Alternative Strategies for Building Soil Health and Enhancing Ecosystems

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National Laboratory for Agriculture and the Environment

PFI Soil Short Course
January 18, 2018
Ames, IA
MOLLISOLS

Midwestern Mollisols: among the most productive soils in the world
SOIL FORMATION occurs over geological time shaped by climate, parent material, topography, and vegetation. Most soils in Iowa formed in the past 10,000-14,000 years on parent material derived from glacial till and wind-blown loess.
Soil Genesis

- **Formative Change: Geologic Time**
  - based on soil forming factors
    - ✓ climate, parent material, topography, and vegetation, all acting over time (Hans Jenny, 1941)
  - Soil texture and mineralogy reflect inherent/natural soil characteristics that don’t change with land management
Soil Change

- **Formative Change**: Ecological time
  - Amount of SOM in a given soil is related to the texture and mineralogy of that soil
Texture & mineralogy effect amount of SOM

GA Ultisols

IA Mollisols

Organic Matter

Texture & mineralogy effect amount of SOM

GA Ultisols

IA Mollisols

Organic Matter

Texture & mineralogy effect amount of SOM

GA Ultisols

IA Mollisols

Organic Matter
Soil Change

- **Formative Change: Ecological time**
  - Amount of SOM in a given soil is related to the texture and mineralogy of that soil

- **Dynamic Change: Human Time**
  - SOM is dynamic soil characteristic that can change with land-use and management
Dynamic equilibrium
Characteristics of a sustainable ecosystem...

- **Resistance**
  - Capacity to resist displacement from equilibrium in the face of disturbance
Midwestern soils have lost >1/2 of their native carbon and are still losing C

Decrease in OM quantity & changes in OM quality
Characteristics of a sustainable ecosystem...

- **Resistance**
  - Capacity to resist displacement from equilibrium in the face of disturbance

- **Resilience**
  - Ability to return to dynamic equilibrium after disturbance
Dynamic Soil Change

Sparling et al. 2003

C content (Mg/ha)

Pasture phase

Return to pasture

Cropping phase

Time (years)
Agricultural Sustainability depends on the system maintaining functional resilience in the face of repeated disturbance
Soil Quality

“...capacity of soil ecosystem to function ...”

Maintain productivity & biodiversity
Store and cycle nutrients
Regulate & partition water flow
Filter, buffer & detoxify
Soil Functions

Maintain productivity and biodiversity
Soil Functions

Store and cycle nutrients

Regulate and partition water flow

Filter, buffer and detoxify

Organic & Inorganic materials

Soil

Watertable
Soil is one of the most diverse habitats on earth and is one of earth's most complex ecosystems.
Bacteria, Fungi
Protozoa, Nematodes
Micro-arthropods

Soil structure

OM cycling

Nutrient cycling
Roots
Where do populations of soil organisms live in the soil?
Soil Bacteria

Nematode living in water-filled pore space

Saprophytic fungi living in air-filled pore space
The Soil Food Web

First trophic level:
Photosynthesizers

Second trophic level:
Decomposers
Mutualists
Pathogens, parasites
Root-feeders

Third trophic level:
Shredders
Predators
Grazers

Fourth trophic level:
Higher level predators

Fifth and higher trophic levels:
Higher level predators
Soil Health

Activity of soil organisms

Soil Quality

Function

Soil biology

Soil Properties
Plant extended rotations, reduce tillage, diversify landscape
Cover crops

Cover crop cocktail (8 sp)

Small grain (fall planted)

Small grain/legume
Retain residue, add manure, compost and green manures
Boone County Field Site

Organic Reduced Tillage Research
ISU Ag Engineering and Agronomy Research Farm
Boone IA

Des Moines Lobe

Iowa State University
Rodale Institute
Michigan State University
Minnesota State University,
University of Wisconsin
USDA-ARS
Winter wheat-Corn-Soybean-Oats Rotation

