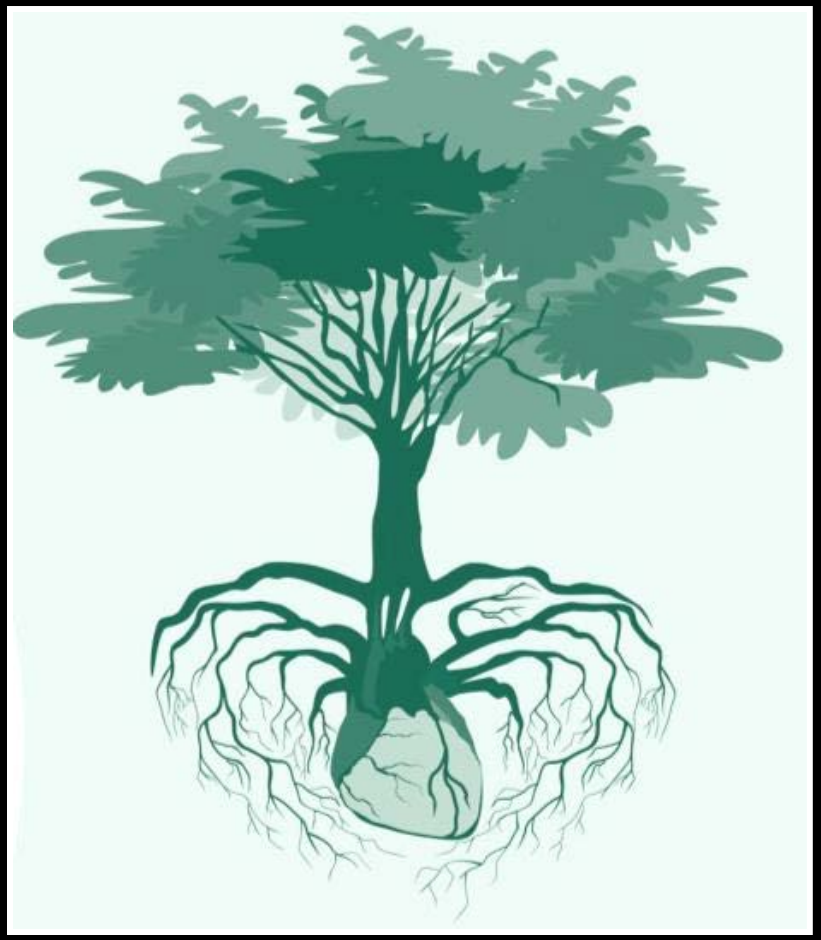
Soil is the Heart of the System

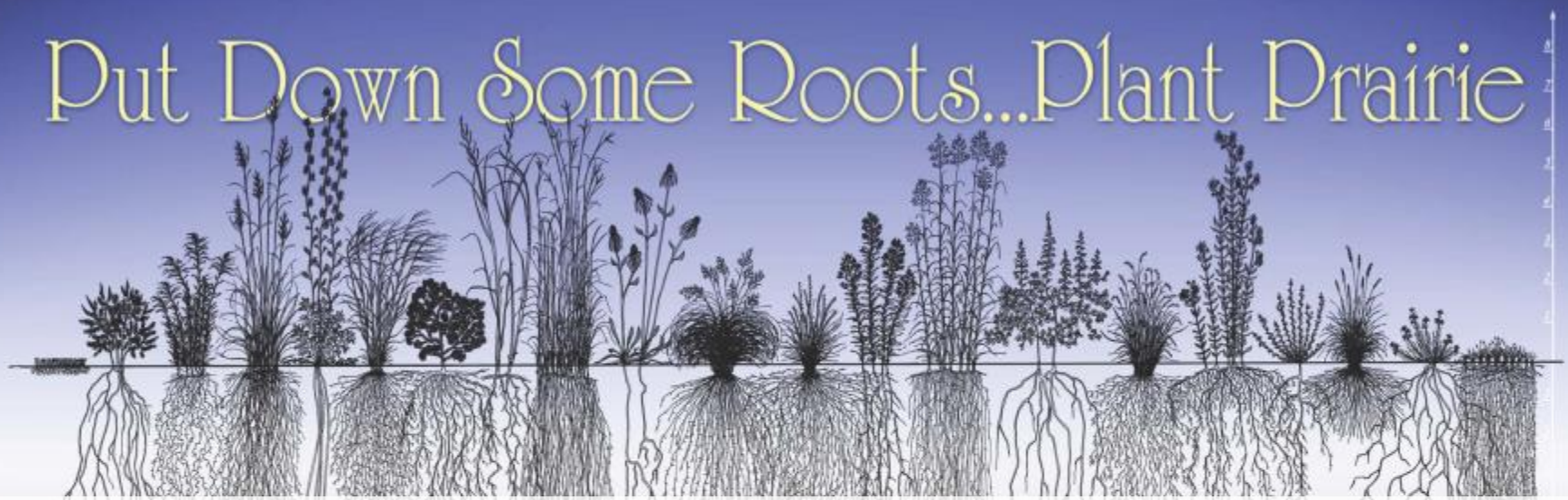
- Connects above and below ground
- Recycles C, N, O, P, water, etc.
- Drives physical, chemical, and biological processes
- Uses the most efficient mechanisms

- Value of soil organic matter (~$600-800 per acre) – Hoorman & Islam, OSU

- Estimated value of soil biota is $1.5 trillion globally per year - Dance, 2008



Root of the problem is the root of the solution.

