Impacts of Cellulosic Feedstock Production on Soil Carbon

Scott Staggenborg
Department of Agronomy

Consortium for Agricultural Soils Mitigation of Greenhouse Gases

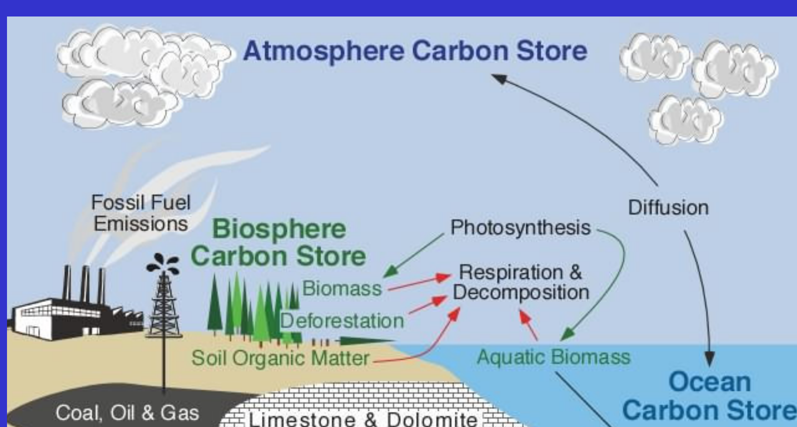
K-State Research and Extension

Carbon Inputs in the System

Photosynthesis

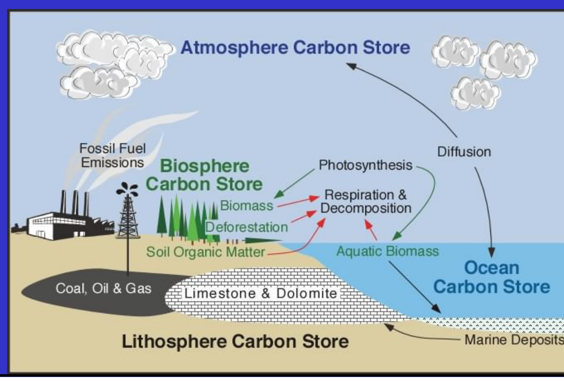
Plant biomass production represents the net conversion of atmospheric carbon to organic carbon.

$$6H_2O + 6CO_2 \text{ ----------> } C6H_{12}O_6 + 6O_2$$



Carbon Losses from the System

- Fossil Fuel Emissions
- Plant, Animal, Microbe Respiration
- Organic Material Decomposition
  - Plant and Animal
  - Soil



Managing Carbon Cycle Losses

- Fossil Fuel Emissions
  - Reduce Emissions
    - More efficient systems (better fuel economy)
    - Conservation (use less fuel)
    - Cleaner systems (reduced emissions at combustion)
- Plant/Animal Respiration
  - Not likely to be a significant contributor
- Organic Matter Decomposition
  - Plant/Animal decomposition is a positive process
  - Soil OM – reducing losses is key to soil C sequestration

Soil Carbon Losses

- Tillage reduces soil carbon / organic matter
- However, tillage has been an integral part of crop production history in the U.S.
  - Eliminated soil compaction
  - Controlled weeds prior to herbicides
  - Eliminated residue
    - Harbor insects and diseases
    - Planting equipment could not operate in residue
  - What hard working people do
    - Sense of accomplishment
    - Cleansing operation

Tillage Reduce SOM

Soil Aeration

- Tillage:
- Increases soil to microbe contact since microbes are immobile.
- Redistributes microbes and soil organic matter and increases oxygen concentration.
- Reduces soil aggregation and physical protection of SOM. This results in the reduction of stable/older SOM.

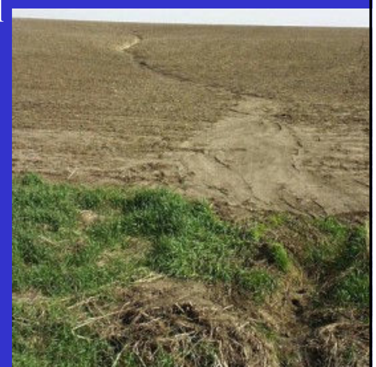
World Plowing record set in 2005:

* Plowed 321 ha in 24 hours
* Tillage depth was 27 cm
* Used 20 furrow plow and 410 KW tractor
* Used 2722 l of fuel = 8.5 l/ha

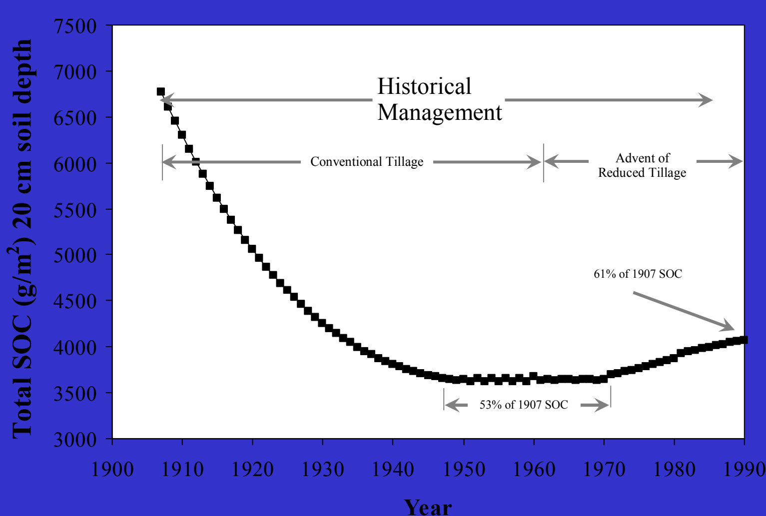
Tillage Reduce SOM

Residue Destruction

- Tillage:
- Mixes residue with microbes at the soil surface.
  - Large percentage of the plant C is lost as CO_2 during rapid decomposition process.
- Reduces residue length and placement at the surface.
  - Resulting in greater soil erosion
- Soil erosion results in the loss of topsoil, the soil with the highest concentration of organic matter.



