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Understanding How Carbon Impacts Soils and Crops

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Carbon is like Water and Oxygen, without it there is no life!

Outline

- Role of carbon in biological systems
- Process of capturing carbon
- Carbon as part of agroecology and farming systems

Carbon in Biological systems

1

Almost 20% of the weight of an organism is carbon

2

Foundation of all macromolecules, e.g., proteins, lipids, nucleic acids, carbohydrates

3

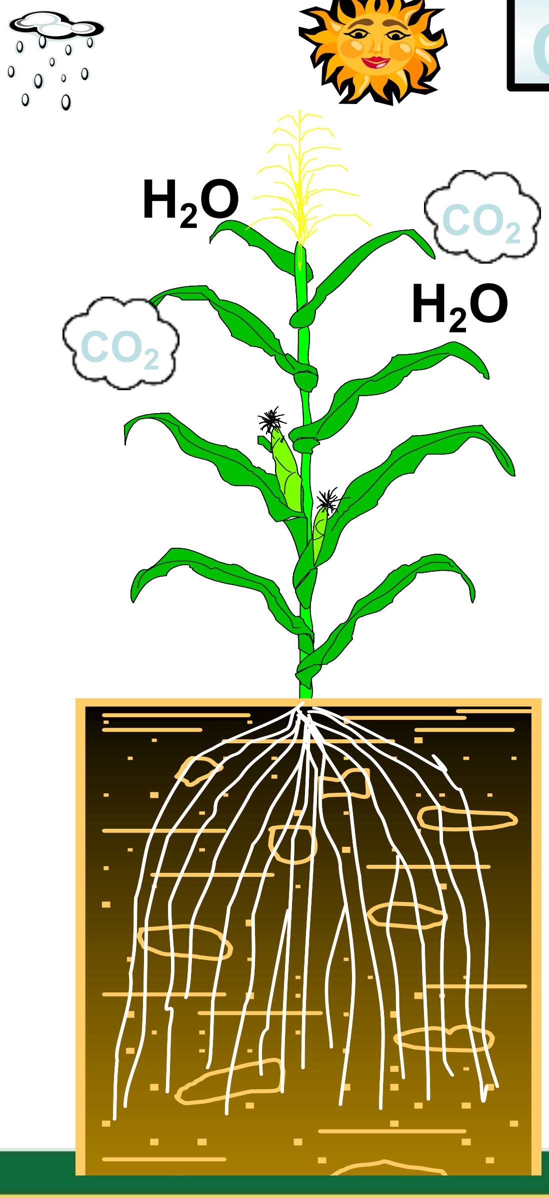
Ability to bond with different elements as part of the life

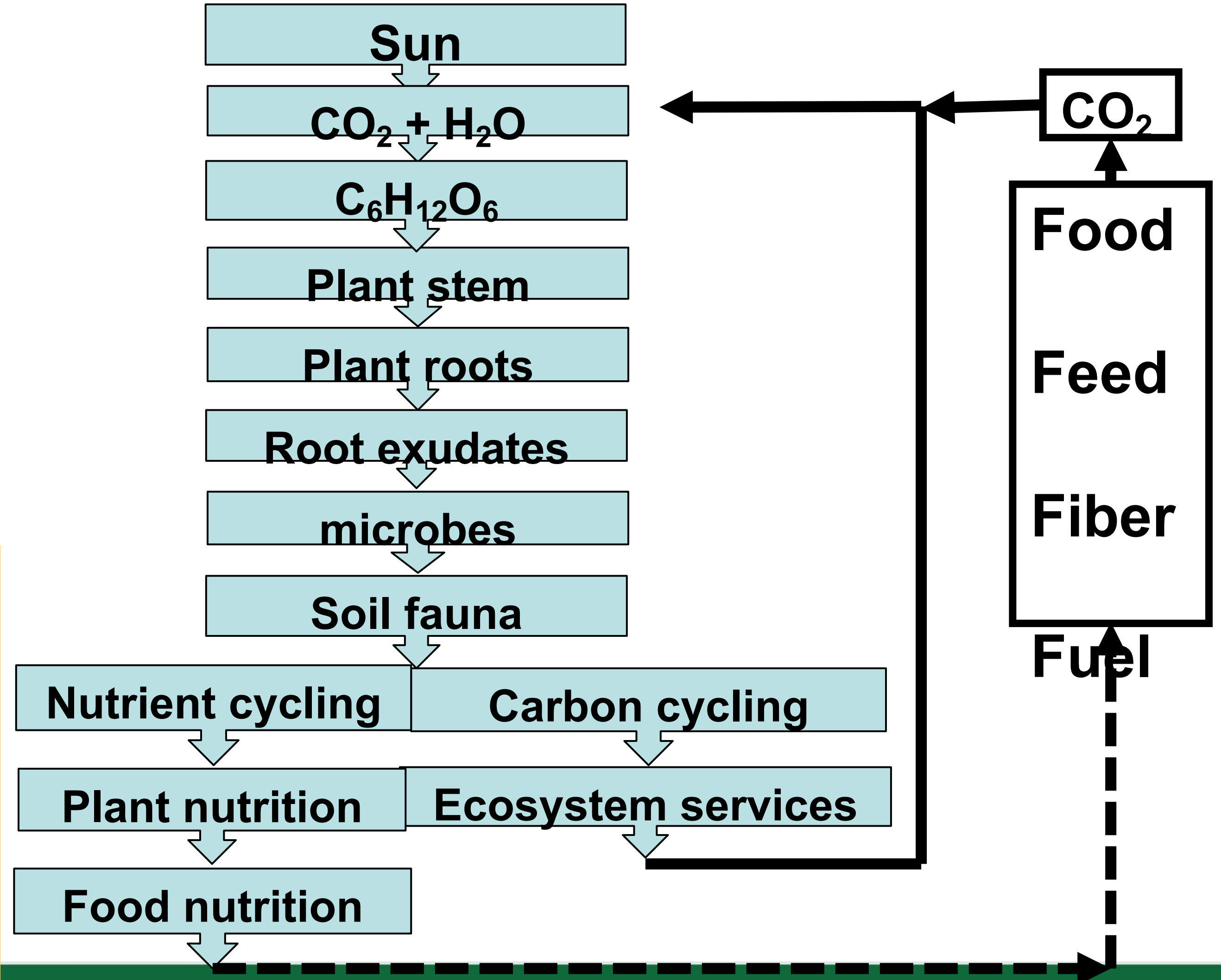
Carbon in Soil

- Carbon based materials are the “glue” that form aggregates
- Carbon is the energy source for soil microbial activity
- Carbon is the foundation of soil formation

Process of Capturing Carbon

Carbon energy flow path





Sun

$CO_2 + H_2O$

$C_6H_{12}O_6$

Plant stem

Plant roots

Root exudates

microbes

Soil fauna

Nutrient cycling

Carbon cycling

Plant nutrition

Ecosystem services

Food nutrition

CO_2

Food

Feed

Fiber

Fuel

Source: A. Gunina, Y. Kuzyakov / Soil Biology & Biochemistry 90 (2015)

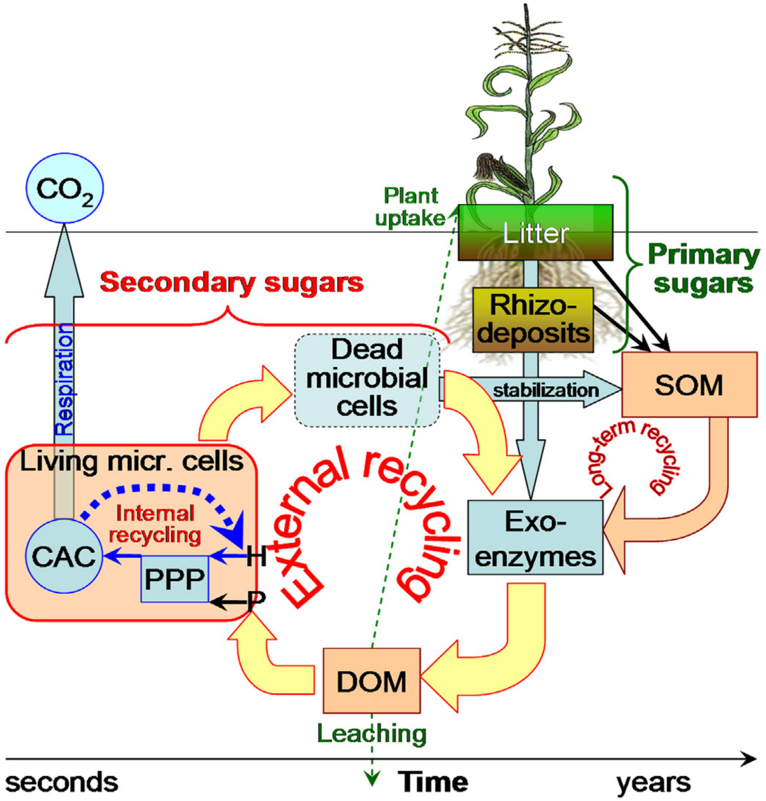


Fig. 6. Fate of sugars in soil. Primary (plant derived) and secondary (microbially derived) inputs of sugars are presented. The importance of three recycling cycles is underlined: internal recycling within microbial cells (in blue, the rates are within seconds to minutes), short-term external recycling (in red, the rates are within weeks to months) and long-term external recycling (in braun, the rates are within months to years and decades). SOM: soil organic matter, DOM: dissolved organic carbon, PPP: pentose phosphate pathway, CAC: citric acid cycle, H: hexoses, P: pentoses. Note that the size of the boxes does not correspond to the amount of sugar C in the pools. However, we tried to reflect the intensity of fluxes by the size of the arrows. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Root Exudates