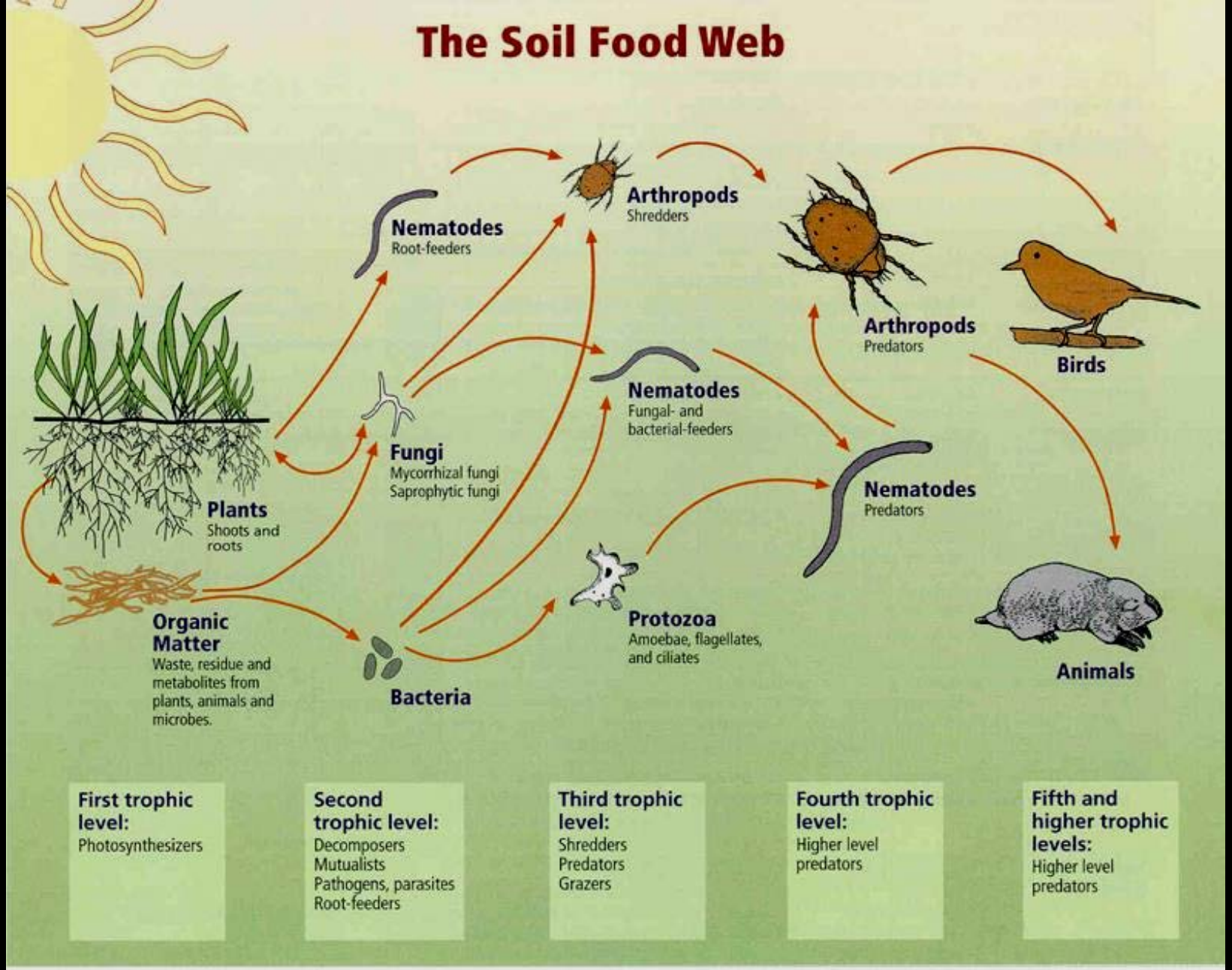


Rhizosphere 0.5-1 inches around roots

- **Twice the number of microbes**
- **Highest biological activity due to photosynthetically-derived carbon (approx. 70%) – Juma, 1993**
- **Greatest impact on soil structure**
- **Majority of the nutrient cycling activity**
- **Most impacted by aboveground management**


Intraradical hyphae
Arbuscules

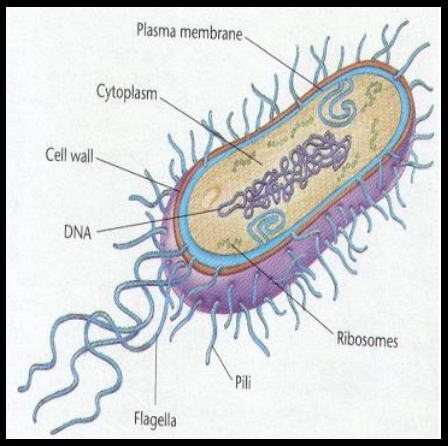
- Soil is organic (i.e. living)
- Billions of different organisms from millions of species
- Total weight of living organisms in the top six inches of an acre of soil can range from 5,000 to 20,000 lbs.
- Soil from one spot may house a very different community from soil just a yard (meter) away, because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

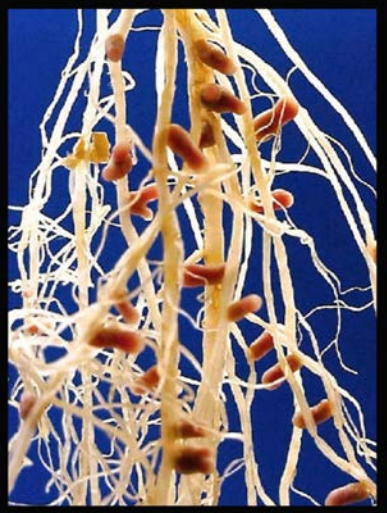


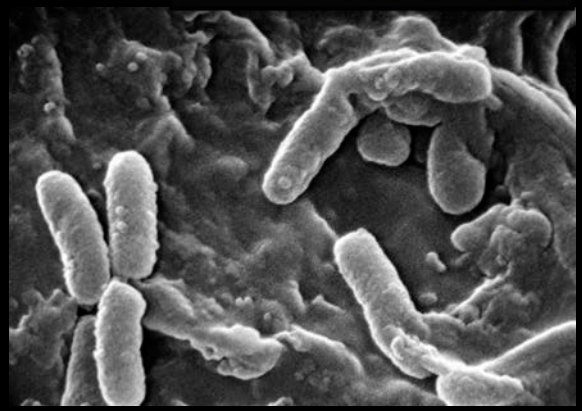
Relationships between soil food web, plants, organic matter, and birds and mammals
Image courtesy of USDA Natural Resources Conservation Service
http://soils.usda.gov/sqi/soil_quality/soil_biology/soil_food_web.html.

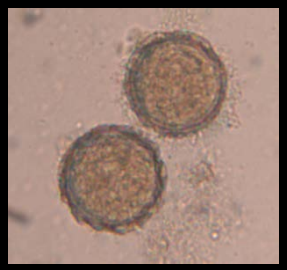
Bacteria

- Five nonillion (5×10^{30}) bacteria on Earth, forming much of the world's biomass.
- Total number of individual bacteria in a gram of soil ranges from millions to billions
- Contribute to soil stability
- Decompose pesticides
- Feed on organic matter that is easy to breakdown
- Store and cycle nitrogen
  - Asymbiotic and symbiotic systems fix ~100-175 million metric tons