Fall planted rye/hairy vetch or rye before corn or soybean

Randomized Block Design
4 Blocks

Chisel Plow Tillage
Roller Crimper

Soil cores (0-15 cm) in fall 2008-2011
<table>
<thead>
<tr>
<th>Fall 2011</th>
<th>Reduced Tillage</th>
<th>Conventional Tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOC (g/kg)*</td>
<td>31.10a</td>
<td>31.93a</td>
</tr>
<tr>
<td>TN (g/kg)</td>
<td>2.84a</td>
<td>2.75a</td>
</tr>
<tr>
<td>POMC (g/kg)</td>
<td>5.74a</td>
<td>3.92a</td>
</tr>
<tr>
<td>MBC (mg/kg)</td>
<td>533a</td>
<td>406b</td>
</tr>
<tr>
<td>PotMinN (mg/kg)</td>
<td>55.0a</td>
<td>46.2b</td>
</tr>
<tr>
<td>pH</td>
<td>6.66a</td>
<td>6.44a</td>
</tr>
<tr>
<td>Macroaggs (%)</td>
<td>40.2a</td>
<td>41.3a</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>1.22a</td>
<td>1.16a</td>
</tr>
</tbody>
</table>

* Depth 0-15 cm

Means followed by same letter within a row are not different at 95%
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<tr>
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<tbody>
<tr>
<td>MBC (mg/kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iowa</td>
<td>533a</td>
<td>406b</td>
</tr>
<tr>
<td>Michigan</td>
<td>318a</td>
<td>282a</td>
</tr>
<tr>
<td>Minnesota</td>
<td>579a</td>
<td>503a</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>418a</td>
<td>358b</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>748a</td>
<td>518a</td>
</tr>
</tbody>
</table>

Depth 0-15 cm

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<td><strong>PotMinN (mg/kg)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iowa</td>
<td>55a</td>
<td>46b</td>
</tr>
<tr>
<td>Michigan</td>
<td>44a</td>
<td>30b</td>
</tr>
<tr>
<td>Minnesota</td>
<td>44a</td>
<td>39a</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>74a</td>
<td>67a</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>79a</td>
<td>68b</td>
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</tbody>
</table>

Depth 0-15 cm

*Means followed by same letter within a row are not different at 95%*
Adair County
Org Veg Site
Organic Vegetable Research, Neely-Kinyon Research Farm, Greenfield, Iowa

Southern IA Drift Plain

Started in 2010
Kathleen Delate, ISU, co-PI
Cindy Cambardella, ARS, co-PI
Tomato-Sweet Corn- Pepper Rotations

Randomized Block Design
4 replicates

Fall Planted
Rye/Hairy Vetch Cover Crop

Spring Applied
Composted Animal Manure

Chisel Plow Tillage
Roller Crimper

Soil cores (0-15 cm)
in fall 2010-2014
Plot size 0.60 m X 0.46 m

2 CO₂ collars per plot
- close to plant
- max dist from plant

CO₂ flux every 2 weeks
Apr-Oct 2012-2014

Lysimeter buried at 100 cm in center of each plot

Soil water sampled every 2 weeks Apr-Oct 2011-2014

Lysimeter access port

Two plots per port
<table>
<thead>
<tr>
<th>Fall 2014*</th>
<th>NCC_T</th>
<th>CC_NT</th>
<th>CC_T</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOC (g/kg)*</td>
<td>26.8c</td>
<td>30.7a</td>
<td>29.0ab</td>
</tr>
<tr>
<td>TN (g/kg)</td>
<td>2.7bc</td>
<td>3.0a</td>
<td>2.9ab</td>
</tr>
<tr>
<td>POMC (g/kg)</td>
<td>3.8b</td>
<td>5.7a</td>
<td>6.0a</td>
</tr>
<tr>
<td>MBC (mg/kg)</td>
<td>220b</td>
<td>283a</td>
<td>286a</td>
</tr>
<tr>
<td>PotMinN (mg/kg)</td>
<td>54.3b</td>
<td>70.4a</td>
<td>70.2a</td>
</tr>
<tr>
<td>Macroaggs (%)</td>
<td>15.0c</td>
<td>27.0a</td>
<td>21.4b</td>
</tr>
</tbody>
</table>

* after peppers

Cover crop > No Cover Crop
Till = No-till with a cover crop
Cover crop reduces negative impacts of tillage for all properties except aggregate stability

