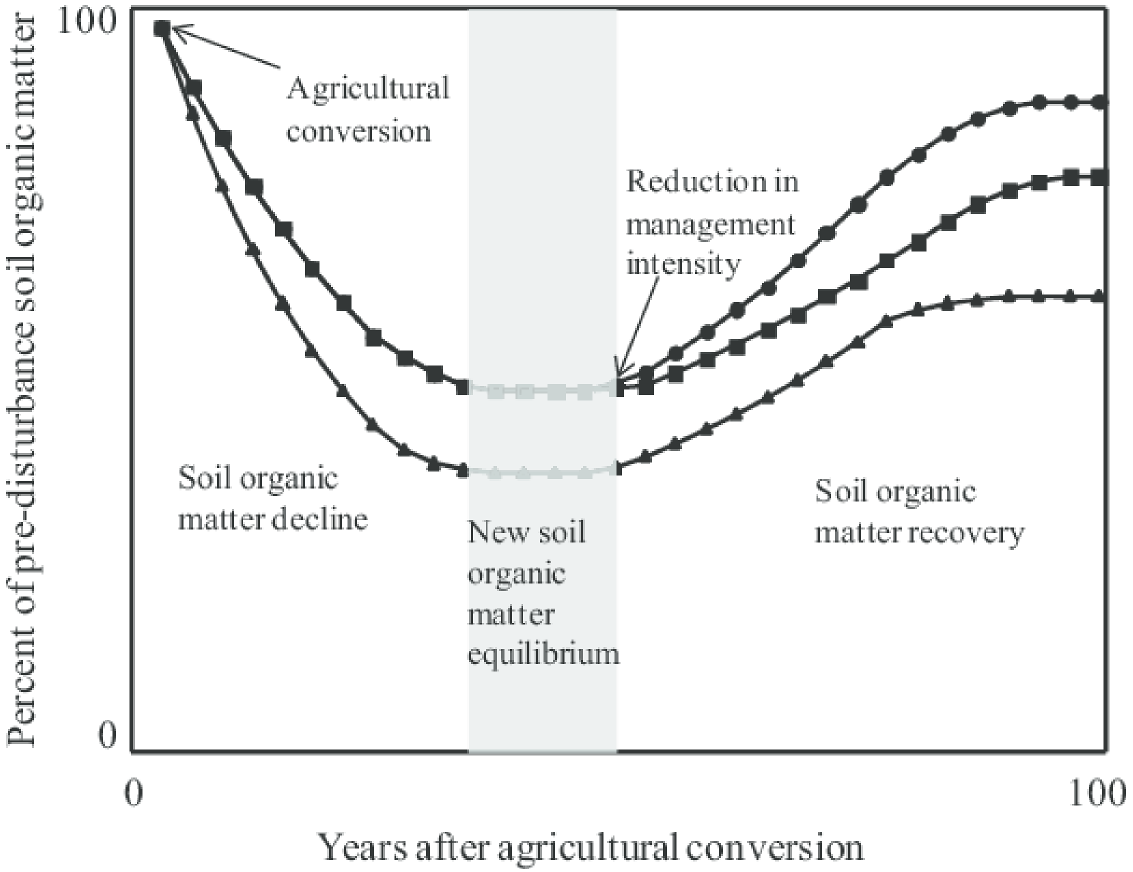
Changes in soil management and soil organic carbon

David Clay

South Dakota State University

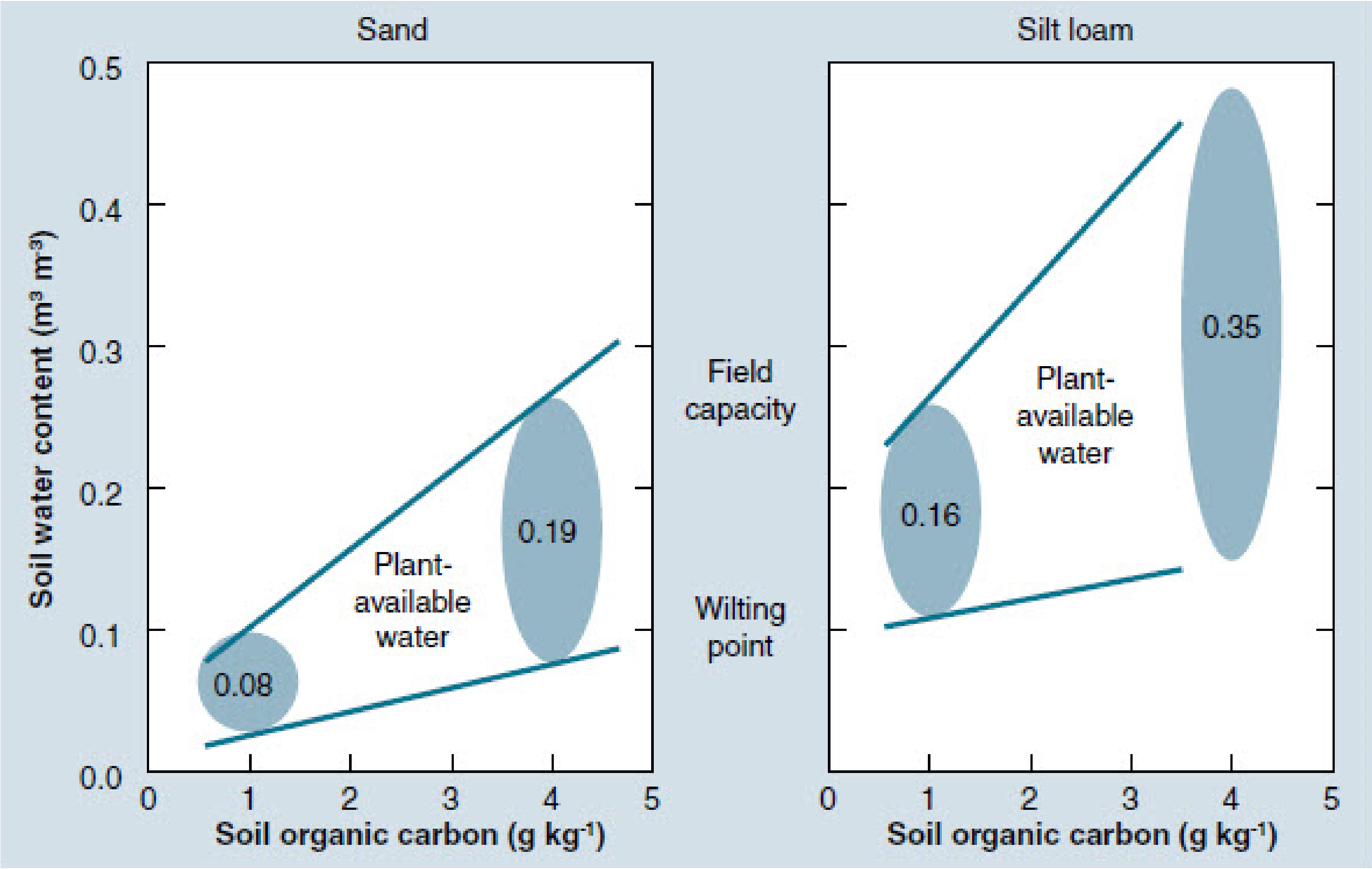
Funding provided by SDSU and South Dakota Corn Utilization Council

Why we care about soil organic matter



Why do we care about soil organic carbon

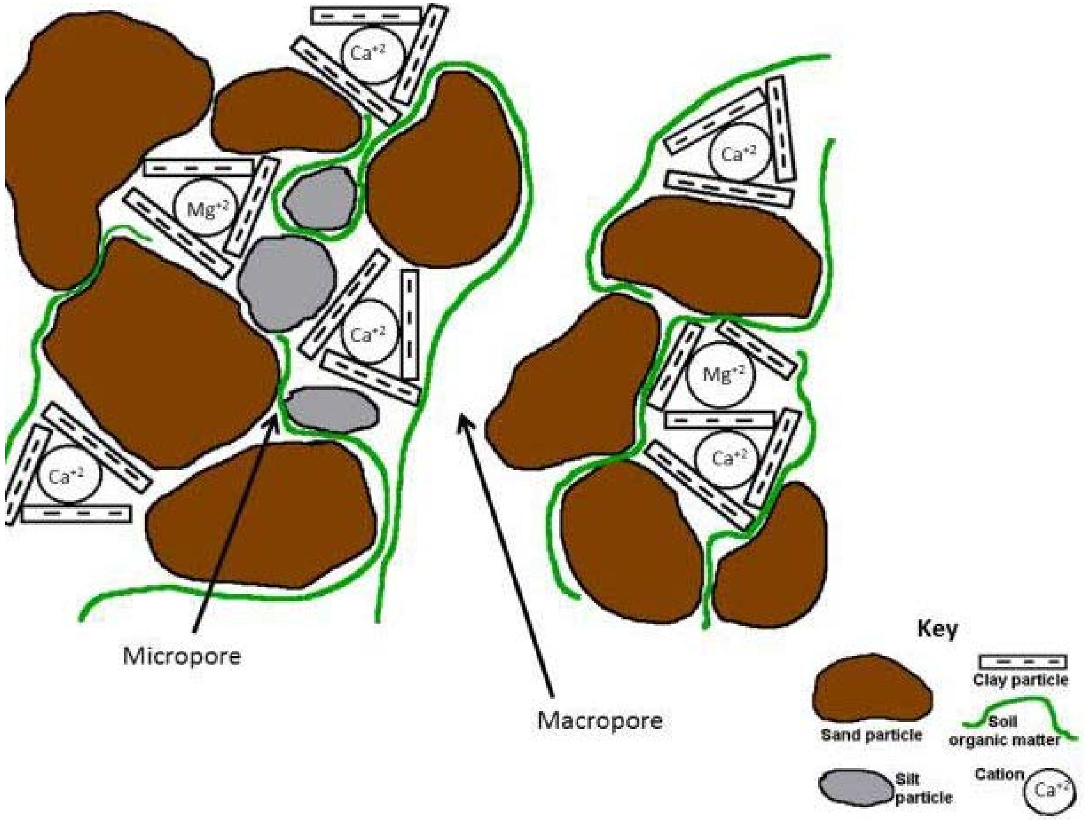
Influences soil water holding capacity



1% increase in soil organic matter can increase water storage by 25,000 gallons/a

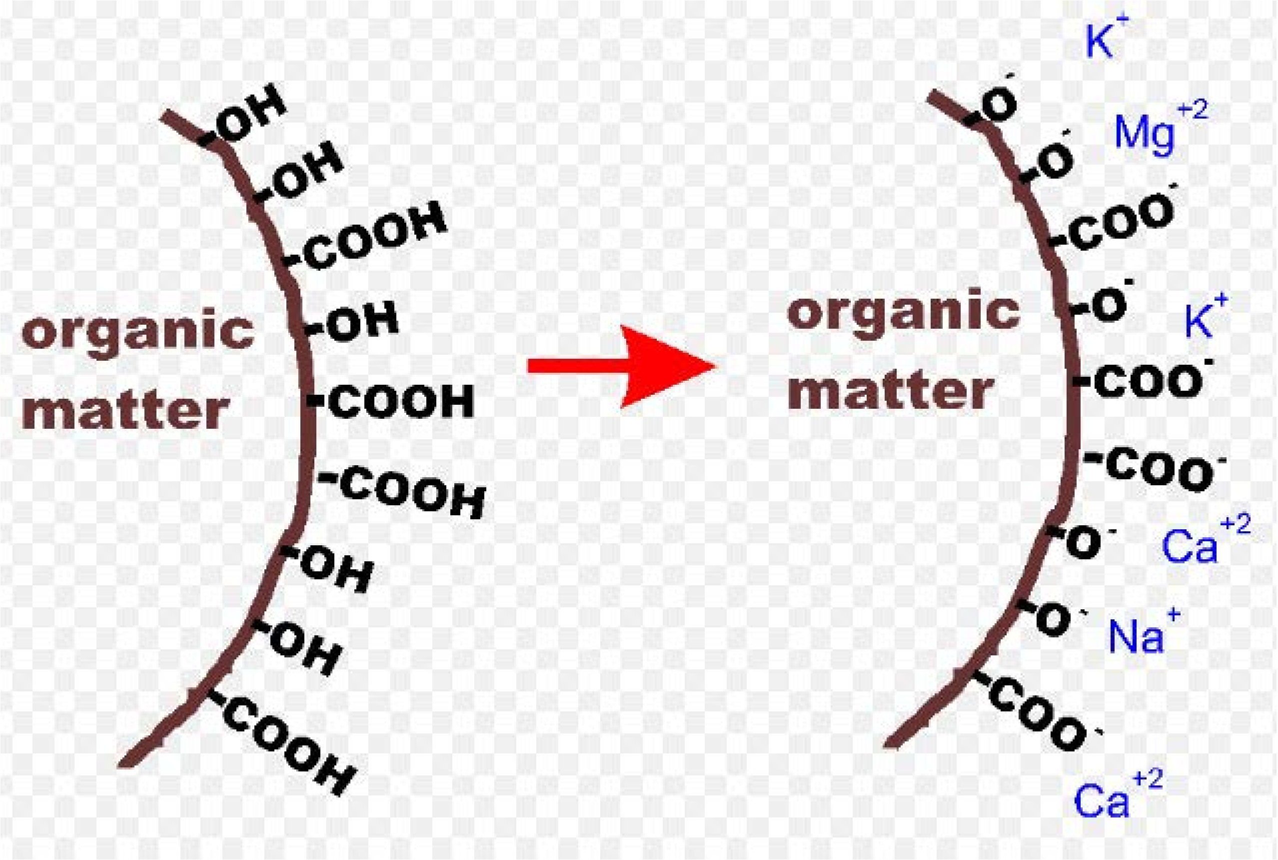
Why do we care about soil organic matter

Soil organic matter helps hold the soil together. The soil structure influences water flow



Why do we care about soil organic matter

Soil organic matter increases the amount of charges contained in the soil. These changes help the soil retain nutrients.