- 15-40% of photosynthetically fixed C is exuded from the roots
- Glucose is the most abundant of root exudates (40-50%) followed by fructose (23%), saccharose (23%) and ribose (8%)
- Estimated that 64-86% of C from roots goes to CO_2, and 2-5% is in SOM

Sugar and Soil Organic Matter

Source: A. Gunina, Y. Kuzyakov / Soil Biology & Biochemistry 90 (2015) 87e100

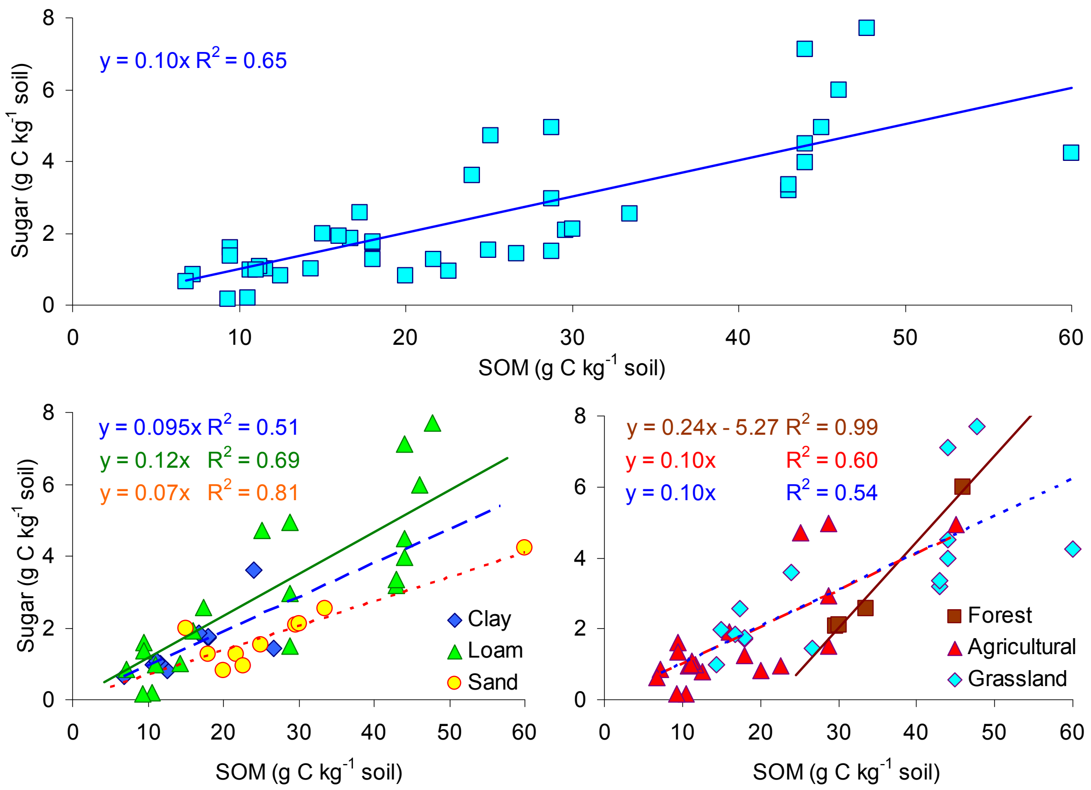


Fig. 2. Total sugar C content depending on: SOM (top), soil texture (bottom left), plant functional types (bottom right). Left and right bottom graphs are created with the same data, but left graph accounts only soil textures and right graph accounts only plant functional types. All regression lines are significant at least by $p < 0.05$. Because the intercepts in the most regression lines were not significantly different from 0, the intercept were fixed as 0 (except for forest). (See references in Supplementary).

Fate of Sugars in the Soil

Aggregate formation (natural glue)

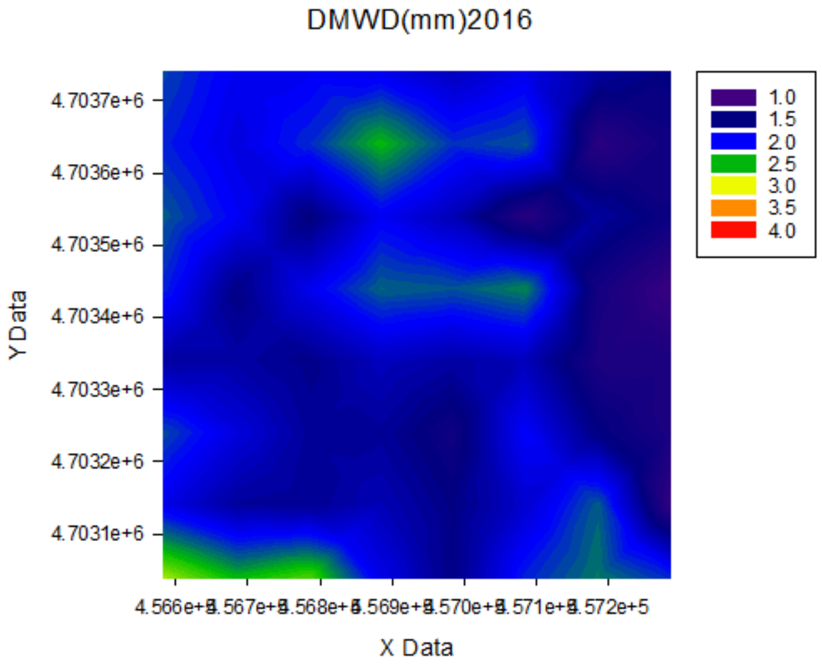
- Monomers- short-term
- Polysaccharides – long-term (clay particles)
- Glucoproteins – bind mineral and organic particles to soil aggregates

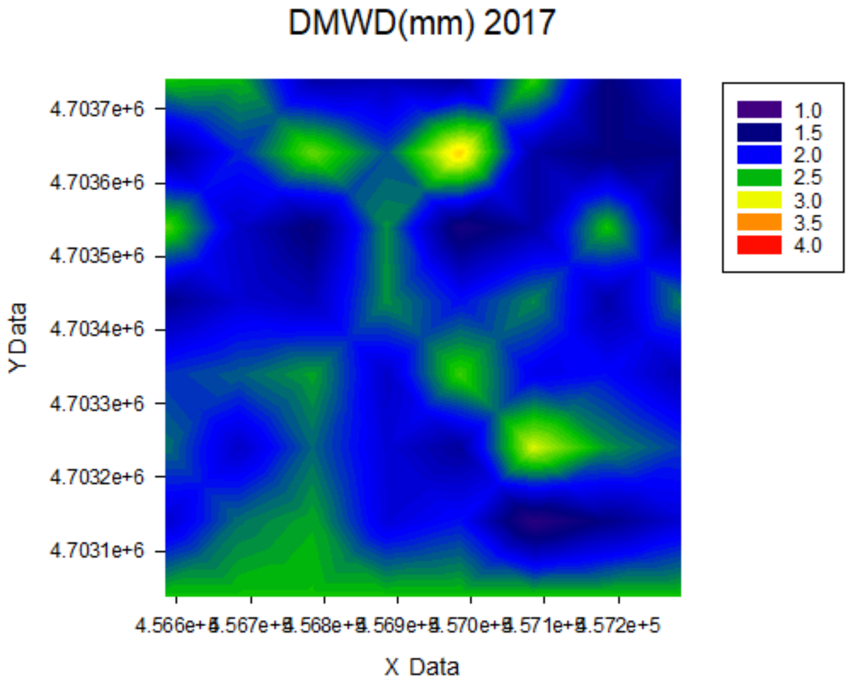
C increases (sequestration)