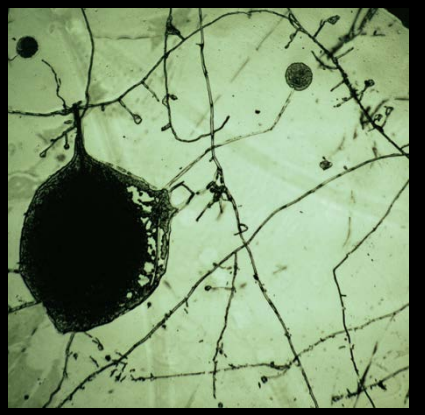


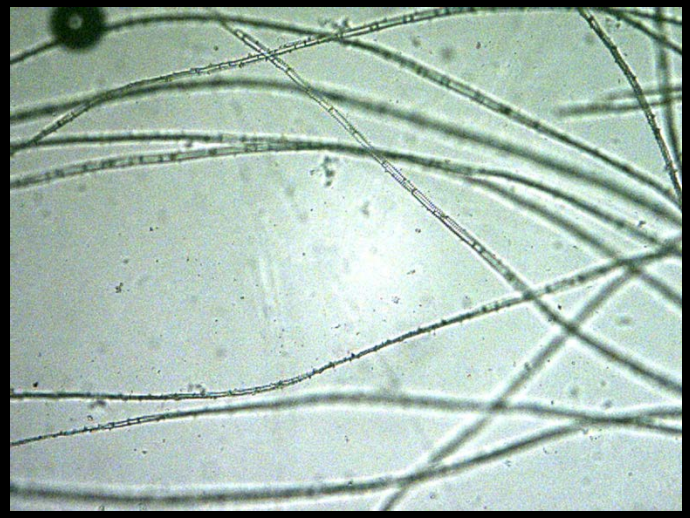




Fungi

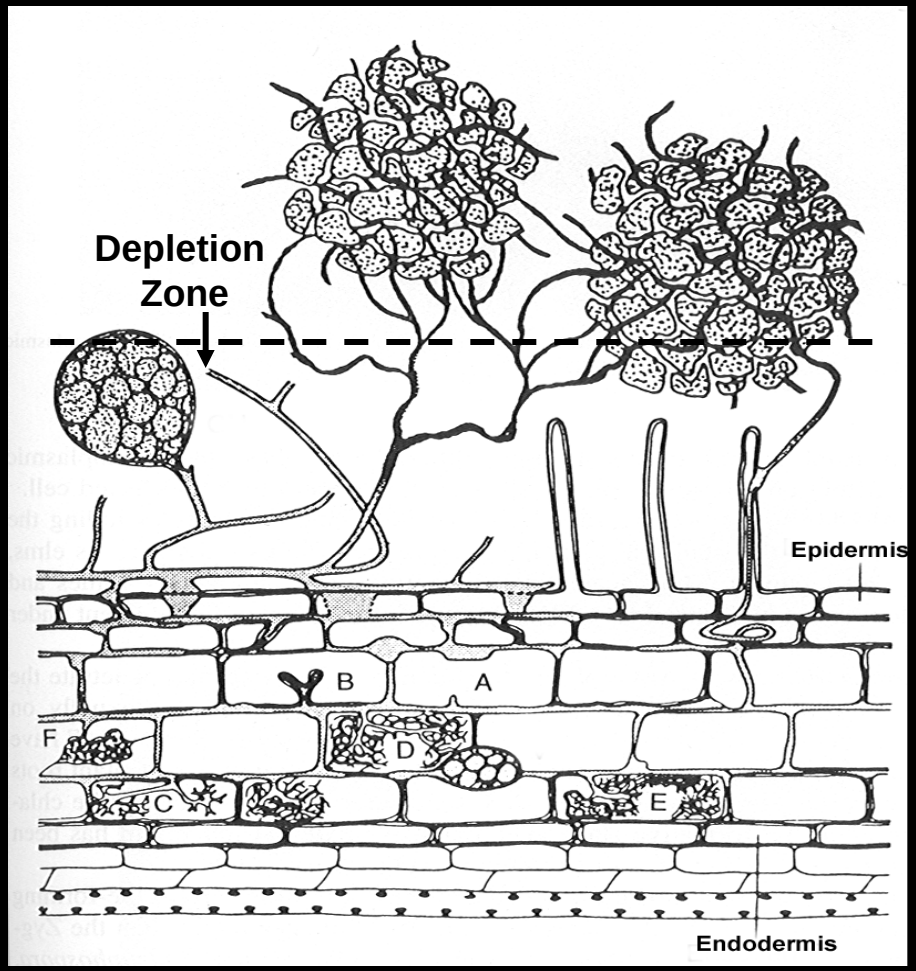
- Up to 3,000 species in cultivated soil
- Three main types: parasites, saprophytes and mutualists
- Saprophytes feed on organic matter that is difficult to breakdown, such as crop residue
- Parasites attack foliar and root plant material, other fungi, nematodes and micro and macroarthropods
- Store nitrogen in hyphal bodies and release nitrogen by decomposition





Mutualistic Fungi
Arbuscular Mycorrhizal Fungi

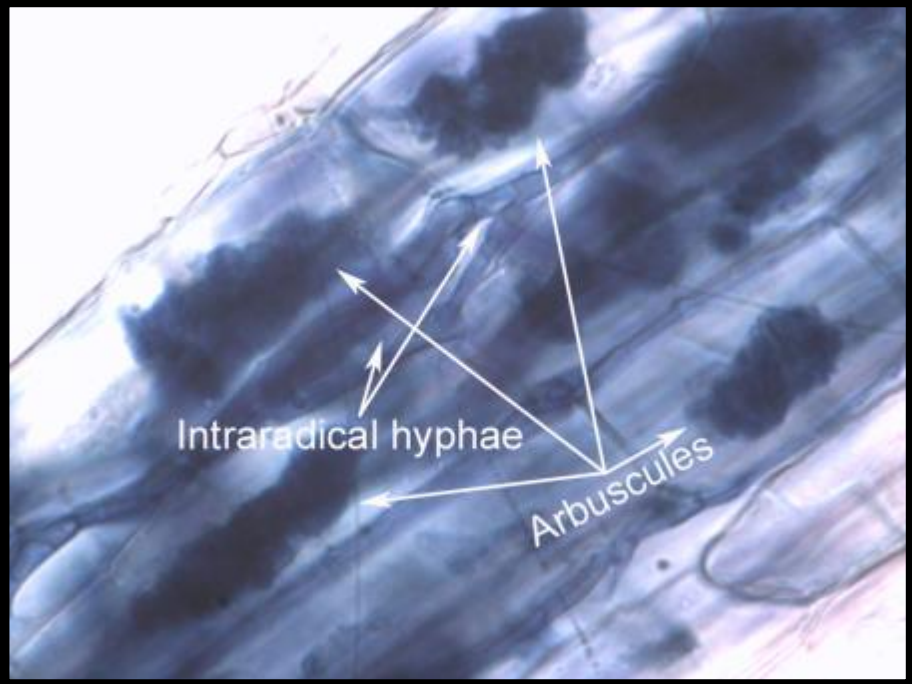
- Mutualists that obtain nutrients (primarily P, but also Cu and Zn) from beyond depletion zones around roots
  - Grow about 1 to 2 inches out into the soil (about 100 meters of fungal hyphae per g of soil)
- Usually broad host range
- Low #s can stress plant



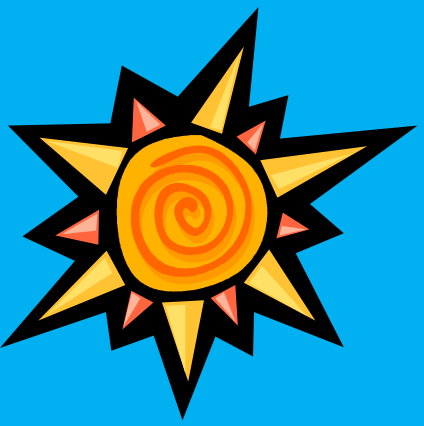
Mutualistic Fungi
Arbuscular Mycorrhizal Fungi