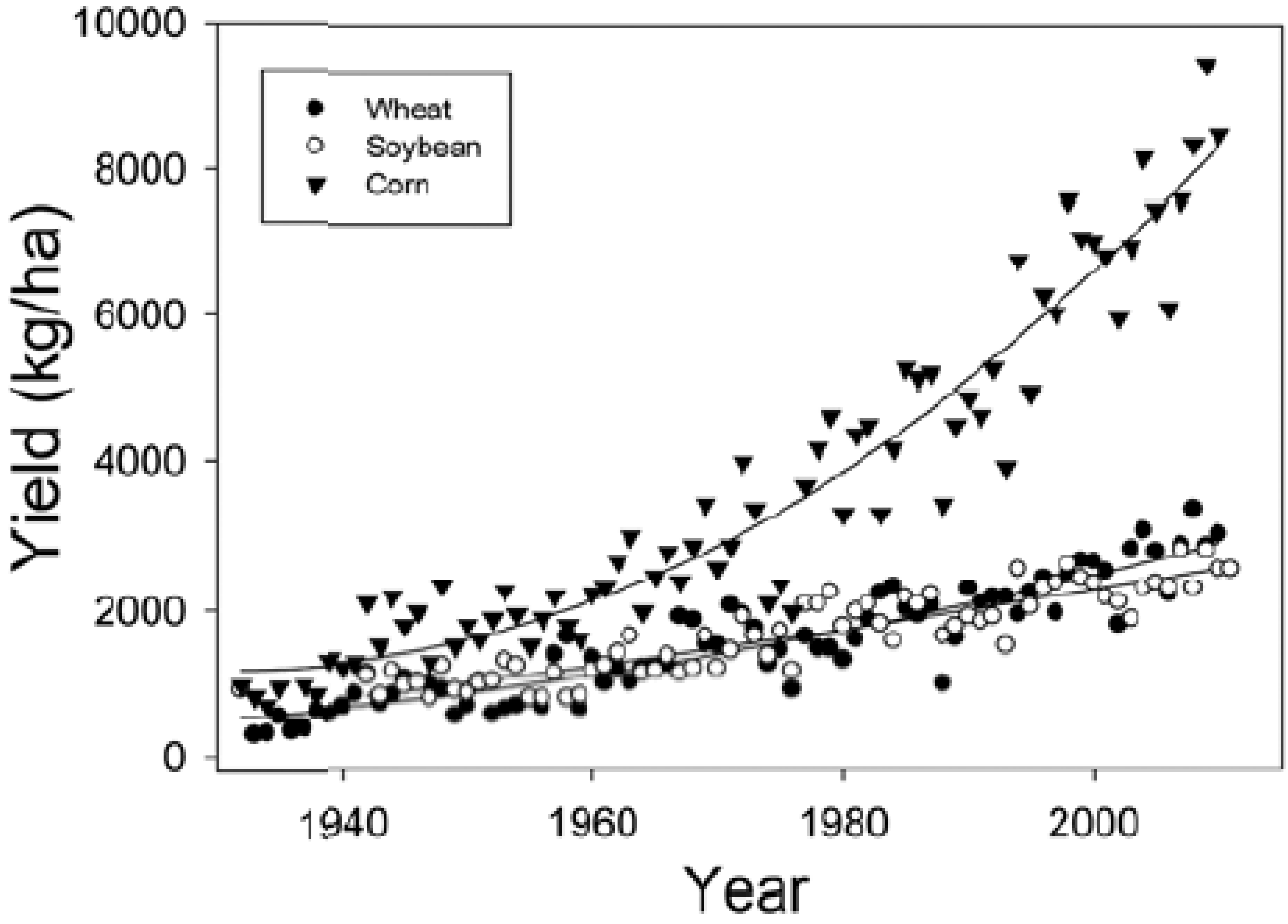
What are the risks of depleting the soil organic matter.

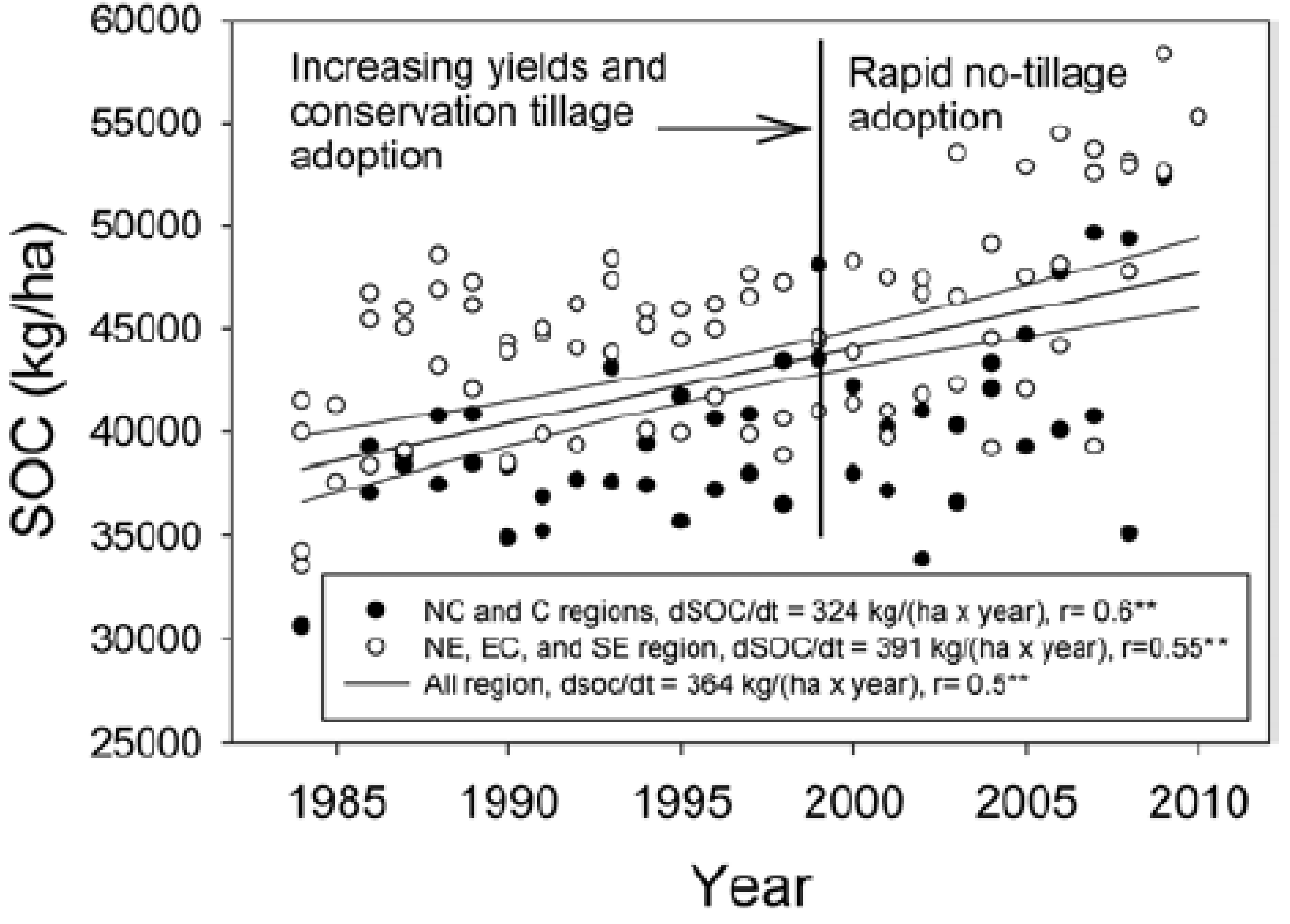
Where are we at:
South Dakota

Region	Bulk density	2004–2007		
		Surveys	Planted corn	No-till adoption
	g cm^{-3}	no.	ha*1000	%
North-central	1.35	934	338	97
Central	1.31	2035	251	68
Northeast	1.29	3289	276	20
East-central	1.24	6777	436	11
Southeast	1.25	3289	434	29

Clay et al., (2012).

Yields: South Dakota





At the same time that SOC was increasing in SD, erosion losses decreased

Causarono et al., 2008, JEQ 37:1345-1353.

Iowa

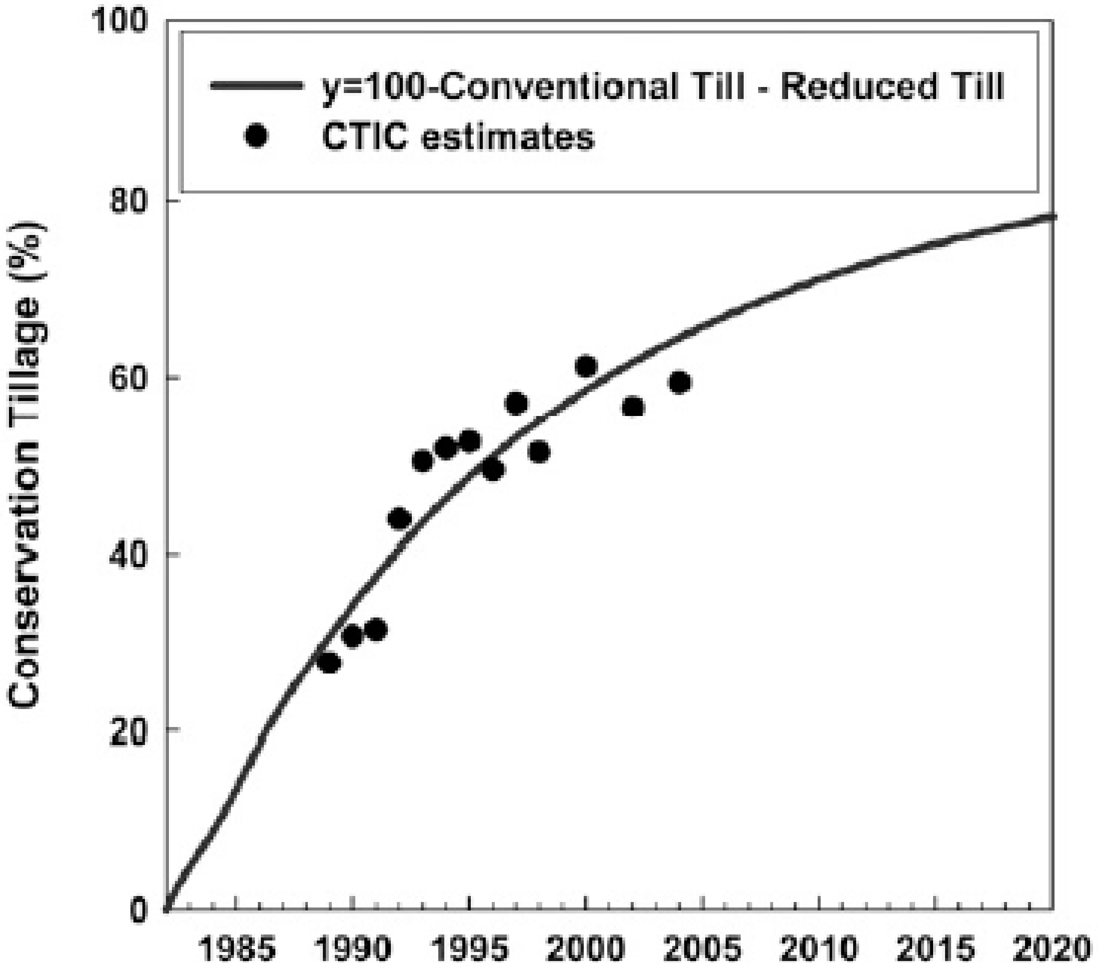
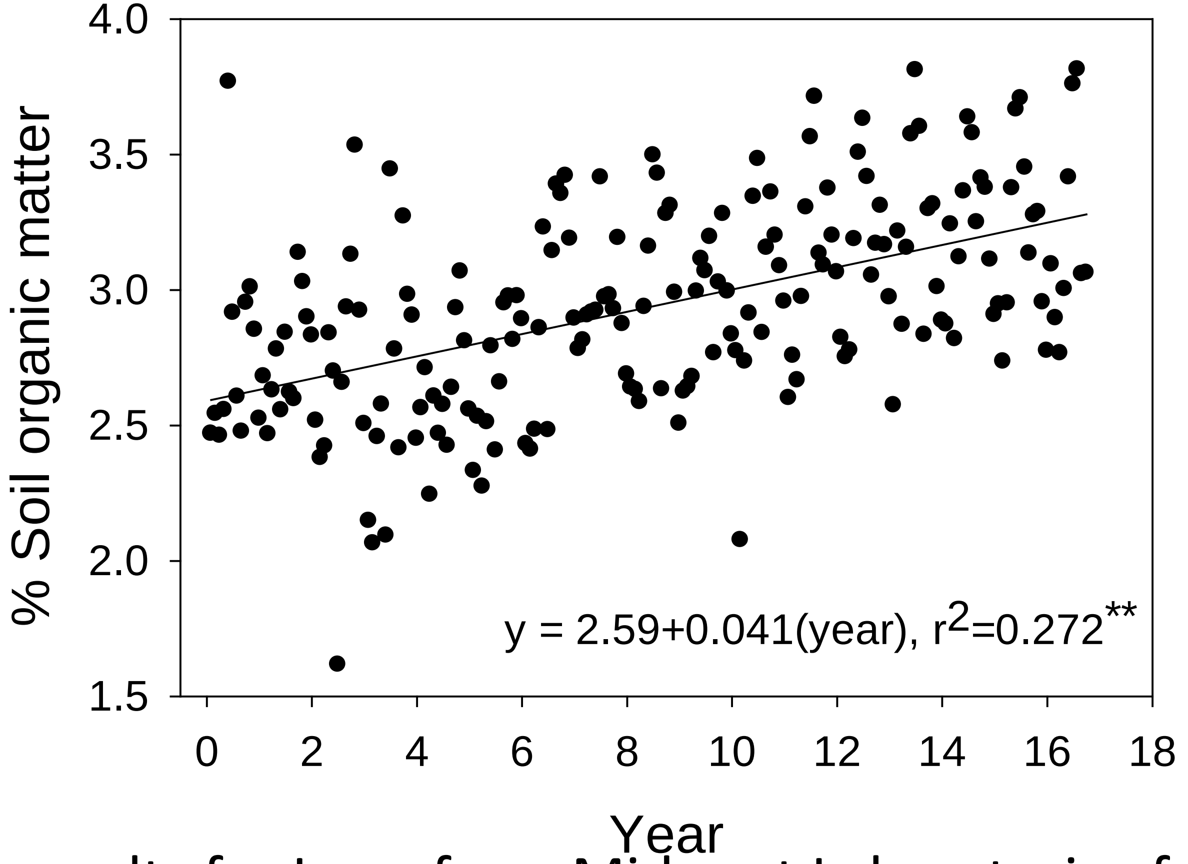