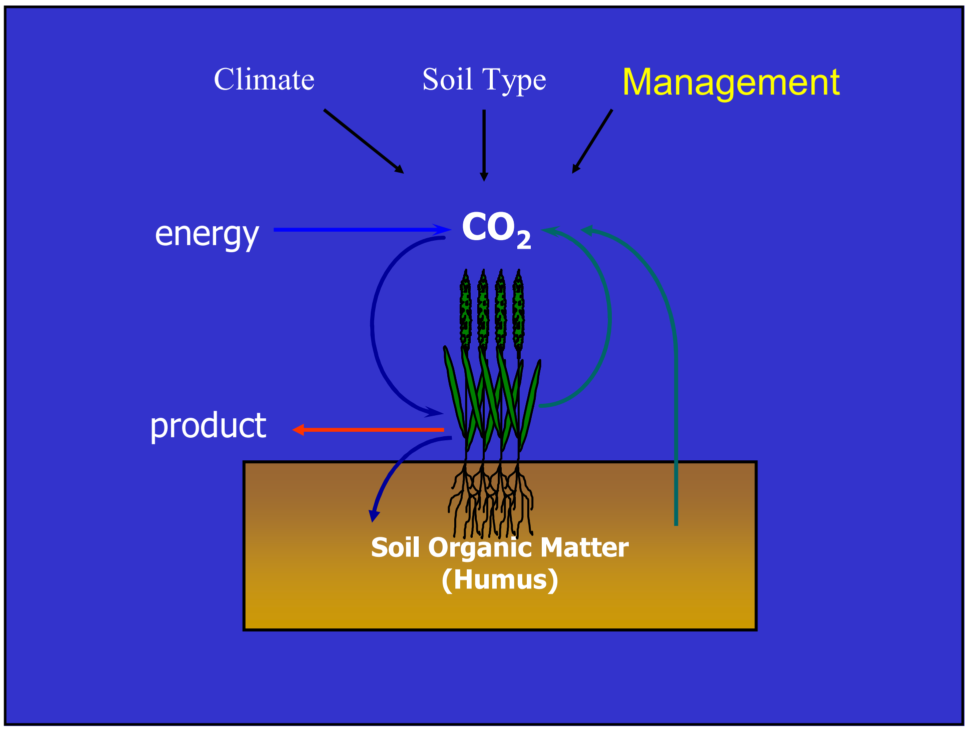
Historical Tillage and SOC



Ten Benefits of Conservation Tillage

1. Reduces labor, saves time
2. Saves fuel
3. Reduces machinery wear
4. Improves soil tilth
5. Increases organic matter
6. Traps soil moisture to improve water availability
7. Reduces soil erosion
8. Improves water quality
9. Increases wildlife
10. Improves air quality

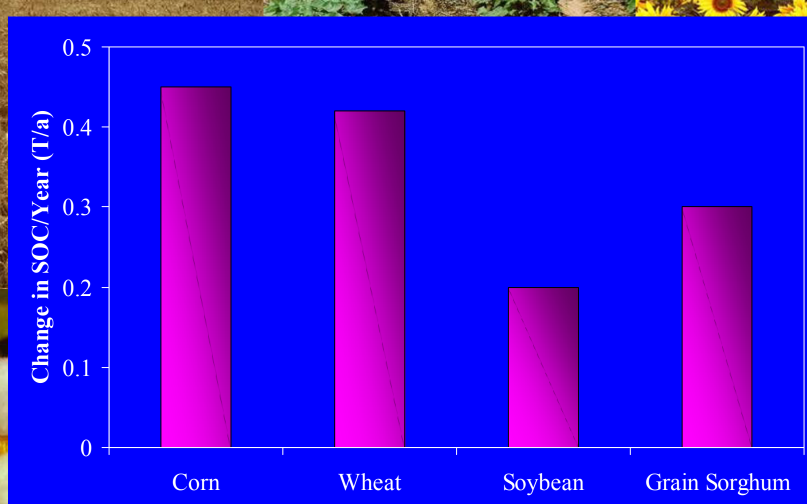
Source CTIC:http://www.ctic.purdue.edu/Core4/CT/CTSurvey/10Benefits.html



Factors Affecting Soil Organic C

- Plant Species
- Environment
  - Productivity (yield)
  - Decomposition/Mineralization rates
  - Soil Texture
- Management
  - Tillage
  - Cropping System Composition
  - Cropping System Itensity (Fallow)

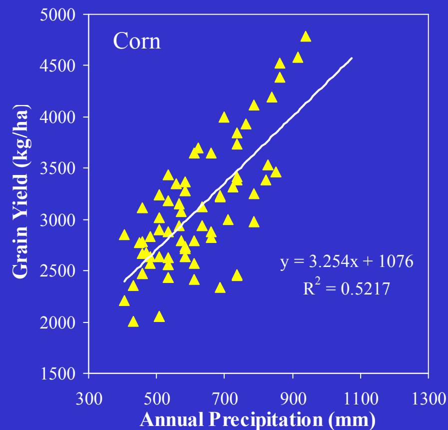
Crop Selection – SOC Sequestration
(Manhattan, KS)

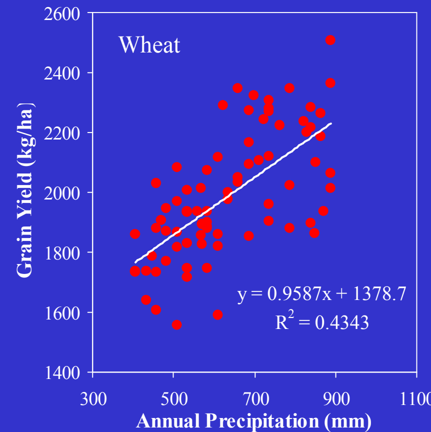


Environment and SOC sequestration

(Productivity)