NCC_T = No Cover Crop, Till
CC_NT = Cover Crop, No-Till
CC_T = Cover Crop, Till
Lysimeter NO$_3$-N to estimate N leaching potential

NO$_3$-N lower with cover crops in all crops in all years

NO$_3$-N lower under no-till in all crops in all years
Soil Respiration as an estimate of Microbial Activity

**Sweet Corn CO₂ Flux 2013**

Average growing season CO₂ flux higher with cover crops in both rotations in all years

Cover crop: 0.74 g CO₂/m²/h
No cover crop: 0.51 g CO₂/m²/h

**Tomato CO₂ Flux 2013**

Average growing season CO₂ flux higher under no-till in both rotations in all years

Till: 0.47 g CO₂/m²/h
No-till: 0.67 g CO₂/m²/h
Summary I

- Organic reduced tillage grain and vegetable rotations that utilize fall-planted cover crops and composted animal manure increase overall soil health, enhance microbial activity, increase C sequestration, and reduce N leaching loss from the rooting zone.
Adair County
LTAR Site
Long-Term Agroecological Research (LTAR) Site Neely-Kinyon Research Farm, Greenfield IA

Southern IA Drift Plain

Started in 1998
Kathleen Delate, ISU, PI
Cindy Cambardella, ARS, co-PI
Soil cores in fall every year after harvest from each plot to a depth of 15 cm

Composted animal manure
organic corn and oats
28% Urea: conventional corn

Soil cores in fall every year after harvest from each plot to a depth of 15 cm
Soil Health Assessment

Biological
MBC, POM, Po, tMinN

Chemical
SOC, TN, P, K, Mg, Ca, pH, EC

Physical
Bulk density, macroaggregation
Uses of SQ Assessment

- Adaptive management tool
<table>
<thead>
<tr>
<th>Fall 2014</th>
<th>Organic</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOC (g/kg)*</td>
<td>24.6a</td>
<td>23.1b</td>
</tr>
<tr>
<td>TN (g/kg)</td>
<td>2.4a</td>
<td>2.3b</td>
</tr>
<tr>
<td>POMC (g/kg)</td>
<td>3.2a</td>
<td>2.4b</td>
</tr>
<tr>
<td>MBC (mg/kg)</td>
<td>452a</td>
<td>372b</td>
</tr>
<tr>
<td>PotMinN (mg/kg)</td>
<td>54a</td>
<td>43b</td>
</tr>
<tr>
<td>InorgN (mg/kg)</td>
<td>3.1a</td>
<td>3.2a</td>
</tr>
<tr>
<td>Macroaggs (%)</td>
<td>24a</td>
<td>22a</td>
</tr>
</tbody>
</table>

* Depth 0-15 cm

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<thead>
<tr>
<th>Fall 2014</th>
<th>Organic</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH*</td>
<td>6.9a</td>
<td>6.3b</td>
</tr>
<tr>
<td>Bray P (mg/kg)</td>
<td>69a</td>
<td>22b</td>
</tr>
<tr>
<td>K (mg/kg)</td>
<td>266a</td>
<td>217b</td>
</tr>
<tr>
<td>Mg (mg/kg)</td>
<td>400a</td>
<td>338b</td>
</tr>
<tr>
<td>Ca (mg/kg)</td>
<td>3702a</td>
<td>3105b</td>
</tr>
<tr>
<td>EC (µS/cm)</td>
<td>186a</td>
<td>143b</td>
</tr>
<tr>
<td>BD (g/cm³)</td>
<td>1.22a</td>
<td>1.26a</td>
</tr>
</tbody>
</table>

* Depth 0-15 cm

Means followed by same letter within a row are not different at 95%
Organic soils had
> total soil C & N
> biologically active soil C and N
> plant nutrients (P,K,Mg)
< soil acidity
= aggregate stability
= bulk density
than conventional soils.
Microbial community structure

Matt Bakker et al submitted
Microbial Community Function

Gene frequency (methane monooxygenase)

Matt Bakker et al submitted
Uses of SQ Assessment

- Monitoring tool

![Diagram showing soil quality over time with stages: baseline, aggregating, sustaining, degrading.](image)
36% more biologically active N in organic surface soil in fall 2010
Summary II