Maintenance of microbial activity and function

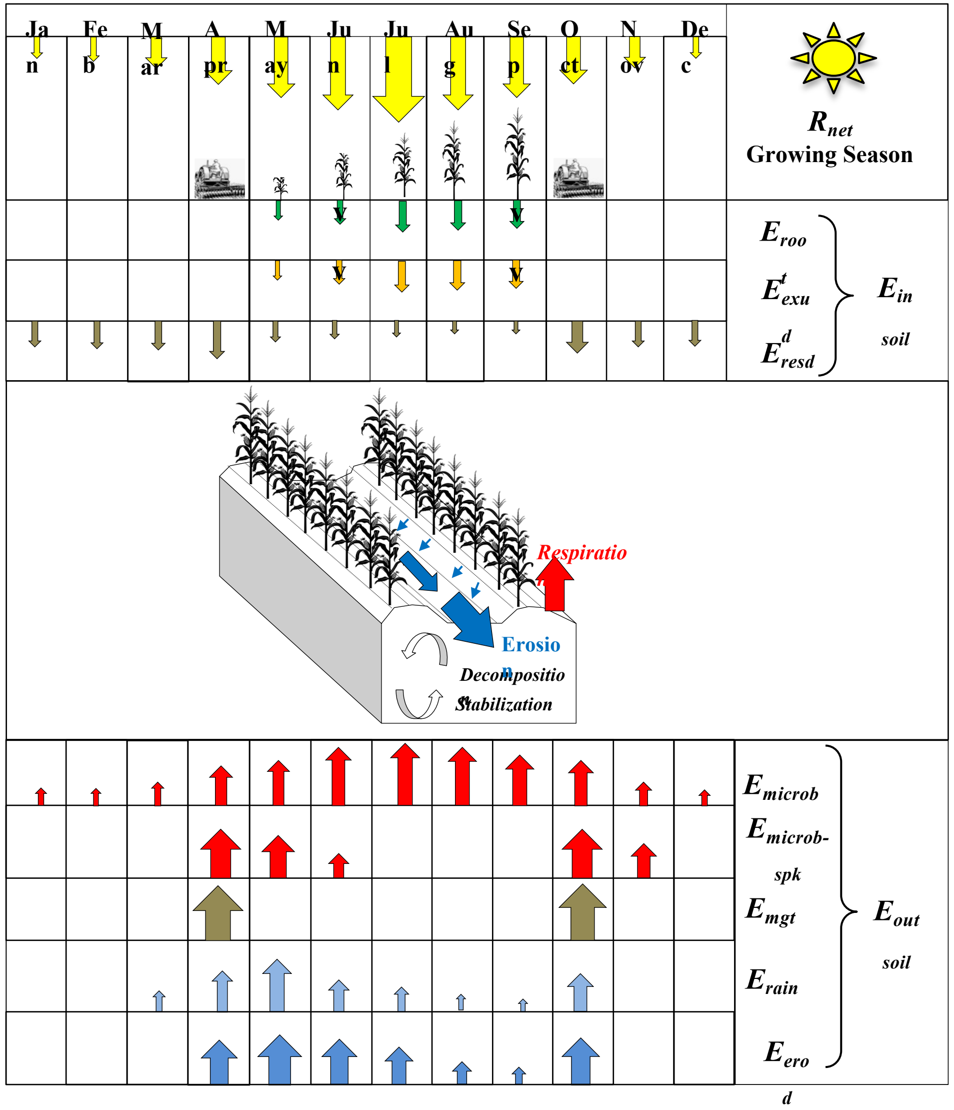
Soils Change Rapidly

- Transition of a field from conventional tillage to no-till with a cover crop showed a rapid change in aggregates and microbial biomass
- The conversion occurred in the fall of 2016 and within one year, there was a doubling of the microbial biomass in the upper soil surface(0-6 in)


DMWD(mm)2016

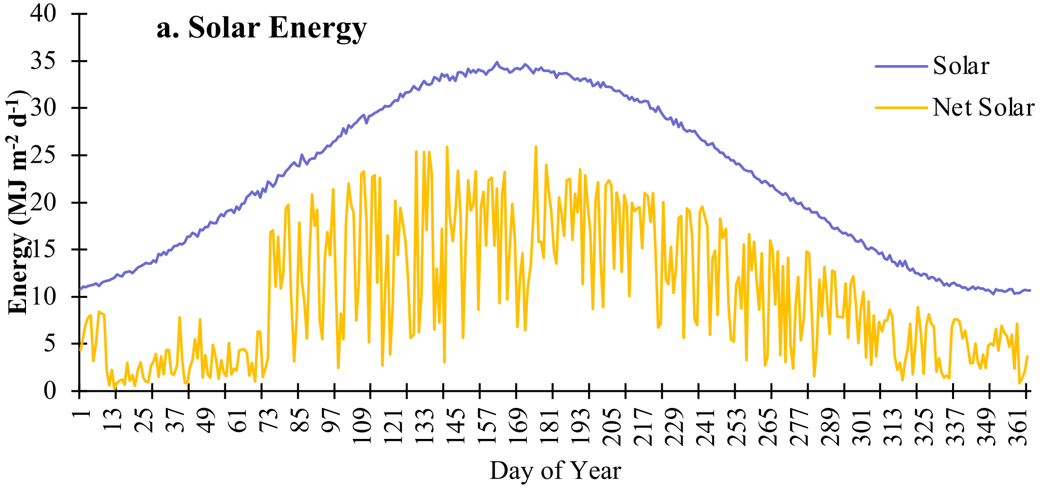

DMWD(mm) 2017

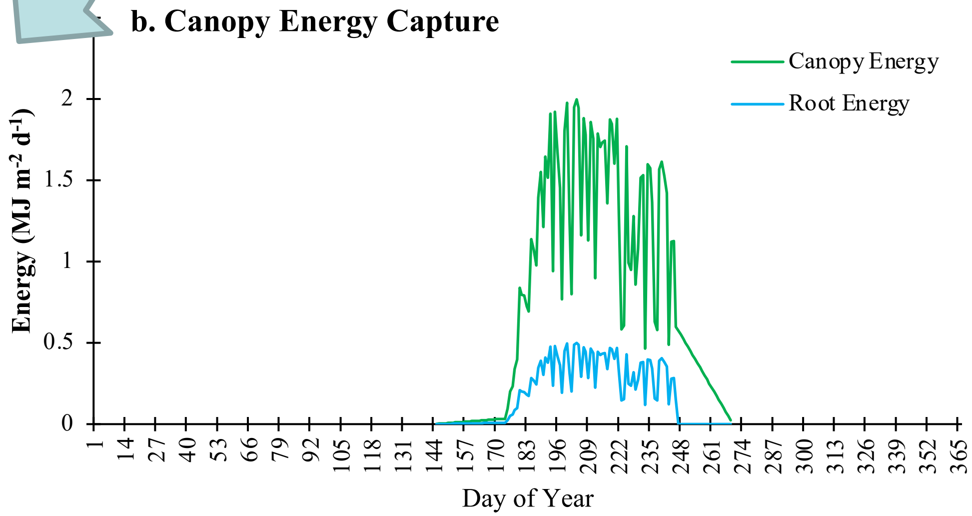
Seasonal input of Energy into a field



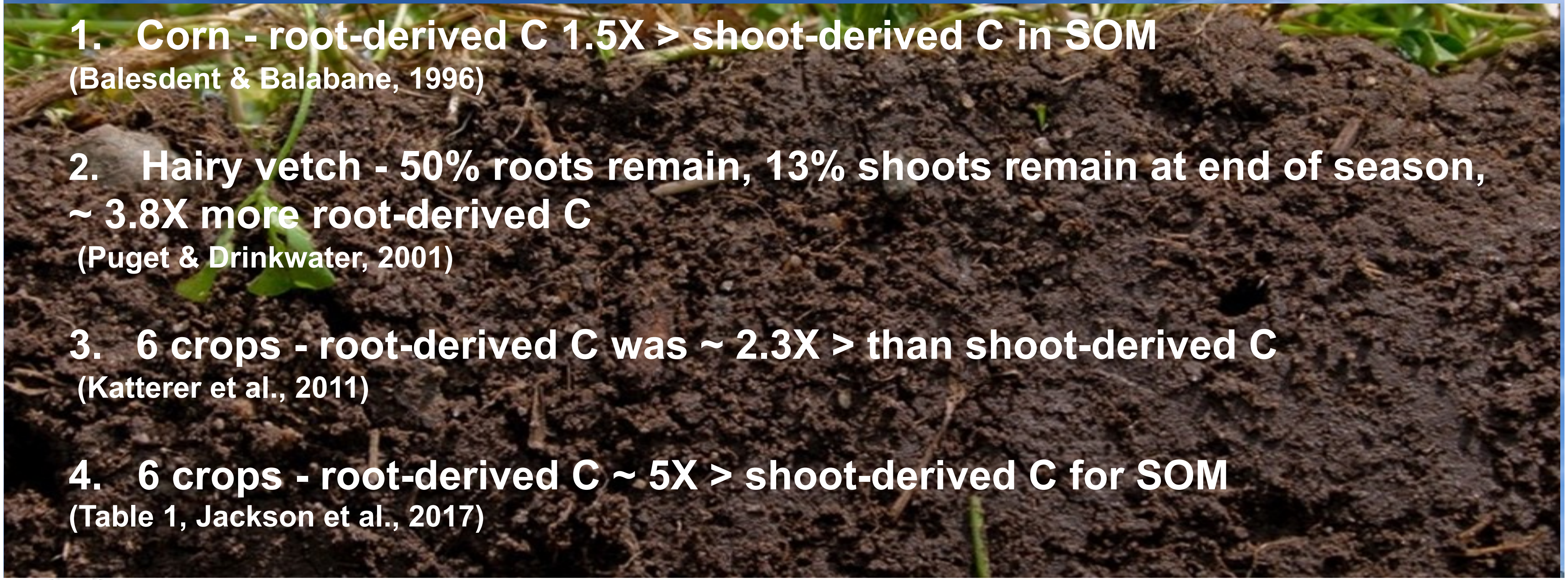
Example of Energy Inputs

1 MJ = 239000 calories





Soil Carbon = "Living Roots" + "Living Soil"