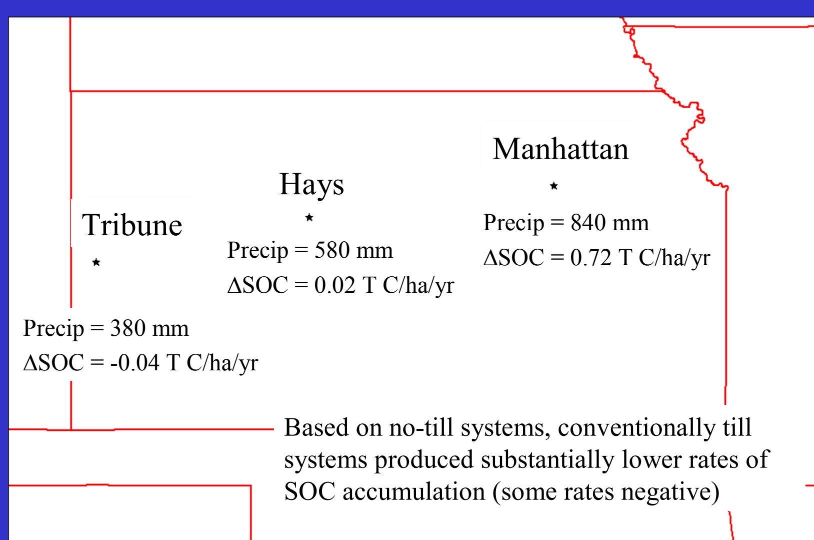
Growing season precipitation and temperatures dictate crop selection and crop yields.





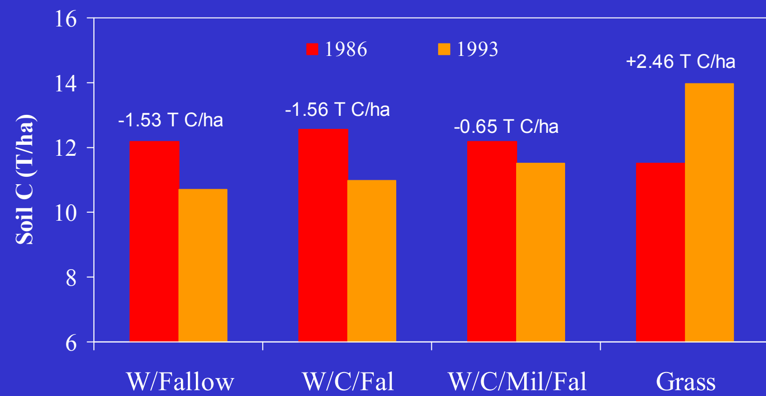
Environment and SOC

Wheat in Kansas



Cropping System Composition and SOC

Eastern Colorado (Sherrod et. al. 1995)



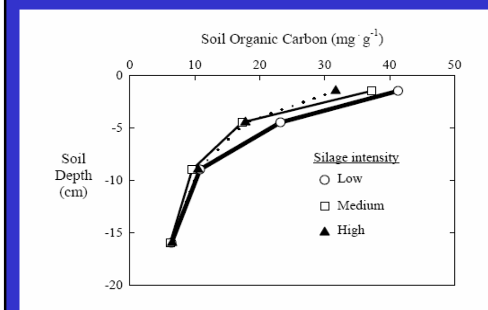
In an arid environment, reducing fallow periods slows the loss of SOC through increased residue production and reduced bare soil periods.

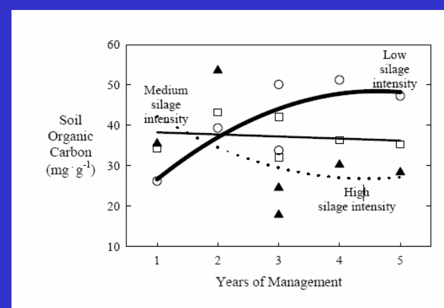
Biofuel Feedstocks = Fallow?

- Fallow reduces
- Is biomass removal the same as fallow?
  - No carbon inputs
  - Still have soil microbial activity (losses in SOC)
  - Increased soil temperatures (no residue on soil surface)

Biofuel Feedstock Production and SOC

- To get a handle on the impact of biofuel feedstock production, we have to look to the literature regarding silage production.

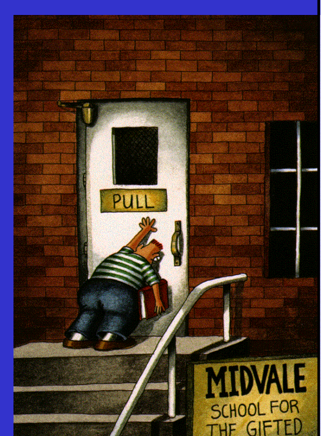




Franzluebbers et. al, 2003.

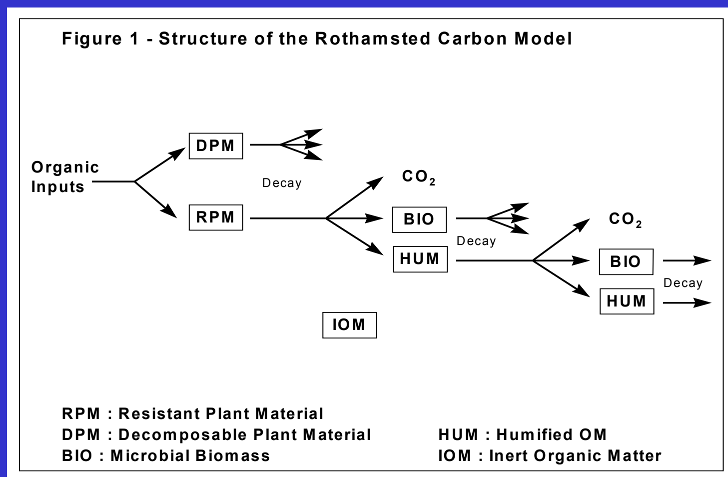
Modeling Soil C

- Cellulosic biomass removal
  - As we change from a feed/food system to a fuel system, the goals and outcomes change.
  - Will we remove all of the biomass in a given crop?
  - Will we remove all of the biomass from every crop in the rotation?
  - How do we manage cropping systems and biomass removal for biofuel feedstocks as environments become drier and less productive.
  - Several approaches can be taken



Soil Carbon Pools

(Roth C Model 26.3)

