Carbon: The Currency for Soil Health

PATH TOWARD INCREASING PRODUCTIVITY AND PROFITABILITY

Value of soil

Wherever the soil is wasted the people are wasted. A poor soil produces only a poor people – poor economically, poor spiritually and intellectually, poor physically.

George Washington Carver, 1938

What do we need most in Agricultural Systems?

Carbon

Water

Nutrients

Oxygen

CARBON IS LIKE WATER AND OXYGEN, WITHOUT IT THERE IS NO LIFE!

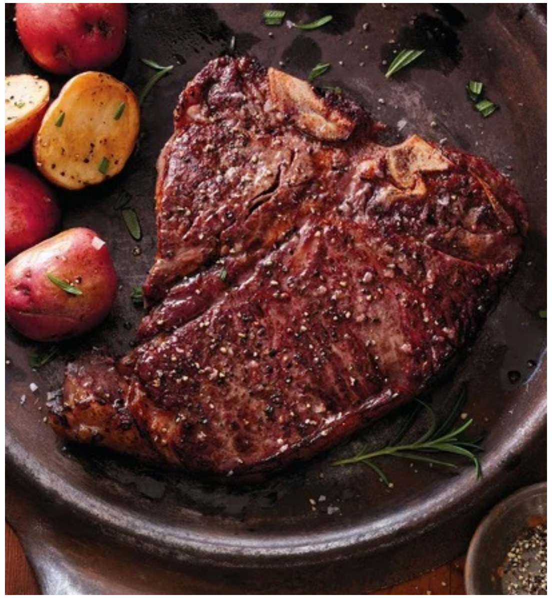
Carbon in Biological systems

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 is energy

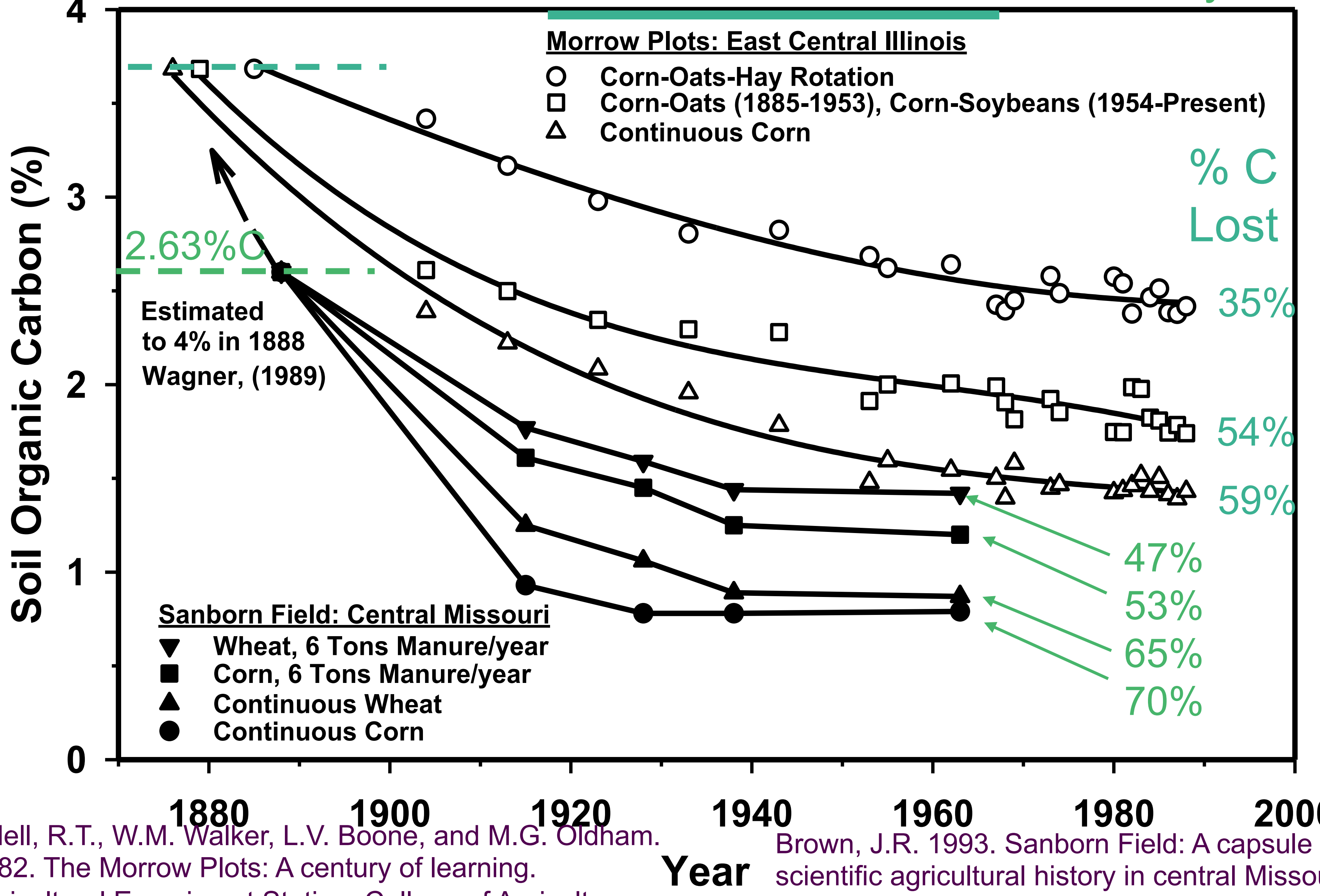
What do you eat if you want a quick burst of energy?

OR



If we want soils to change, we have to invest carbon into them

Long Term Effects of Crop Rotations-110 years

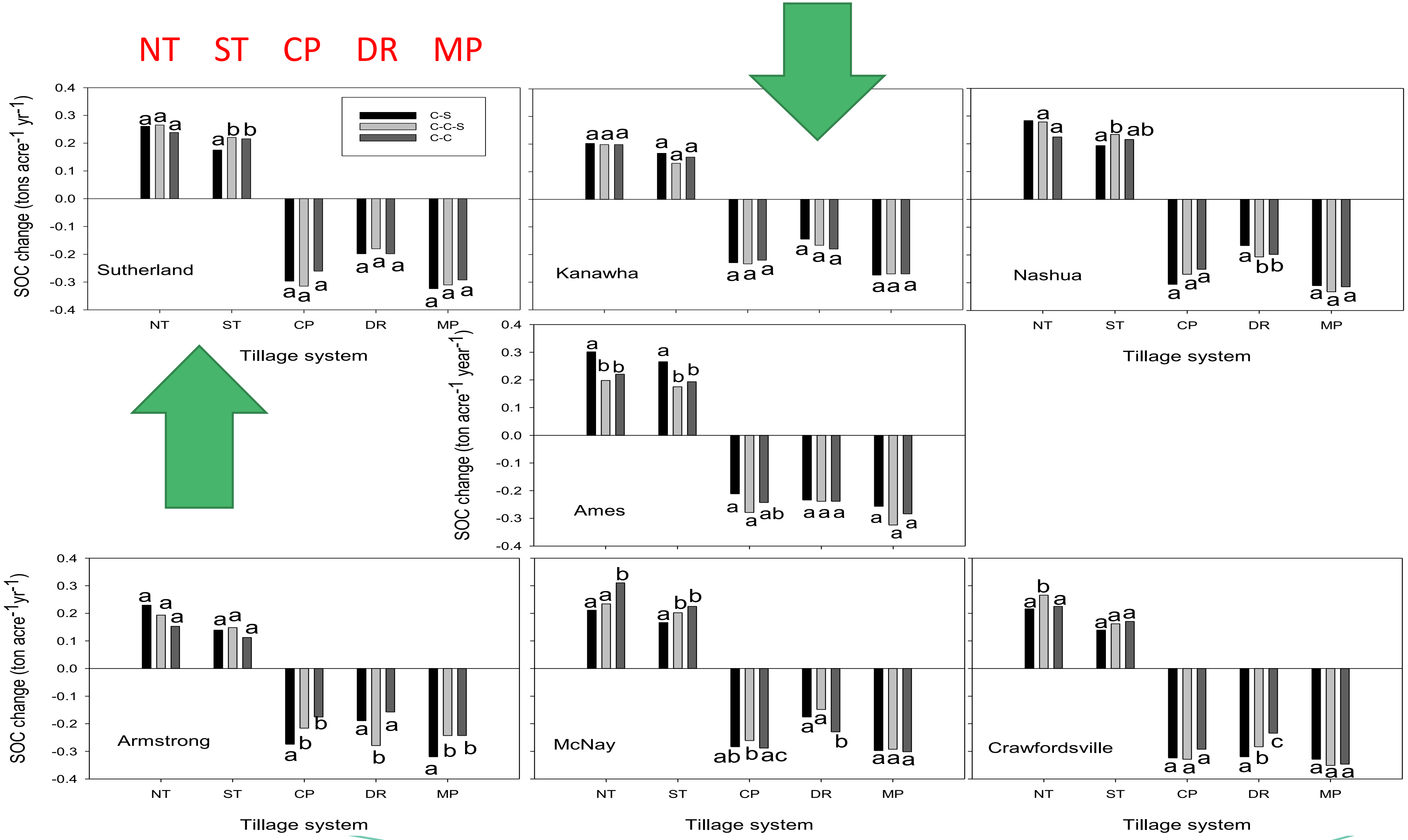


Odell, R.T., W.M. Walker, L.V. Boone, and M.G. Oldham. 1982. The Morrow Plots: A century of learning. Agricultural Experiment Station, College of Agriculture, Univ. of Illinois Bull. 775, Urbana-Champaign, IL.

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

TILLAGE AND CROP ROTATION EFFECTS ON SOIL CARBON IN THE TOP 0-24 INCHES OVER 12 YEARS AT ISU FARMS

Ave SOC gain=0.22 ton/acre/yr
.



Ave SOC loss=-0.25 ton/acre/yr.

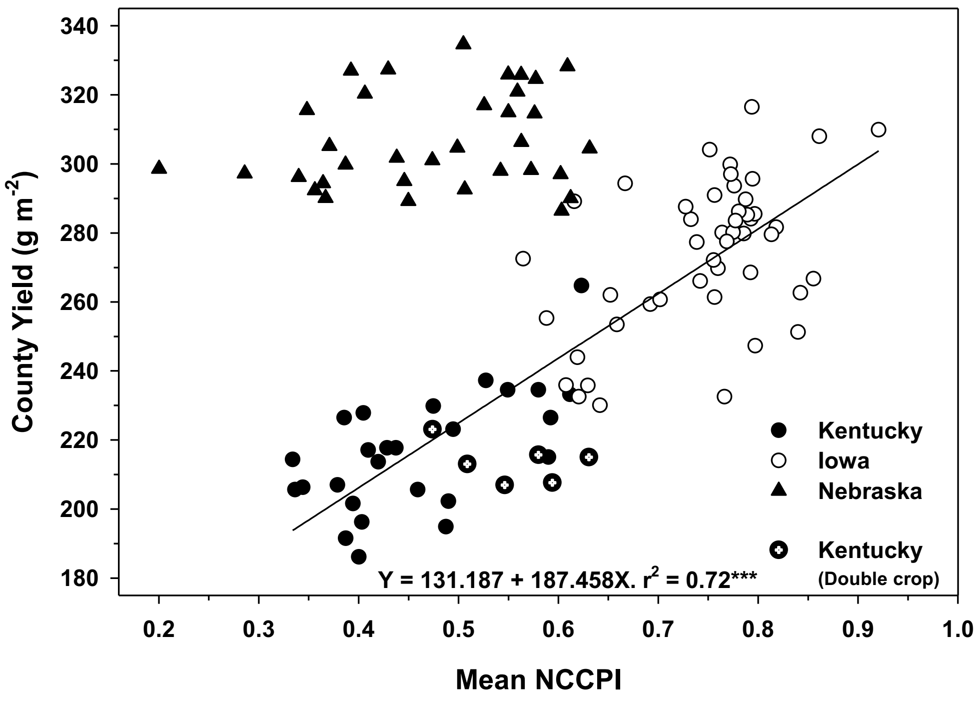
Ave SOC gain=0.19 ton/acre/yr.

Ave SOC loss=-0.27 ton/acre/yr.