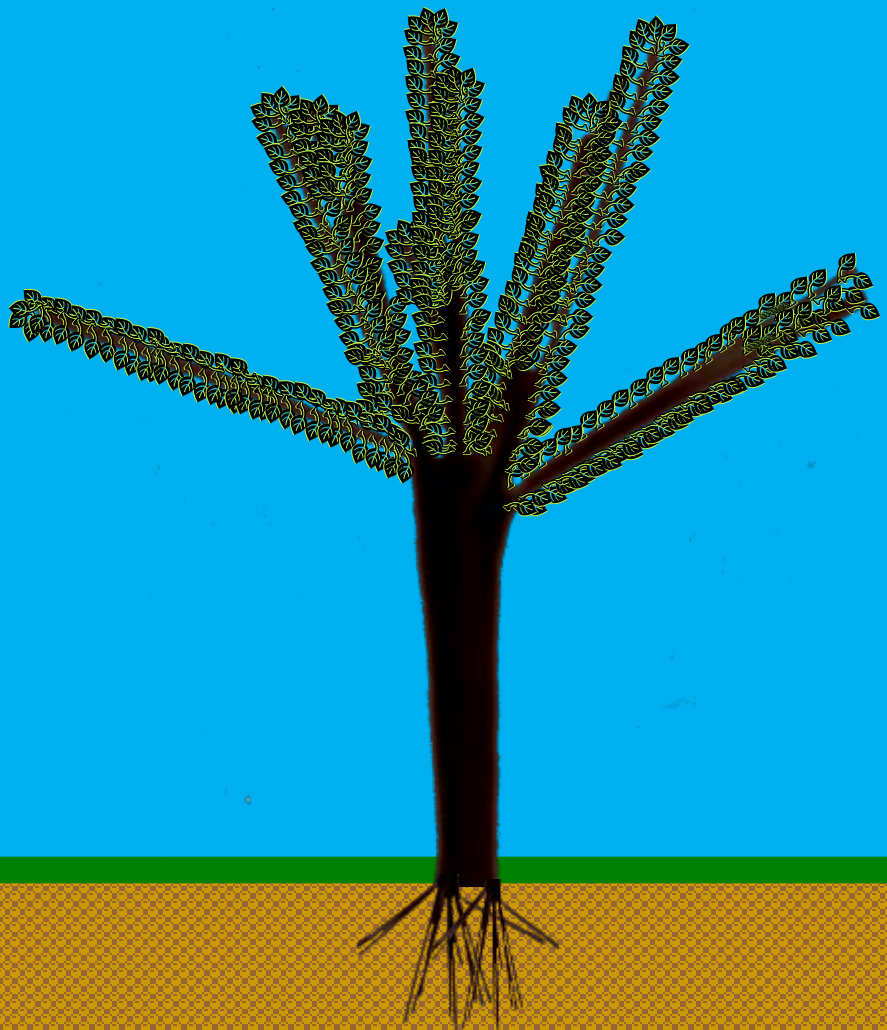
4-30% of C is transferred to AM – Jansa et al 2013

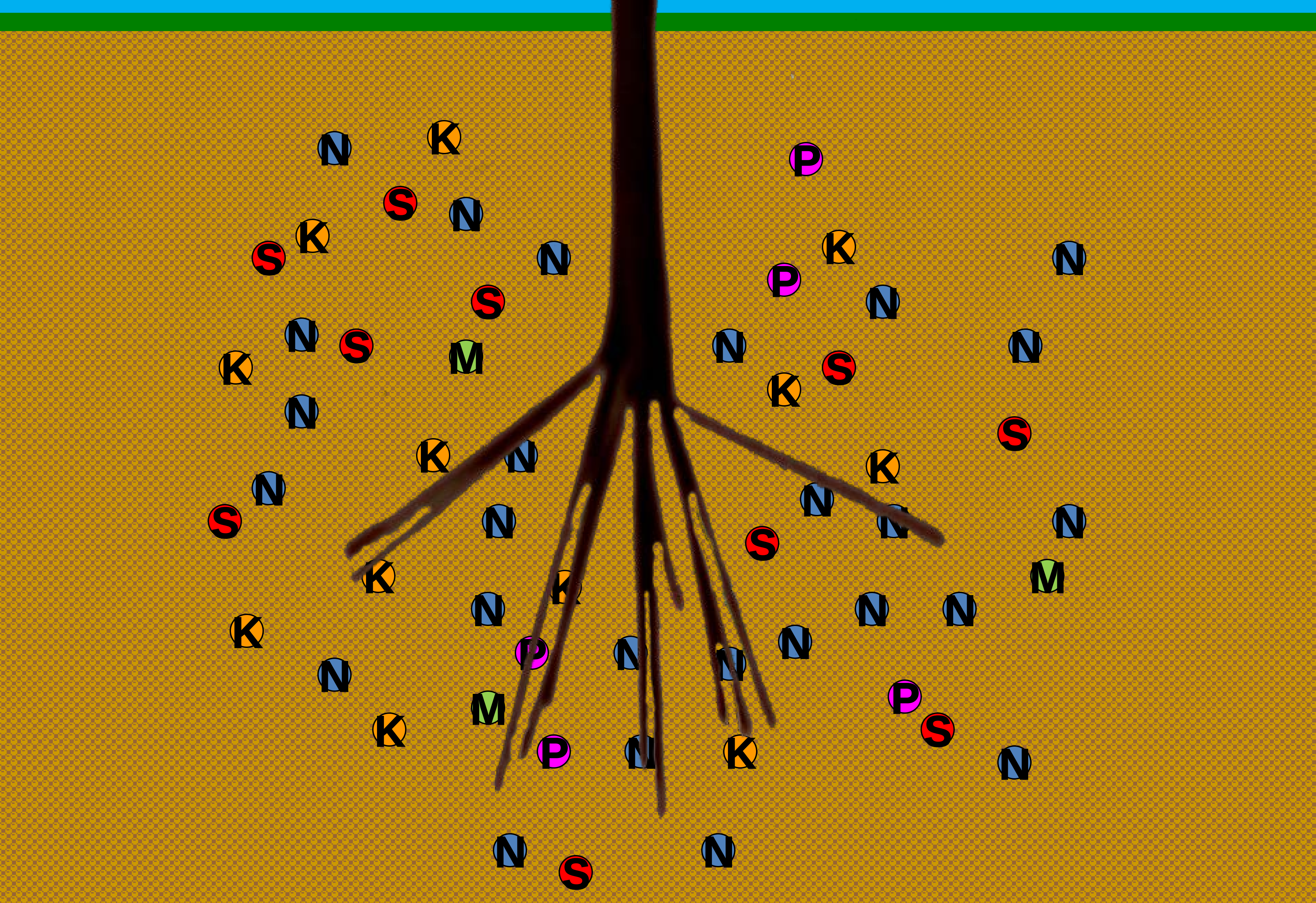
- **Affected by:**
  - **rotation (incl. cover crops)**
  - **fallow**
  - **flooding**
- **Create mycorrhizosphere in soil**
  - **Assist with nutrient cycling**
  - **Form soil aggregates**