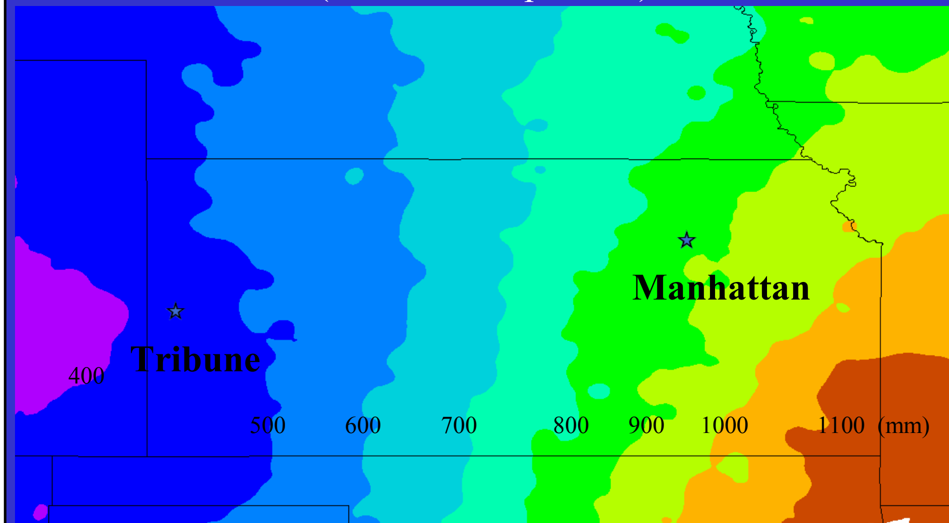


Soil Model Inputs

- Evaluate several rotations and locations
  - Environmental inputs
    - Temperature
    - Precipitation
  - Soil Inputs (Silt Loam Soil)
    - Soil carbon levels (initial pools) = 2.2% O.M
    - Clay content = 25%
    - Layer depth = 0.3 m
  - Crop Inputs
    - Residue amounts
    - Decomposition characteristics

Simulation Locations

(Annual Precipitation)



Soil Model Inputs

- Crop Residue Inputs
  - Two long term studies
    - Continuous corn (NT, CT) at Manhattan
    - Wheat-Sorghum-Fallow at Tribune, KS
  - Kansas Crop Performance Test
    - Corn, grain sorghum, soybean, wheat evaluated annually at approximately 10 to 15 locations in the state.
    - Database of most data is available back to 1992.
    - Use harvest indices to convert grain yields to biomass

Soil Model Inputs

- Photoperiod sensitive forage sorghum
  - Kansas Crop Performance Test
    - Evaluated forage sorghum at three locations from 2003 through 2005.
    - Used grain sorghum VPT tests at same locations to develop a "model" to estimate PS forage sorghum values.

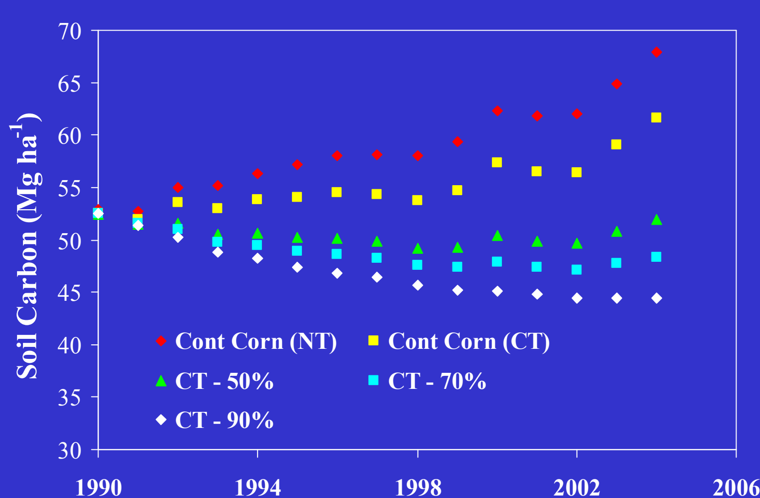
- Switchgrass
  - Modeled with Almanac using information from Manhattan, KS.

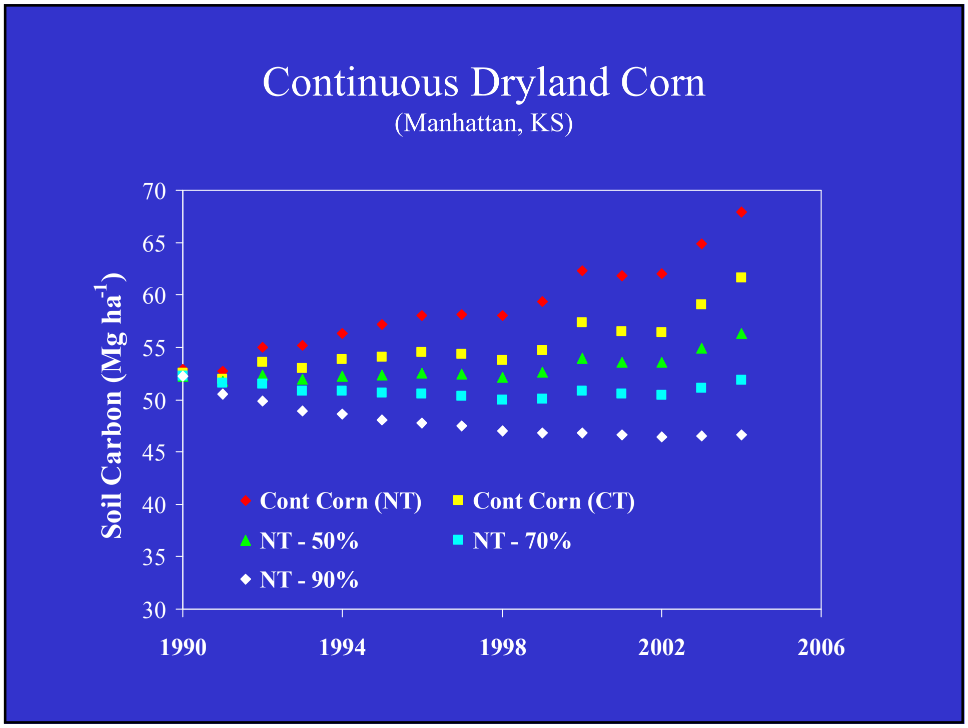
- Imposed harvest removal rates of 50, 70, and 90% within several cropping sequences at each location.