Soil quality enhancement was particularly evident in:

- **labile soil N**
  - critical to organic systems where N fertility is maintained through forage legumes and organic amendments

- **cation concentrations**
  - related to CEC which controls nutrient availability other than N

Nutrient cycling efficiency is an ecosystem function that is critical to the sustainability of organically managed crop rotations
<table>
<thead>
<tr>
<th>Rotation</th>
<th>C-S-O/A</th>
<th>C-S-O/A-A</th>
<th>C-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residue C</td>
<td>41.5</td>
<td>41.1</td>
<td>58.5</td>
</tr>
<tr>
<td>Compost C</td>
<td>17.5</td>
<td>17.5</td>
<td>0</td>
</tr>
<tr>
<td>Total C inputs</td>
<td>59.0</td>
<td>58.6</td>
<td>58.5</td>
</tr>
<tr>
<td>SOC 1998</td>
<td>40.9</td>
<td>40.9</td>
<td>40.9</td>
</tr>
<tr>
<td>SOC 2007</td>
<td>43.6</td>
<td>46.2</td>
<td>40.7</td>
</tr>
<tr>
<td>ΔSOC 98-07</td>
<td>2.7</td>
<td>5.3</td>
<td>0</td>
</tr>
<tr>
<td>ΔSOC/ y</td>
<td>0.27</td>
<td><strong>0.53</strong></td>
<td>0</td>
</tr>
</tbody>
</table>

Partial Carbon Budget 1998-2007 (Mg C ha\(^{-1}\))
Summary III

- Cumulative carbon inputs over 10 years ~equal for conventional and organic
  - More carbon is retained in the organic systems

- Carbon change over 10 years for C-S-O/A-A rotation is similar to estimates of C sequestration potential converting CT to NT (0.57 Mg ha⁻¹ West and Post, 2002)
Organic Water Quality Research (OWQ) Site
ISU Ag Engineering and Agronomy Research Farm
Boone IA

Experimental site managed by USDA-ARS-NLAE
Field History
No chemicals since 2006
Planted to oat/alfalfa 2006-2011
Pre-2006, conventional corn-soybean

Soils
Clarion: moderately well drained, Typic Argiudoll
Canisteo: poorly drained, Typic Haplaquoll
Webster: poorly drained, Typic Haplaquoll
Monitoring Sump Flow Barrier (8 ft deep)

Non-perforated pipe (4 ft deep)

30 Plots (100 ft x 100 ft)

Flow Barrier (8 ft deep)

Perforated pipe (4 ft deep)

Non-perforated pipe (4 ft deep)

Isolate drainage from each plot

*Perimeter tile drain (50 in diam)*

*Tile drain (30 in diam) at N and S end of each plot*

*Plastic flow barrier at E and W end of each plot*

*Tile water from 3 plots routed each sump pit*

10 acre field site
Cropping Systems
Organic C-S-O/A-A
Organic pasture/hay
(alfalfa, fescue, timothy, orchard grass)
Conventional C-S

Randomized block design
5 replicates per system

Continuous tile flow monitoring
Tile water quality samples collected weekly
Fertility
Composted manure before organic corn (150 lb N/ac) and oats (50 lb N/ac)

28% UAN before conventional corn; side dress (150 lb N/ac)

Weather station on site with continuous monitoring
Weed Management
Spring chisel plow/disk
Rotary hoe and cultivator ~3X
Walk soybean every other week

Herbicide in conventional
Prefix®, soybean; Lumax®, corn

Soil CO₂ flux every other week
during growing season
Continuous Monitoring

Tile flow
Weather data: precipitation, temperature, etc

Monitoring
Weekly tile drainage water NO$_3$-N
Soil health (to 6 in) in fall after harvest
Growing season soil CO$_2$ flux
Water table depth & soil moisture content

Soil Health Measurements
Total soil C&N; microbial biomass C&N; N mineralization potential; soil enzyme activity; inorganic N, P, K, Mg, Ca; aggregate stability; pH; EC; bulk density
microbial community structure and function

Plant Measurements
Yield; plant populations; total aboveground biomass C&N; weed density; insect pest and disease populations; stalk nitrate
2013: wet spring – dry summer
2014: normal spring – wet summer
2015: wet spring – very wet summer
2016: normal spring – wet summer
Tile Flow, liters