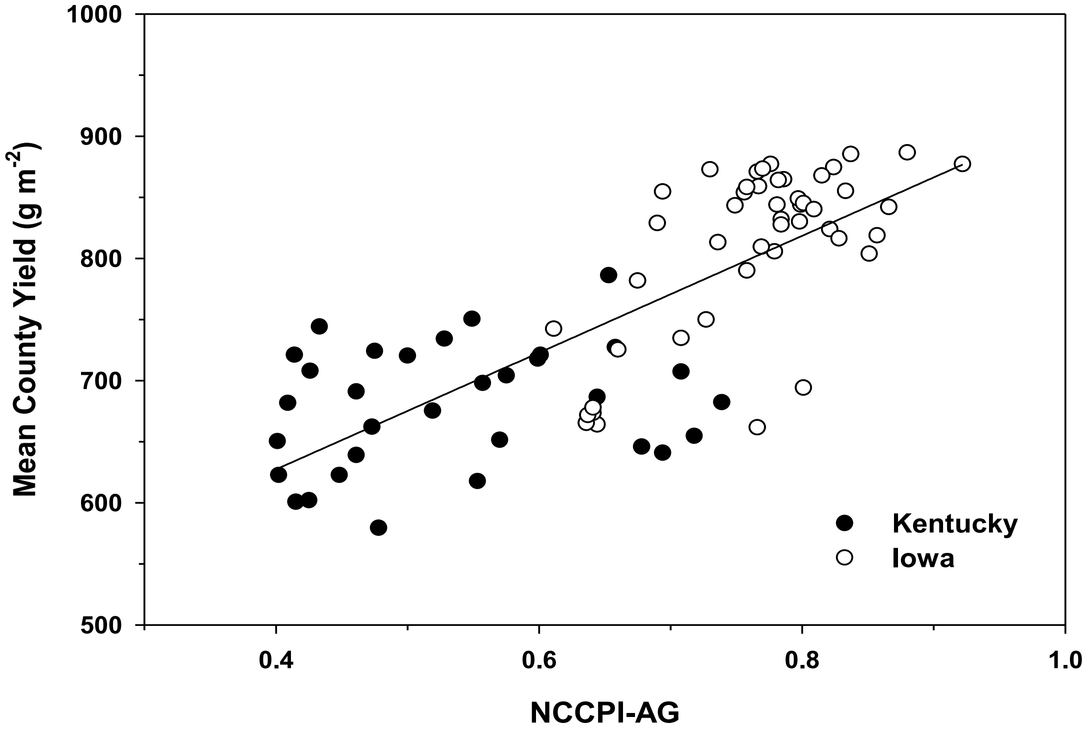
Al-Kaisi, 2020

GOOD SOILS = GOOD YIELDS

Soybean



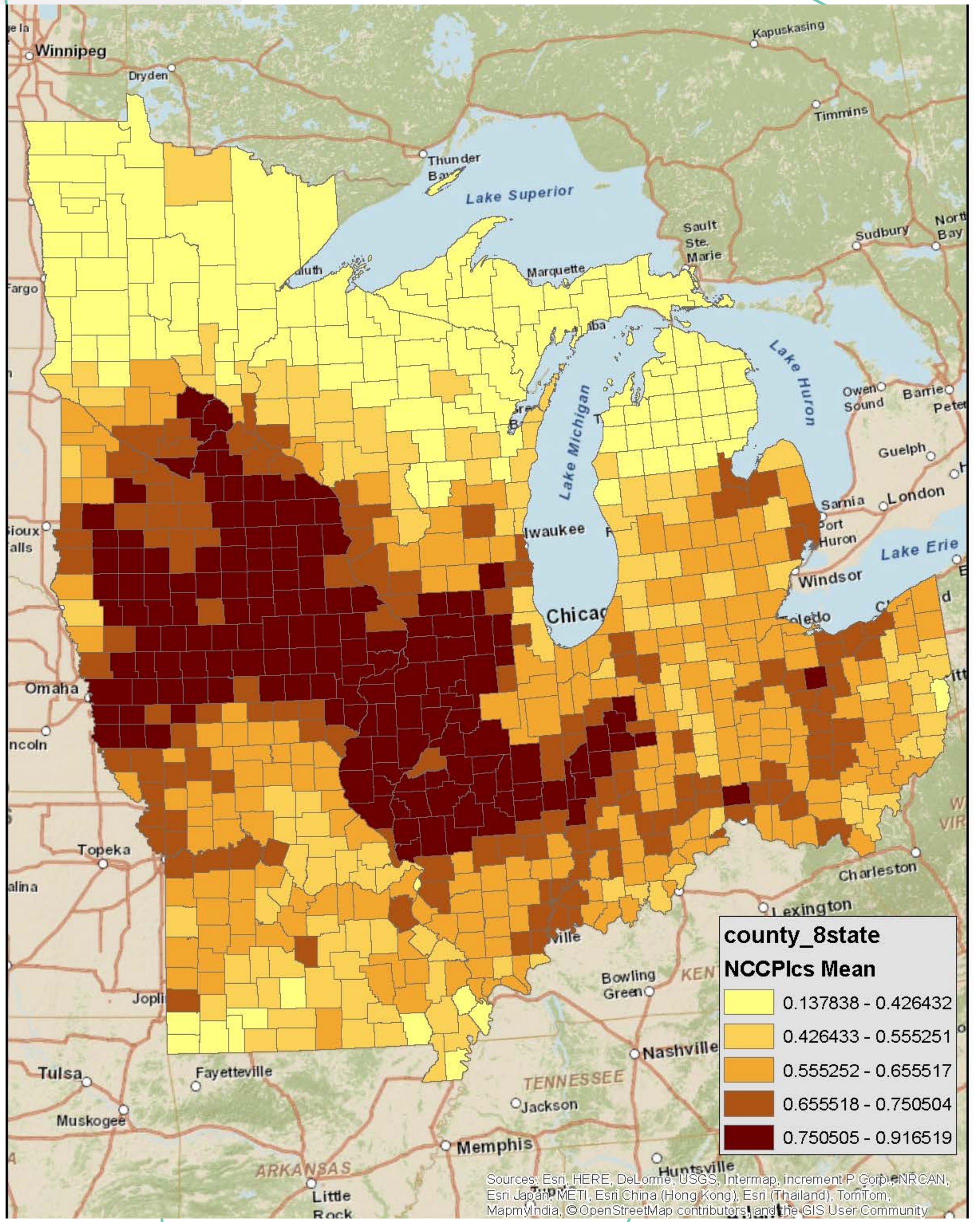
Maize



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

VARIATION IN NCCPI ACROSS THE CORN BELT

National Commodity Crop Productivity Index

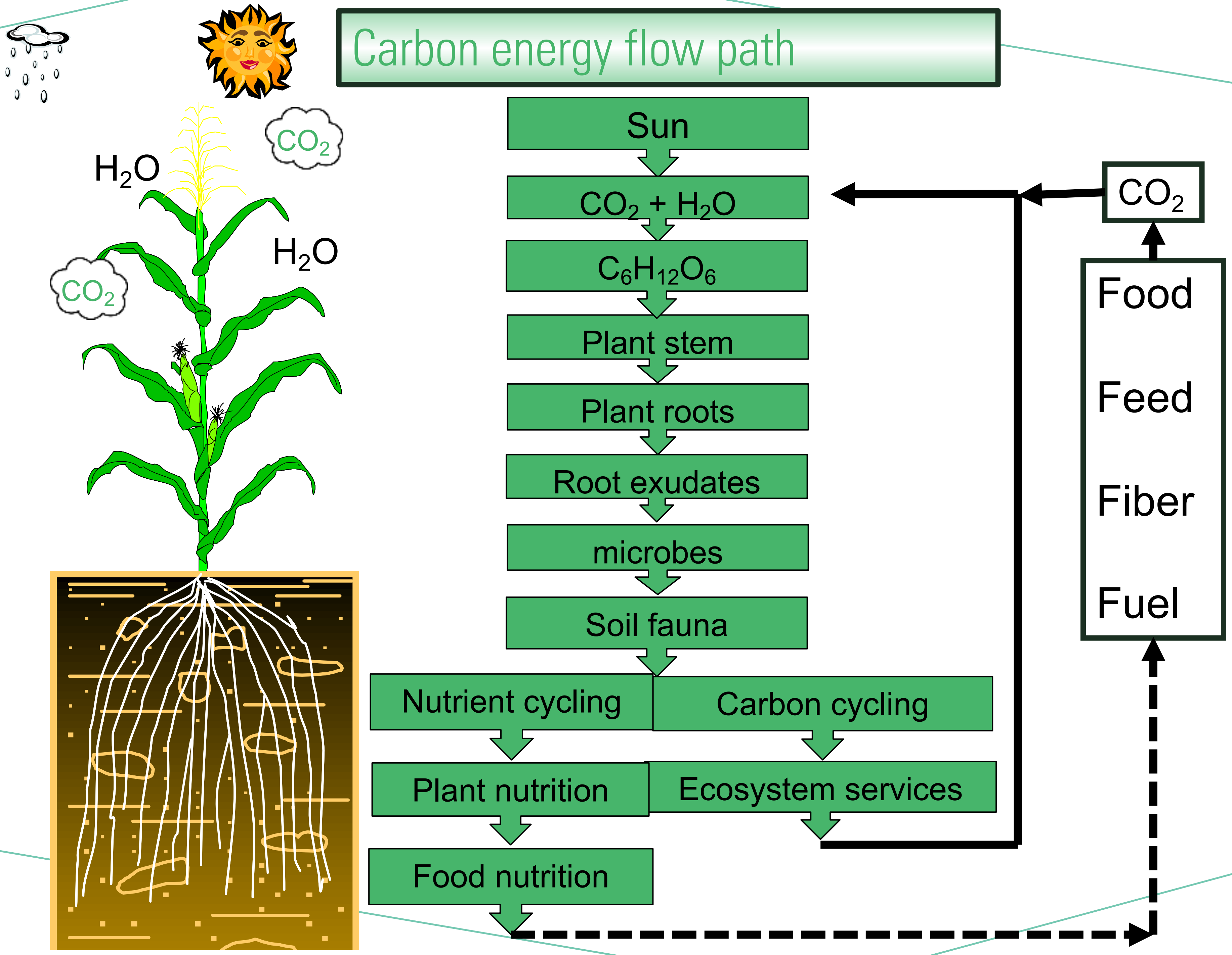


CURRENT CROPPING SYSTEMS IN THE MIDWEST

- 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

Process of capturing carbon

Carbon energy flow path



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

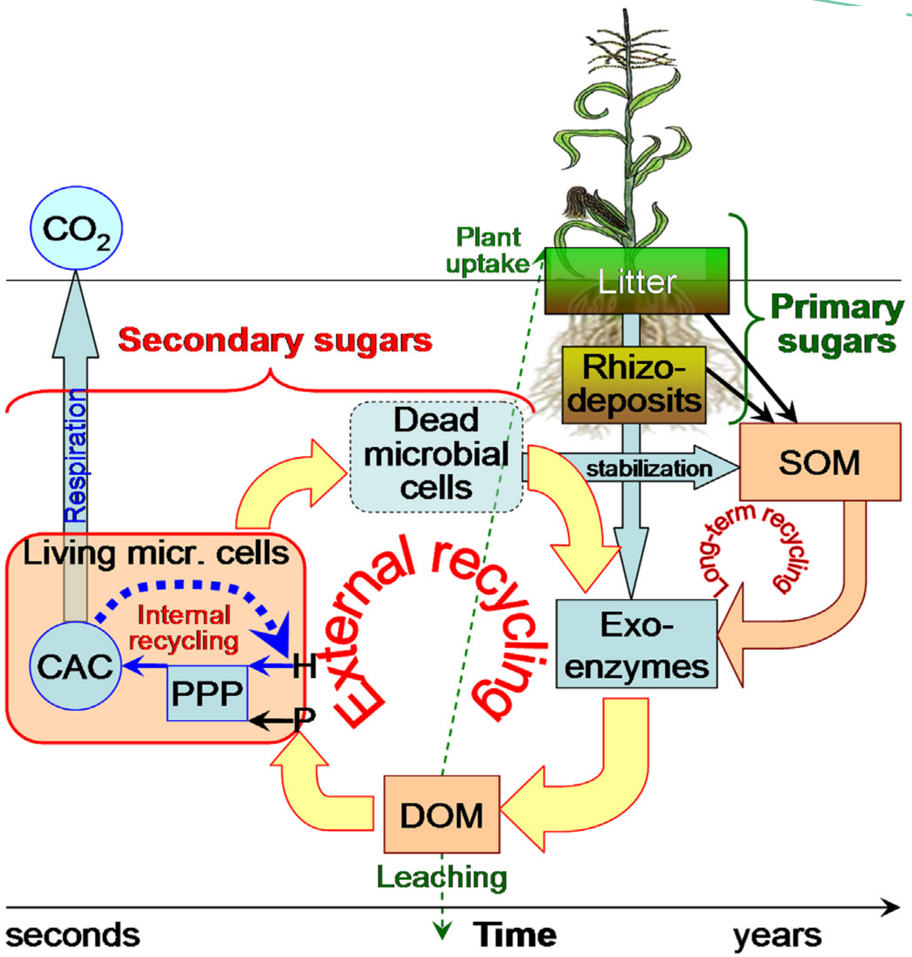


Fig. 6. Fate of sugars in soil. Primary (plant derived) and secondary (microbially derived) inputs of sugars are presented. The importance of three recycling cycles is underlined: internal recycling within microbial cells (in blue, the rates are within seconds to minutes), short-term external recycling (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 via microbial processes, and 2-5% is in SOM