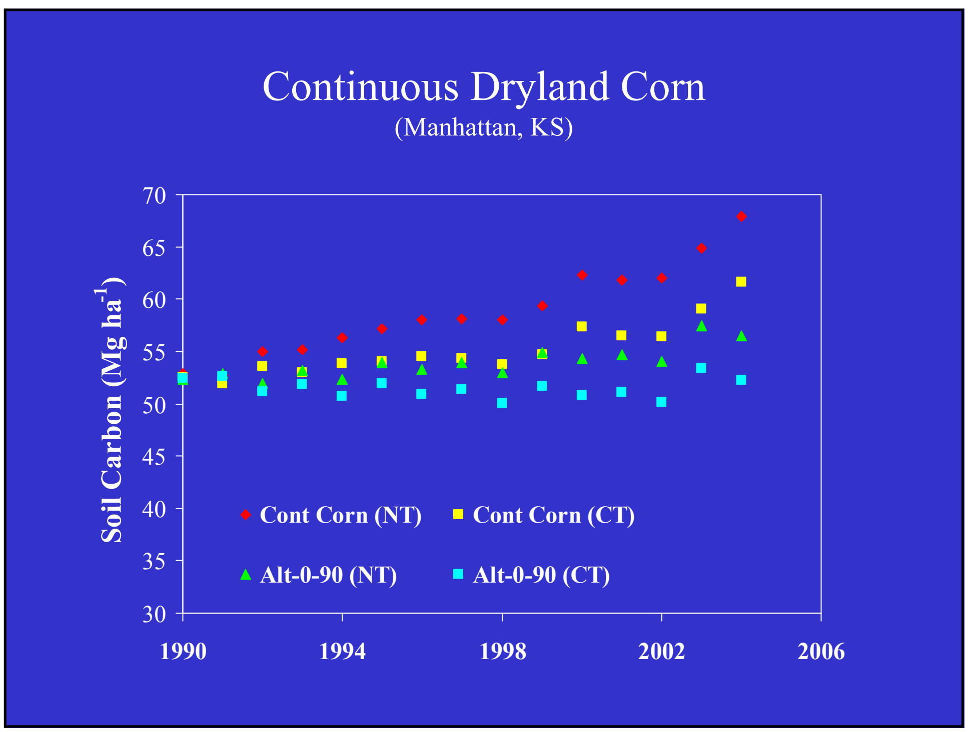
Biofuel Feedstock Production
(Manhattan, KS 2007)

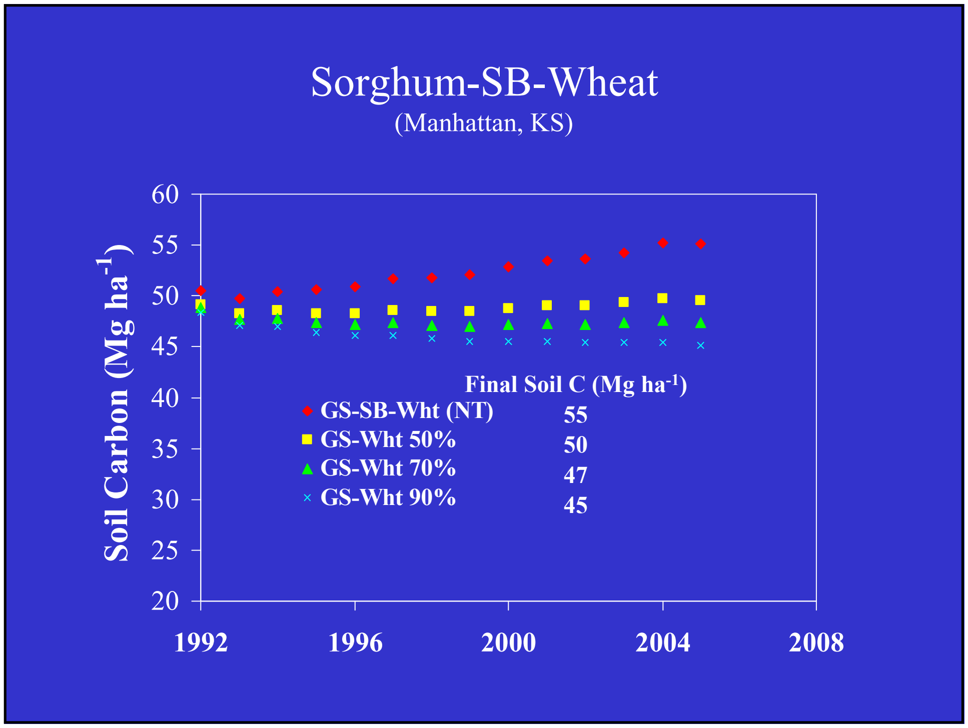
Species	Grain Yield (bu/a)	Dry D.M. (ton/a)	Total Yield (ton/a)
Corn	177	2.1	7.0
Forage Sorghum	105	1.0	4.0
BMR Forage Sorghum	73	3.0	5.1
P.S. Forage Sorghum	0	11.9	11.9
Sweet Sorghum	30	8.5	9.3
Miscanthus			1.2
Switchgrass			1.7
Big Bluestem			1.7