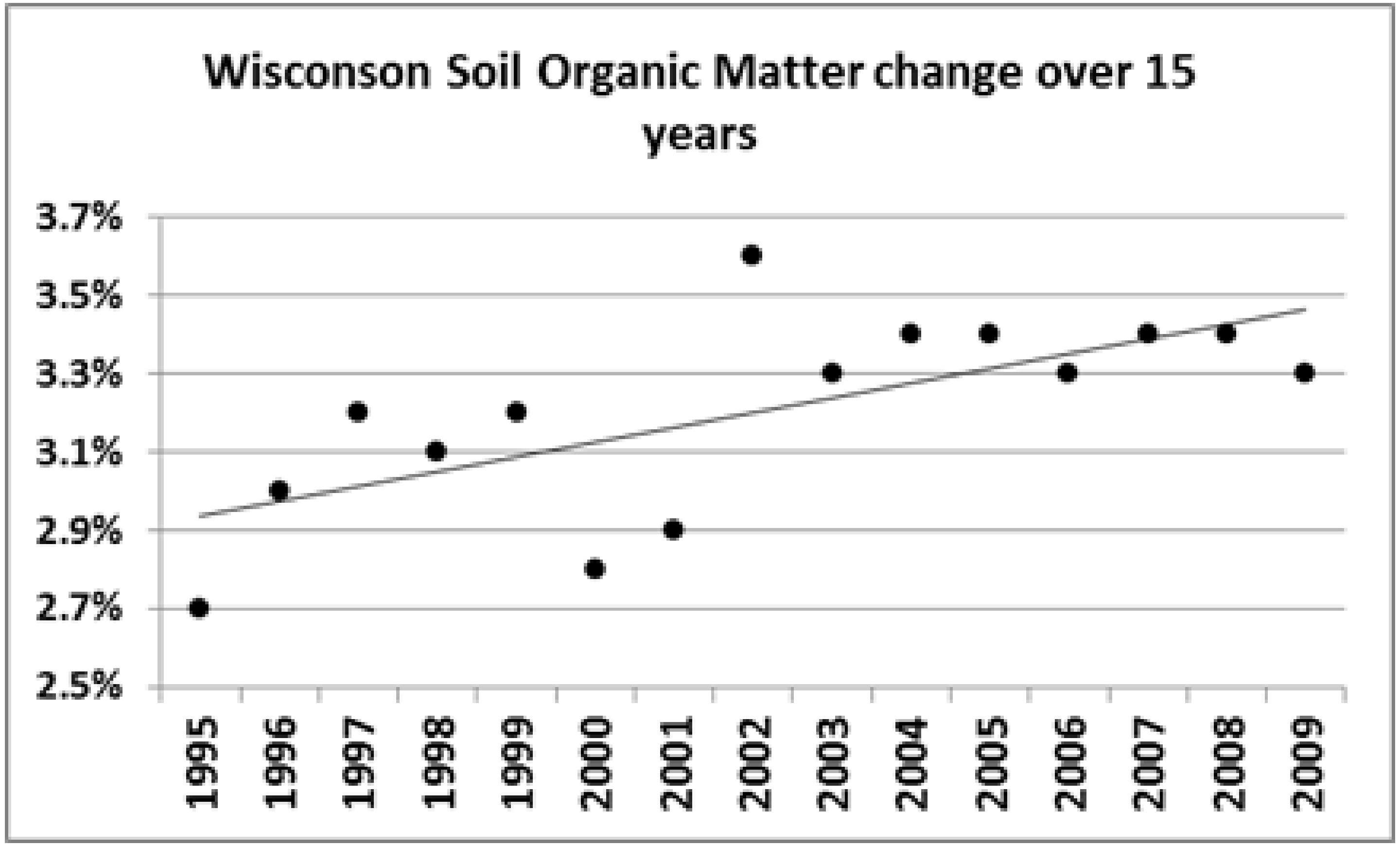
Fig. 2. Adoption of conventional tillage, reduced tillage, and conservation tillage in the state of Iowa. Dots are Conservation Tillage Information Center (CTIC) estimates; solid lines are the estimated adoption of a particular tillage system.

Iowa soil organic matter from 1997 to 2013



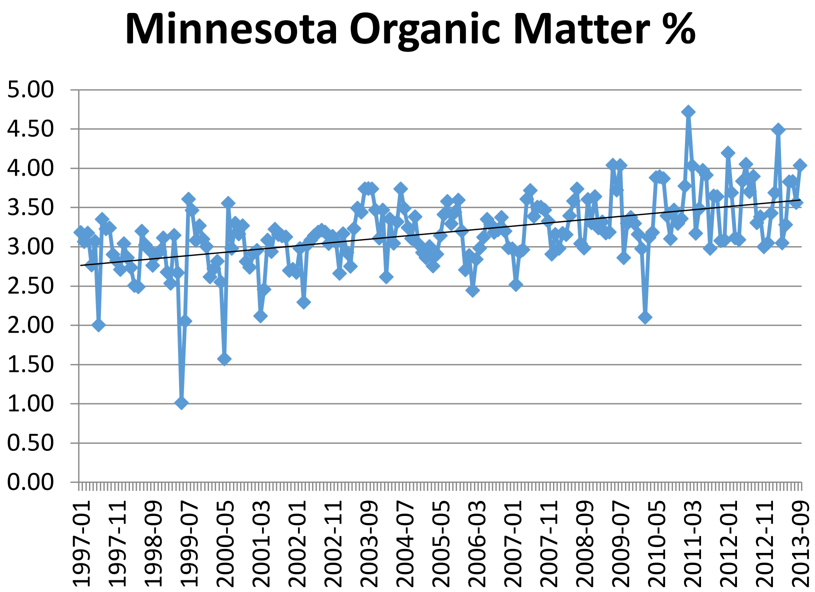
Soil test results for Iowa from Midwest Laboratories from 1997 to 2013. In this chart, year 0 is 1997. Data provided in this chart were provided by Midwest Laboratories. These samples, were collected from the production fields similar to Clay et al. (2012).

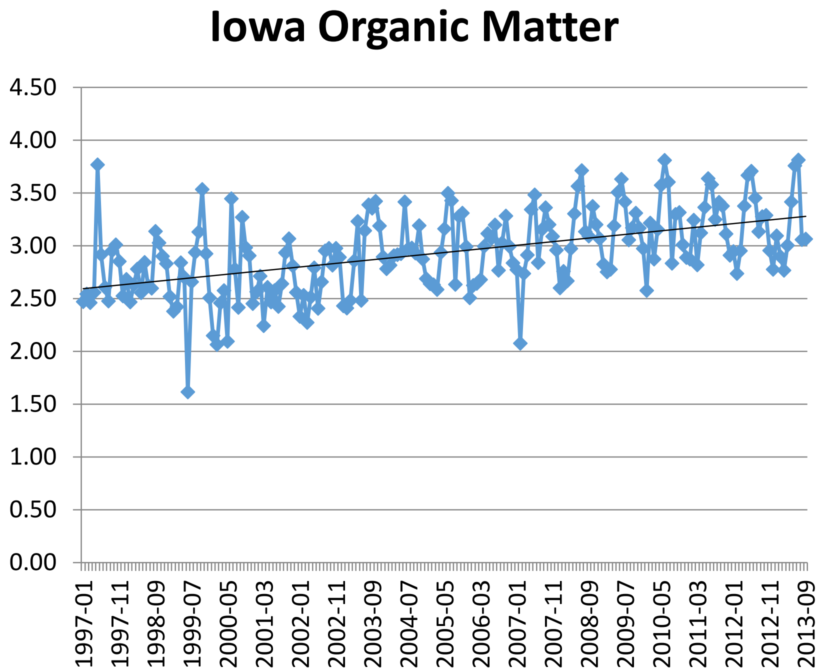
Wisconsin

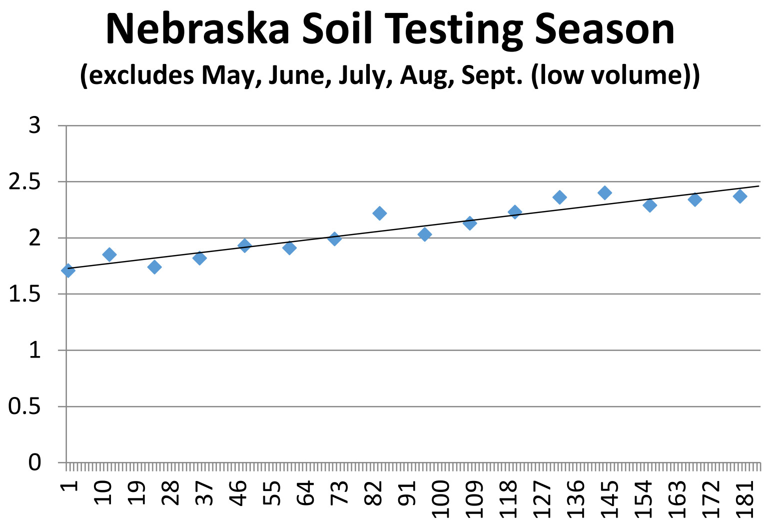


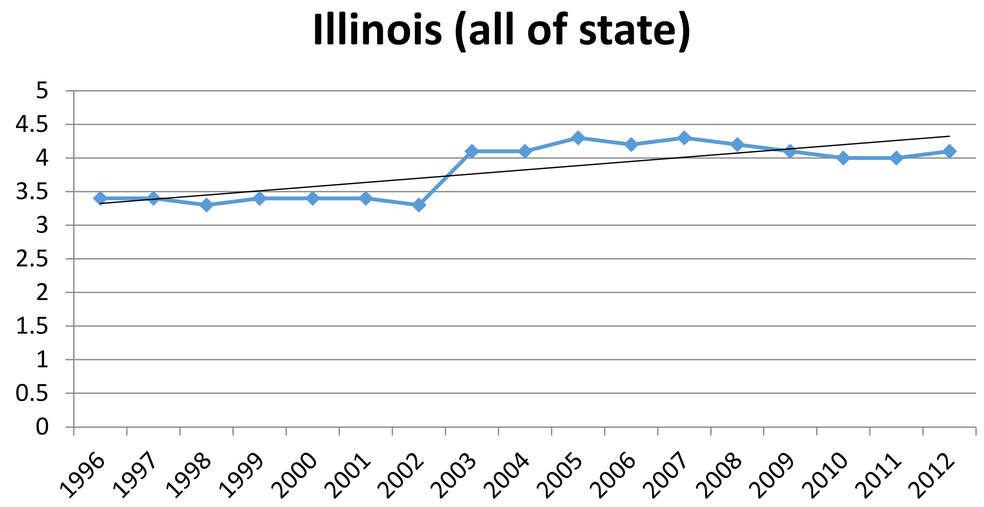
Midwest labs. Over half a million soil samples collected from farmers fields in Wisconsin that shows that C has been stored in the soil.