SUGAR AND SOM

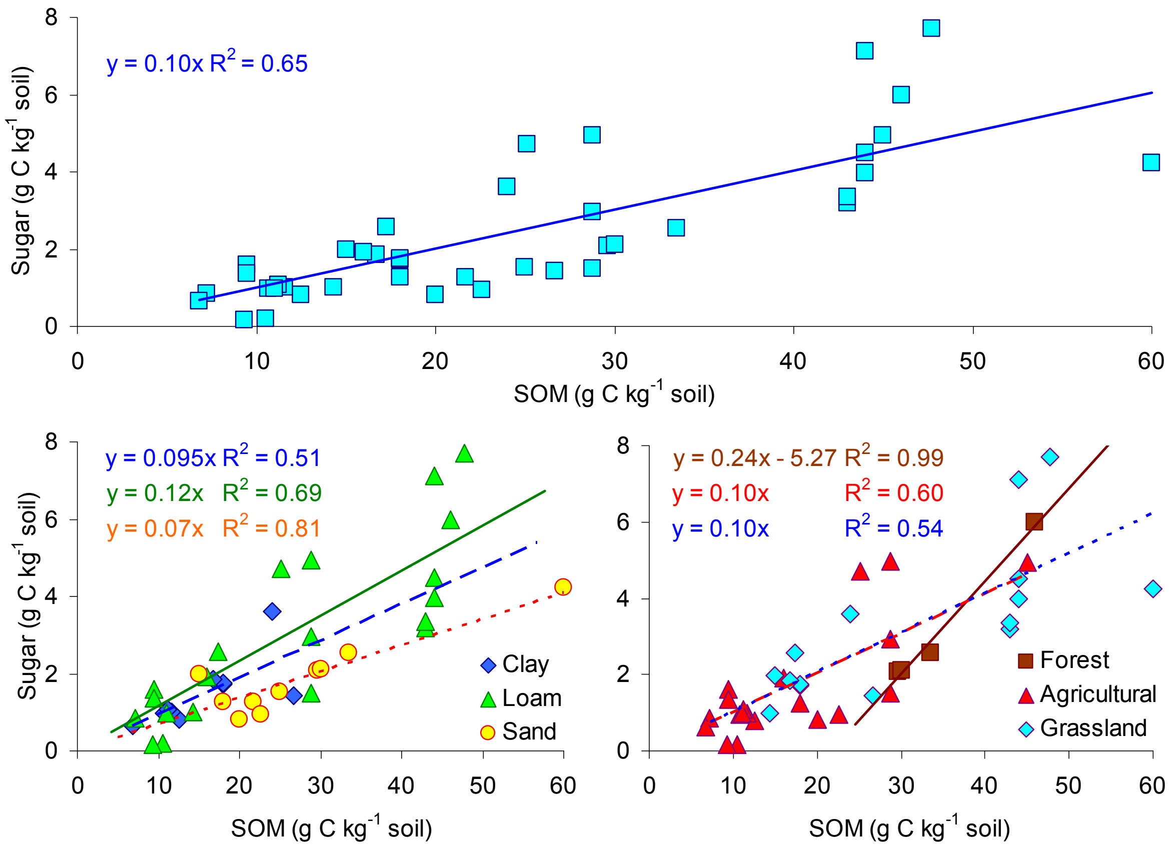


Fig. 2. Total sugar C content depending on: SOM (top), soil texture (bottom left), plant functional types (bottom right). Left and right bottom graphs are created with the same data, but left graph accounts only soil textures and right graph accounts only plant functional types. All regression lines 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).

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

FATE OF SUGARS IN THE SOIL

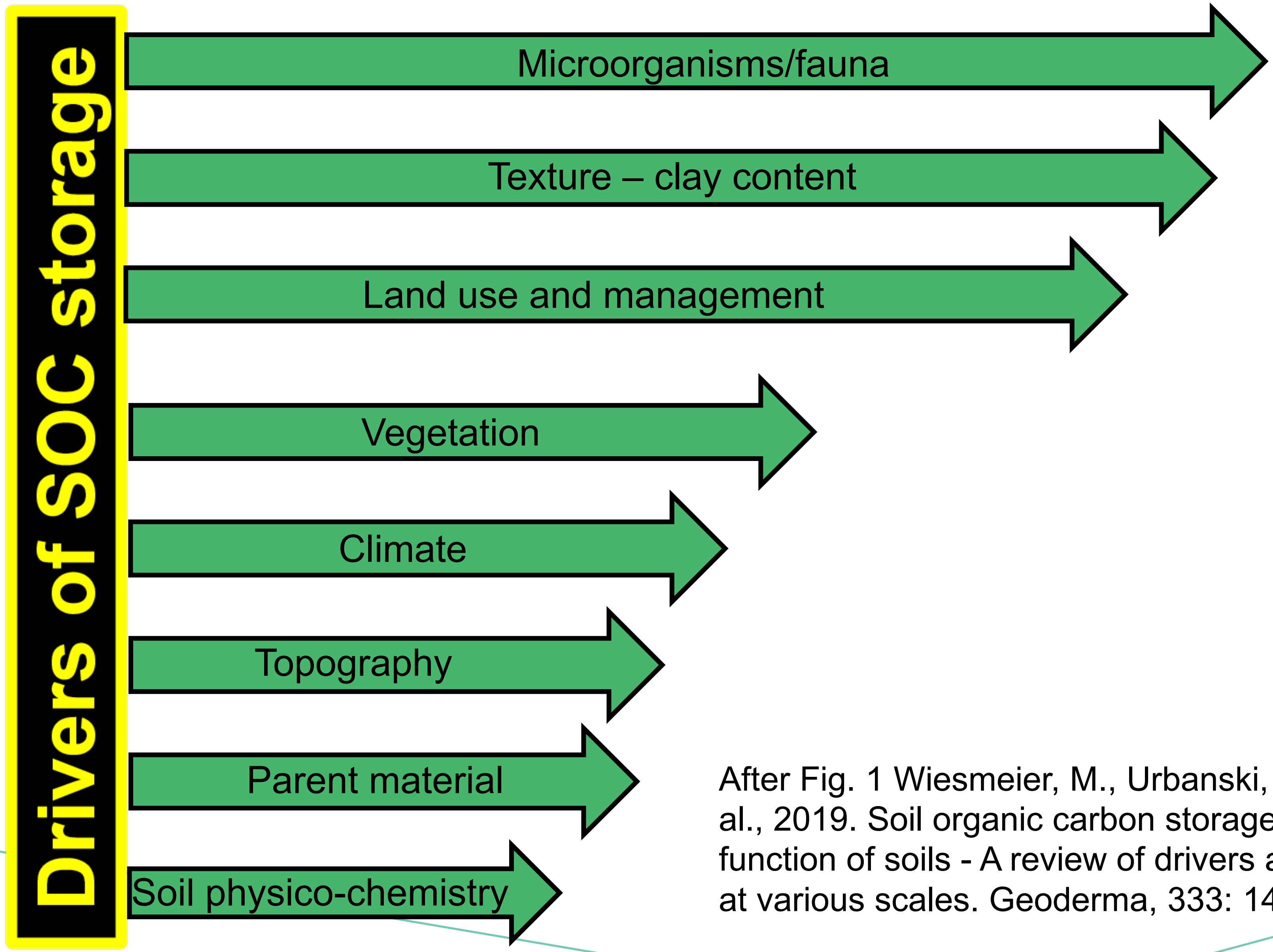
Aggregate formation (natural glue)

- 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

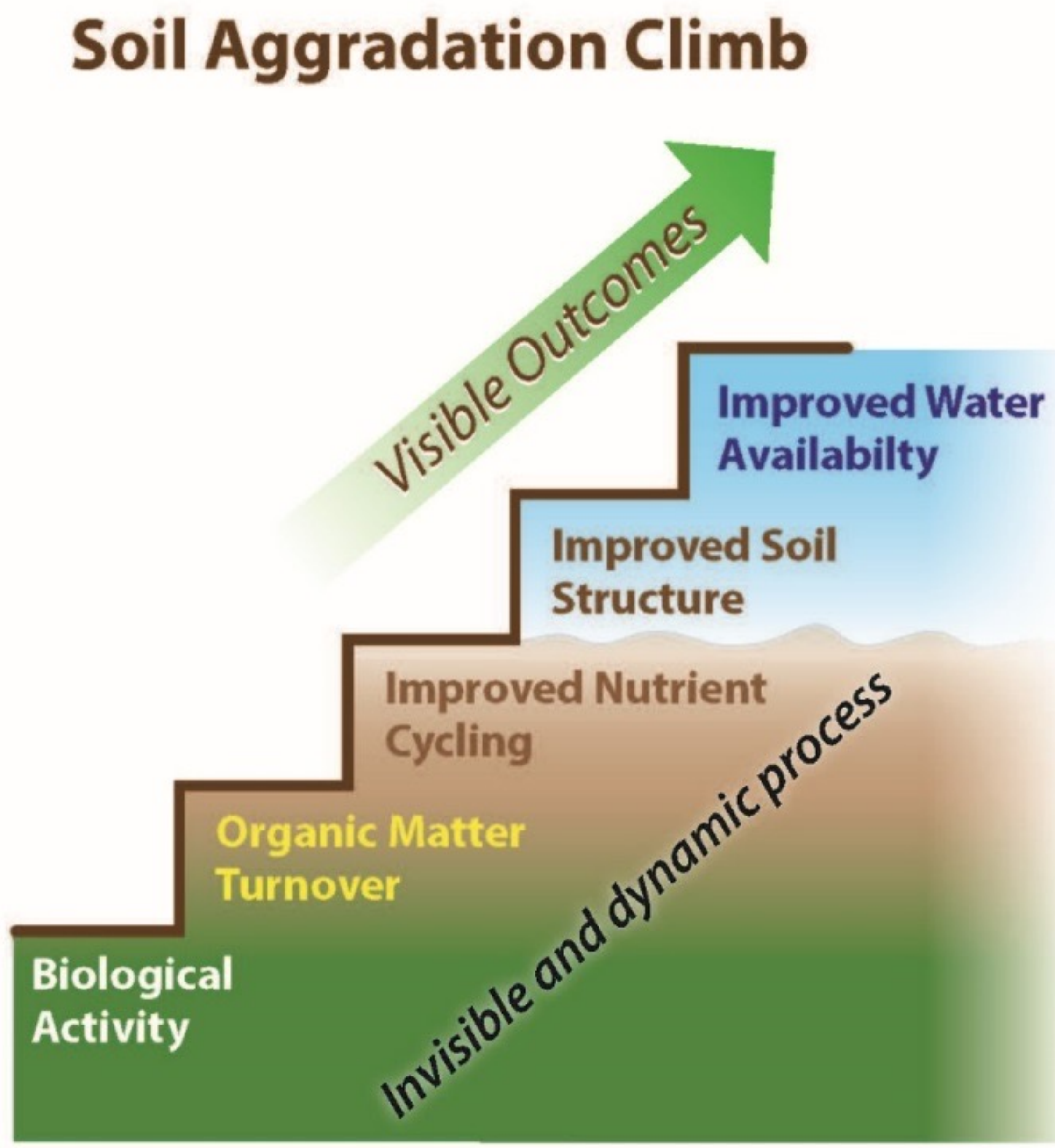
Relative ranking of SOC storage drivers



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.

RENGERATIVE PATHWAY

- TO SUSTAIN BIOLOGICAL ACTIVITY
  - FOOD
  - WATER
  - AIR
  - SHELTER



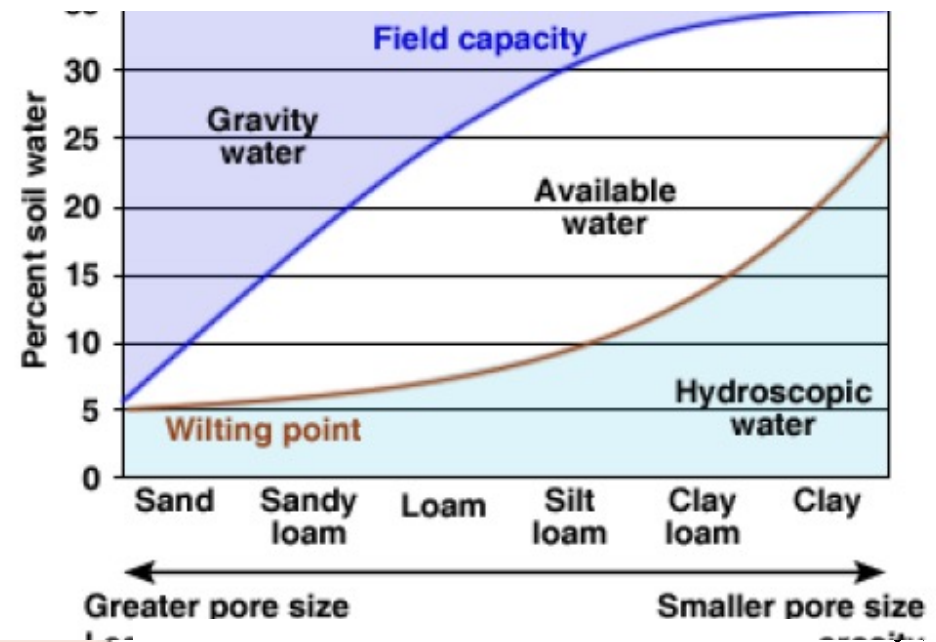
WHAT IS THE VALUE OF CARBON?