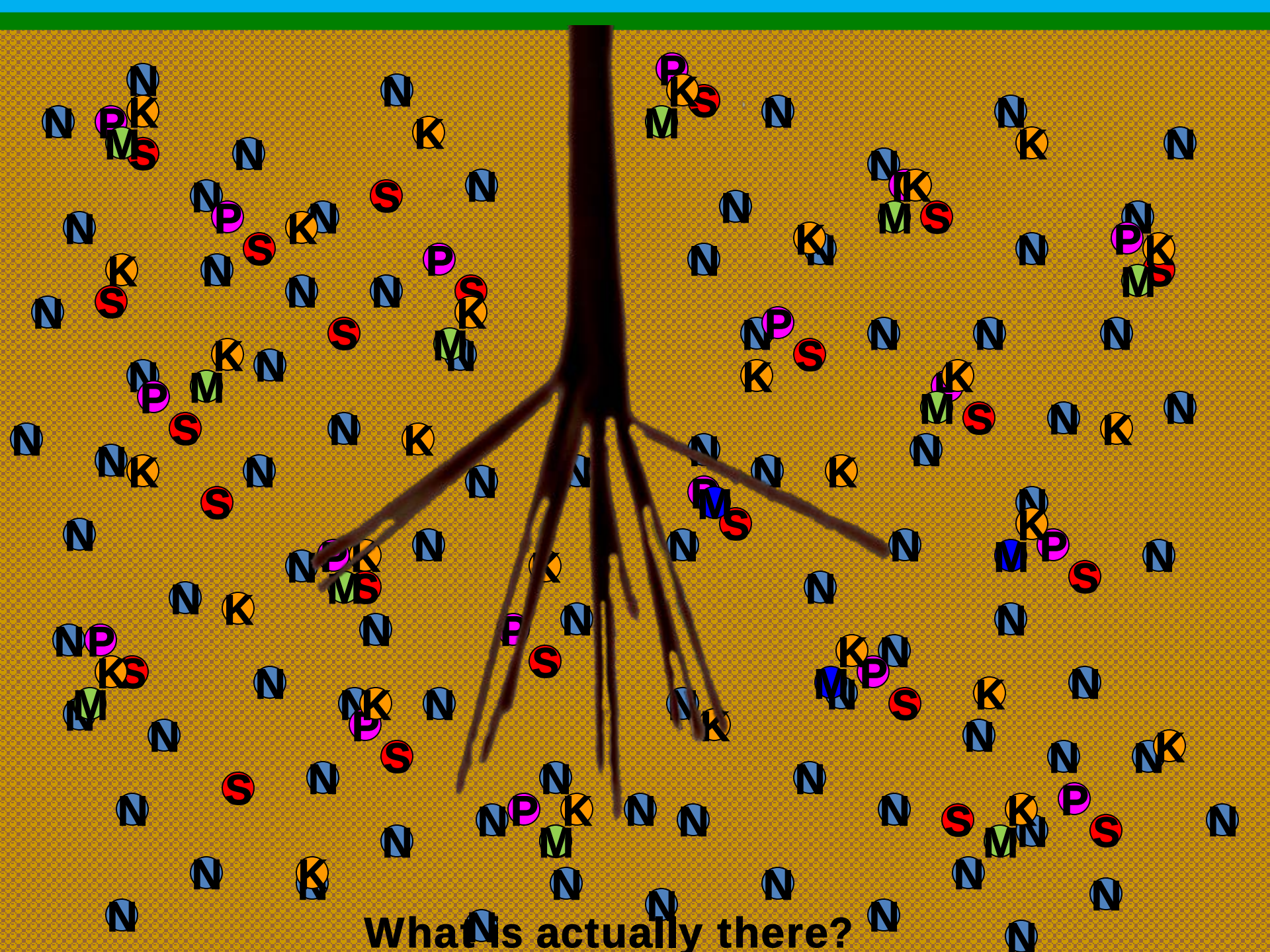
Efficiency

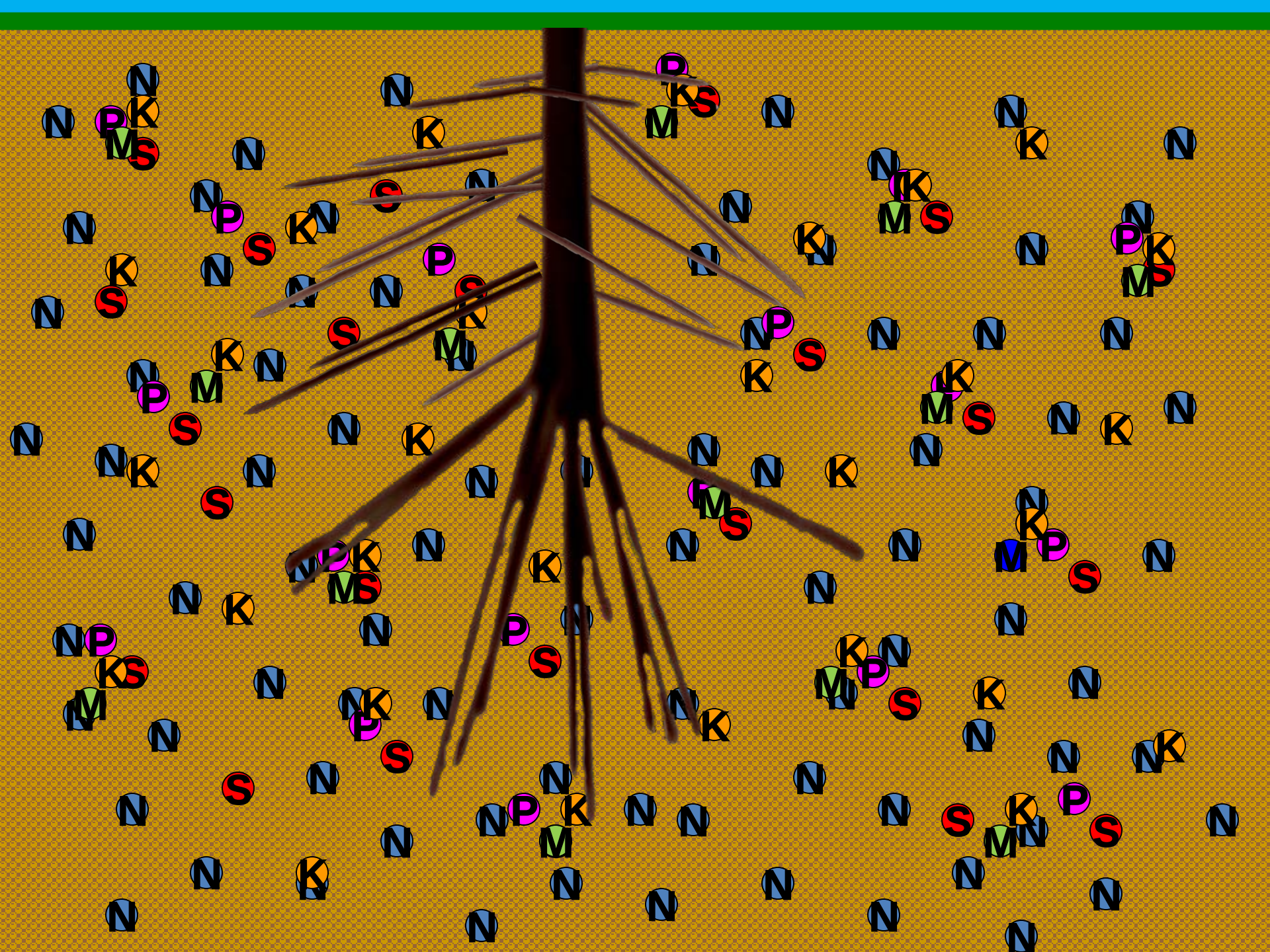


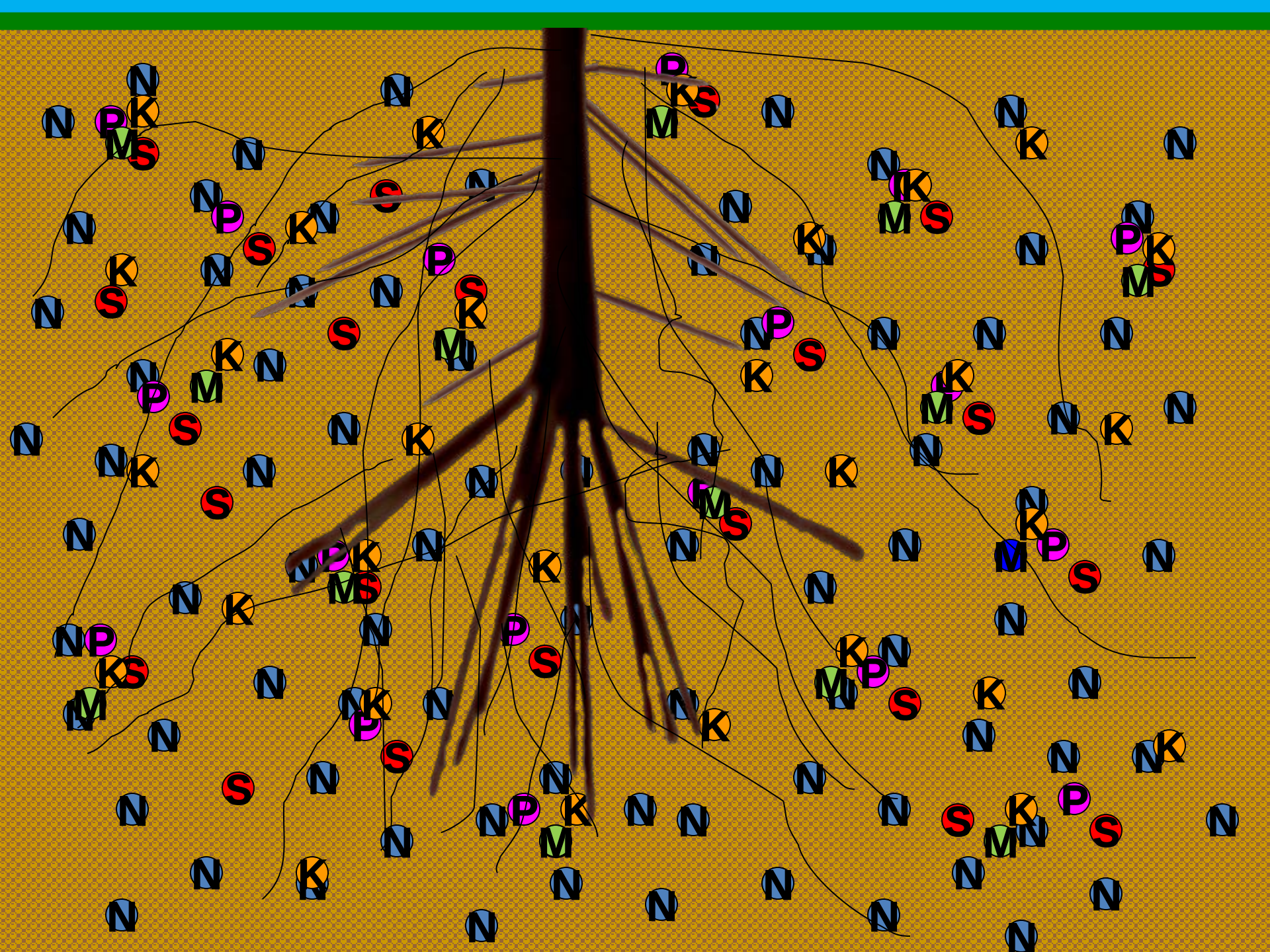




What the plant can access alone?

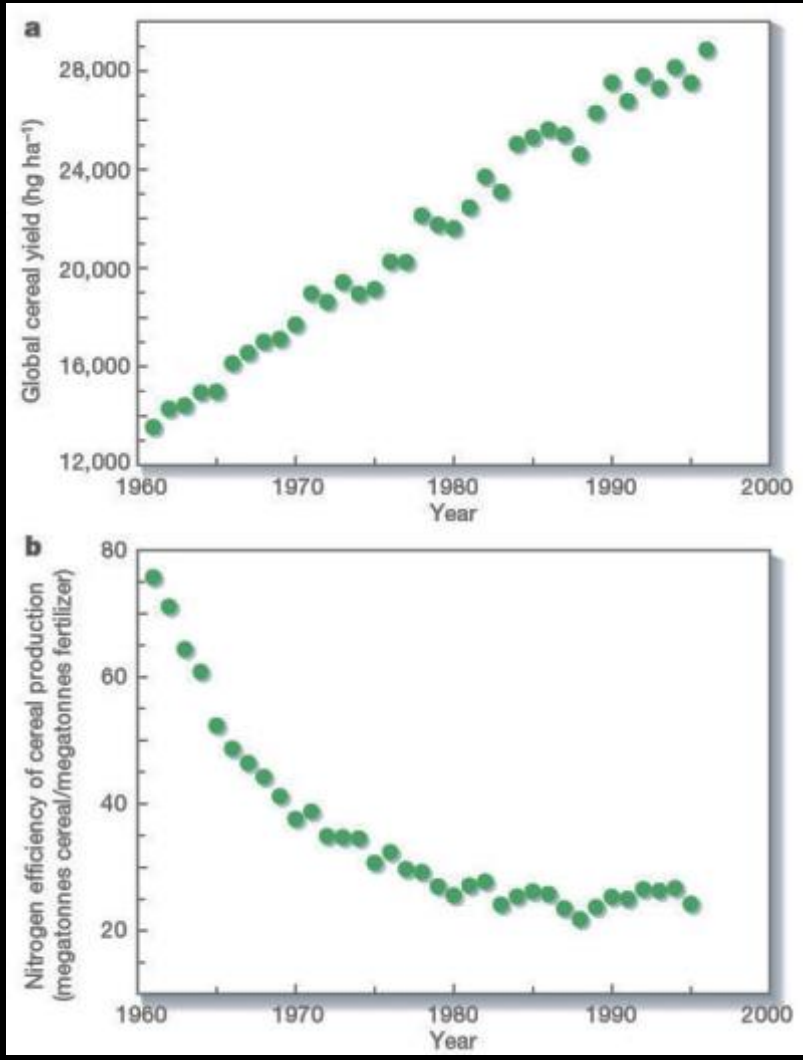

What is actually there?


N
P
K
S
M


