Alternative Strategies for Building Soil Health and Enhancing Ecosystems

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PFI Soil Short Course
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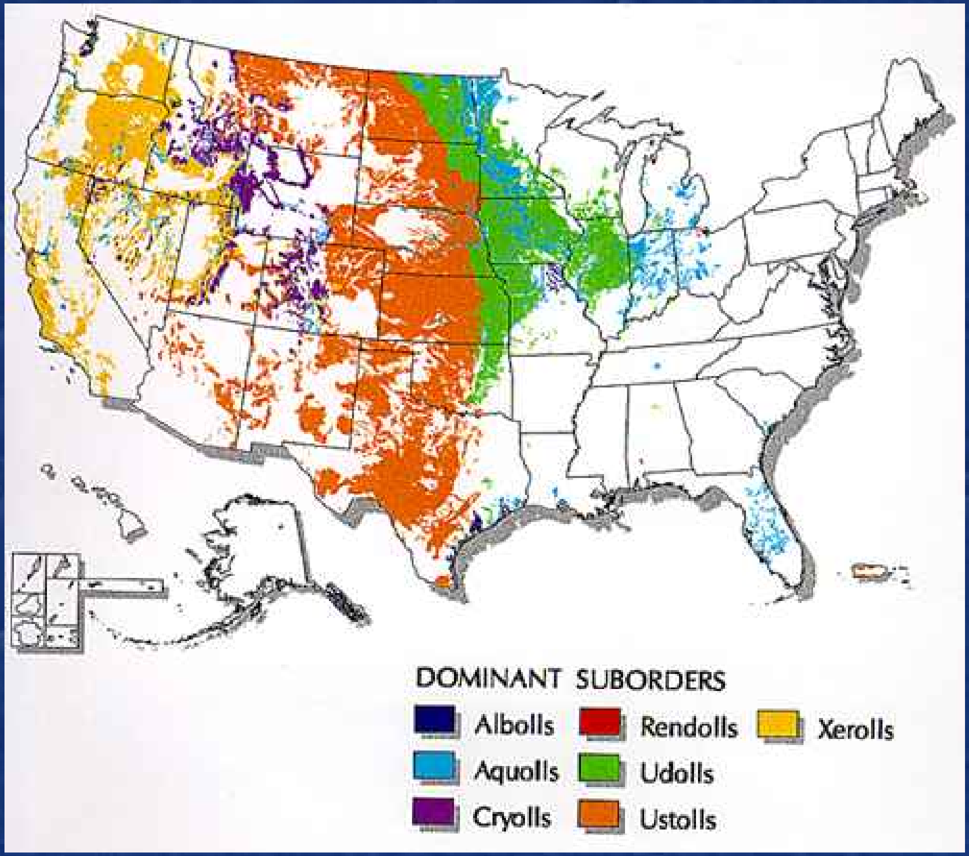
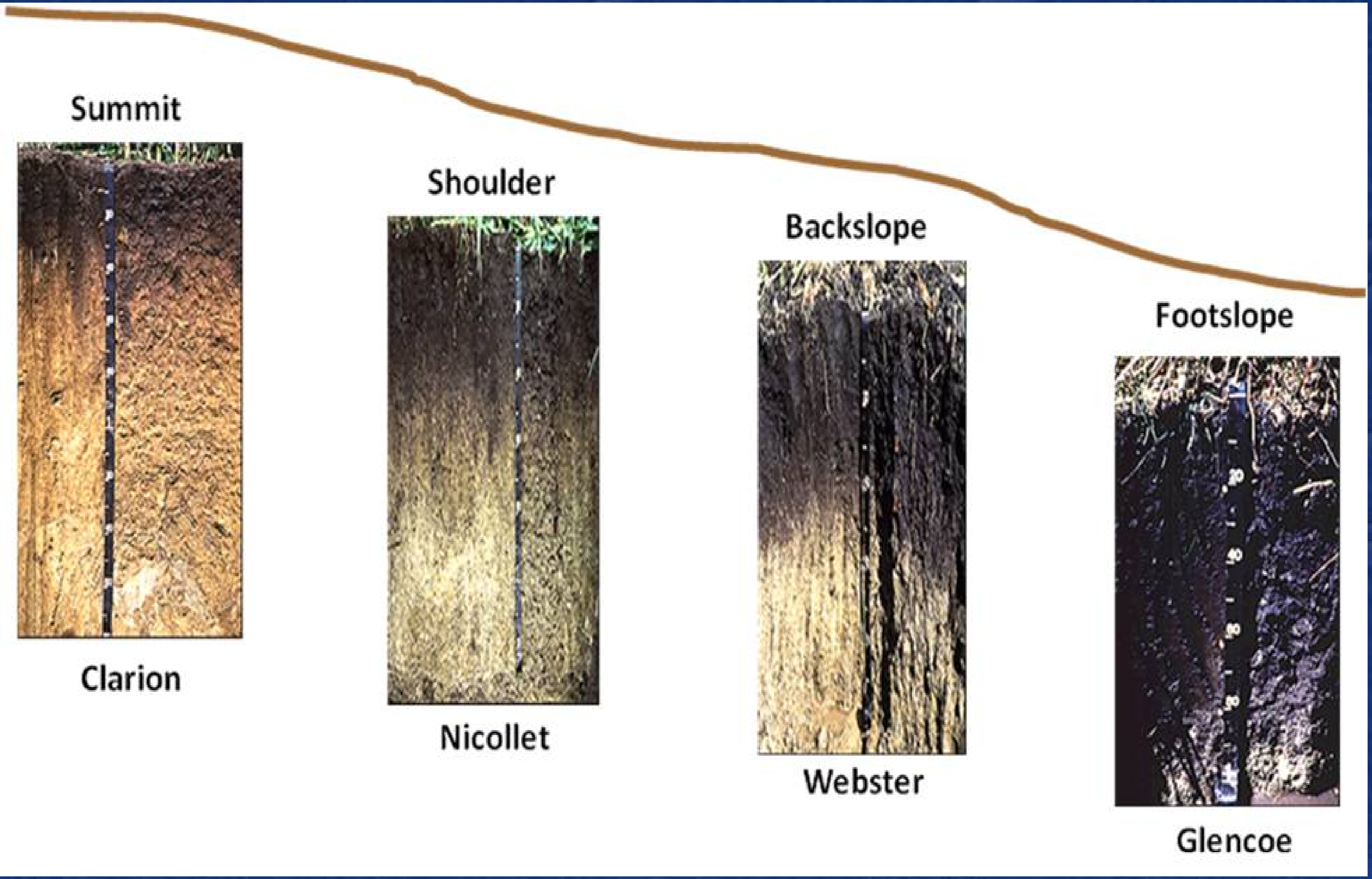
Ames, IA