Other States:









Summary

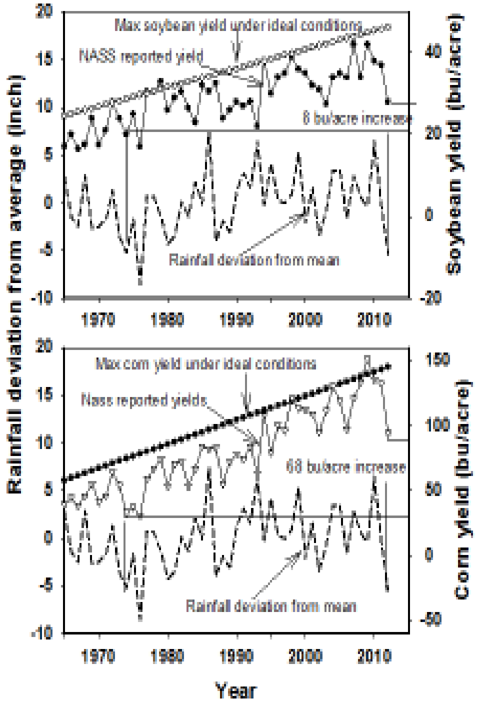
- Findings from these soil samples represent millions of samples that were collected over many years. These samples were collected from farmers that rely on soil sampling for fertilizer recommendations.

- The samples were collected from fields, where the producer is attempting to optimize yields and minimize fertilizer costs. They are soil sampling in order to apply to appropriate amount of fertilizer.

Does the increase in soil carbon matter?

- In 2012, the United States experienced one of the most severe droughts over the last 25 years.
- The drought reduced yields at numerous locations across the Midwest.
- The Congressional Budget Office, estimated that there was around a 14 billion dollar liability to the crop insurance program.

Management + genetics improvements have increased the resilience of our cropping systems



Compare drought of 1974 vs 2012

- Increased SOC and adoption of conservation practices increased plant available water 4.55 cm in 2012.
- Increased water had a 1 billion dollars impact on SD crop production in 2012.
- It is likely that similar responses occurred across the region

Crop	1974 (kg/ha)	2012 (kg/ha)
Wheat	1230 (18bu/acre)	3070 (46 bu/acre)
Soybean	1340 (20 bu/acre)	2012 (30 bu/acre)
Corn	2060 (33 bu/acre)	6321 (100 bu/acre)

Management improvements has reduced evaporation and increased soil water storage.

Return in 2012 (compared to 1974) due to increased water

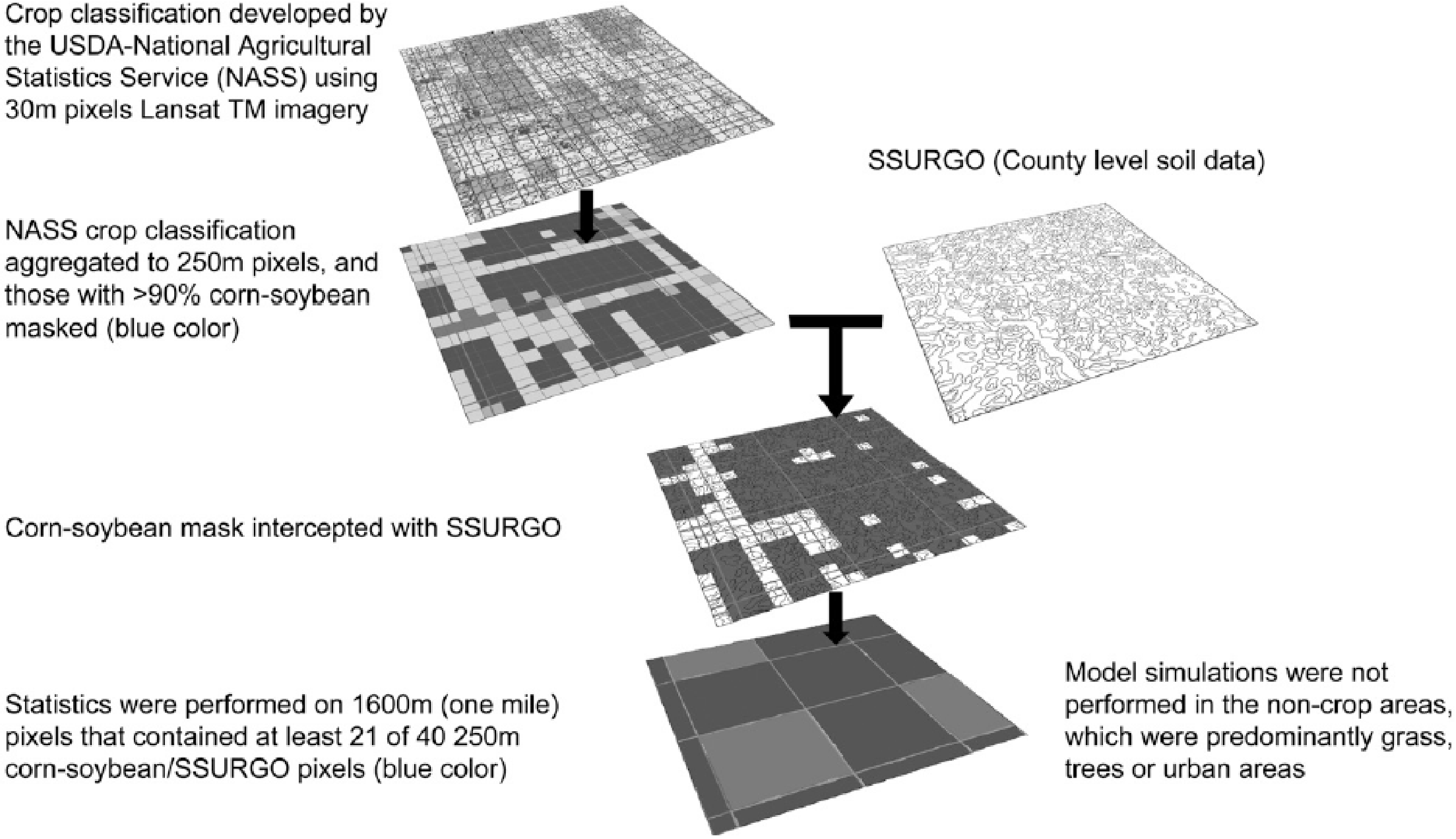
Crop	Inches of water	Acres	WUE	Price	Return due To water
	State	million	Bu/inch	$/bu	$ million
Corn	1.61	5.2	8.81	7.25	534
Soybean	1.61	4.1	3.60	14.25	338
Wheat	1.61	2.43	5.85	7.83	177
Total		11.73			1,050

This results in an annual return of $89.6/acre resulting from increased water

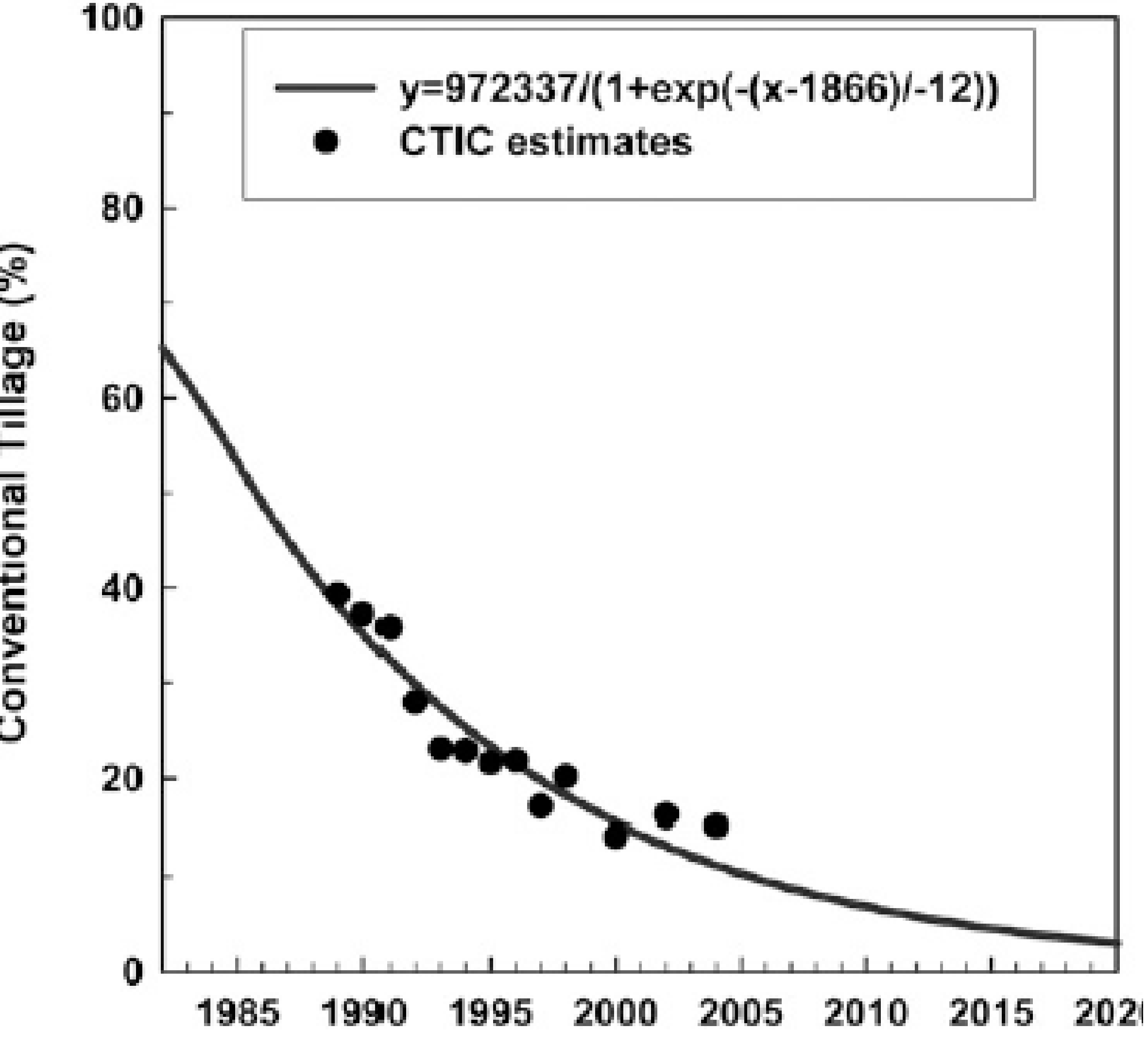
We care about soil organic matter because

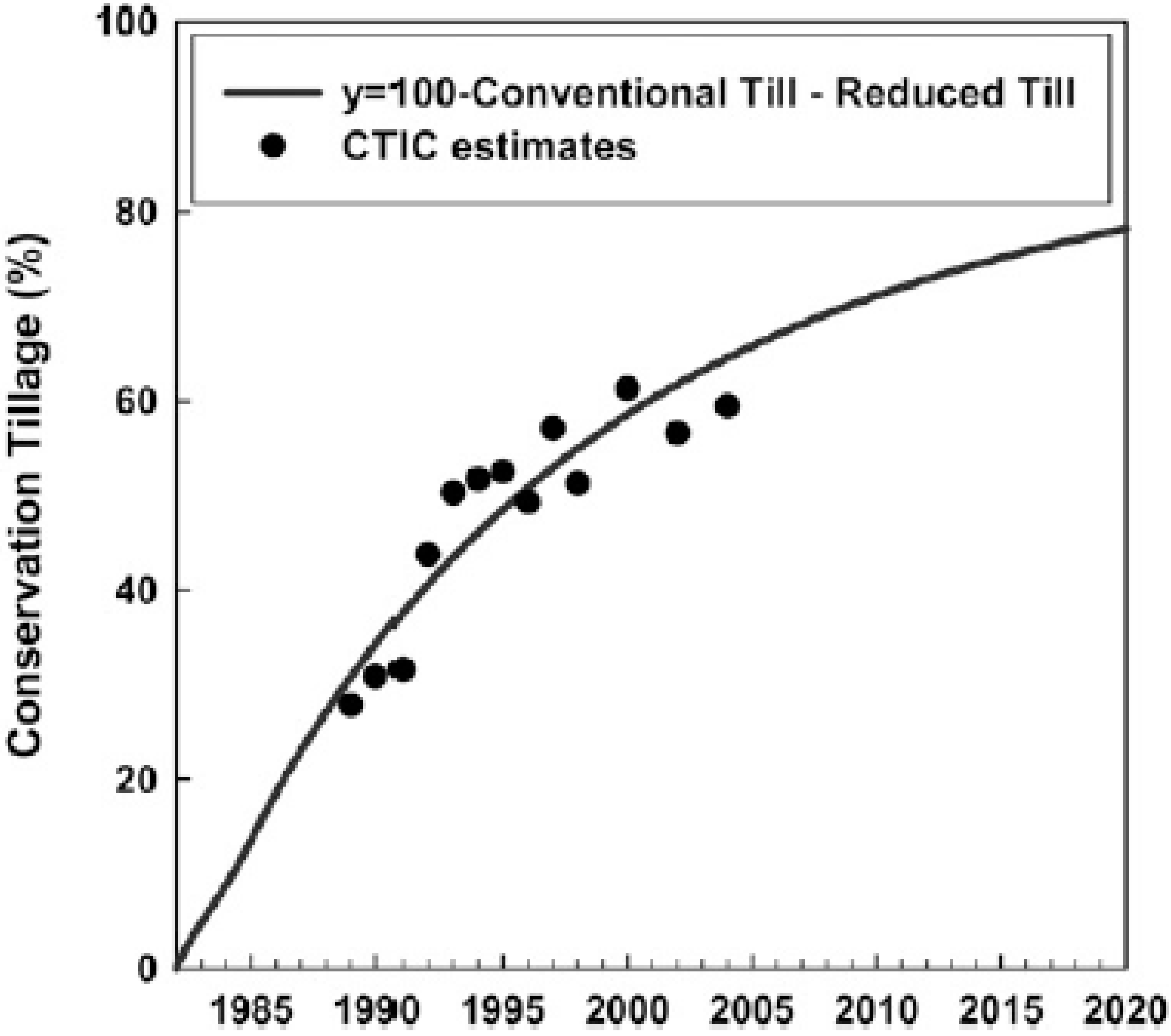
- We like to eat.
- Increasing carbon reduces the impact of agriculture on the environment.
- Creates wealth and jobs.
- Reduces government payments.
- We like to pay low prices for our food.
- Soil carbon improves the soil resilience to adverse conditions.