N
P
K
S
M

Nutrient Use Efficiency

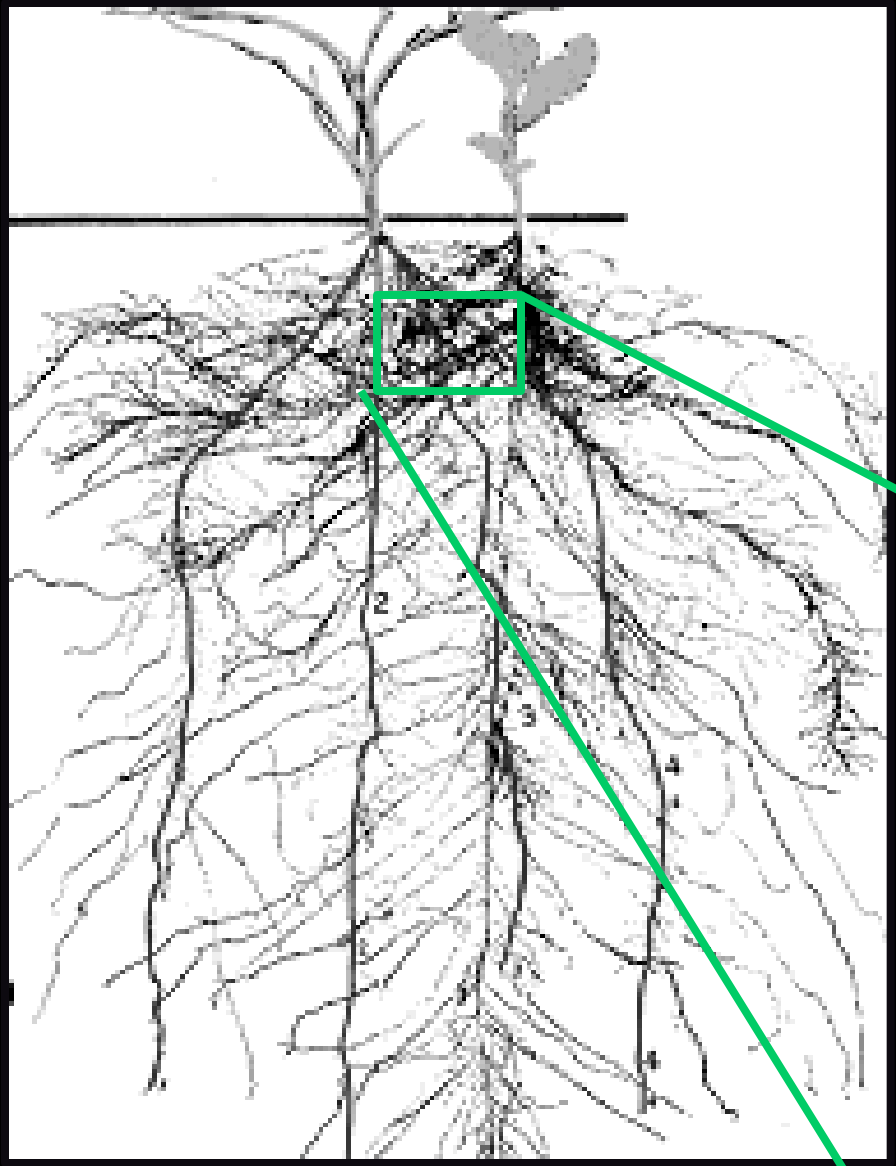
- Plant available – synthetic vs. biologic
- 30-50% of nitrogen fertilizer is used by the plant
- 30% of phosphorus is used by the plant
- Availability, timing, water, and pH