1. Corn - root-derived C 1.5X > shoot-derived C in SOM
(Balesdent & Balabane, 1996)

2. Hairy vetch - 50% roots remain, 13% shoots remain at end of season, ~ 3.8X more root-derived C
(Puget & Drinkwater, 2001)

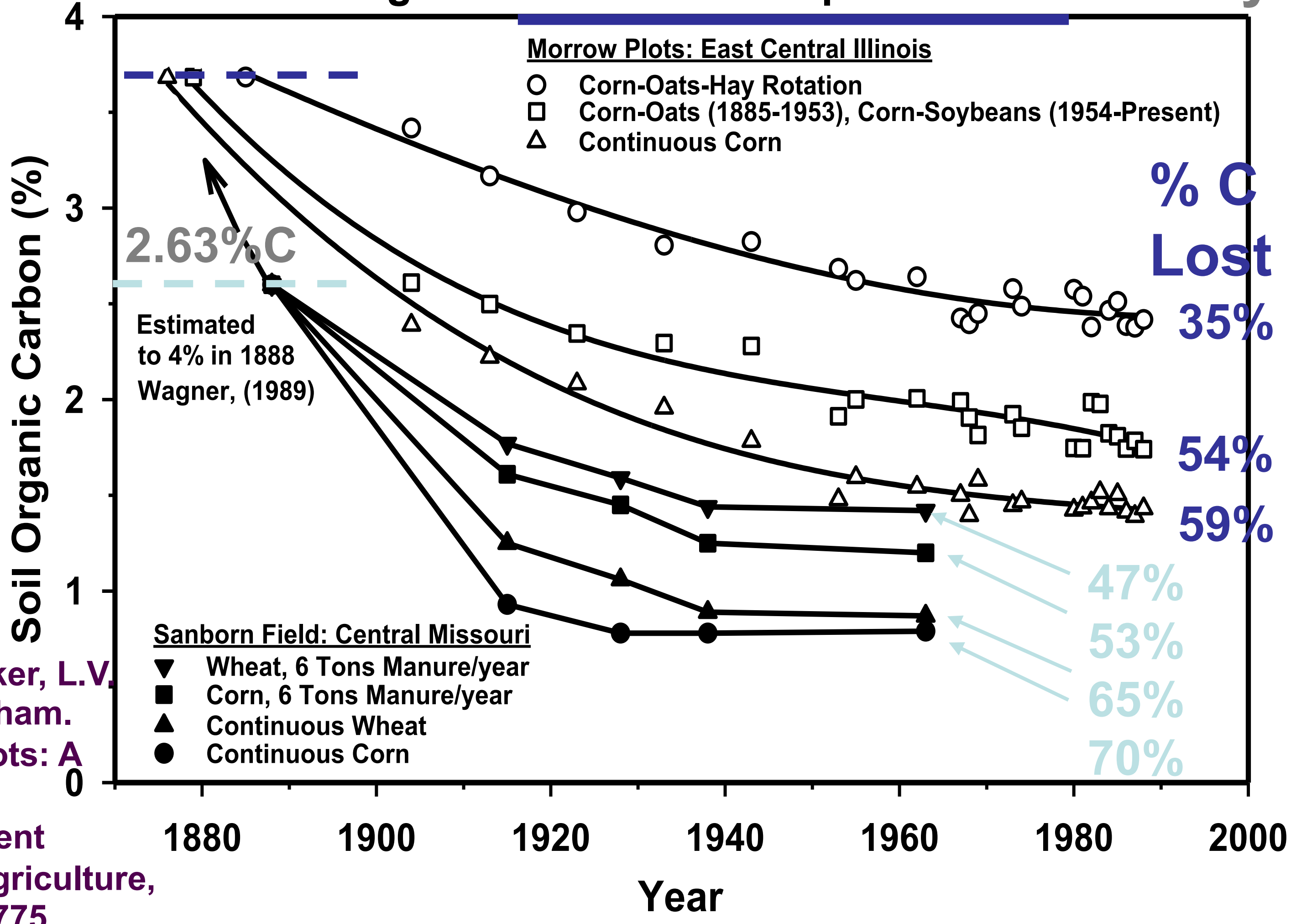
3. 6 crops - root-derived C was ~ 2.3X > than shoot-derived C
(Katterer et al., 2011)

4. 6 crops - root-derived C ~ 5X > shoot-derived C for SOM
(Table 1, Jackson et al., 2017)

Current Conventional Tillage Cropping Systems in the Midwest

- Losing carbon at the rate of 1000 lbs C/acre/year (8000 lbs water/acre/year)
- If you farm 40 years, lost 20 tons of C
- What we consider as proper management is slowly degrading our soils
- We have lost our ability to infiltrate, store, and make water available
- Created yield variation across fields because of limited soil water holding capacity

Long Term Effects of Crop Rotations -110 years



Odell, R.T., W.M. Walker, L.V. Boone, and M.G. Oldham. 1982. The Morrow Plots: A century of learning. Agricultural Experiment Station, College of Agriculture, Univ. of Illinois Bull. 775, Urbana-Champaign, IL.

Brown, J.R. 1993. Sanborn Field: A capsule of scientific agricultural history in central Missouri. Missouri Agric. Experiment Station, Columbia, MO.

Removed organic matter through tillage

Cropping practices that limit return of carbon to the soil

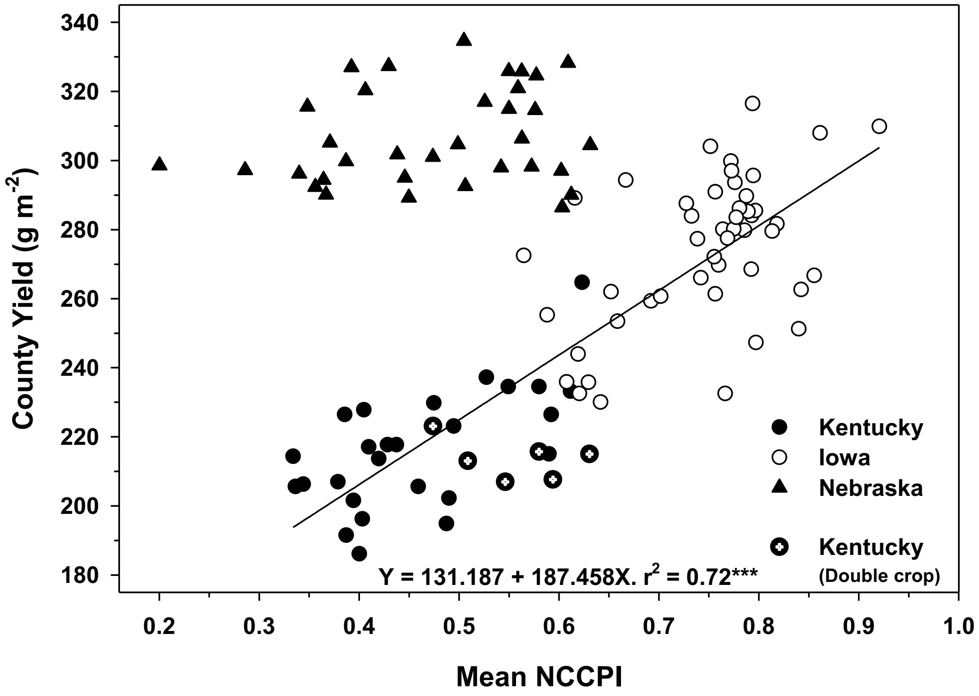
Reduced the functionality of soils and increased reliance on external inputs

Increased erosion rates and increased soil degradation

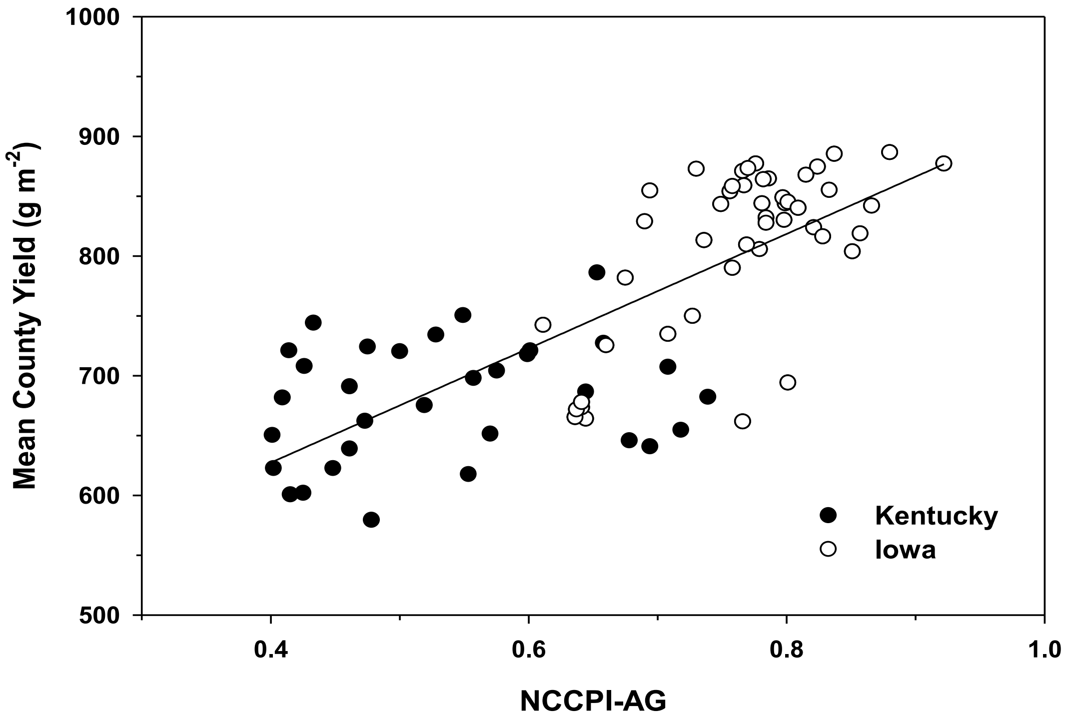
Agricultural systems have changed our soils and reduced our ability to support ecosystem services