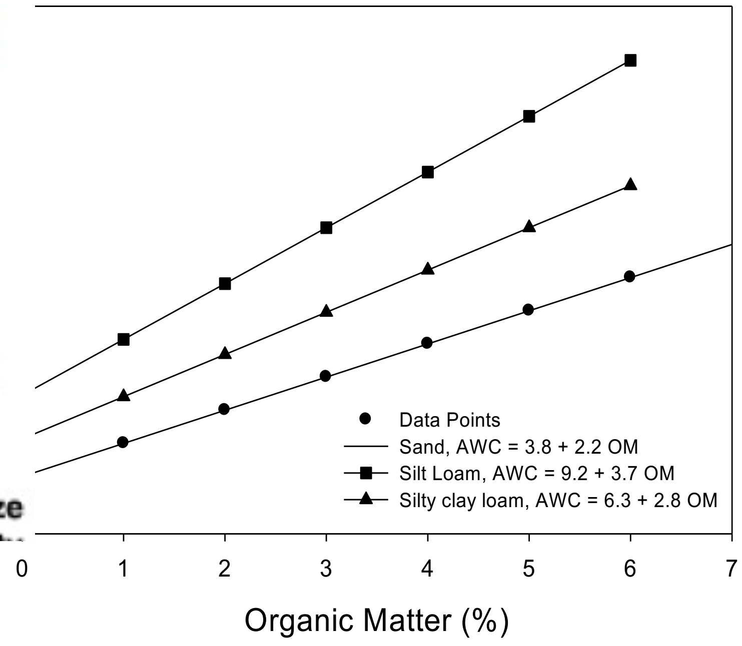
WHAT IS THE MOST LIMITING FACTOR IN CROP PRODUCTION?

HOW DOES WATER AND CARBON FIT TOGETHER?

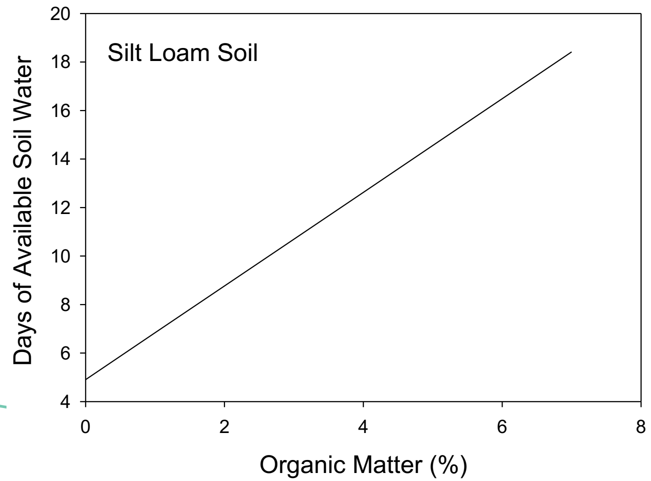
SOILS, CARBON, AND WATER

Available water capacity by soil text	
Textural class	Available water capa (inches/foot of dep
Coarse sand	0.25–0.75
Fine sand	0.75–1.00
Loamy sand	1.10–1.20
Sandy loam	1.25–1.40
Fine sandy loam	1.50–2.00
Silt loam	2.00–2.50
Silty clay loam	1.80–2.00
Silty clay	1.50–1.70
Clay	1.20–1.50

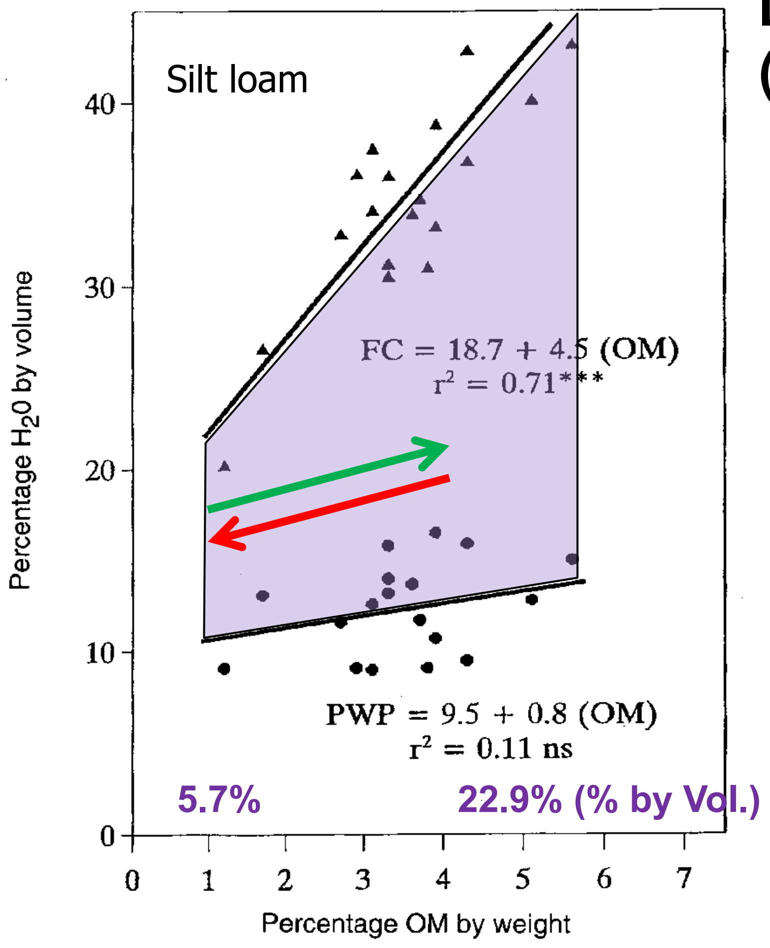




Hudson, 1994



Organic Matter Effects on Available Water Capacity



Data from Soil Survey Investigation Reports (surface horizons only)

- **Sands: FL (n = 20)**
- **Silt loams: IA, WI, MN, KS (n = 18)**
- **Silty clay loams: IA, WI, MN, KS (n = 21)**

Sands AWC = 3.8 + 2.2 (OM), $r^2 = 0.79$

Silt loams AWC = 9.2 + 3.7(OM), $r^2 = 0.58$

Silty clay loams AWC = 6.3 + 2.8 (OM), $r^2 = 0.76$

OM increase from 1% to 4.5% AWC doubles!

Hudson, B. D. 1994. Soil organic matter and available water capacity. J. Soil Water Conserv. 49(2):189-194.

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

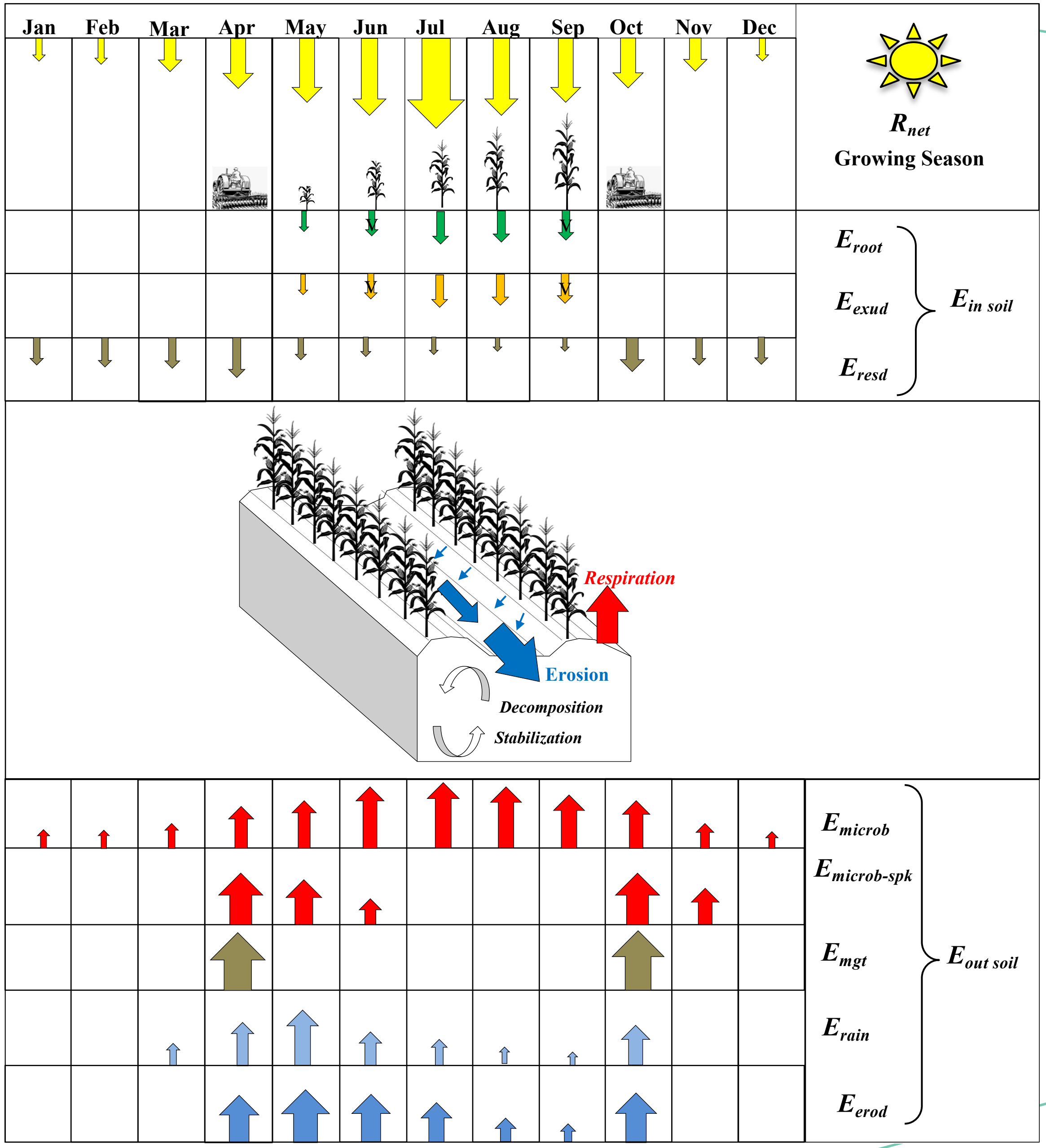
AGRICULTURAL SYSTEMS HAVE CHANGED OUR SOILS

HOW DO WE RESTORE SOIL PRODUCTIVITY?

PRINCIPLES OF REGENERATIVE AGRICULTURE

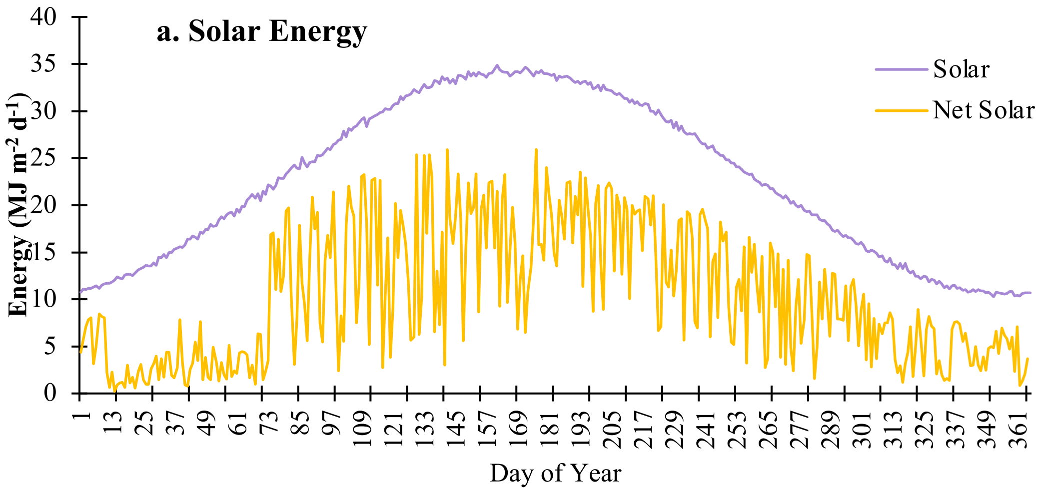
- Maintaining Soil Armor (crop residue).
- Minimizing Soil Disturbance (less tillage).
- Maintaining Continual Living Plant Roots (continual input of energy to the soil microbial system).
- Adding Planting Diversity (diversity pays).
- Integrating Livestock (incorporation of carbon and nutrients).