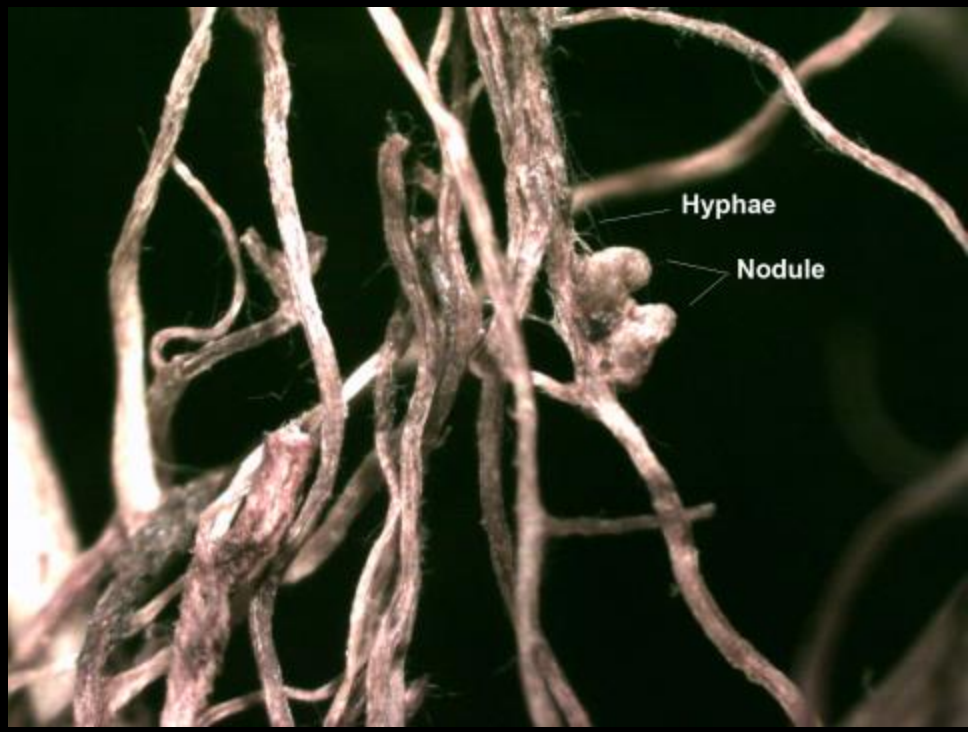
- Tilman et al., 2002

AMF and Nutrients

- Supply up to 90% of the N and P – Smith and Read, 2008
- Phosphate-solubilizing bacteria – Toro and Barea, 1996
- Hyphae from one network can fuse with another network increasing size – Giovannetti et al., 2004
- Mixed cultures were more efficient in uptake of 33P and 15N than in monocultures, but this was also AMF species dependent – Walder et al 2012
- Non-legume trades P for N via AMF and rhizobia activity



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



Water Use Efficiency

- 45% greater porosity increases infiltration by 167% for the first inch and 650% for the second inch - Karlen et al., 1998
- Plants use 180 to 900 kg (400 to 2000 lbs) of water per kg (2.2 lbs) of dry matter
- Unfertilized corn - 26,000 gallons of water per bushel and 18 bushels per acre; Fertilized corn - 5,600 gallons of water per bushel and 79 bushels per acre – W.A. Albrecht, University of Missouri, 1930-1974

Cover Crop Enhancement
Burleigh County SCD Demo Farm, 2006

Seven-way cover crop mix yielded ~ 3X single crop on 7 in of soil moisture

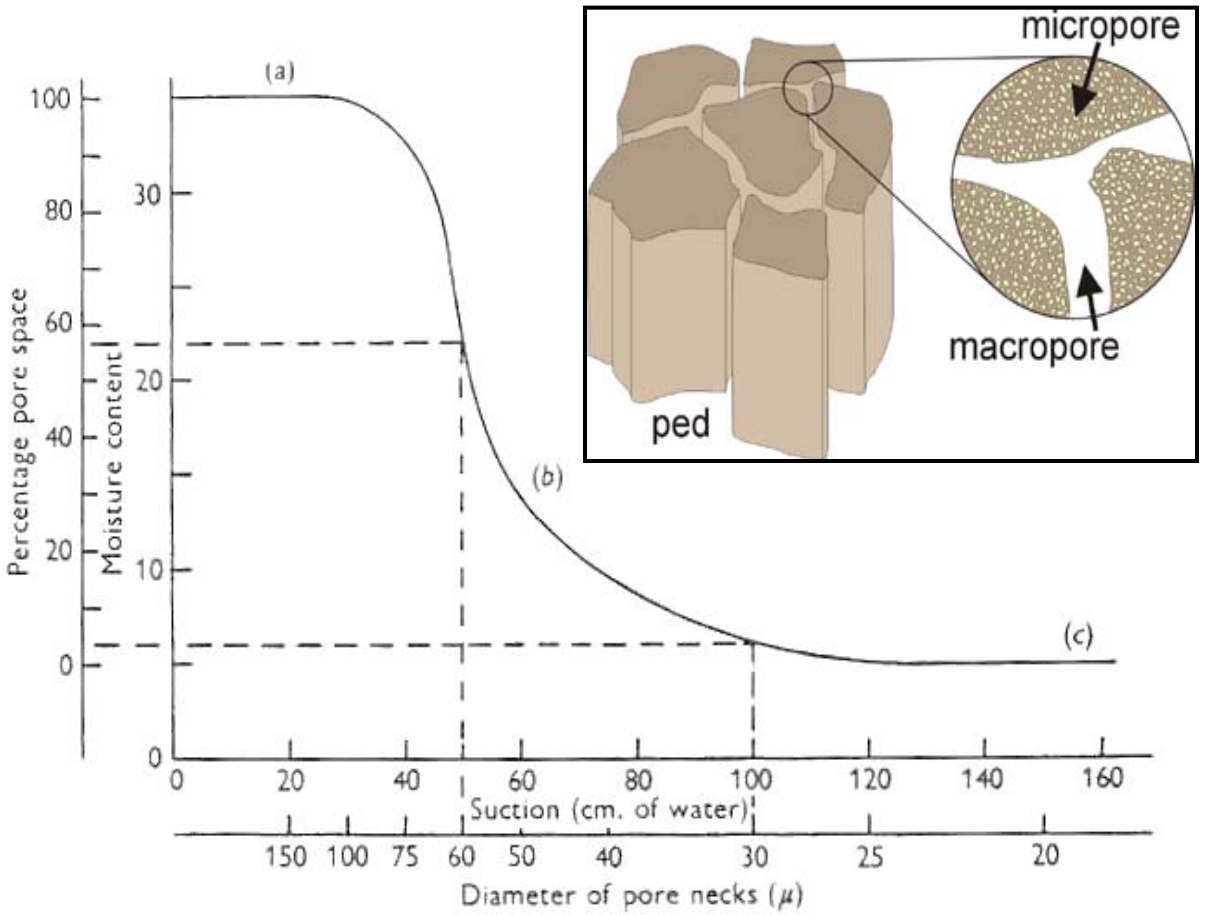
Field with manure and no commercial fertilizer yielded the same as a fertilized field and plant tissues tested sufficient or high for N, P, K, and S