Good Soils = Good Yields

Soybean

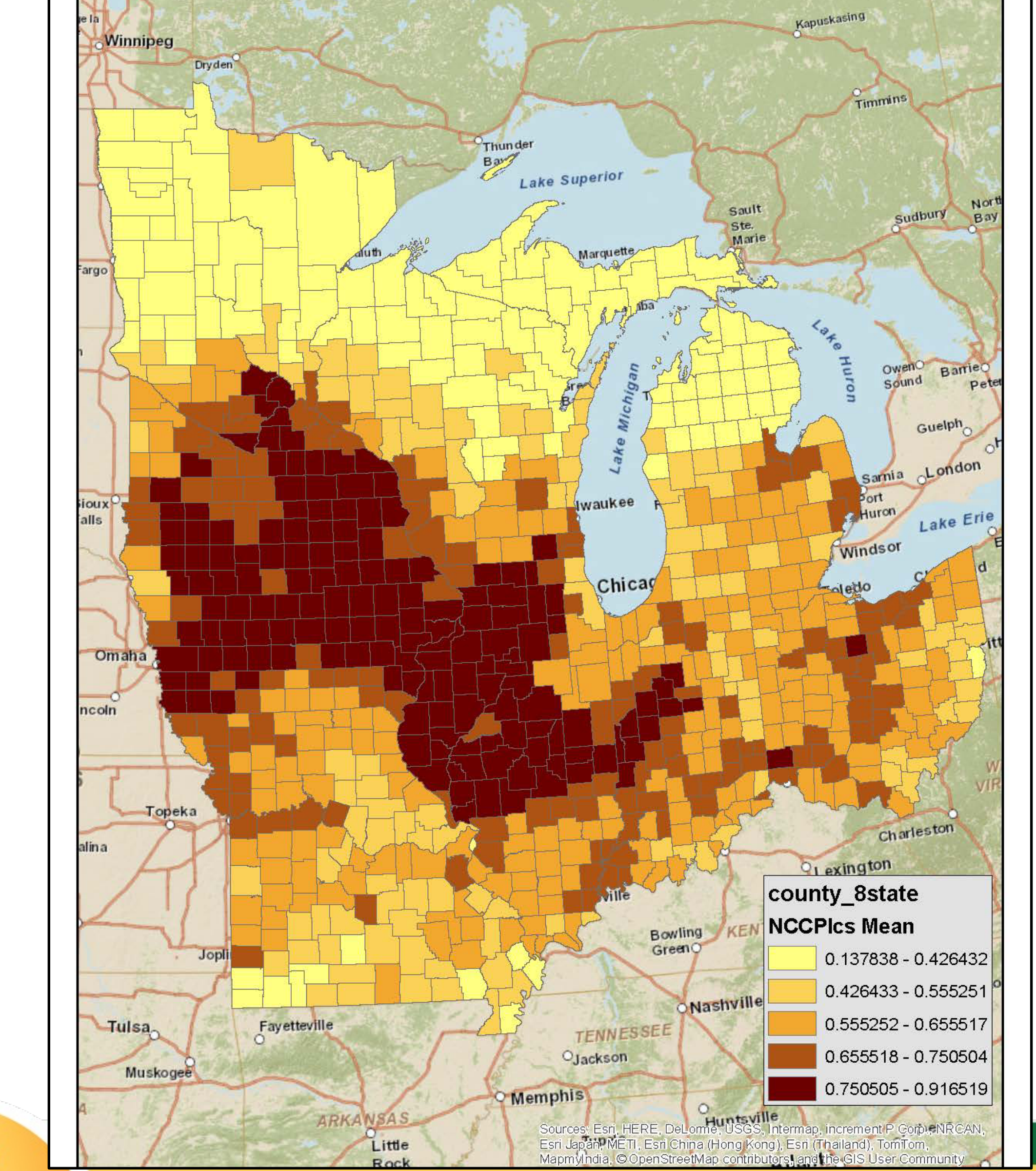


Corn



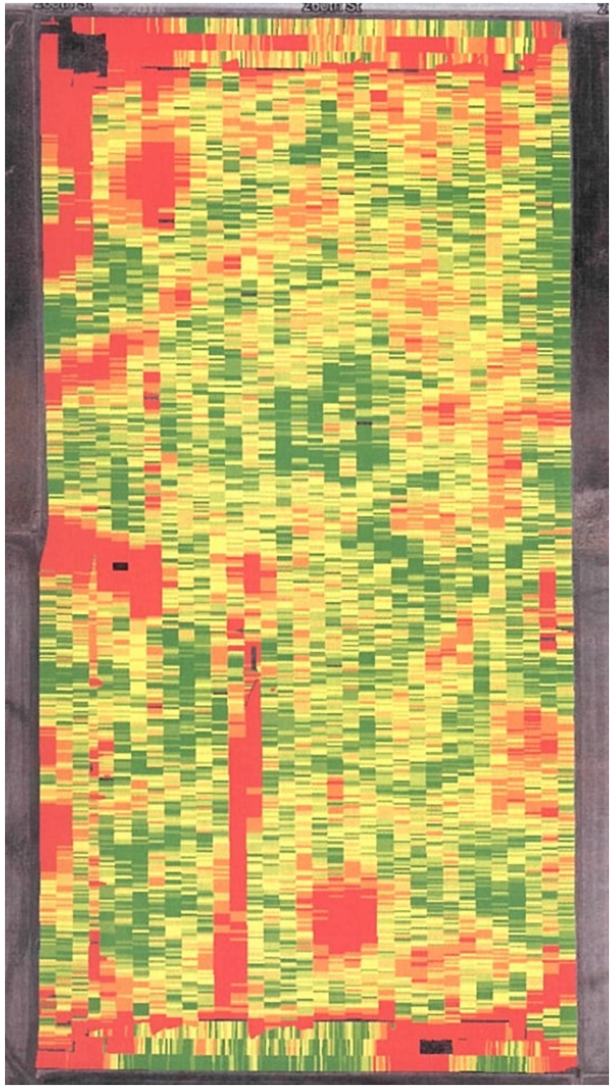
Egli and Hatfield, Agronomy Journal, 2014a and 2014b

Variation in National Crop and Commodity Production Index (NCCPI) across the Midwest



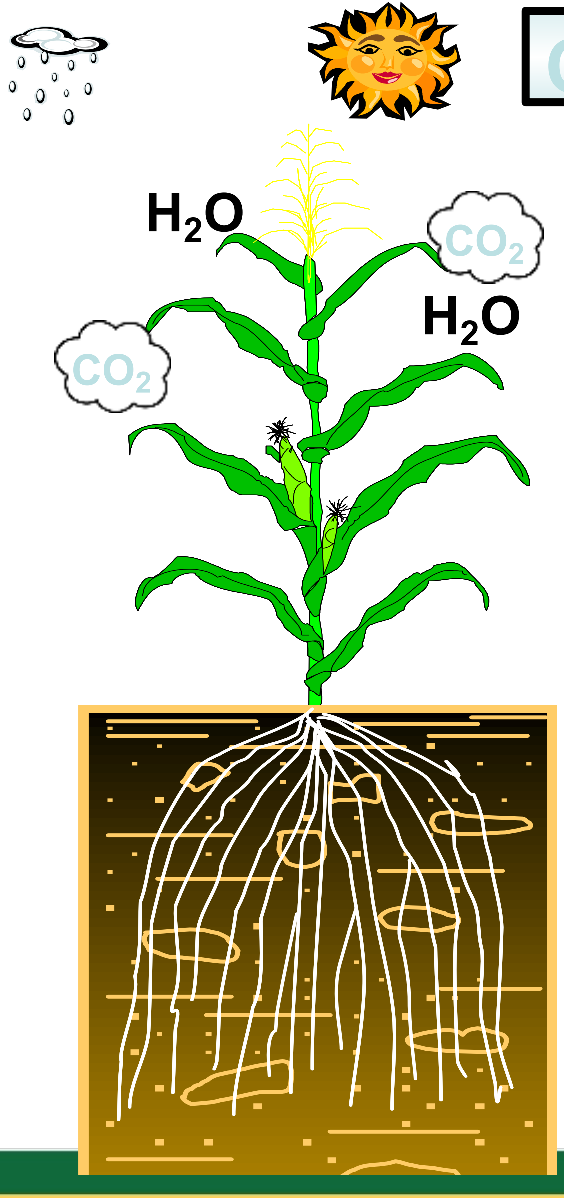
Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