Modeling carbon dynamics



Iowa land use





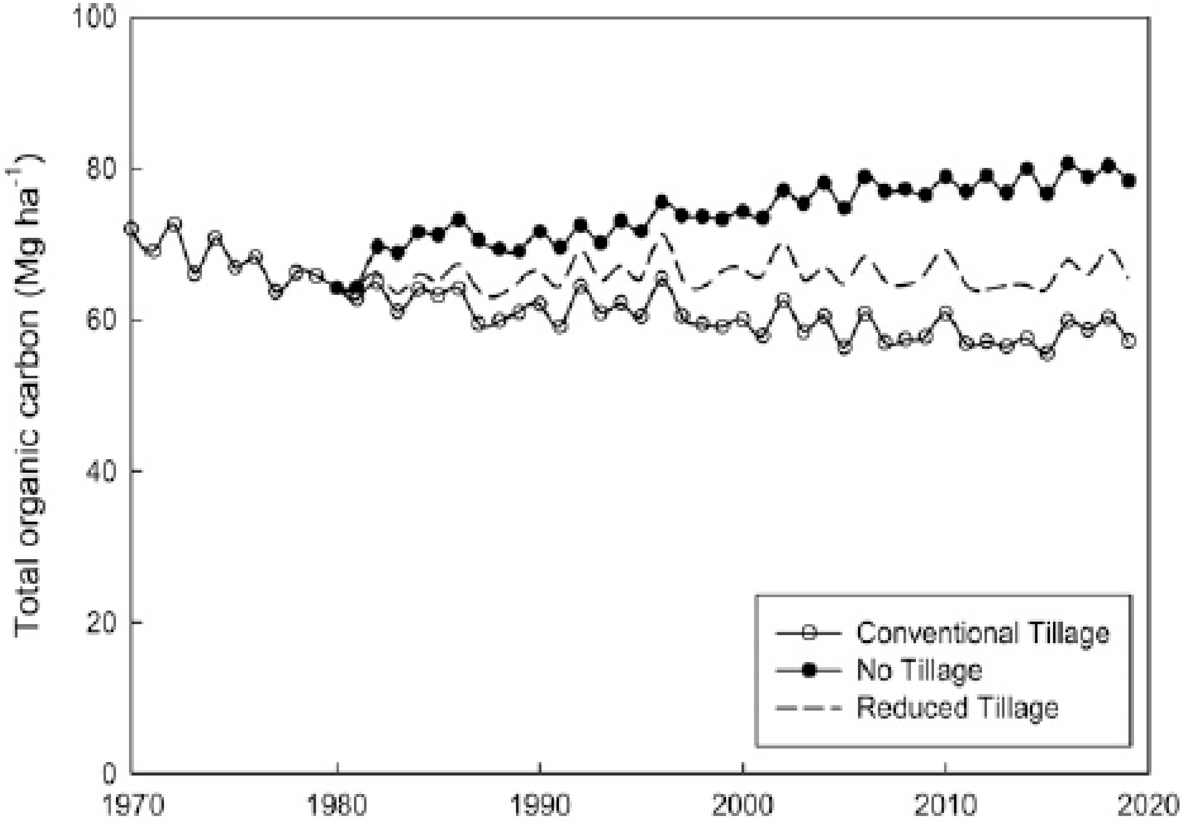
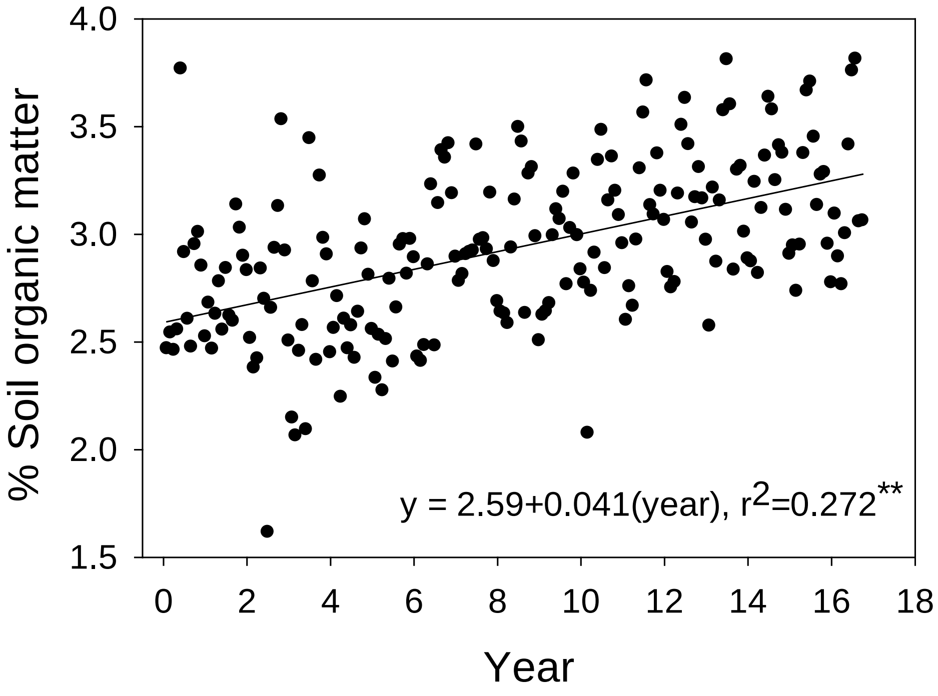


Fig. 6. Simulation results showing the effects of conventional tillage, reduced tillage, and no-tillage practices on soil organic C stocks (0–20 cm) in the state of Iowa.

Increase SOC 5.5% from 1980 to 2019, whereas samples from farmers fields showed a 24% increase in SOC



They predicted a net loss of SOC from deeper soil layers

EPIC Modeling of Soil Organic Carbon Sequestration in Croplands of Iowa

Hector J. Causarano,* Paul C. Doraiswamy, Gregory W. McCarty, Jerry L. Hatfield, Sushil Milak, and Alan. J. Stern USDA-ARS

Tillage system effects on 15-year carbon-based and simulated N budgets in a tile-drained Iowa field

D.L. Karlen[a,*], Ajay Kumar[b], R.S. Kanwar[c], C.A. Cambardella[a], T.S. Colvin[a]

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[b] Department of Soil and Environmental Sciences, University of California, Riverside, CA 92521, USA
[c] Agricultural and Biosystems Engineering Dept., Iowa State University, Ames, IA 50011, USA

Moldboard	1977	1992	**Change**		**Chisel**	1977	1992	**Change**
0-5	15.5	23.7	**0.529**		0-5	17.4	29.1	**0.6724**
5-10	18	23	**0.278**		5-10	19.6	28.9	**0.4745**
10-20	16	19.9	**0.244**		10-20	16.9	20.9	**0.2367**
Ridge tillage					**No-tillage**			
0-5	17.3	32.9	**0.902**		0-5	19.6	37.3	**0.9031**
5-10	18.8	25.5	**0.356**		5-10	18	19.6	**0.0889**
10-20	16.1	18.6	**0.155**		10-20	16.2	18.3	**0.1296**

		Yield corn	Yield beans
		Mg/ha	Mg/ha
No-tillage		8.58	2.91
Strip tillage		8.85	2.92

Soil carbon and nitrogen changes as affected by tillage system and crop biomass in a corn–soybean rotation

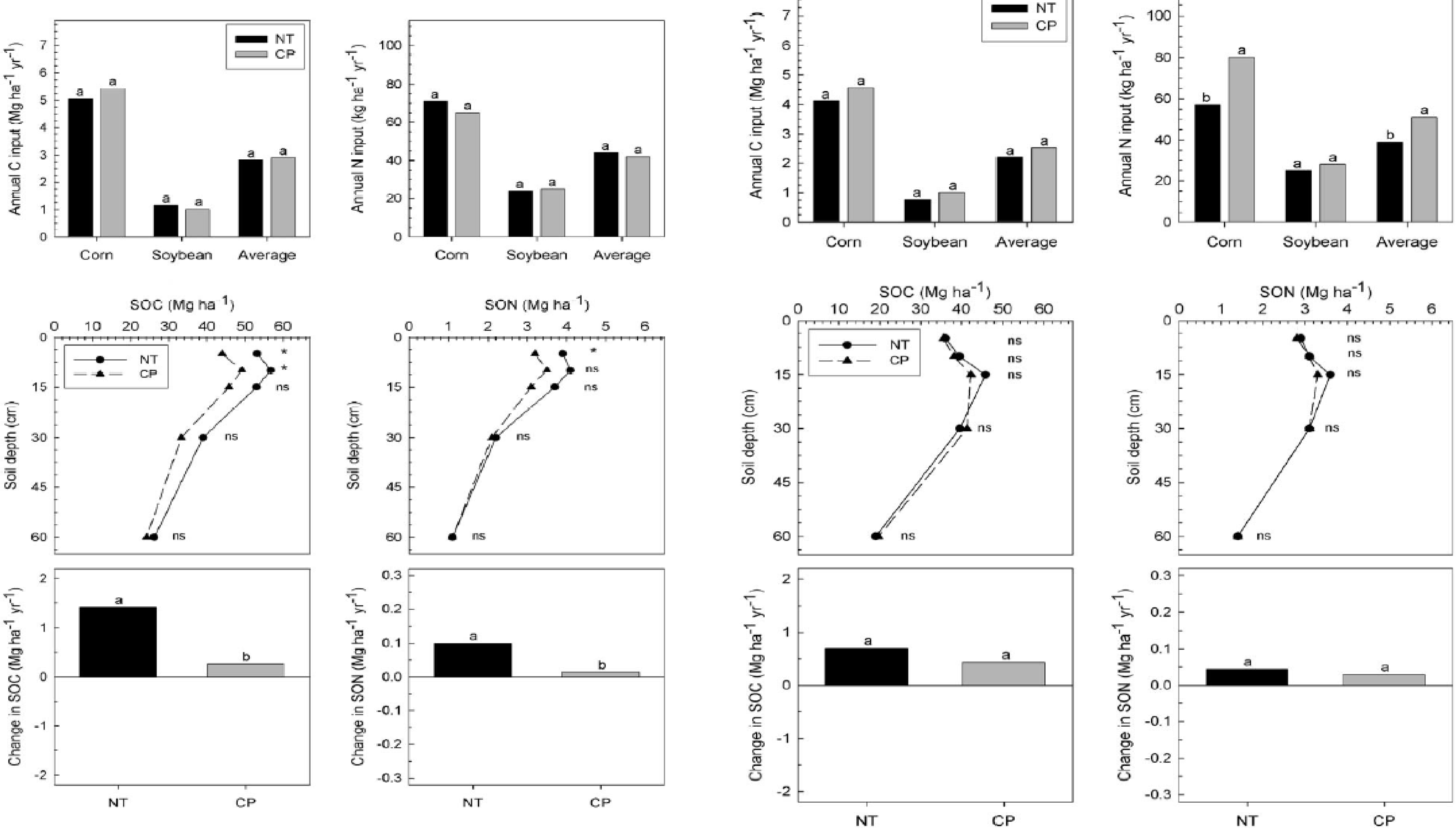
Mahdi M. Al-Kaisi *, Xinhua Yin, Mark A. Licht