Maximum Diversity with Cover Crops
How can you not grow a cover crop during a drought?

Nutrient and Water Use Efficiency
Carbon Allocation Equation:

Carbon input = primary + secondary

Soil Porosity



- Mineral soils: 35-65%
- Organic soils: 80-90%

➢ Macropores

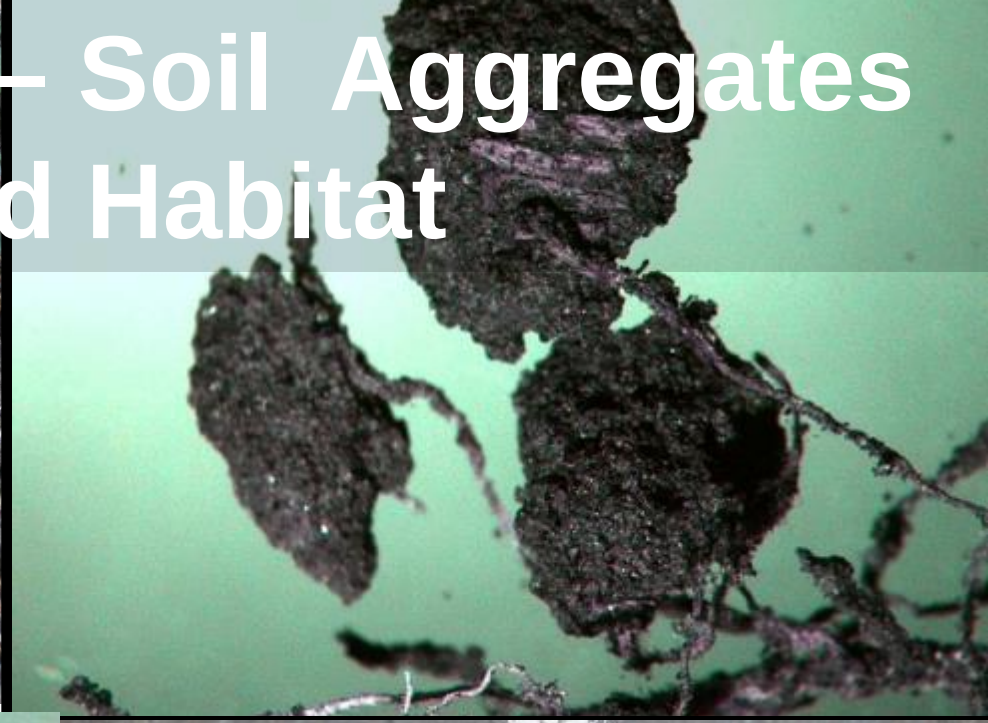
- **(>10 µm)**
- **Between aggregates**
- **Nematodes, Protozoa, Microarthropods**

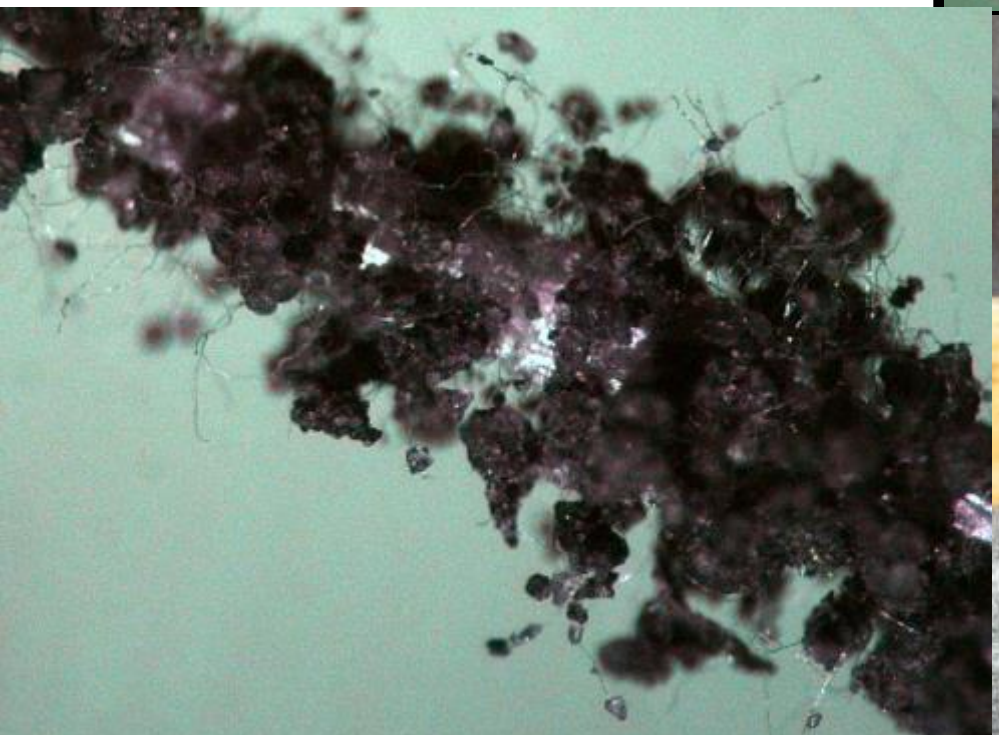
➢ Micropores

- **(<10 µm)**
- **Inside aggregates**
- **Bacteria and Fungi**

- **Linn and Doran, 1984**

Soil Architecture – Soil Aggregates Food and Habitat





Glomalin on Water Stable Aggregates

- **WSA**
  - **Ag soils**
    - **Conventional - 10-25%**
    - **No-till – 25-50%**
    - **Range – 80-100%**
  - **Secondary biomolecules**

Brown Revolution

- **To cultivate soil organisms, they need:**
  - **Food – residue, roots, exudates**
    - Diverse crop rotation
    - Consistent source from continuous cover provided by perennials, cover crops, or long-season crops
  - **Habitat**
    - Stable aggregates that are not destroyed by tillage

To be a successful farmer one must first know the nature of the soil.
- Xenophon, Oeconomicus, 400 B.C.

Thank You!

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