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



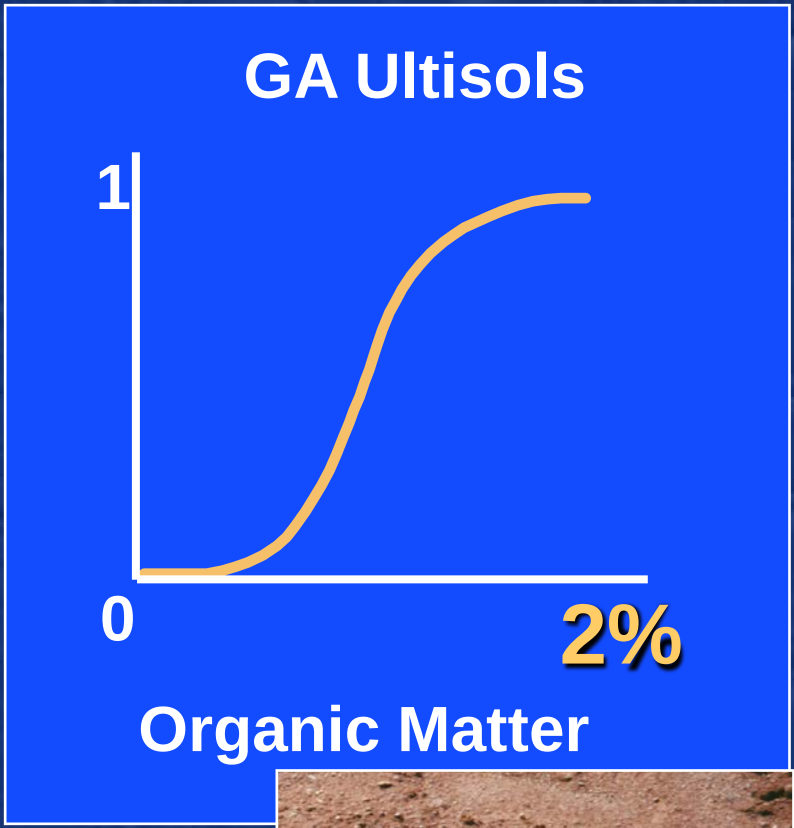
Soil Genesis

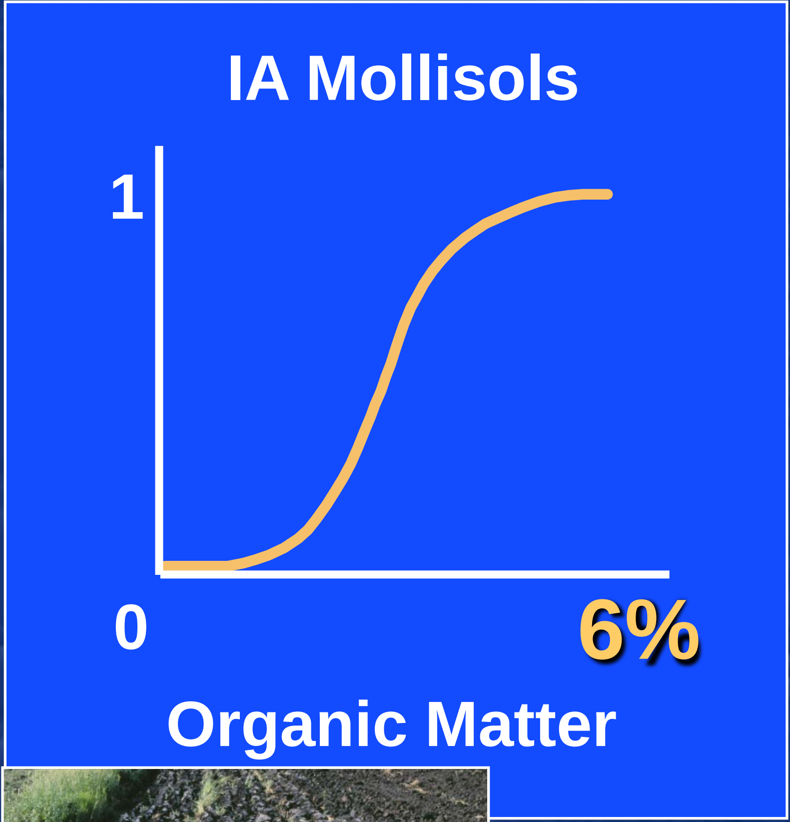
- Formative Change: Geologic Time
  - based on soil forming factors
    - climate, parent material, topography, and