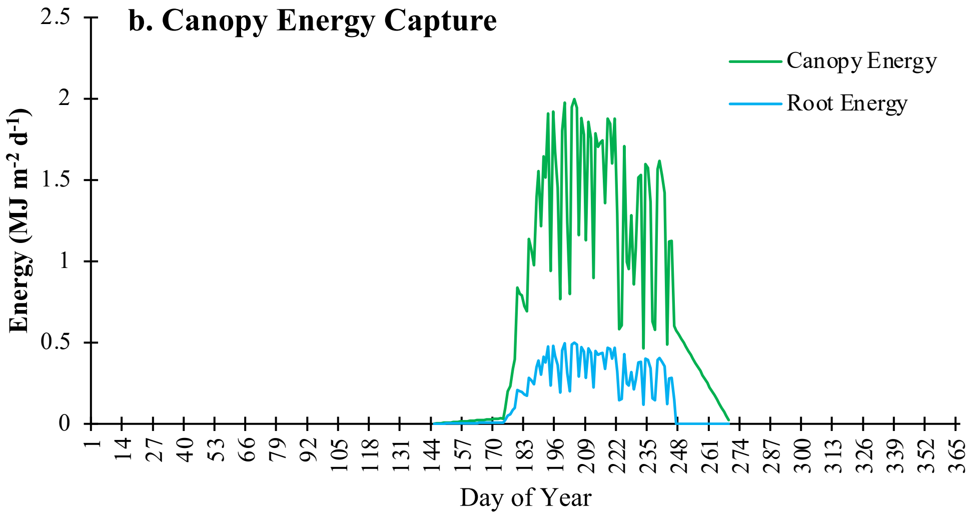
SEASONAL INPUT OF ENERGY



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)

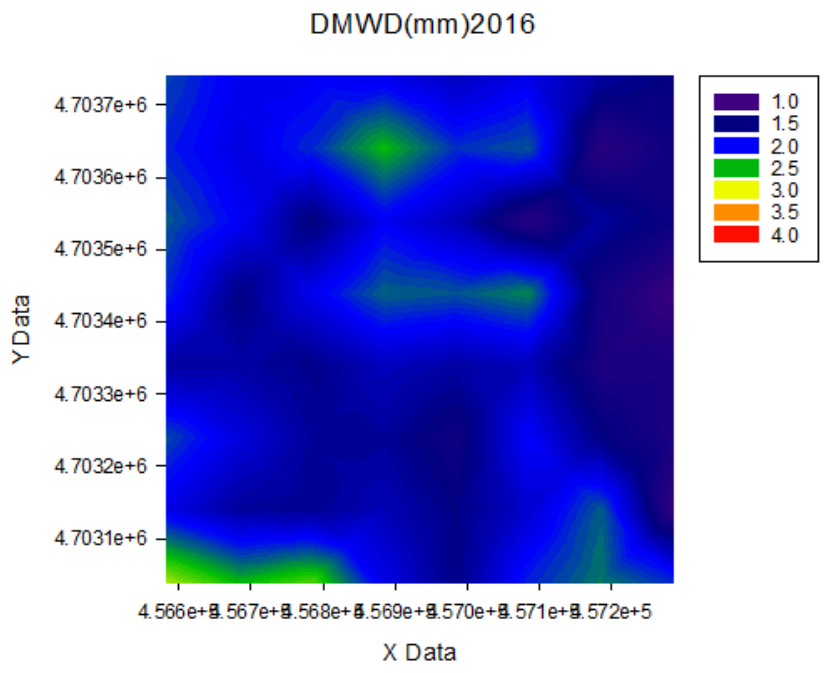
3. 6 crops - root-derived C was ~ 2.3X > than shoot-derived C
(Katterer et al., 2011)

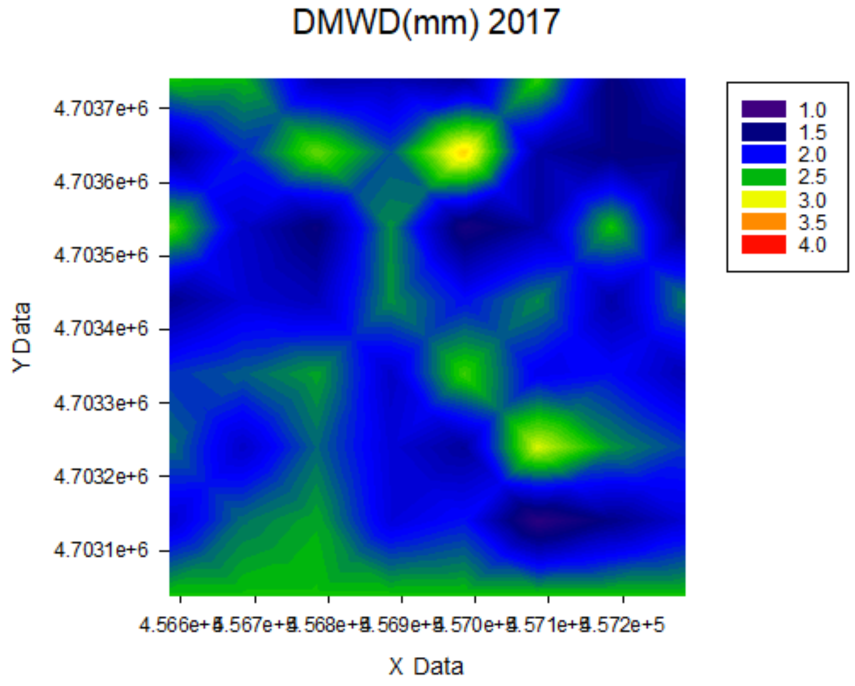
4. 6 crops - root-derived C ~ 5X > shoot-derived C for SOM
(Table 1, Jackson et al., 2017)

5. Root-derived C was 2.4 times shoot-derived C for SOM
(Raase et al., 2005)

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)





Maintaining soil armor

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

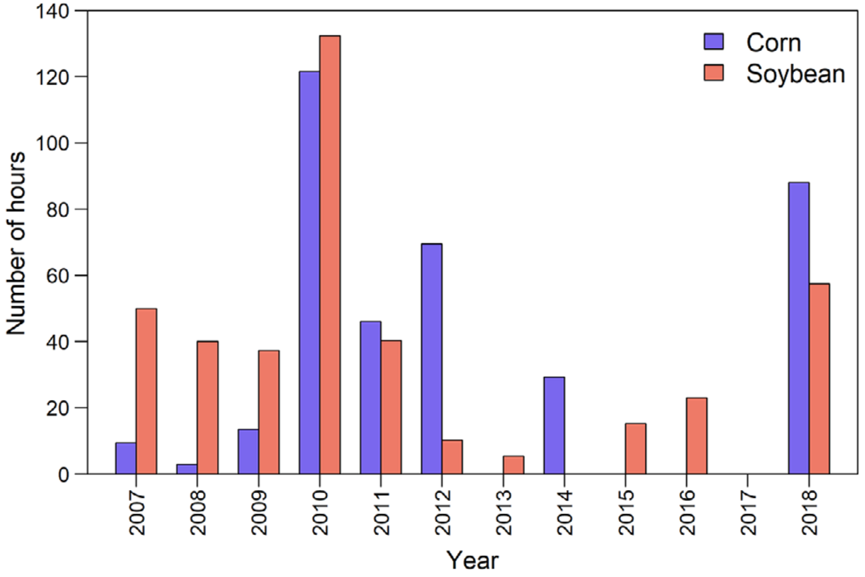
Continual cover provides three advantages for soil water

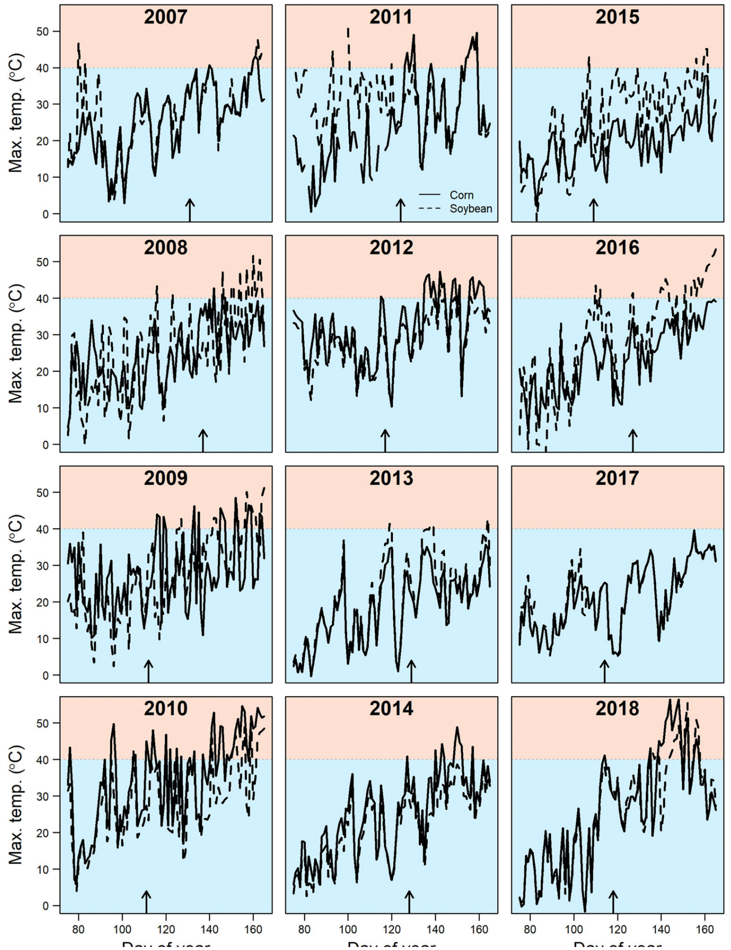
- First, protection against raindrop energy so soil aggregates are protected and infiltration rates are maintained
- Second, soil water evaporation is reduced so water is used by the plant for transpiration
- Third, plant roots are near the surface so take advantage of small rainfall events

Maintaining soil armor

- Attributes of regenerative agriculture that impact soil microclimate significantly are the focus on continual cover of the soil
- Continual soil cover
  - Reduces temperature extremes
  - Maintains the temperature in an optimal range for microbial activity

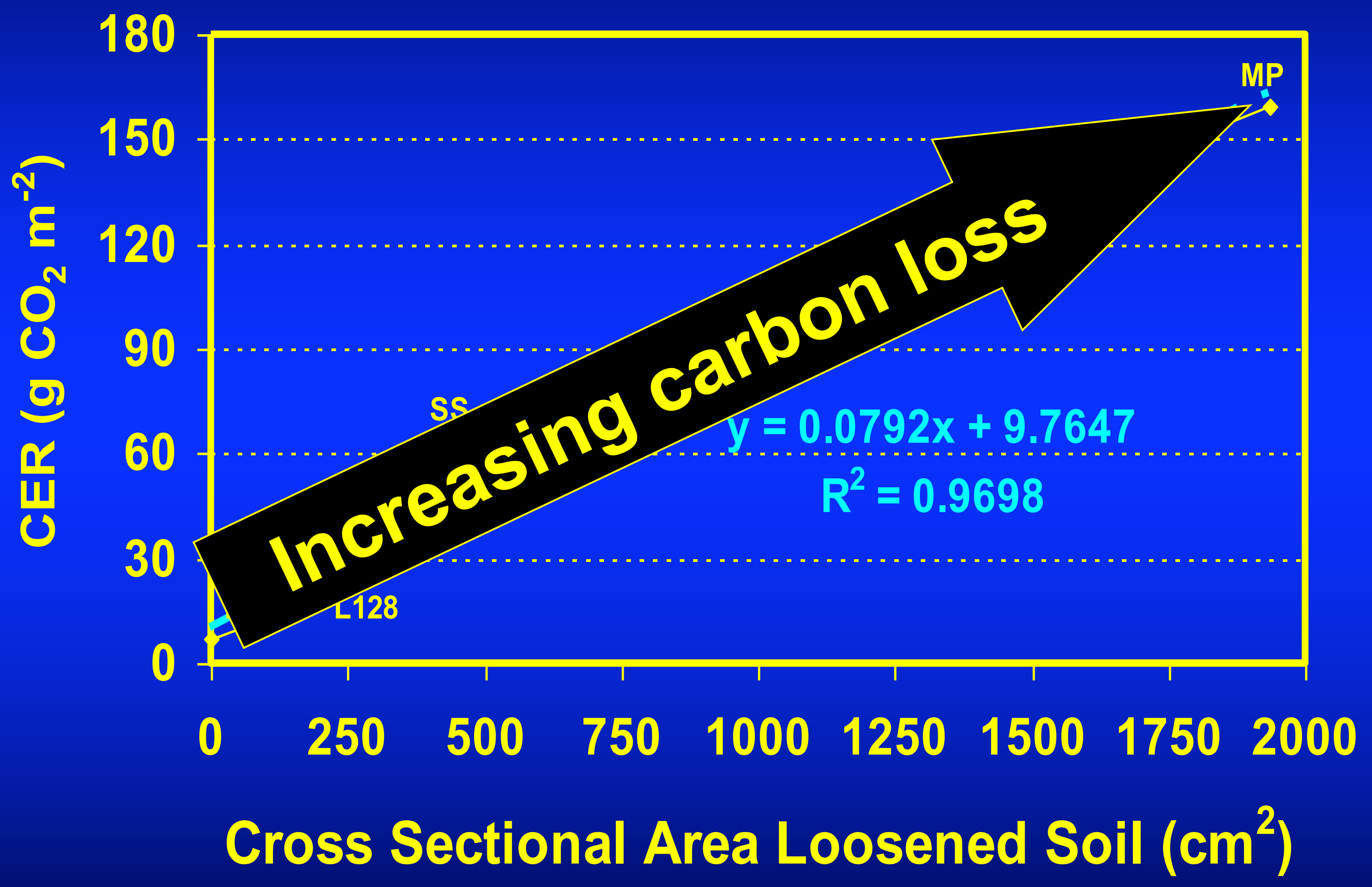
Surface temperatures under conventional tillage systems