Department of Agronomy, Iowa State University, Ames, IA 50011-1010 USA

Received 13 September 2004; accepted 23 February 2005

Clarion-Nicollet-Webster

Galva-Primghar-SAC



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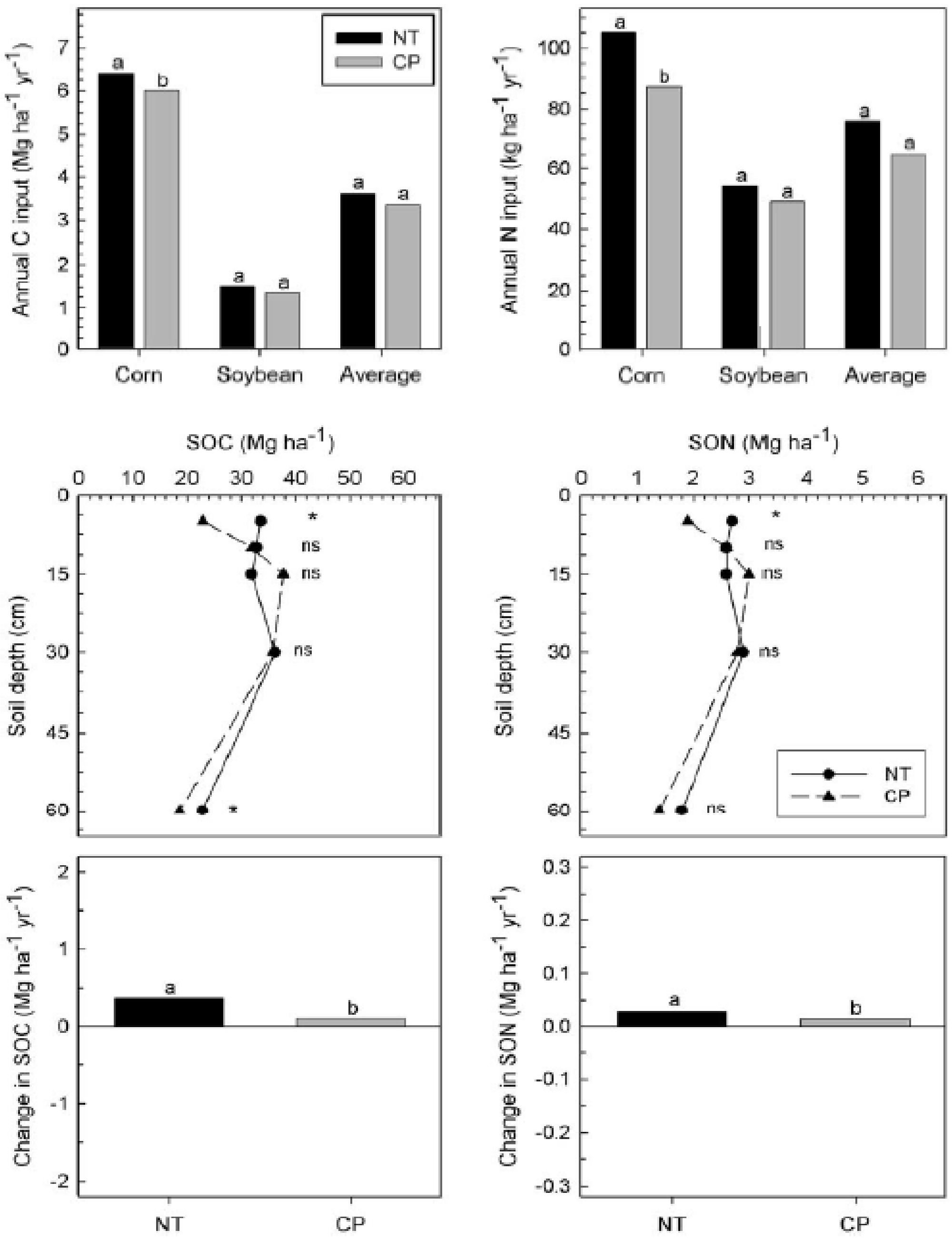
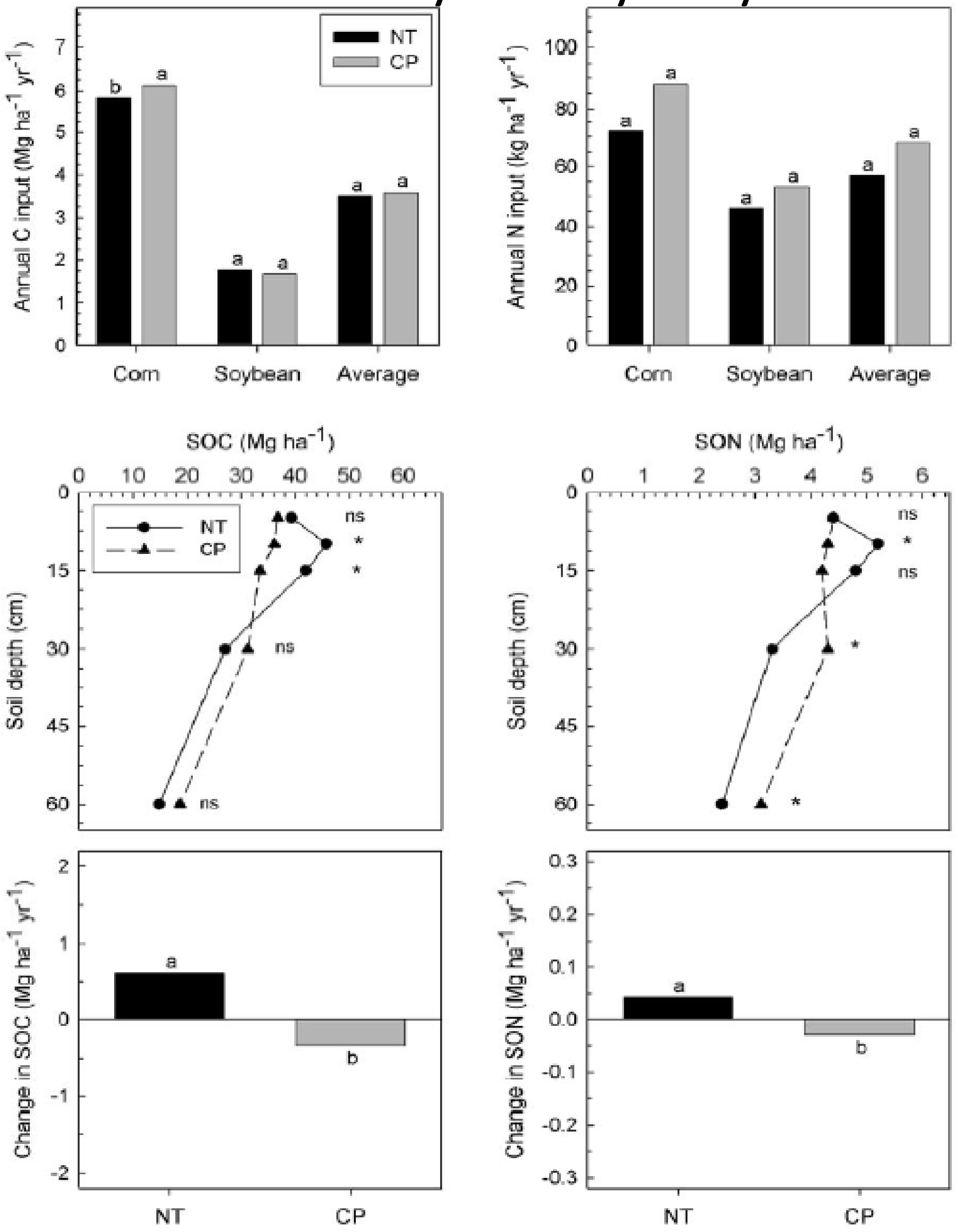
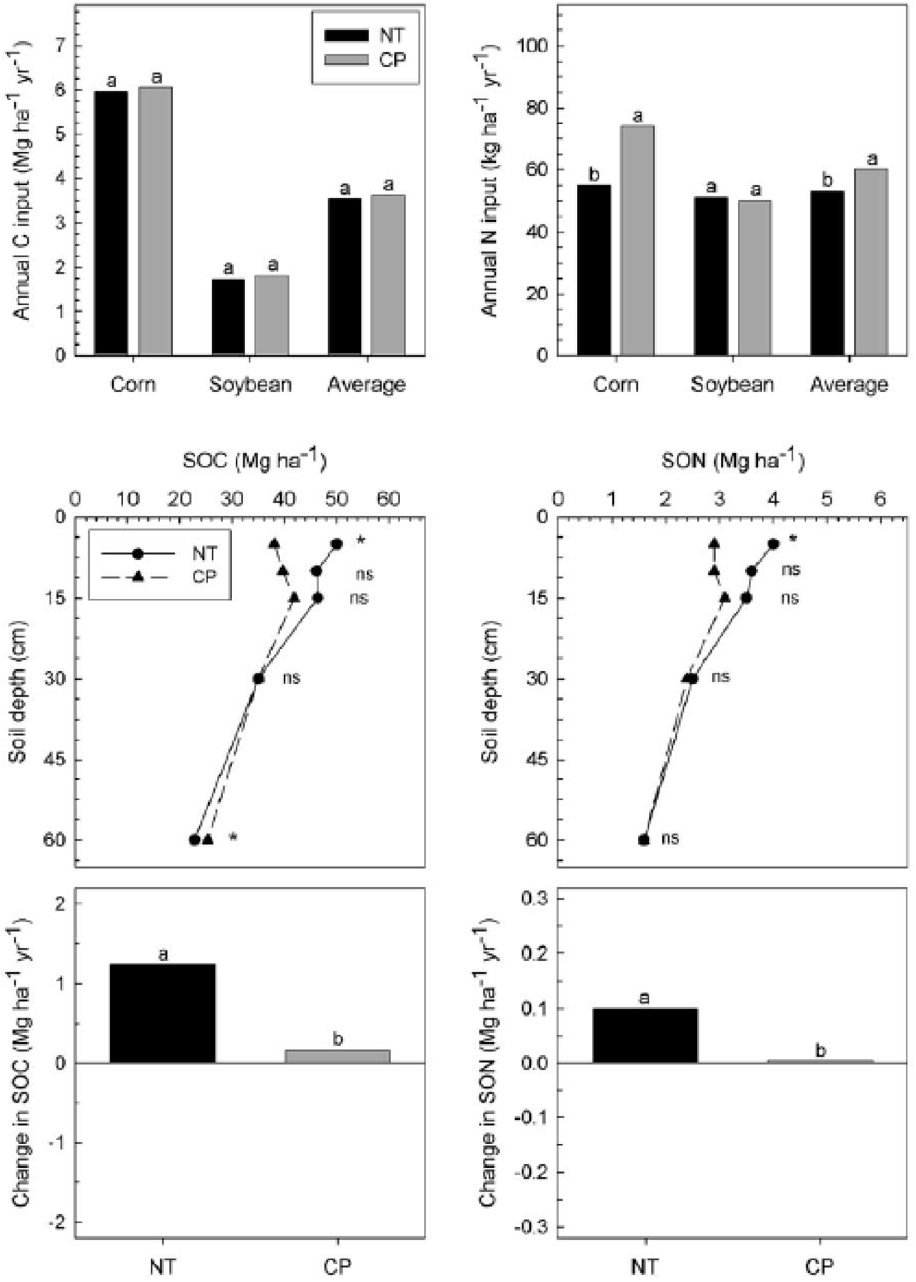


Fenyon-Floyd-Clyde



Otley-Mahaska-Taintor



Quantifying SOC changes

- The classical approach to assess changes in SOC is to measure bulk density and soil organic C.

- Using this approach can take many years to calculate responses.

We developed the ^{13}C approach that accounts for 13C fractionation during mineralization.

- The mathematics is relatively intensive
- Can determine
  - Amount of new carbon integrated into the soil
  - Amount of old carbon mineralized
  - Rate constants of old and new carbon mineralization

The Use of Enriched and Natural Abundance Nitrogen and Carbon Isotopes in Soil Fertility Research

David Clay,* Cheryl Reese, Stephanie A.H. Bruggeman, and Janet Moriles-Miller

Removal impact on yield (Mg/ha and bu/acre)

% removal	2008	2009	2010	2011	2012
0	196 (12.2)	183(11.4)	172(10.8)	183(11.5)	172(10.8)
60%	207 (12.9)	200 (12.5)	176 (11.0)	175(10.9)	164(10.3)
p	ns	<0.05	ns	<0.05	ns

There may be a positive impact of harvesting crop residues

However this gain may be short lived.