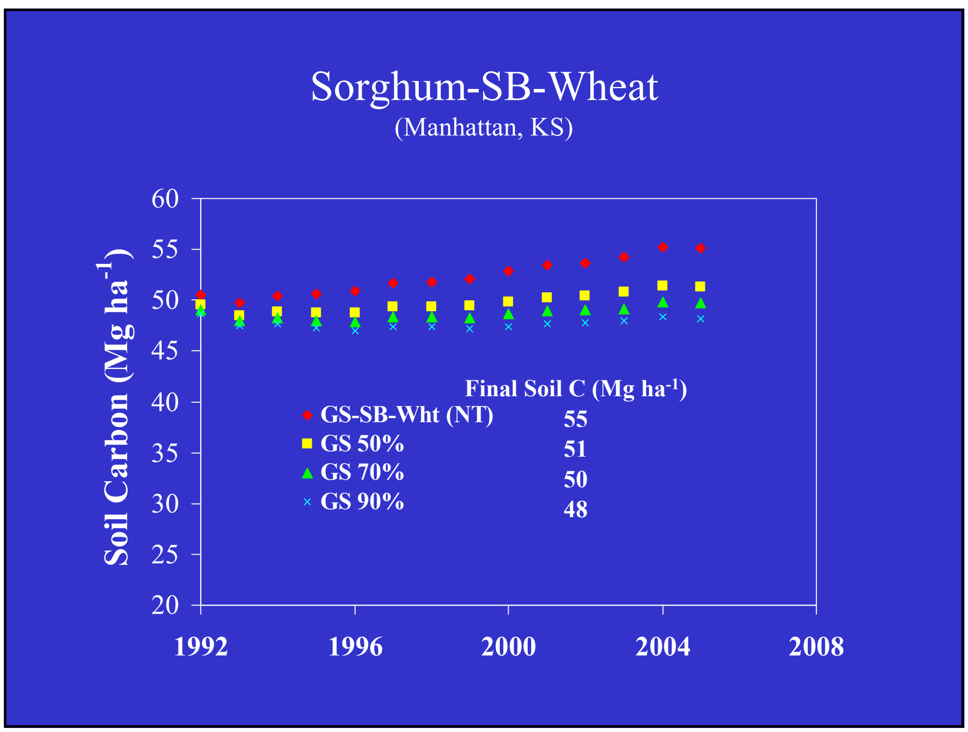
Continuous Dryland Corn
(Manhattan, KS)

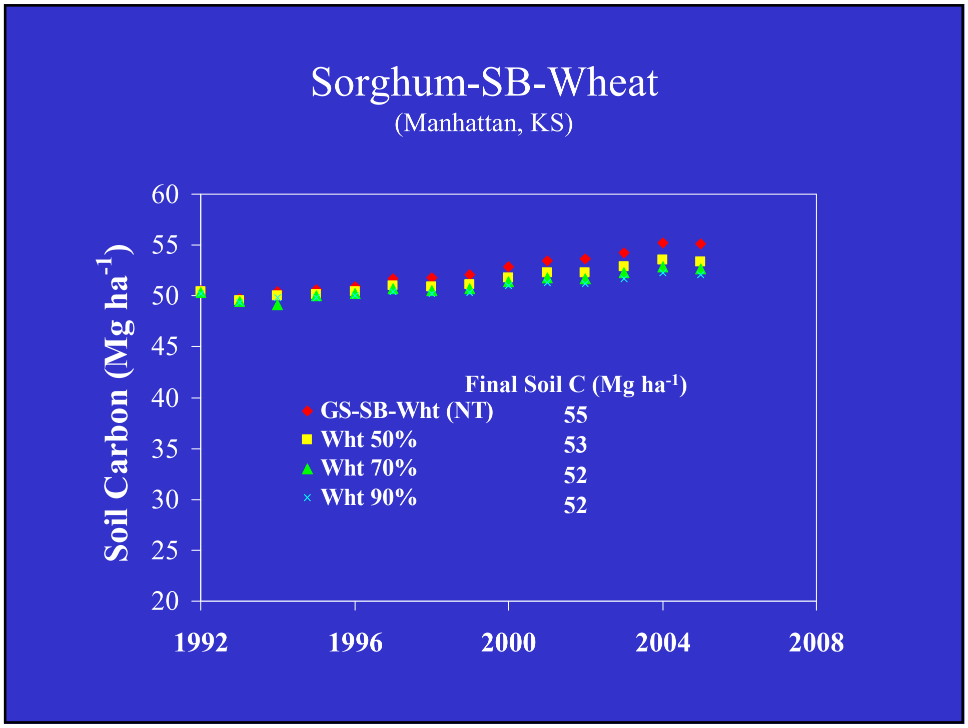



Continuous Dryland Corn
(Manhattan, KS)
Soil Carbon (Mg ha-1)
70
65
60
55
50
45
40
35
30
1990
1994
1998
2002
2006
Cont Corn (NT)
Cont Corn (CT)
NT - 50%
NT - 70%
NT - 90%

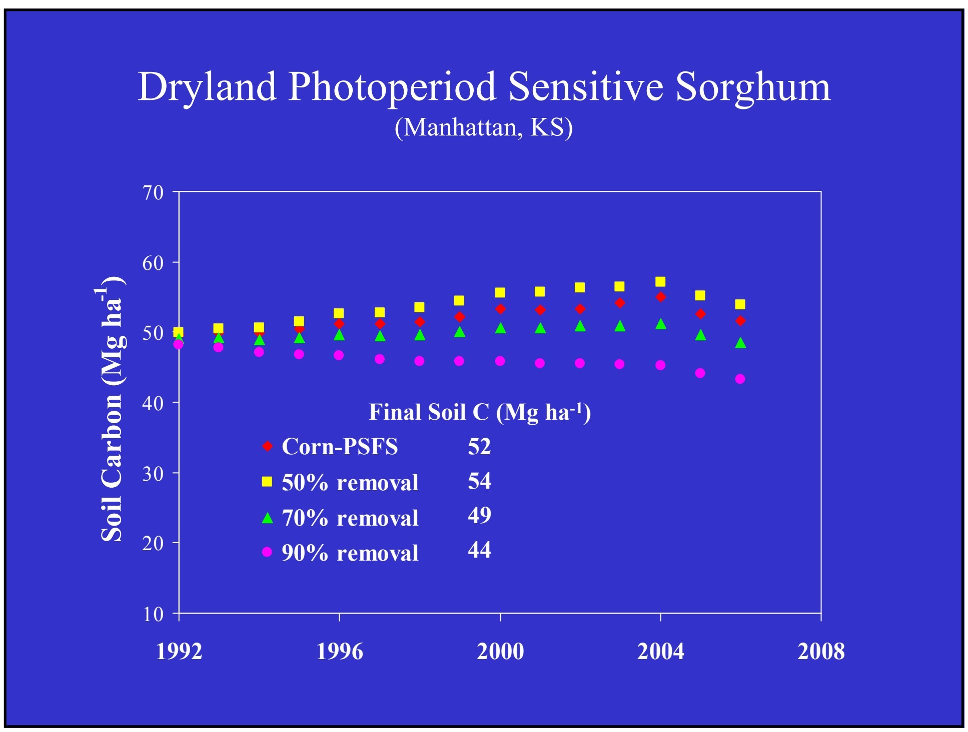

Continuous Dryland Corn
(Manhattan, KS)
Soil Carbon (Mg ha-1)
70
65
60
55
50
45
40
35
30
1990
1994
1998
2002
2006
Cont Corn (NT)
Cont Corn (CT)
Alt-0-90 (NT)
Alt-0-90 (CT)