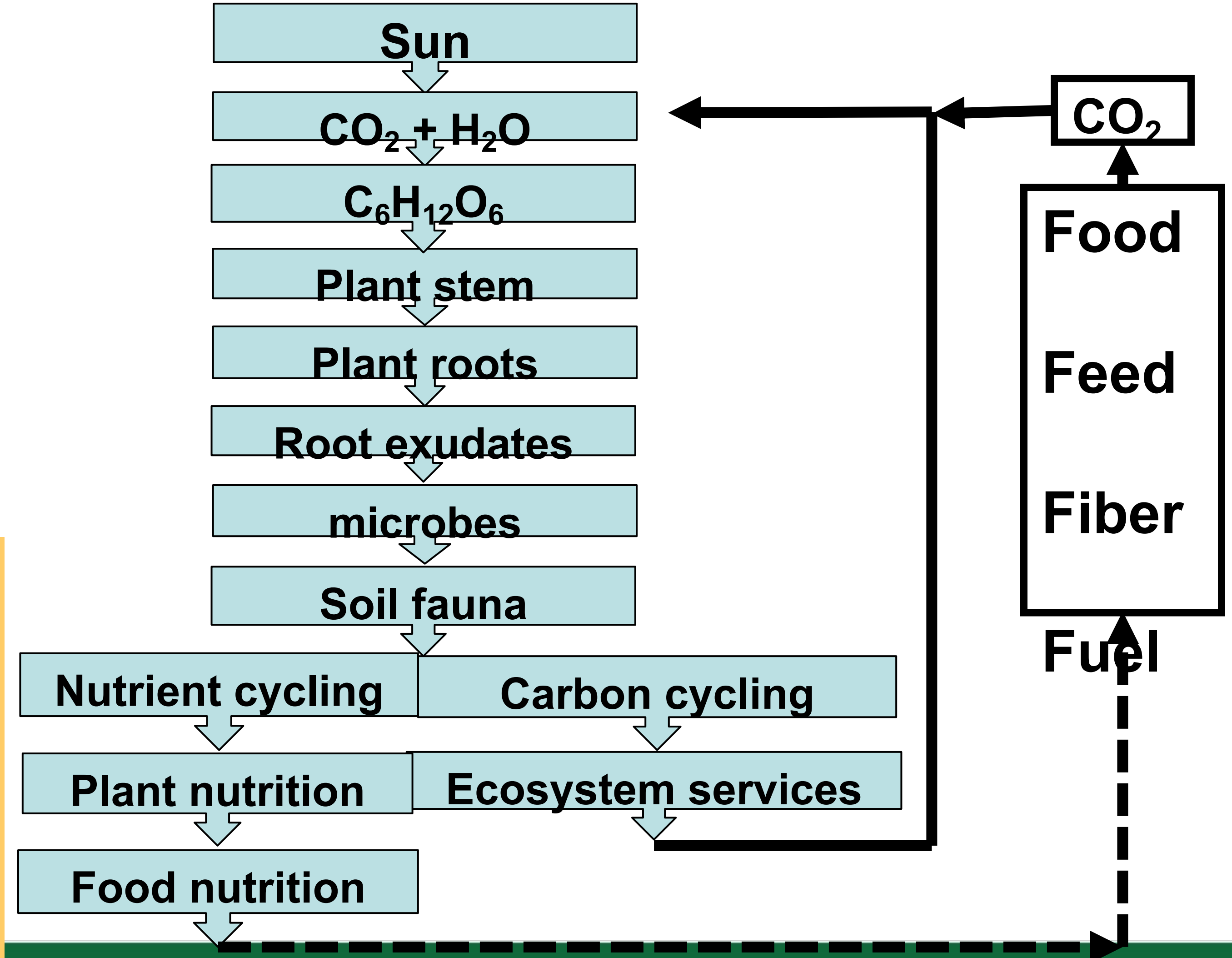
Corn Yield
Field Variation



Yield (Dry)
(bu/ac)
🟩 249.14 - 389.20 (10.79 ac)
🟩 234.64 - 249.14 (11.35 ac)
🟨 223.29 - 234.64 (11.46 ac)
🟨 211.72 - 223.29 (11.38 ac)
🟧 196.84 - 211.72 (11.21 ac)
🟧 167.61 - 196.84 (10.80 ac)
🟥 10.09 - 167.61 (10.04 ac)

Carbon energy flow path





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CO_2

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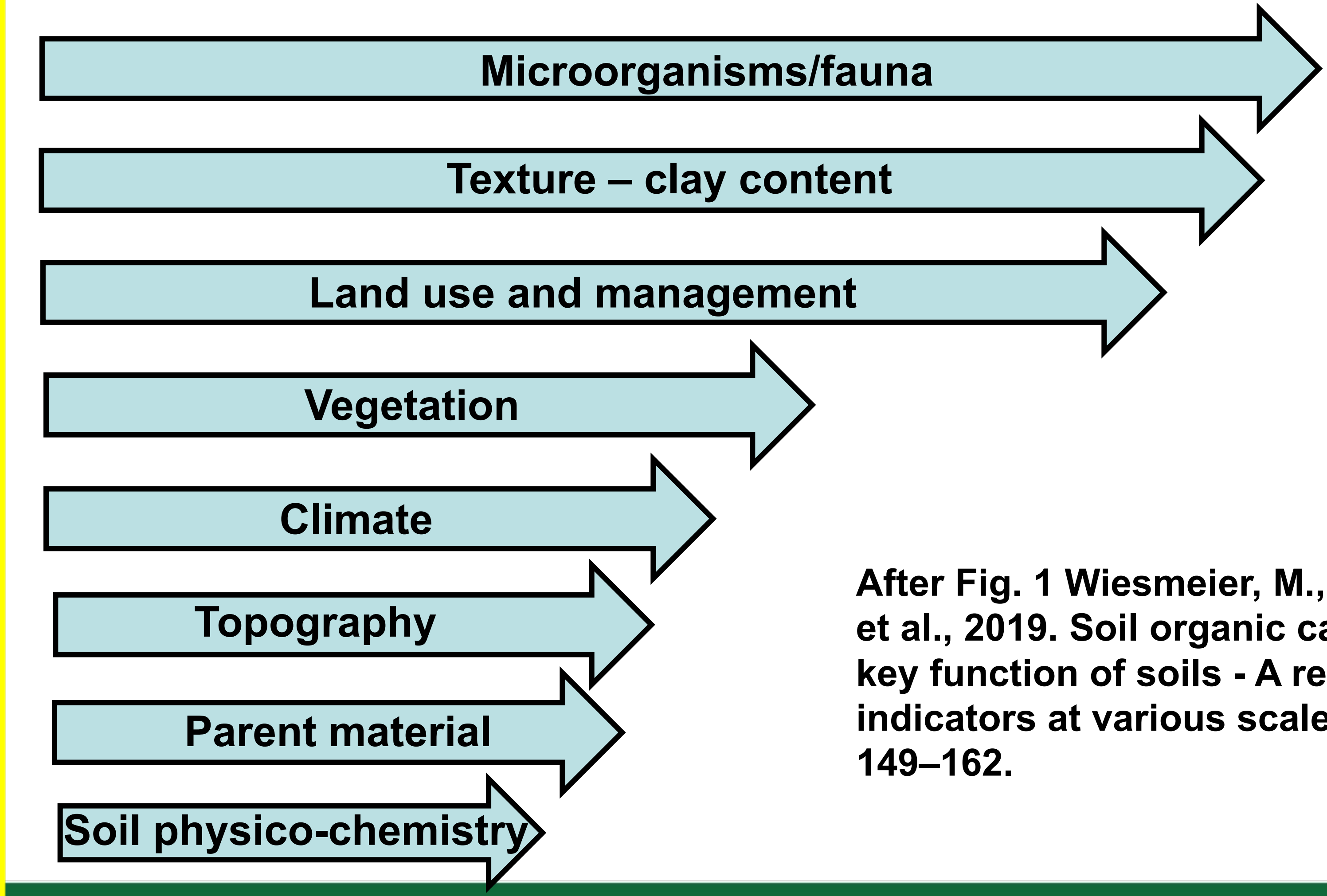
Fuel

Relative ranking of SOC storage drivers

Drivers of SOC storage



After Fig. 1 Wiesmeier, M., Urbanski, L., Hobley, et al., 2019. Soil organic carbon storage as a key function of soils - A review of drivers and indicators at various scales. Geoderma, 333: 149–162.