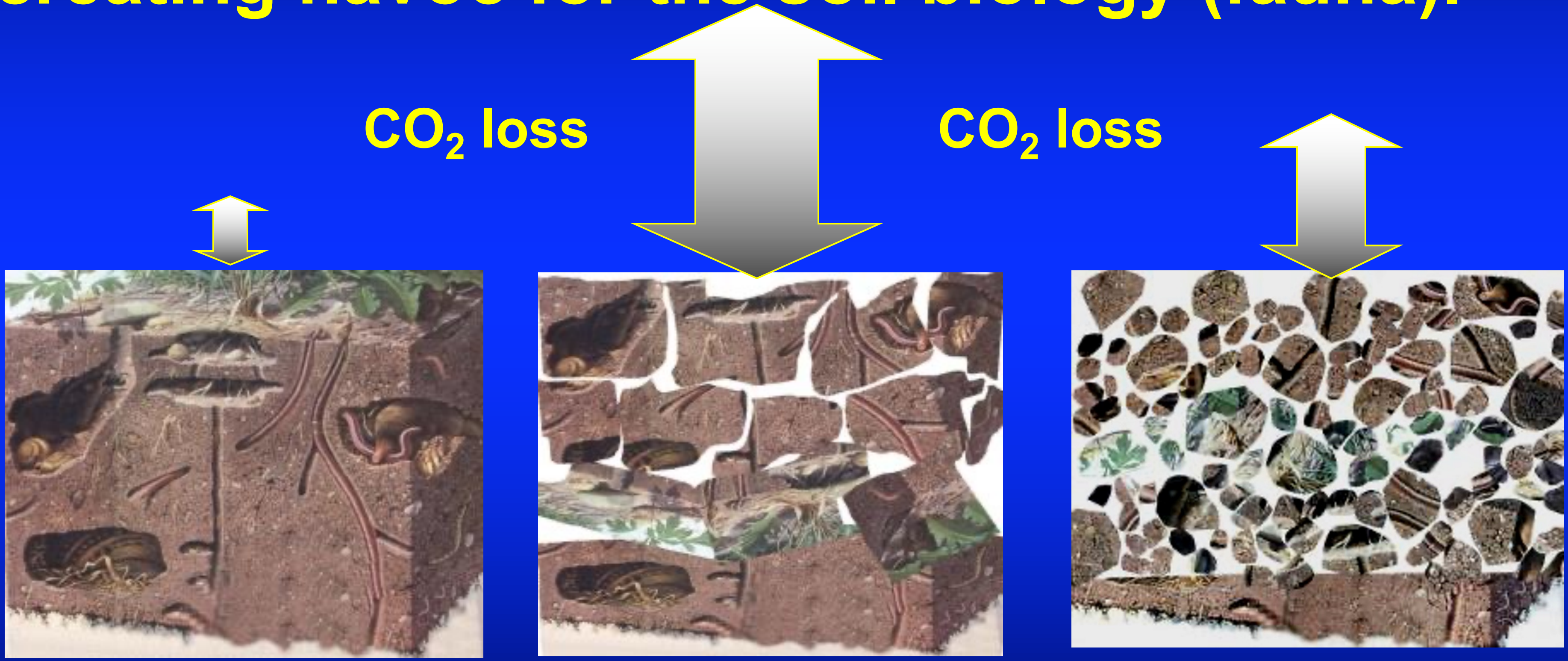
Typical conventional systems are exposed to temperatures above lethal limits (40 C or 104 F) for biological activity

Strip Tillage #1 3 June 1997 Swan Lake
Cumulative Carbon Dioxide Loss after 24 hours



Courtesy of Don Reicosky

Intensive tillage “disrupts the biology” in the soil. It cuts, slices, and dices the soil and blend’s, mixes, and inverts the soil creating havoc for the soil biology (fauna).

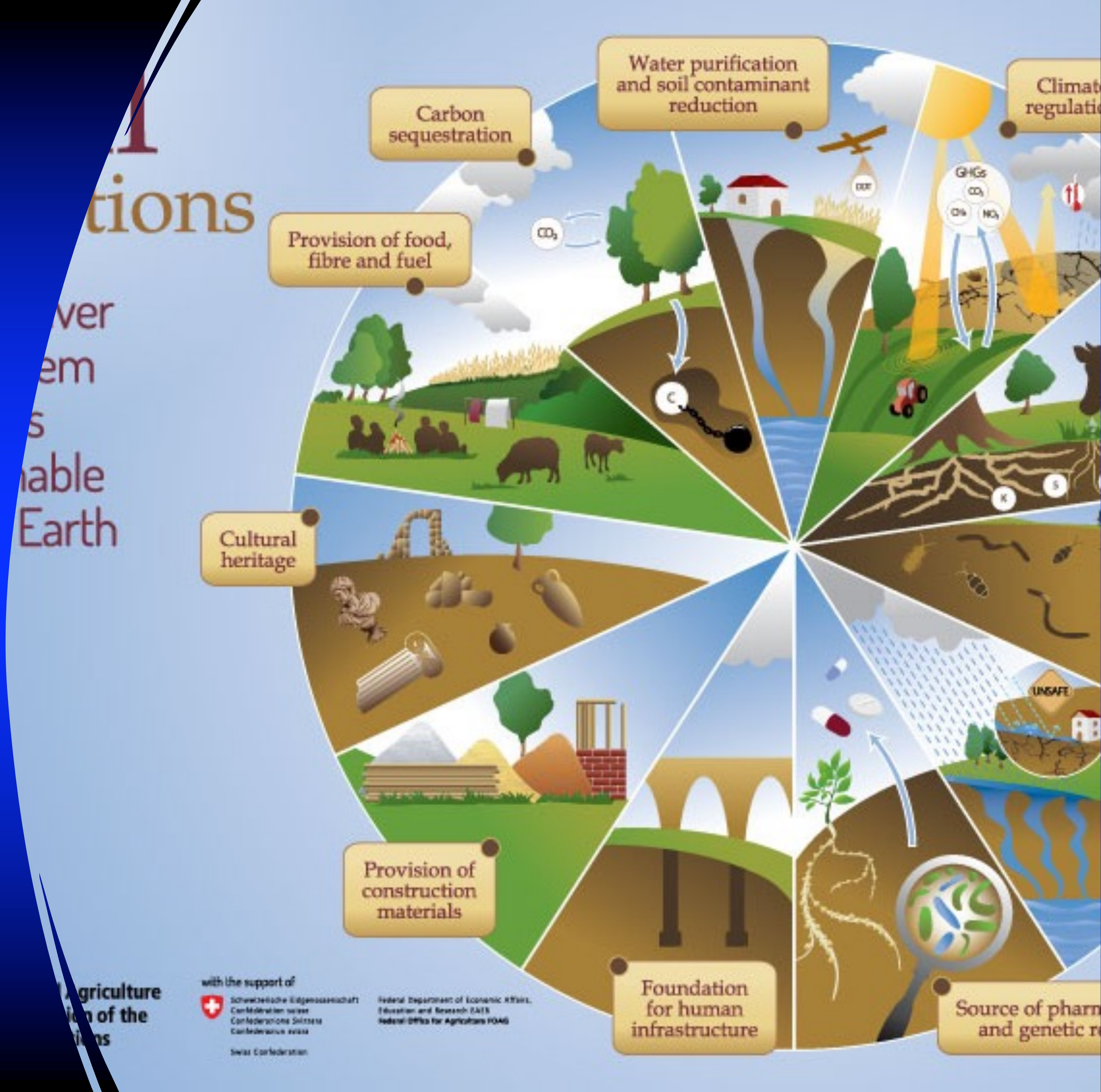


Courtesy of Don Reicosky

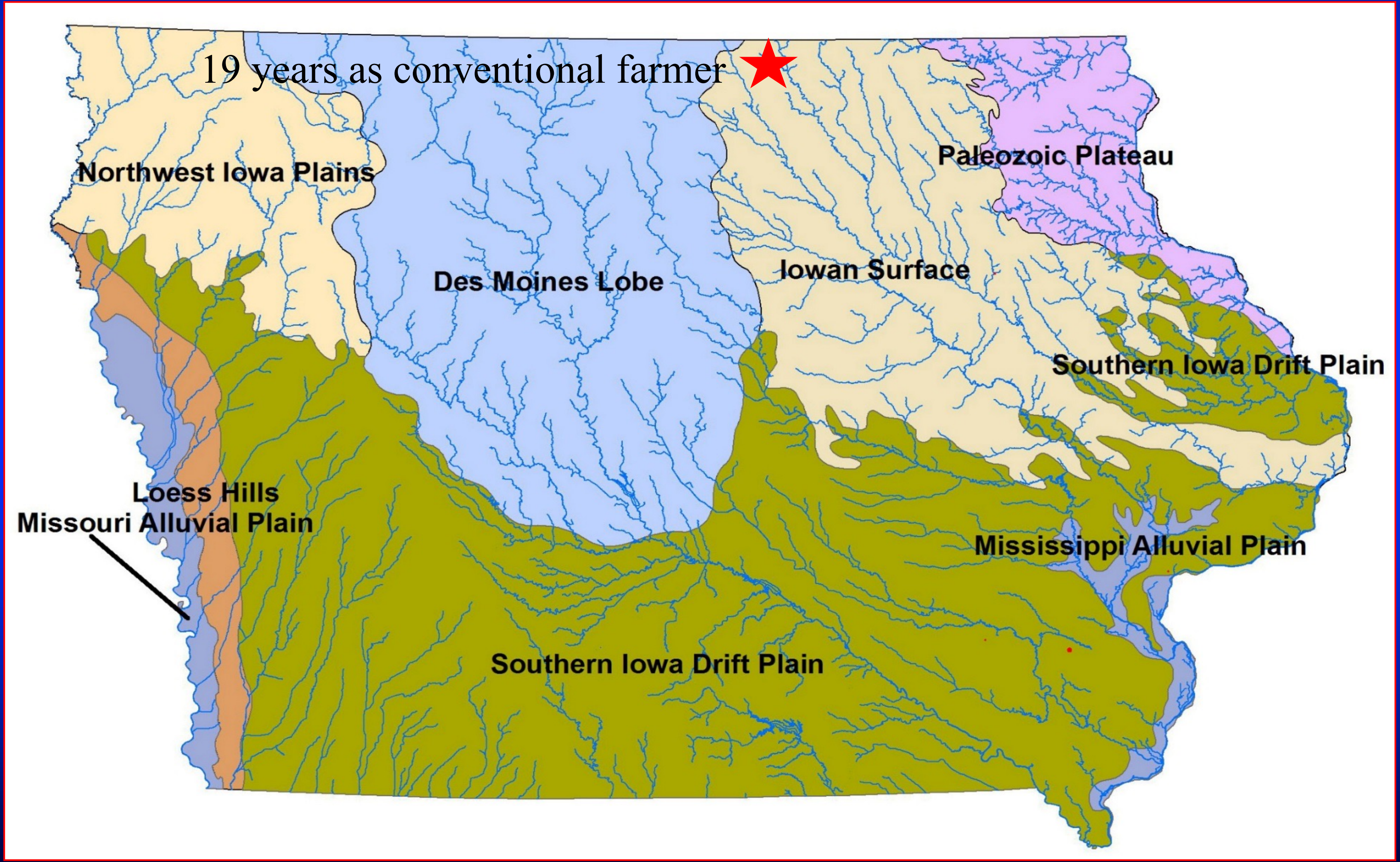
Before Primary Tillage | **After Primary Tillage** | **After Secondary Tillage**

Functions of Soil-Agriculture

- Provide support for plants
- Serve as a water reservoir
- Nutrient source for plants
- Carbon cycling
- Efficient gas exchange
- Decomposition of pesticides, antibiotics



Case study from Wayne Fredericks



CHANGES AT WAYNE FREDERICKS

1992

No-till soybeans in 1992

2003

Strip-till corn in 2003

2012

Cover crops beginning in 2010, over all fields in 2012



DATA

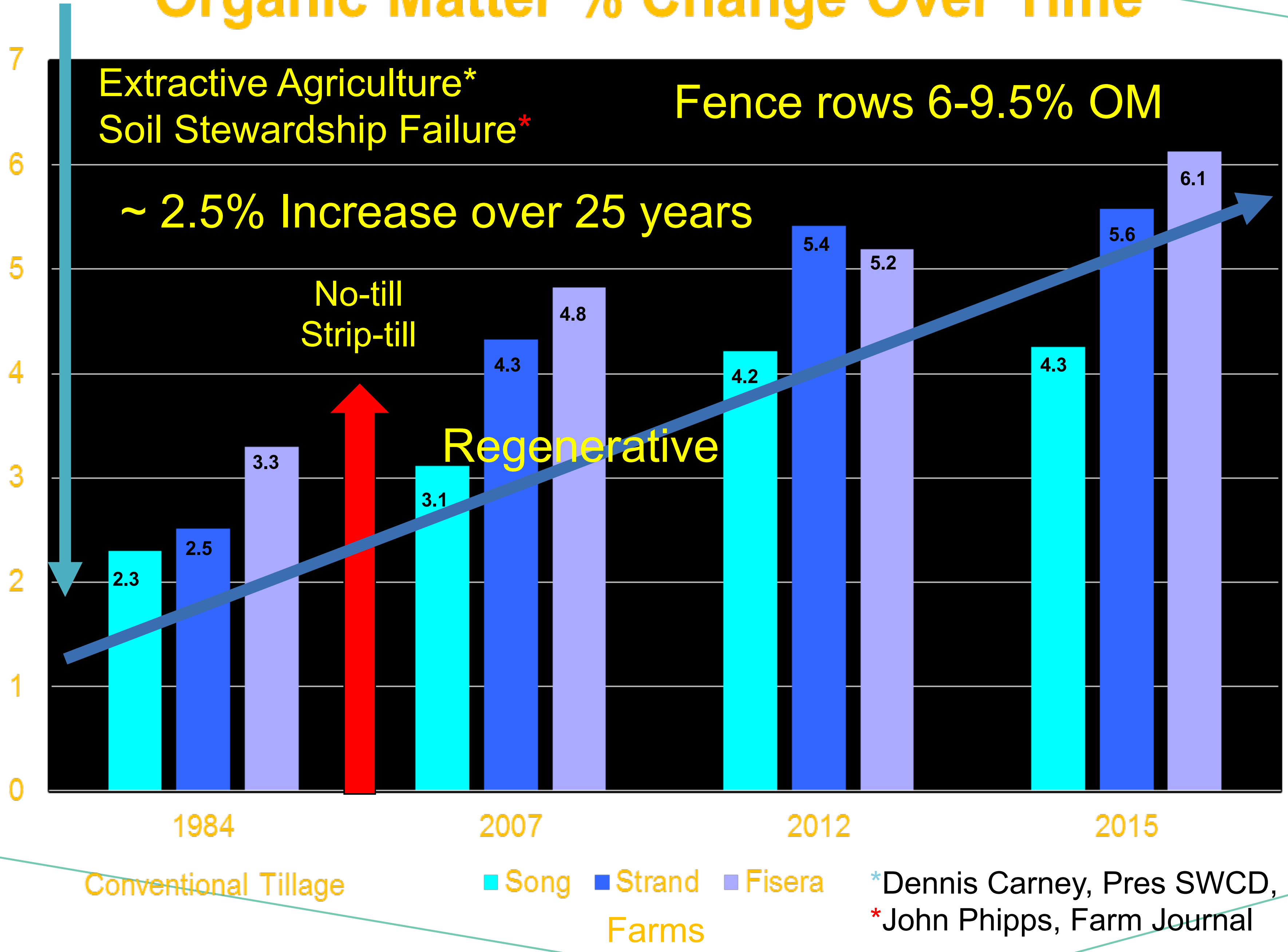
Availability

- Soil organic matter samples in fields
- Yield monitor data
- Weather data
- Mitchell county yield data