Tillage and Corn Residue Harvesting Impact Surface and Subsurface Carbon Sequestration

David E. Clay,* Graig Reicks, C. Gregg Carlson, Janet Moriles-Miller, James J. Stone, and Sharon A. Clay

Yield and tillage impact

Yield zone	SOC 0-15	SOC 15-30	PCR 0-15	PCR 15-30
Moderate	2.18	1.02	2.85	1.5
High	1.49	1.20	2.74	1.60
	0.048	ns	ns	ns

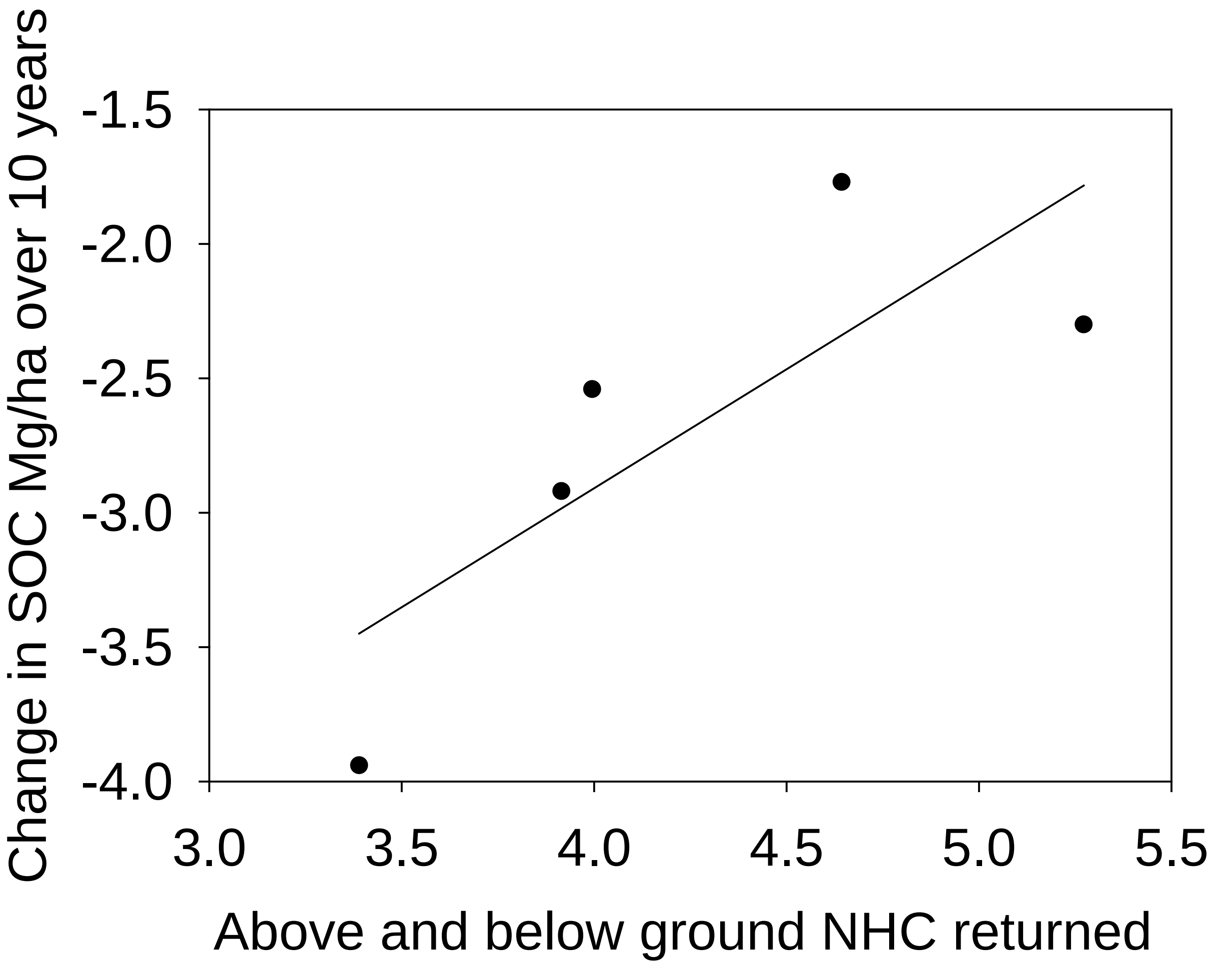
Tillage	SOC 0-15	SOC 15-30	PCR 0-15	PCR 15-30
No-tillage	1.49	0.86	2.77	2.09
Chisel	2.19	1.34	2.87	1.02
	0.032	0.052	ns	0.021

Yield zone impact

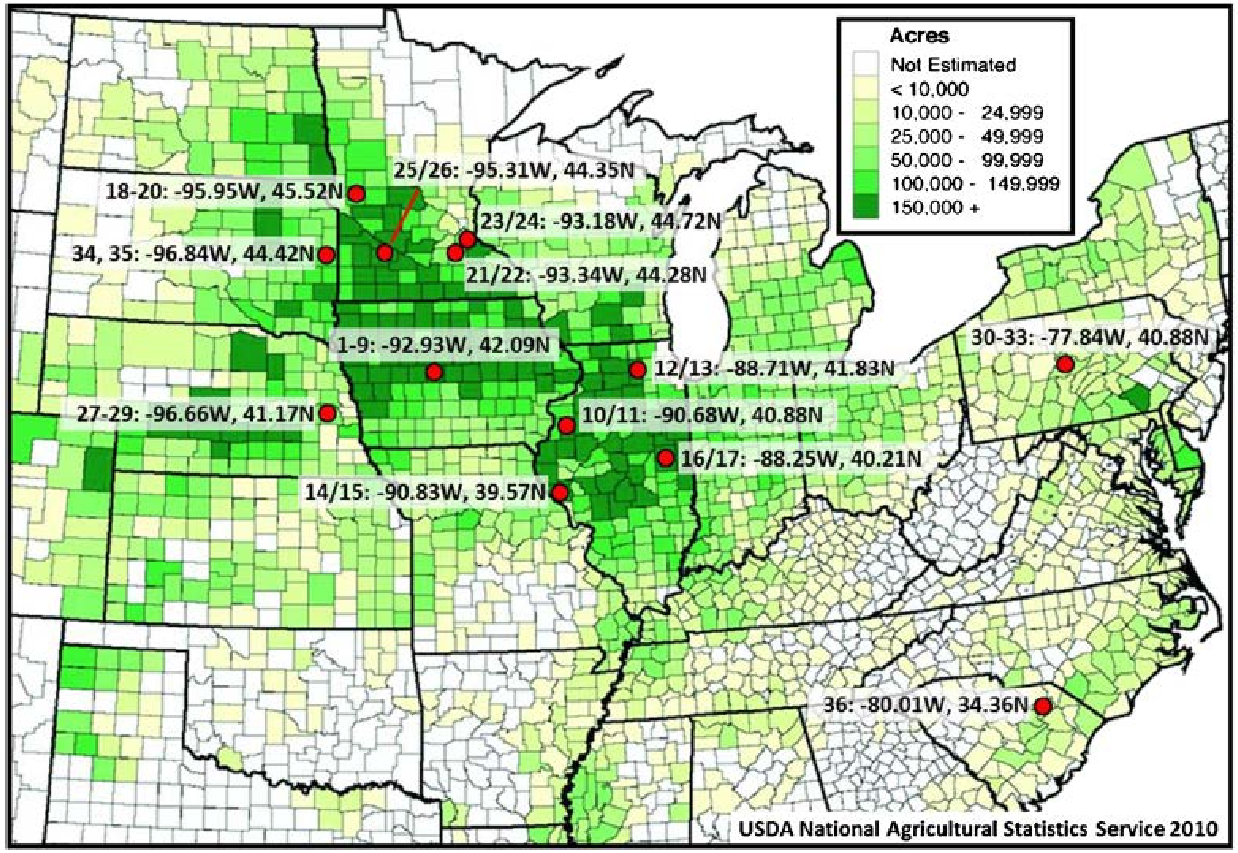
Removal	SOC 0-15	SOC 15-30	PCR 0-15	PCR 15-30
60	1.85	1.38	1.97	1.41
0	1.83	0.82	3.63	1.71
	ns	0.024	0.001	ns

Pikul et al (2008

- Reported that over a 10 year period, under high N fertilizer, there was a loss of 2.3Mg C/ha.
- Yields in this study were 118 bu/acre, whereas in the study above yields ranged from 160-210.
- Carbon was lost because the amount of NHC was less than the maintenance requirement.



Pikul et al., 2008



Karlen et al., 2014

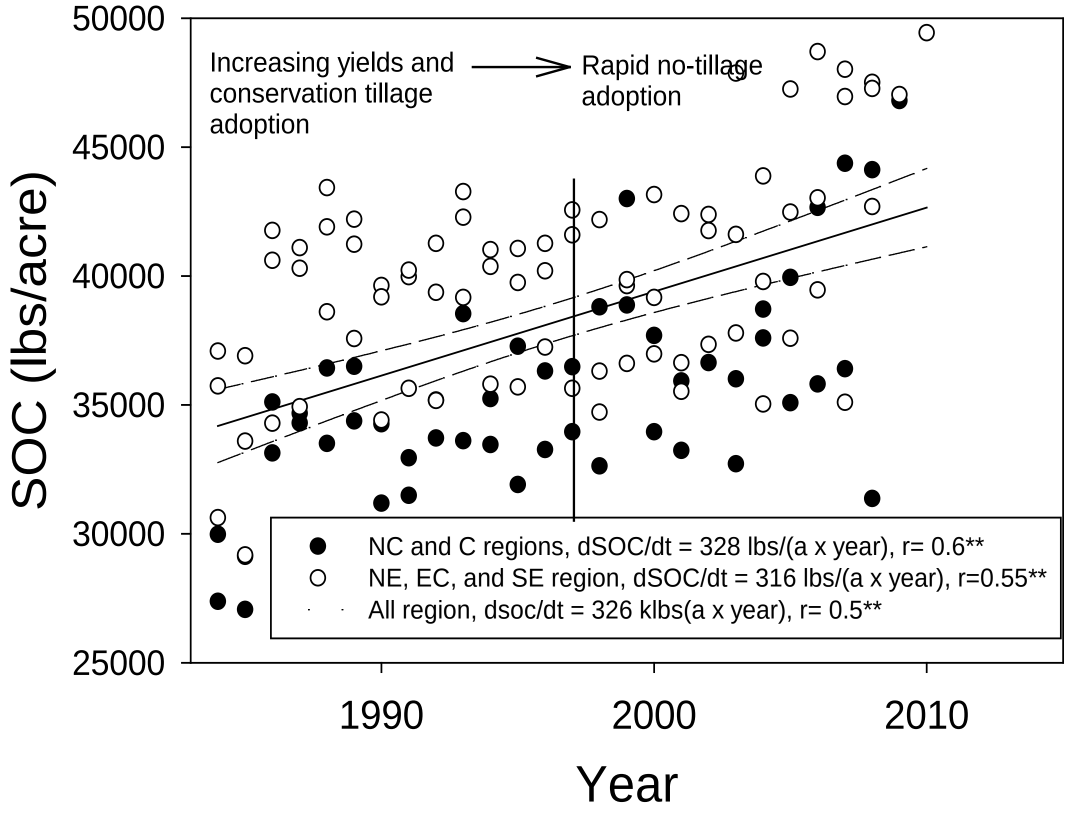
Karlen et al. (2014)

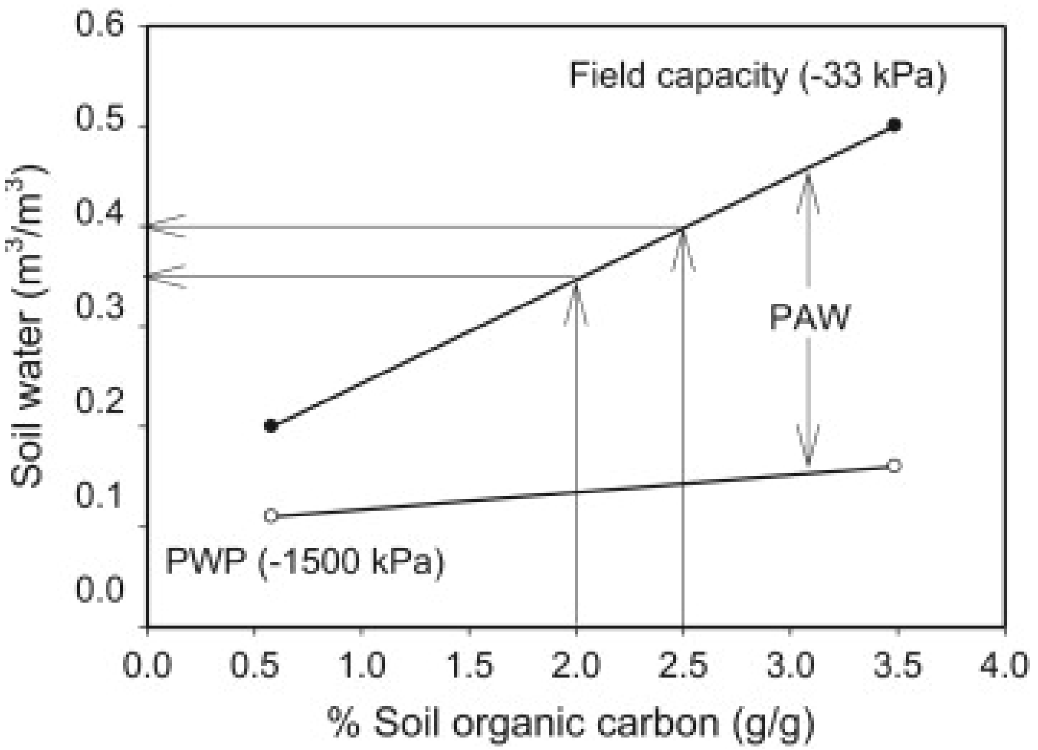
- Reported that moderate and heavy harvesting of crop residue resulted in a slight increase at 57 and 51% of the sites, respectively
- All yields < NASS yields (10 of 36)
  - 6 sites yields were increased by 0.433 Mg/ha (6.9 bu/a) moderate removal
  - 4 sites yields were reduced by 0.775/ha (12.4 bu/a) by moderate removal
- All yields > NASS yield (9 of 36 sites)
  - 6 sites yields were reduced by 0.2 Mg/ha (3.2 bu/a) by moderate removal
  - 3 sites yields were increased by 0.53 Mg/ha (8.5 bu/a) moderate removal

Summary

- SOC is important
  - Provide financial protection from extreme climatic conditions
  - Reduces erosion
- Producers have slowly been adopting conservation techniques
- Producer samples indicate that in many areas, SOC is increasing
- Research models often do not predict these results
- Studies on SOC changes are dependent on yields.
  - Low yields can bias results.
- No-tillage reduces mineralization and can increase C storage
- Tillage does not mean that carbon will be lost, this depends on the amount of SOC in the soil and the amount of C returned to the soil.
- Farming is site-specific and management is important.