Peak tile flow correlated with rainfall
March-May rainfall 12.7 in

Wet spring – Dry summer

No tile flow after August 1
Tile Drainage Water Nitrate N 2013

- Conv C/S
- Organic C/S/OA/A
- Organic Pasture
Tile flow peaked early July and late August, following 8.7 in of rain in June and 7.9 in of rain in August.
Tile Drainage Water Nitrate N 2014

Conventional C-S **13.0**, Organic C-S-O/A-A **3.8**, Organic Pasture **0.3** ppm
Site was flooded 8 times in 2015:
June 24, July 29, August 10, 20 and 31, September 2 and 8, December 14

Tile Flow 2015

Wet spring – Very wet summer – Wet Fall

December 14, 2015 after 5.0 inches of rain
Tile Drainage Water Nitrate N 2015

- Organic Rotation
- Organic Pasture
- Conventional Rotation

Nitraten, ppm

1/2/2015, 2/2/2015, 3/2/2015, 4/2/2015, 5/2/2015, 6/2/2015, 7/2/2015, 8/2/2015, 9/2/2015, 10/2/2015, 11/2/2015, 12/2/2015
**2013-2016**

Tile water NO$_3$-N concentrations exceeded the national 10 ppm drinking water standard

**65% of the time in conventional C-S**

**21% of the time in organic C-S-O/A-A**
# Nitrogen Loss (lb N/ac) to Tile Drainage Water

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic C-S-O/A-A</td>
<td>21.3</td>
<td>13.3</td>
<td>8.9</td>
<td>7.7</td>
<td>51.2</td>
</tr>
<tr>
<td>Conventional C-S</td>
<td>44.7</td>
<td>32.2</td>
<td>13.9</td>
<td>9.7</td>
<td>100.5</td>
</tr>
<tr>
<td>Organic Pasture</td>
<td>10.0</td>
<td>3.6</td>
<td>1.0</td>
<td>0.6</td>
<td>15.2</td>
</tr>
</tbody>
</table>

Tile water N loading loss (lb N/ac) from 2013-2016 from organic C-S-O/A-A was 50% lower than conventional C-S.
### Nitrogen Loss (lb N/ac) to Tile Drainage Water

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<tbody>
<tr>
<td>Organic Alfalfa</td>
<td>12.6</td>
<td>12.2</td>
<td>5.74</td>
<td>2.35</td>
<td>32.9</td>
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<tr>
<td>Organic Corn</td>
<td>12.9</td>
<td>5.56</td>
<td>11.3</td>
<td>8.86</td>
<td>38.6</td>
</tr>
<tr>
<td>Organic Oat</td>
<td>32.3</td>
<td>13.3</td>
<td>9.14</td>
<td>3.41</td>
<td>58.2</td>
</tr>
<tr>
<td>Organic Soybean</td>
<td>27.2</td>
<td>22.4</td>
<td>9.35</td>
<td>13.1</td>
<td>75.0</td>
</tr>
<tr>
<td>Organic Corn/Soybean</td>
<td>20.1</td>
<td>14.0</td>
<td>10.3</td>
<td>12.5</td>
<td>56.9</td>
</tr>
<tr>
<td>Conventional Corn/Soybean</td>
<td>44.7</td>
<td>32.2</td>
<td>13.9</td>
<td>9.73</td>
<td>100.5</td>
</tr>
<tr>
<td>Organic C/S/O/A</td>
<td>21.3</td>
<td>13.4</td>
<td>8.89</td>
<td>7.68</td>
<td>51.2</td>
</tr>
</tbody>
</table>
Tile water NO3-N concentrations from organic soybean plots in spring to early summer contributing most to tile N loss.

Fall planted cover crops after soybean could help minimize N loss.
Overall Conclusions

- Organic grain and vegetable cropping rotations in Iowa are stable and resilient systems
  - Enhance soil health
  - Retain C and nutrients
- Organic C-S-O/A-A-A rotations show great promise to improve surface water quality in Iowa
  - Reduce tile drainage water [NO$_3$-N]
  - Reduce annual N loading loss
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