Analysis

- Soil organic matter changes
- Field vs county level yields
- Field uniformity of yield
- Weather resilience

Organic Matter % Change Over Time

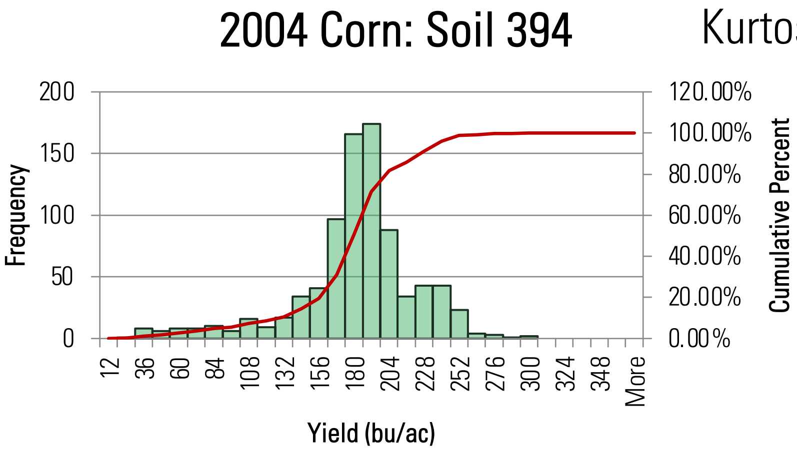


*Dennis Carney, Pres SWCD, IA
*John Phipps, Farm Journal

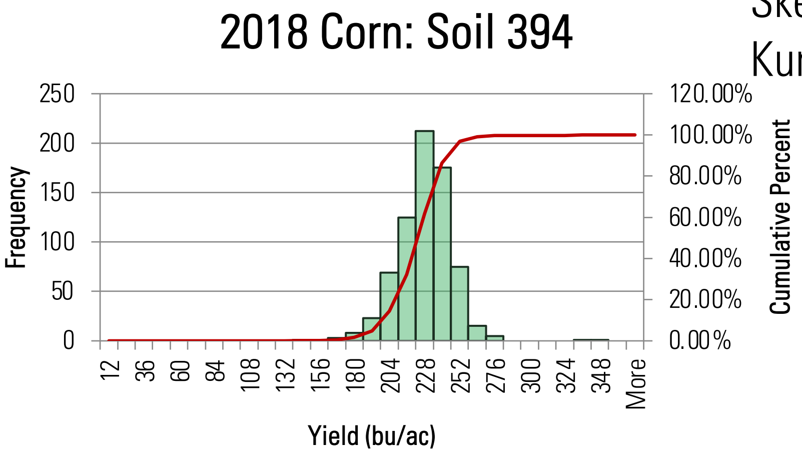
INCREASING UNIFORMITY IN FIELDS

Soil 394 Ostrander loam

Skewness -1.01
Kurtosis 2.30

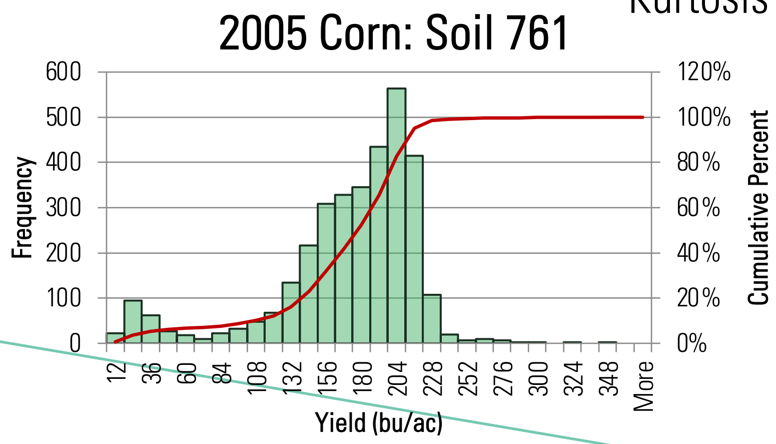


Skewness 0.19
Kurtosis 4.48

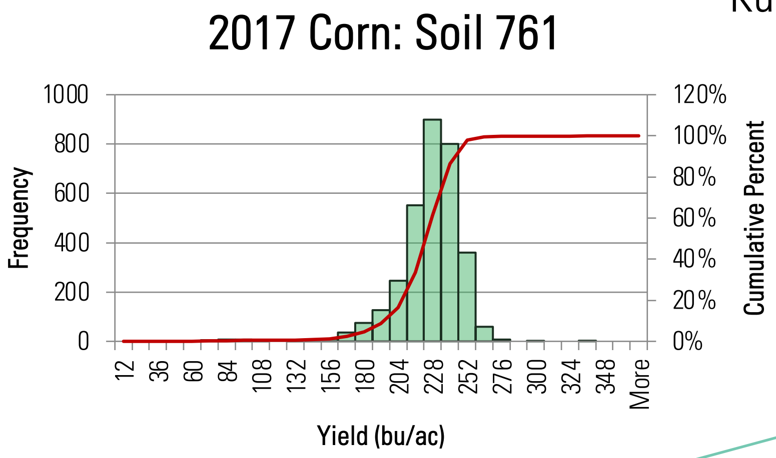


Soil 761 Franklin silt loam

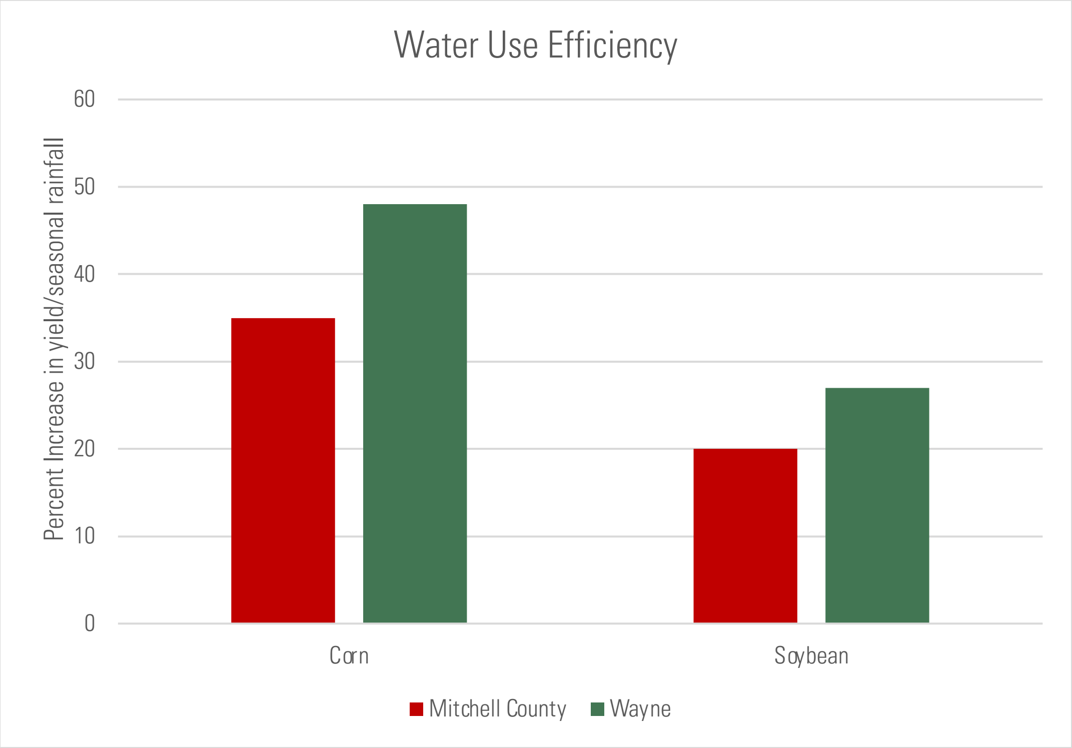
Skewness -1.99
Kurtosis 2.21



Skewness -0.86
Kurtosis 7.91



WATER USE EFFICIENCY

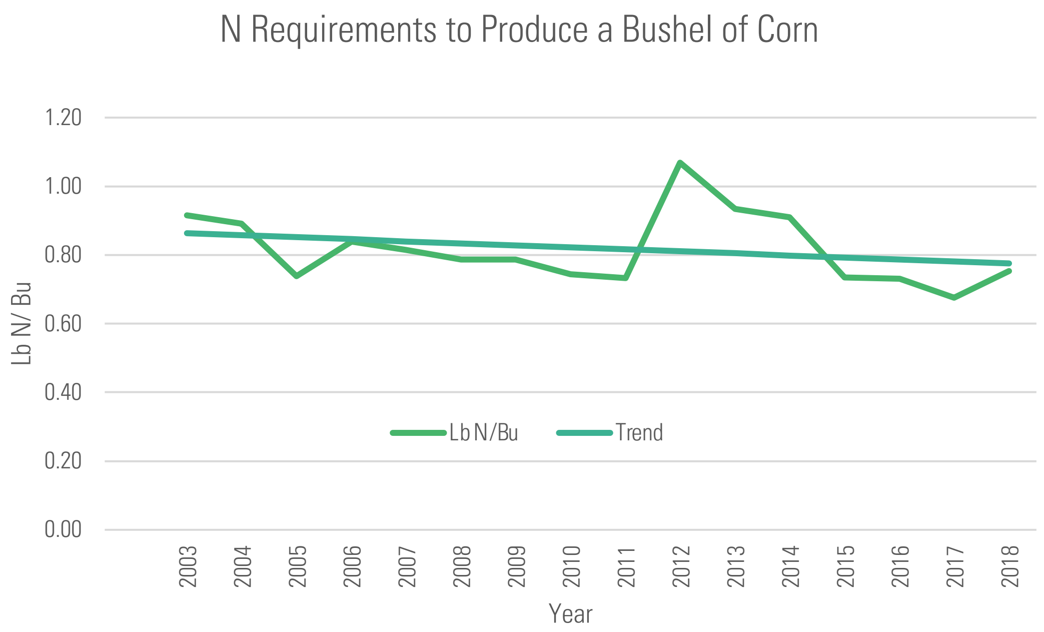


Yield stability among years, less variation among years, standard deviation in yields half of conventional tillage

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

CHANGES IN N RESPONSE



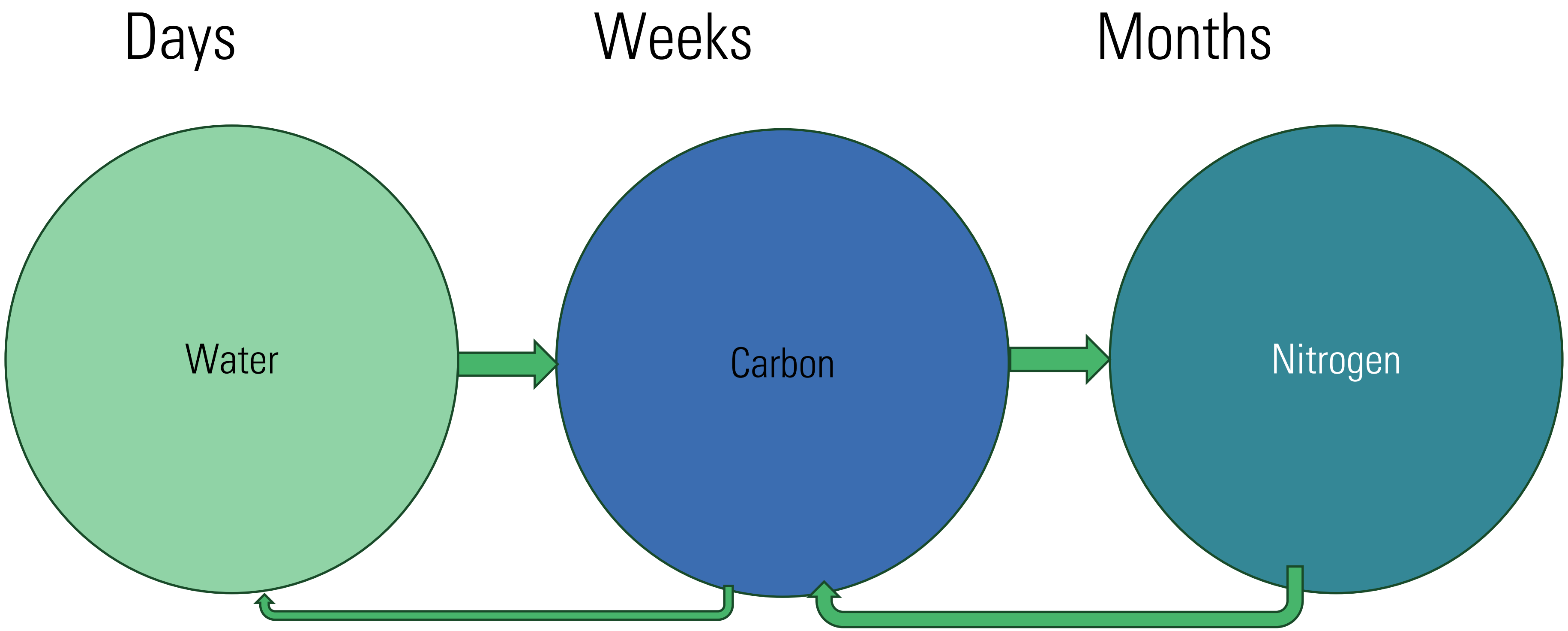
With enhanced soil organic carbon and more water available the N requirements have decreased

WHAT IS EXTRA CARBON WORTH?