Sorghum-SB-Wheat
(Manhattan, KS)
Soil Carbon (Mg ha-1)
60
55
50
45
40
35
30
25
20
1992
1996
2000
2004
2008
Final Soil C (Mg ha-1)
GS-SB-Wht (NT) 55
GS-Wht 50% 50
GS-Wht 70% 47
GS-Wht 90% 45

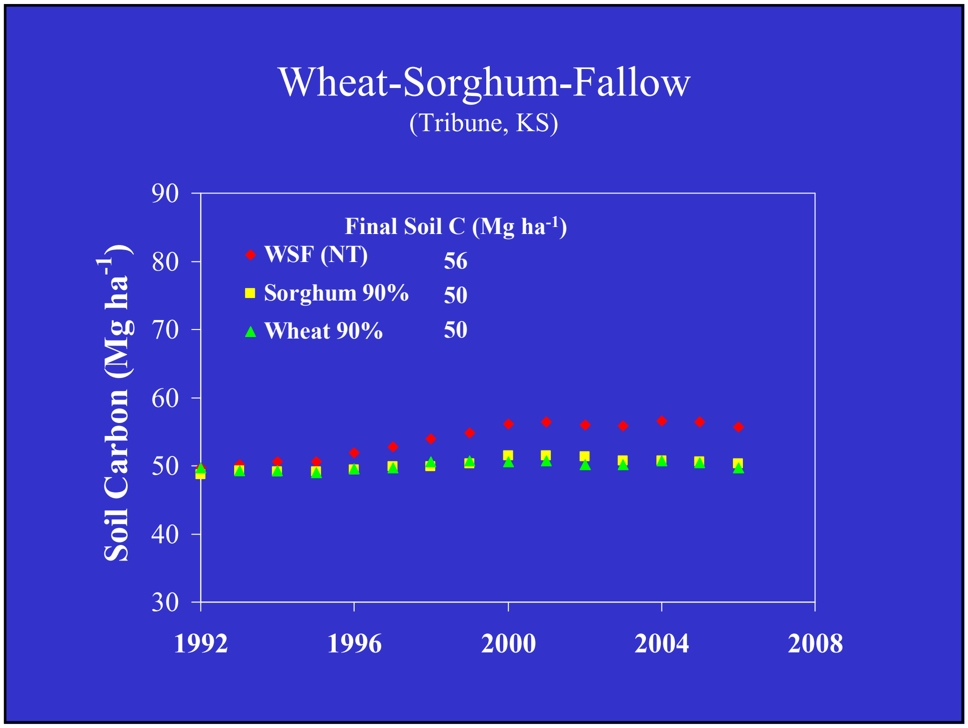

Sorghum-SB-Wheat
(Manhattan, KS)
Soil Carbon (Mg ha-1)
60
55
50
45
40
35
30
25
20
1992
1996
2000
2004
2008
Final Soil C (Mg ha-1)
GS-SB-Wht (NT) 55
GS 50% 51
GS 70% 50
GS 90% 48



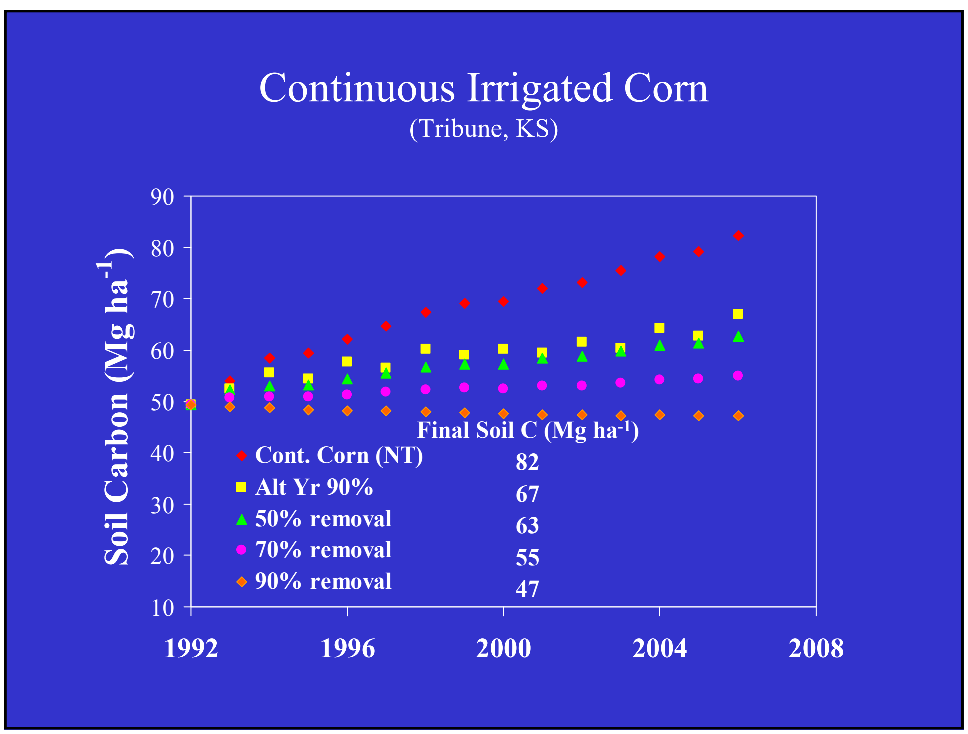
Sorghum-SB-Wheat
(Manhattan, KS)
Soil Carbon (Mg ha-1)
60
55
50
45
40
35
30
25
20
1992
1996
2000
2004
2008
Final Soil C (Mg ha-1)
GS-SB-Wht (NT) 55
Wht 50% 53
Wht 70% 52
Wht 90% 52