Returning crop residue increases soil organic carbon and plant available water

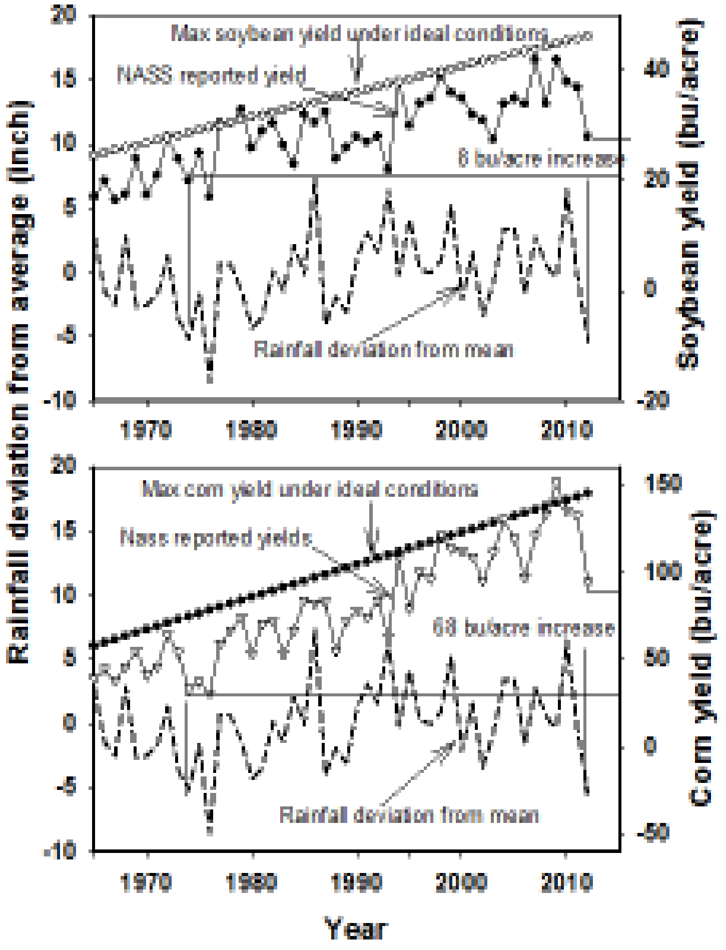




Clay, D.E., S.A. Clay, K.D. Reitsma, B.H. Dunn, A.J. Smart, C.G. Carlson, D. Horvath, and J.L. Stone. 2014. Does the conversion of grasslands to row crop production in semi-arid areas threaten global food security? Global Food Security. 3:22-30

Benefits may be most noticeable during droughts.

Management + genetics improvements have increased the resilience of our cropping systems



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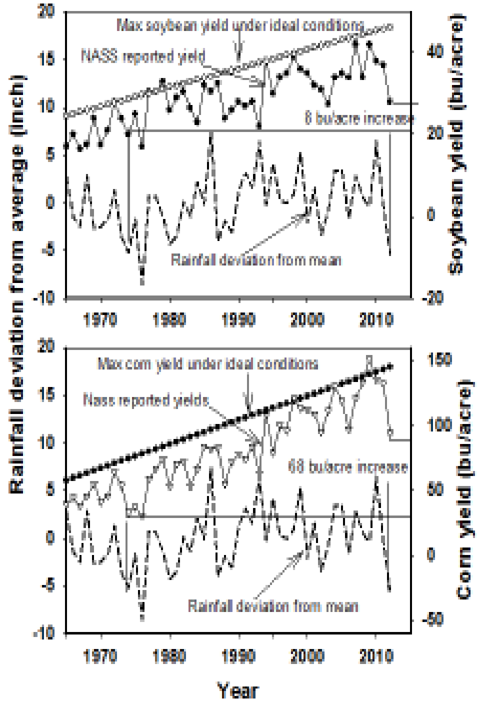

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Soybean	1340 (20 bu/acre)	2012 (30 bu/acre)
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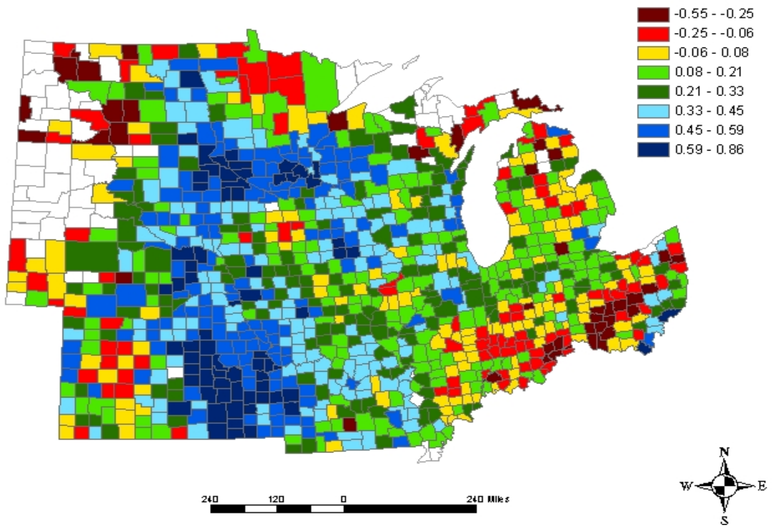
Greatest benefits of returning crop residues may be observed in areas where yields are limited by available water.

Soybean yields



Corn yields

Summary

- Different approaches for managing crop residues have profound impacts on C turnover.

- Depending on the limiting factor, harvesting surface residues will likely have different impacts on profitability and GHG emissions.

- Harvesting residues can change the rate that SOC is mineralized.

Previous work

- Previous research has produced mixed impacts of stover harvesting on crop yields and soil organic carbon.

- Problems
  - Different soil sampling depths
  - May only report values after the study
  - Different papers define factors differently

  - Most papers do not report information required to calculate the rate constants
    - Yields may be reported separately from soil numbers
  - Methods have changes
  - Based on simulation models that may not be adequately validated
  - Different calculation approaches can produce different answers

Below ground biomass estimates

- Generally not measured
- Plant roots make an important contribution to the soil system, often reported as the root to shoot ratio.
- These values have been reported to vary widely.
- Root to shoot ratios are defined differently by different studies.
- Amos and Walters (2006) did not include exudates in the estimates, and they also did not include grain in the biomass estimates,

Soil data bases provide different numbers

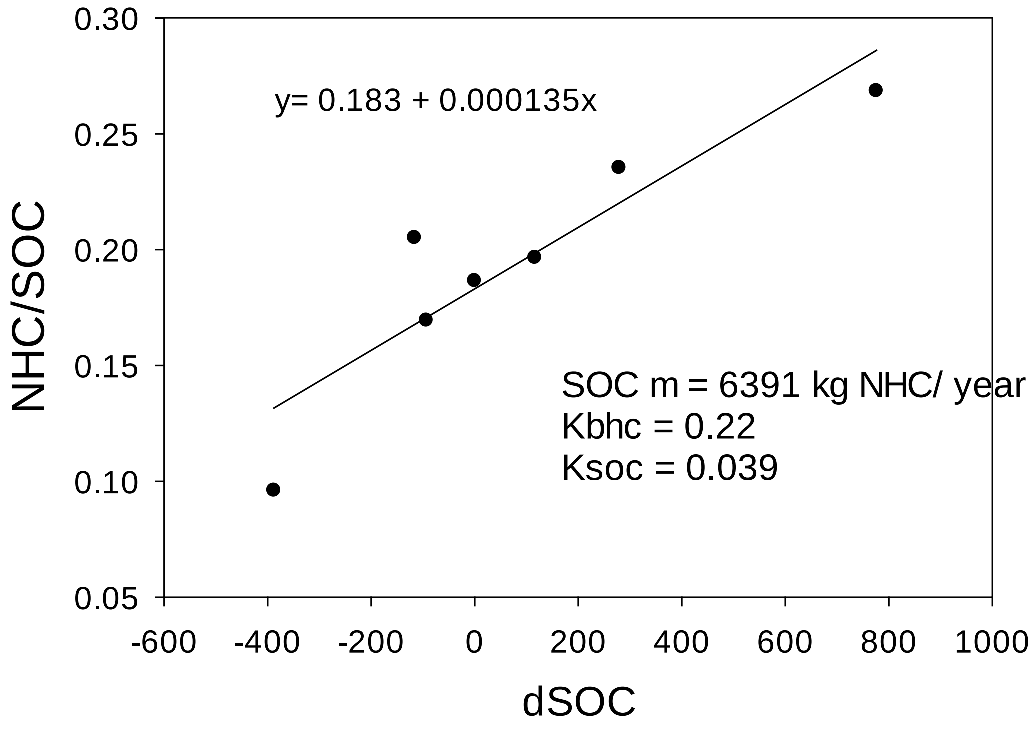
	Skewness	Kurtosis	Mean
SSURGO2	2.49	13.3	18.9
Statsgo2	0.69	-0.33	18.4
USGS benchmark	1.24	1.98	20.7

Converting organic matter to SOC

- Many people assume that SOM contains 58% carbon, divide SOM by 1.72.
- Steson et al. (2012), SSAJ 76:1399-1406, showed that the value may range from 2 to 2.2.

Examples

- Barber AJ 71:625-627
- Conducted a 12 year experiment, soil samples from the 0-15 sample depth were collected after the 6th and 11th year.
- Samples were analyzed for total carbon using the Walkley-Black method and con using a conversion factor of 1.34.
- Values were multiplied by 1.72 to estimate SOM



Based on a number of assumptions they concluded that 2.4 of the SOM was mineralized annually.

Pro and Cons

- May increase or decrease yields
- May increase erosions
- Simplify residue management
- Increase economic returns from the land
- Using models to assess the implications are limited by different data bases providing different information.

Table 3. The influence of NASS region and year on yield, no-tillage adoption rate, nonharvested C returned to soil (NHC), SOC mineralization rate, the SOC benchmark, and calculated sequestered SOC. The standard deviations are shown in parenthesis.

Region	Yield 2004–2007	Yield 2008– 2010	NHC 2004–2007	NHC 2008–2010	SOC benchmark	Sequest. SOC 2004–2007	Sequest. SOC 2008–2010
	Mg/ha					kg/(ha yr)	
NC	6.17	8.45	3.46	4.73	39.5(8.96)	229	412
C	5.45	8.95	3.06	4.36	40.2(9.76)	69	329
NE	8.27	7.76	4.64	5.02	45.2(9.51)	182	231
EC	7.98	9.33	4.46	5.24	44.8(9.60)	125	264
SE	7.2	9.51	4.04	5.34	39.1(8.50)	266	454

Table 4. The influence of sampling region and the short-term sequestered C rates on partial C footprints for the 2004 to 2007 and 2008 and 2010 time periods.

Region	2004–2007 Sequestered C	2004–2007 Partial C footprint	2008–2010 Sequestered C	2008–2010 Partial C footprint
	kg SOC/(ha × yr)	g CO_2eq/MJ	kg SOC/(ha × yr)	g CO_2eq/MJ
North-central	229	–14.9	412	–19.6
Central	69	–5.10	329	–14.8
Northeast	182	–8.86	231	–12.0
East-central	125	–6.31	264	–11.4
Southeast	266	–14.9	454	–19.2

- The three databases showed different C distributions. Across the South Dakota, the skewness value was higher in the SSURGO (2.49) than the USGS-benchmark (1.24) or STATSGO2 (0.69) data sets. The higher skewness value in SSURGO suggests that data was not symmetric and it was skewed toward large values. In addition, the kurtosis values were higher in the SSURGO (13.3) than the USGS-benchmark (1.98) or STATSGO2 (-0.33). Normal distributions have a kurtosis value of 0, whereas population distributions with a positive value are peaked. The STATSGO2 ($p=0.02$) had a lower SOC (18.4 g/kg) than the USGS (20.7 g/kg), whereas the SSURGO (18.9 g/kg) and USGS were different at the 10% level ($p=0.06$). These results are important because they show that the USGS benchmark information is statistically different from STATSGO2 and SSURGO.

The three data sets were correlated. For example, the r value between USGS and SSURGO was 0.33*, whereas the correlation between SSURGO and STATSGO2 was 0.41**. Others have reported inconsistent results between STATGO and SSURGO (Mednick et al., 2008). The lack of consistency between the data sets complicates the interpretation of the simulation results. Differences between measured and SSURGO values have been reported by several investigators (Reinsch and West, 2010; Grunwald and Vasques, 2010). Reinsch and West (2010) reported that SSURGO overestimated clay contents and underestimated SOC contents in the Ap horizon of a Miami Soil Series.

The SSURGO or STATSGO2 data bases have been used as soils benchmarks in a number of regional modeling efforts that were designed to assess the ramifications of changing the soil and crop management practices on sustainability. For example, Liska et al. (2014) predicted that the annual removal of 6 Mg ha of surface residues across the Midwestern United States would reduce SOC levels. In a similar study, Causarano et al. (2008) used the EPIC model and NRCS-SSURGO and STATSGO data bases to assess C sequestration in Iowa. The dominant crops in the study area was maize and soybean (Glycine max). They assumed that conventional tillage decreased while conservation tillage increased. Based on this analysis, they reported that from 1980 to 2019 soil C stocks in the surface soil in the surface 20 cm would decrease from 72 to 57 Mg ha^{-1} from 1971 to 2019 in conventional management, whereas no-tillage would result in a modest increase in SOC (78 Mg ha^{-1}).