- Machinery costs - $44.00 per acre
- Labor savings - $27.00 per acre
- P and K fertilizer - $9.00 per acre
- N fertilizer - $30.00 per acre
- Increased profit - $100.00 per acre

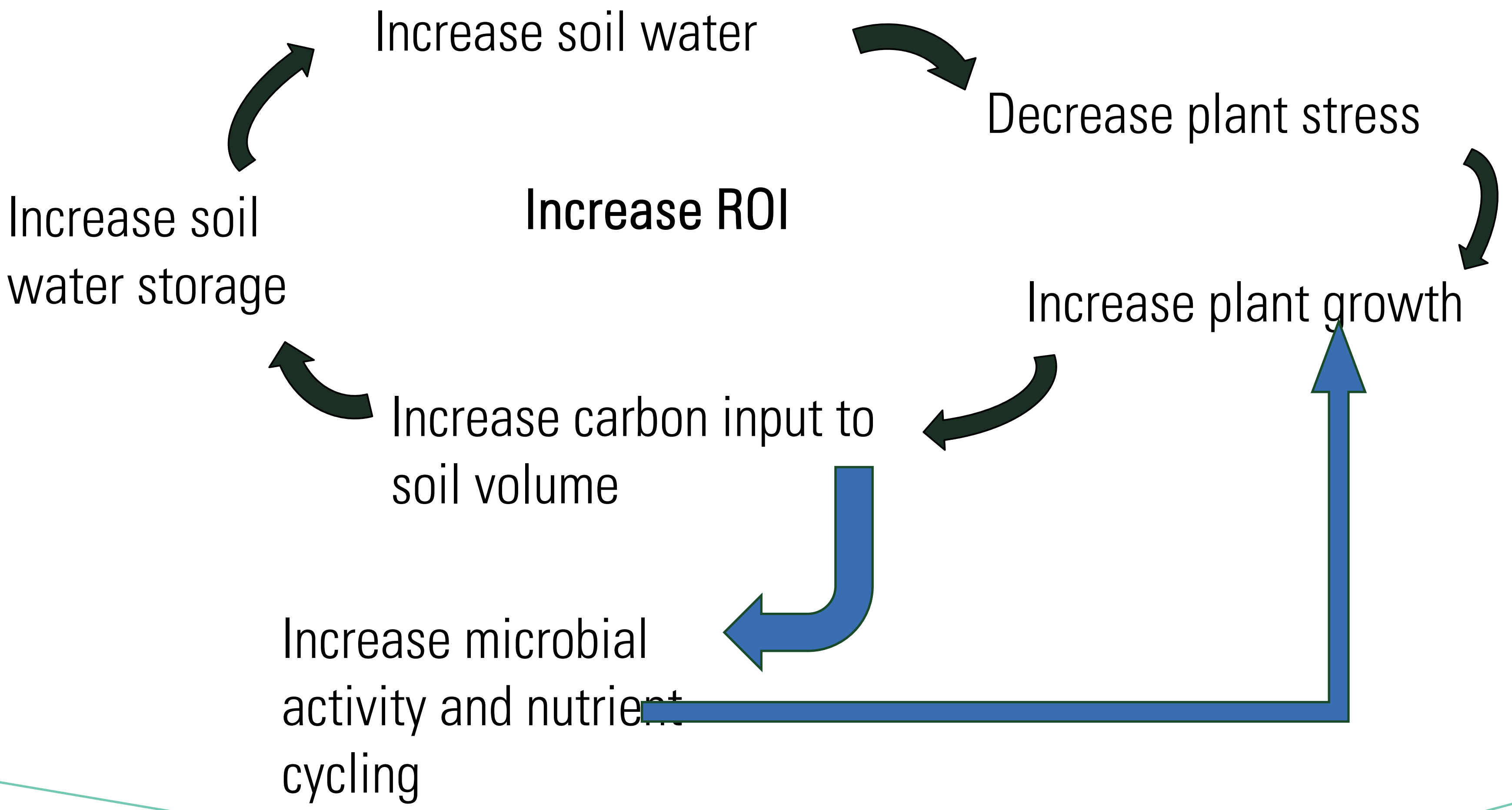
WHAT DO WE NEED TO UNDERSTAND?

PROCESS OF CHANGE



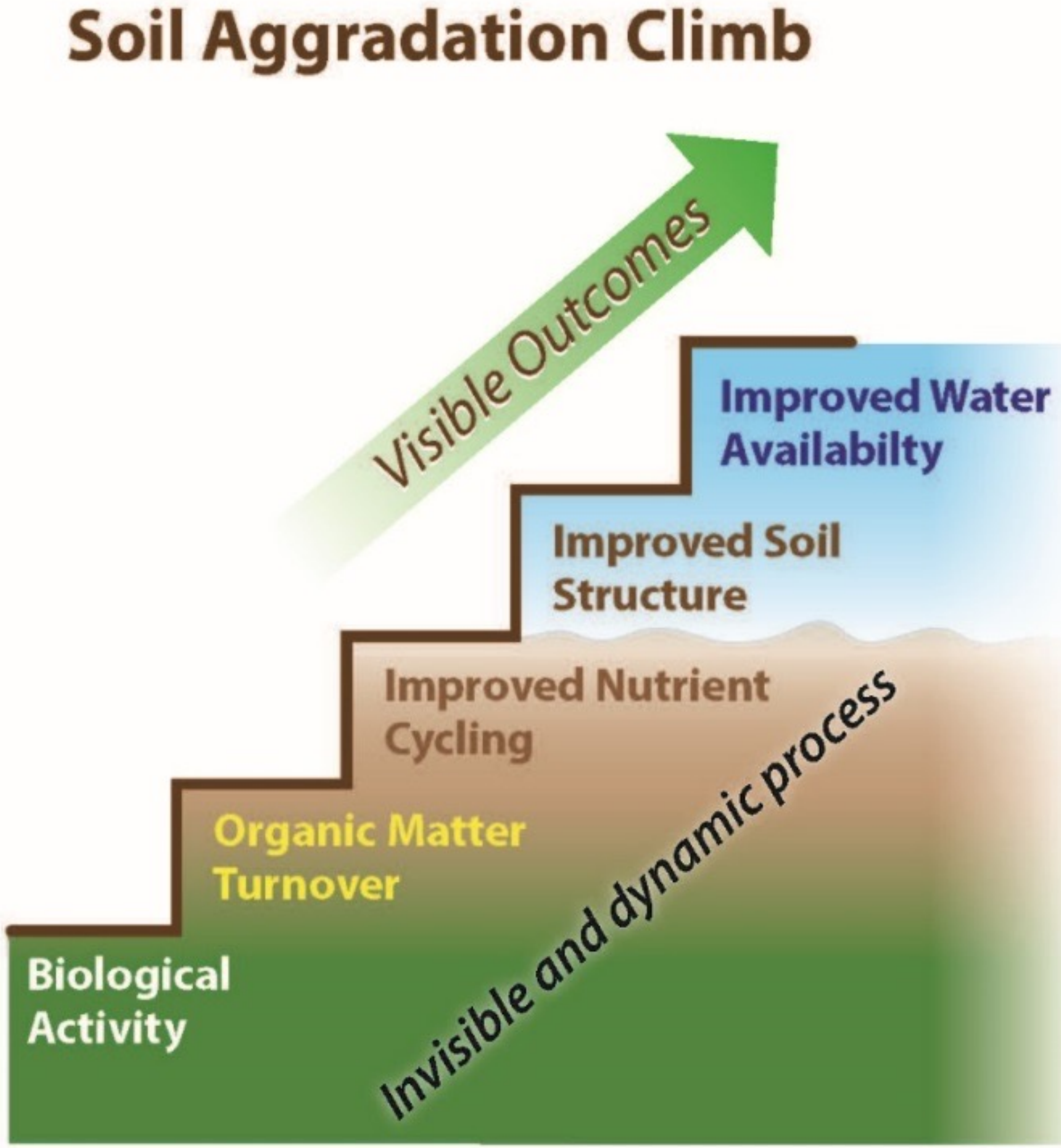
Regenerative practices affect water availability, then carbon, then nitrogen

SOIL WATER AND SOIL CARBON



SOIL HEALTH PATHWAY

- TO CHANGE SOIL CARBON
- FOOD
- WATER
- AIR
- SHELTER

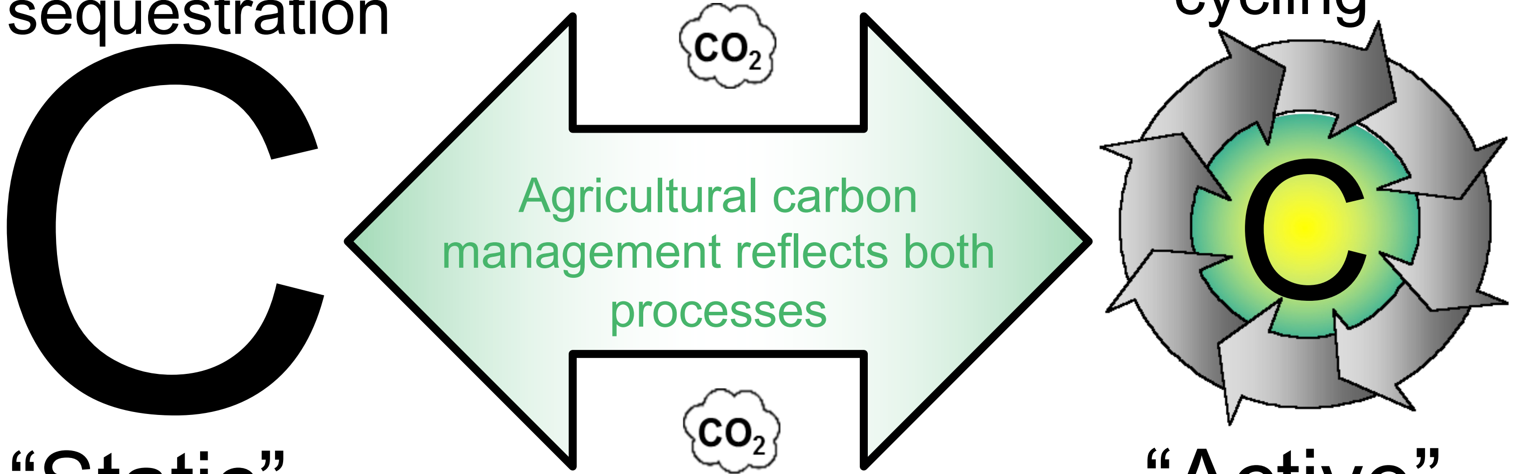


Our Carbon Conundrum!

Is it C “sequestration” or is it C “cycling”?

C sequestration

C cycling



“Static”

Stored energy

Sequestered carbon is energy stored for use at sometime in the future.

“Active”

Useful energy

Carbon cycling is carbon in transition fueling ecosystem services.

Janzen, H.H. 2006.The soil carbon dilemma: Shall we hoard it or use it? Soil Biology and Biochemistry, Volume 389 (3):419-424.

CHALLENGES AND OPPORTUNITIES

- Agriculture is best understood in the Genetics x Environment x Management (G x E x M) framework
- Continue to evaluate and implement practices that increase the value of our soils and create resilience in our cropping systems
- Understand the dynamics of management practices that enhance the soil and that there is no single answer or practice
- Need to begin to think and act holistically to achieve multiple goals: production, profitability, environmental quality, and farming satisfaction
- Develop communities of producers to share experiences, successes, failures, and learning
- Opportunity exists for agriculture to meet the demands of the future through our ability to be innovators and revolutionaries

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