Indicators of Soil Change

- Microbial activity
- Organic matter changes
- Nutrient availability
- Aggregate stability
- Improved infiltration
- Water availability

Soil Aggradation Climb

Visible Outcomes

Improved Water Availabilty

Improved Soil Structure

Improved Nutrient Cycling

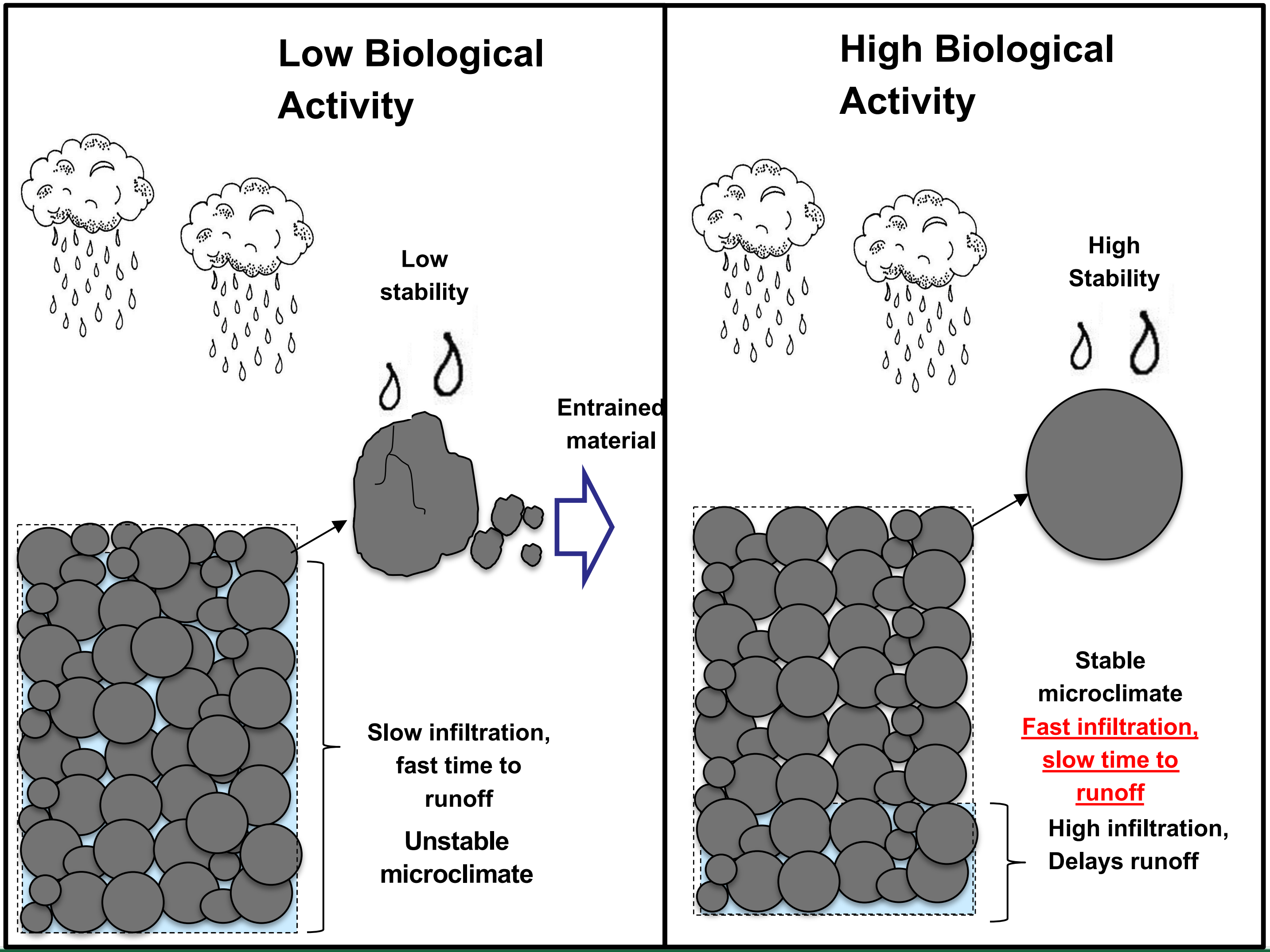
Organic Matter Turnover

Biological Activity

Invisible and dynamic process

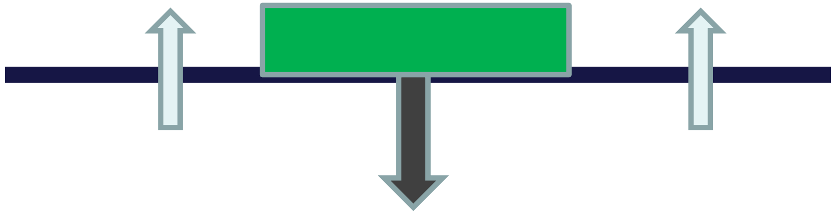
graphic 3.1

Assessing the Dynamics of the Upper Soil Layer Relative to Soil Management Practices

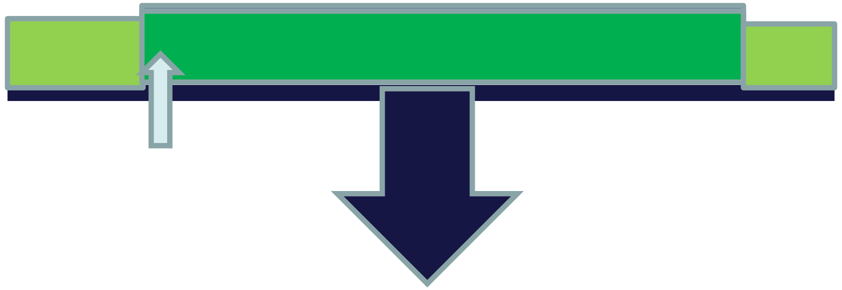


Role of different cropping systems

Limited time for input and losses due to tillage, losses equal the gains or exceed



Increased time for inputs into the soil volume with minimal loss due to soil disturbance



Estimate 25% of the available solar radiation in Ames, Iowa is in these shoulder periods

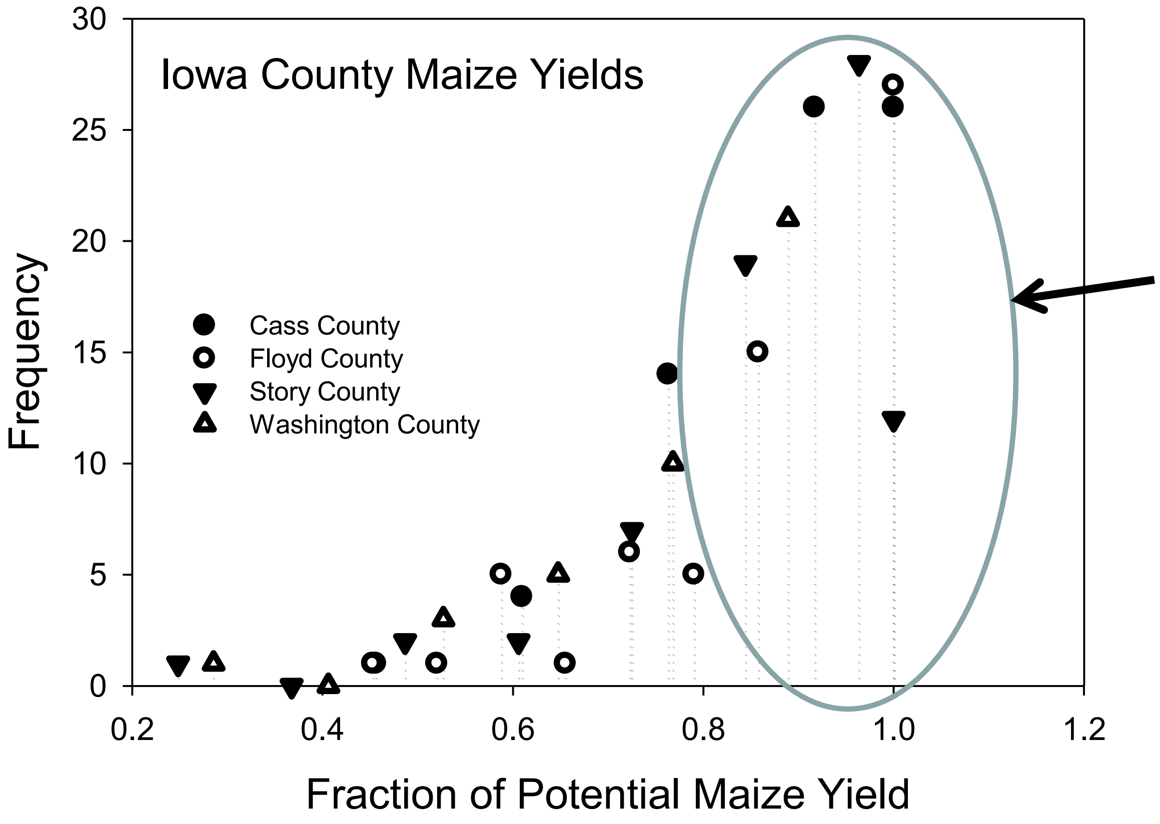
Continuous Cover and Soil Water

Attributes of soil health that impact water significantly are the focus on continual cover of the soil