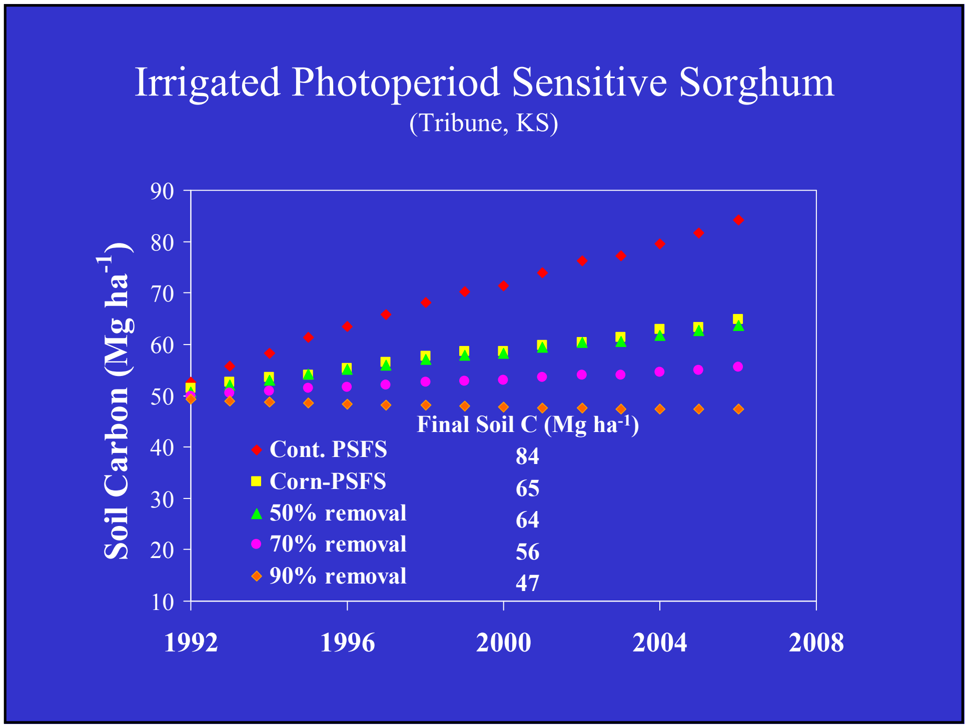
Dryland Photoperiod Sensitive Sorghum
(Manhattan, KS)
Soil Carbon (Mg ha-1)
70
60
50
40
30
20
10
1992
1996
2000
2004
2008
Final Soil C (Mg ha-1)
Corn-PSFS 52
50% removal 54
70% removal 49
90% removal 44

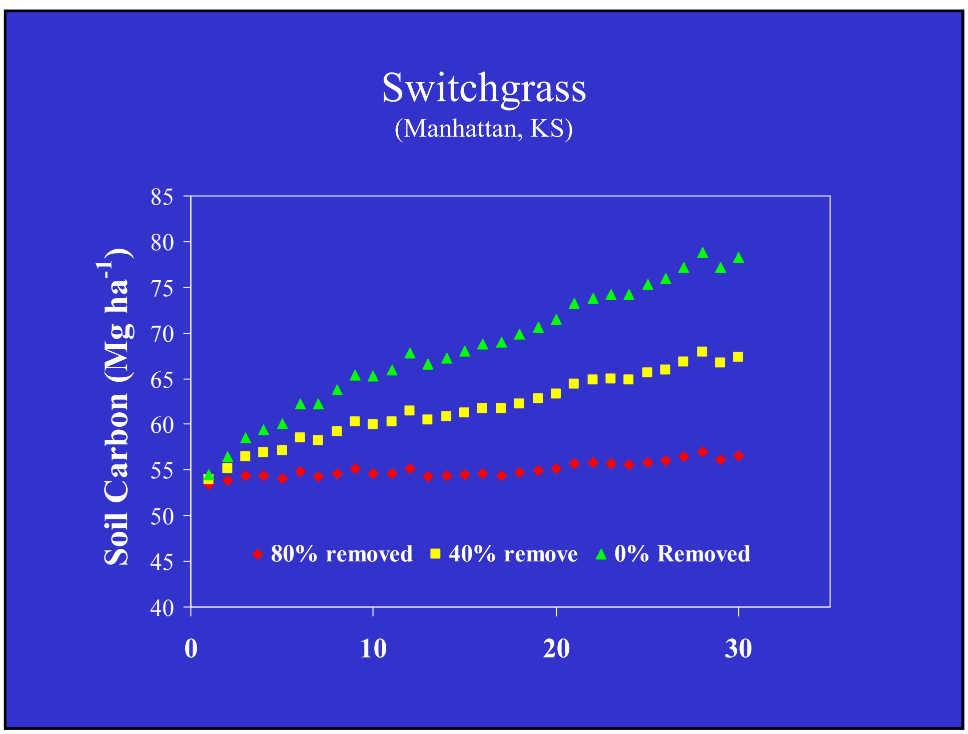


Wheat-Sorghum-Fallow
(Tribune, KS)
Soil Carbon (Mg ha-1)
90
80
70
60
50
40
30
1992
1996
2000
2004
2008
Final Soil C (Mg ha-1)
WSF (NT) 56
Sorghum 90% 50
Wheat 90% 50



Continuous Irrigated Corn
(Tribune, KS)
Soil Carbon (Mg ha-1)
90
80
70
60
50
40
30
20
10
1992
1996
2000
2004
2008
Final Soil C (Mg ha-1)
Cont. Corn (NT) 82
Alt Yr 90% 67
50% removal 63
70% removal 55
90% removal 47


Irrigated Photoperiod Sensitive Sorghum
(Tribune, KS)
Soil Carbon (Mg ha-1)
90
80
70
60
50
40
30
20
10
1992
1996
2000
2004
2008
Final Soil C (Mg ha-1)
Cont. PSFS 84
Corn-PSFS 65
50% removal 64
70% removal 56
90% removal 47


Switchgrass
(Manhattan, KS)
Soil Carbon (Mg ha-1)
85
80
75
70
65
60
55
50
45
40
0
10
20
30
80% removed
40% remove
0% Removed

Conclusions

- No-till cropping systems will be essential to maintaining soil carbon levels in biofuel feedstock systems. Even more critical to soil erosion potential.
- Cropping systems that remove approximately 70% or less of the biomass appears to have the greatest potential at maintaining SOC levels.
- Alternating biomass and grain crops appears to have potential in maintaining SOC levels.