Continual cover provides three advantages for soil water

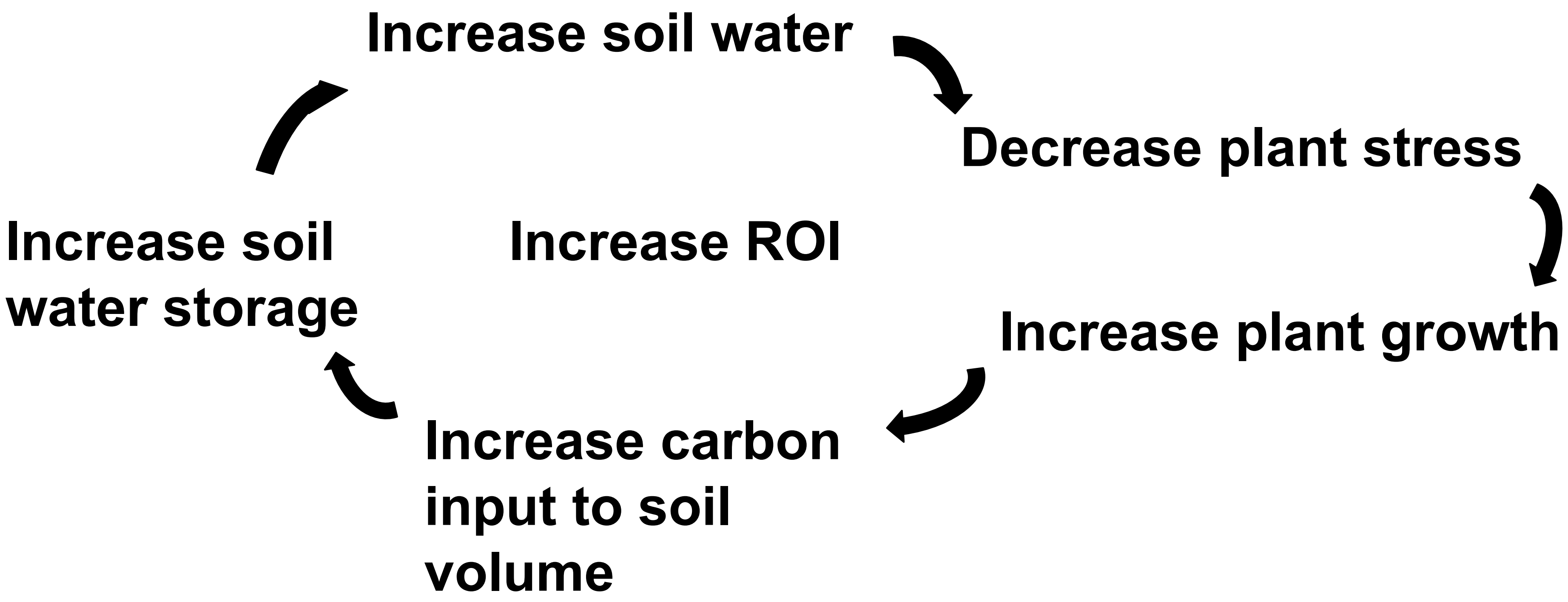
- First, protection against raindrop energy so soil aggregates are protected and infiltration rates are maintained
- Second, soil water evaporation is reduced so water is used by the plant for transpiration
- Third, plant roots are near the surface so take advantage of small rainfall events

Variation in Yields



20% of the yield loss occurs 80% of the time due to water availability

Soil Water and Soil Carbon



Increase soil water

Decrease plant stress

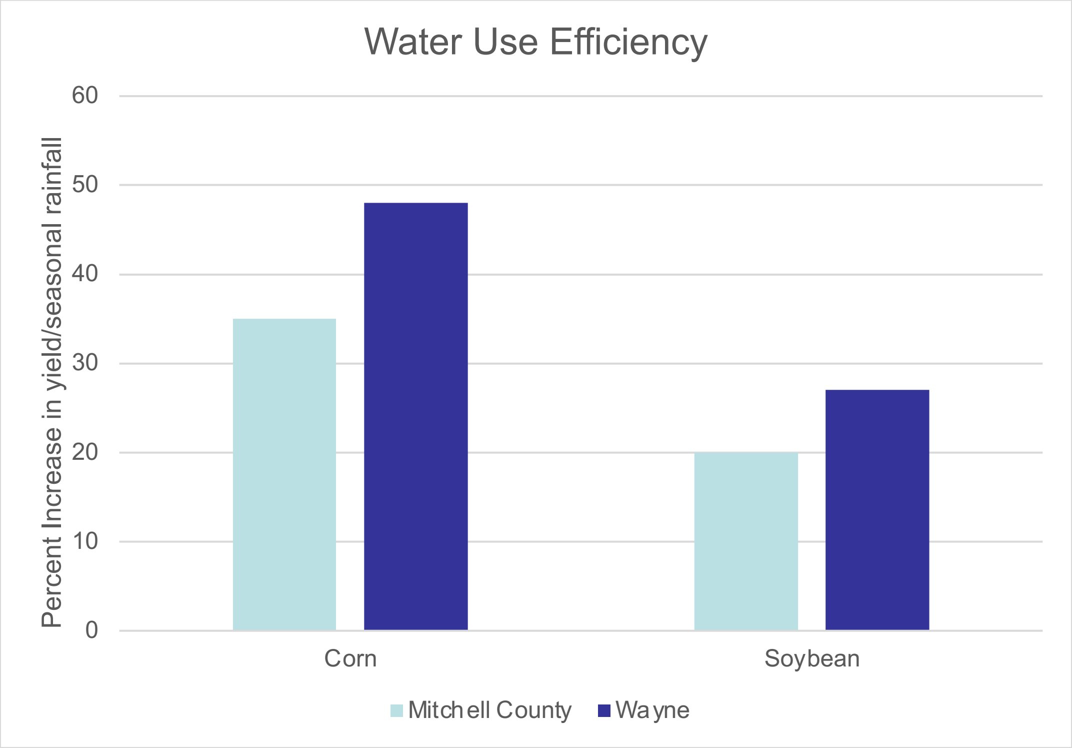
Increase plant growth

Increase carbon input to soil volume

Increase soil water storage

Increase ROI

Water Use Efficiency changes after 20 years of strip-till (Wayne Fredericks)



Yield stability among years, less variation among years, standard deviation in yields half of conventional tillage

Increased water use efficiency in terms of grain produced per unit of seasonal rainfall, increases in corn of nearly 50%

Broke the correlation between April-May rainfall and low yields, and July-August rainfall and high yields

What does this extra soil water mean?

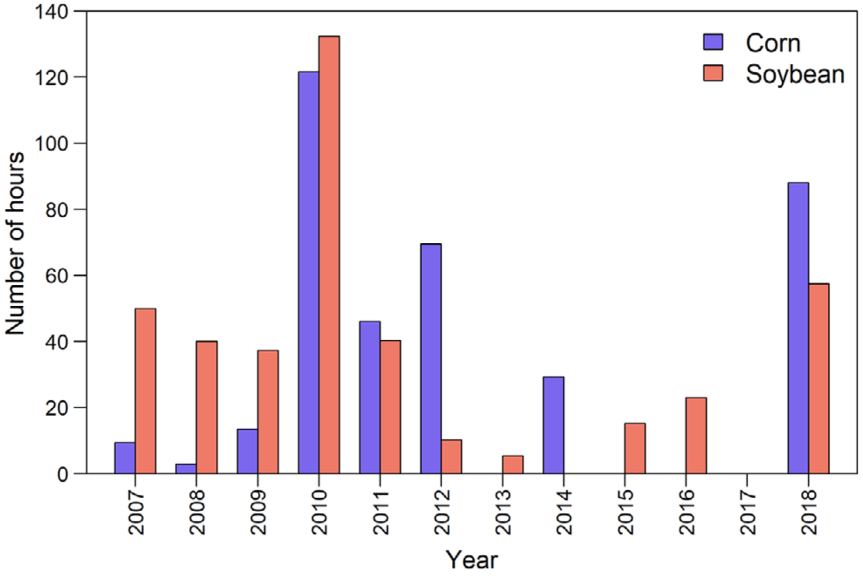
- Have water available to provide a supply between rain events
- Alleviates the stress that reduces yield
- Stabilizes grain yields among years, less variation
- Creates a climate-smart system of production

Managing soil water will become the major challenge to enhance productivity and increase profitability

Maintaining cover on the soil

- Reduces the temperature extremes in the upper soil surface
- Maximum temperatures 85F vs 120-130F for a bare soil
- Destroy the biological activity in the soil with high temperatures above 104F

Hours above 104F for corn and soybean crops at Ames, Iowa until complete canopy



Summary

- Increasing carbon storage in soil depends on
  - Reducing the intensity of tillage operation
  - Maintaining continuous soil cover
  - Continual supply of energy (carbon) into the soil
    - Crop diversity
    - Bio-based fertilizers

Challenges

- Understand and quantify the current state of your soils in terms of ROI (water, nutrients, inputs)
- Understand why variation is occurring within fields and a path toward improvement
- Adopt an approach of adaptive management and continuous improvement (implement, evaluate, tweak, evaluate, etc.)

Contact

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