vegetation, all acting over time (Hans Jenny, 1941)
  - Soil texture and mineralogy reflect inherent/natural soil characteristics that don't change with land management

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

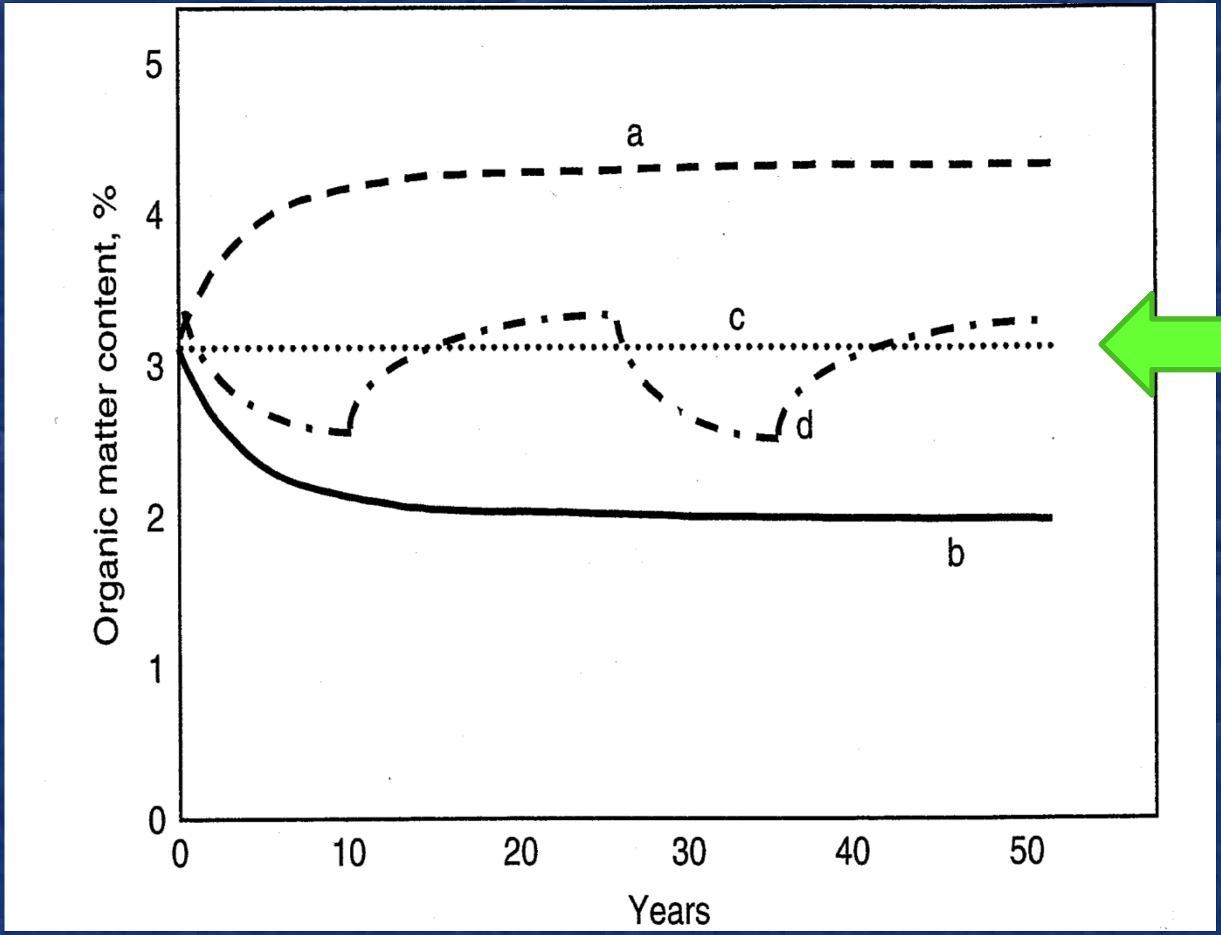




Soil Change

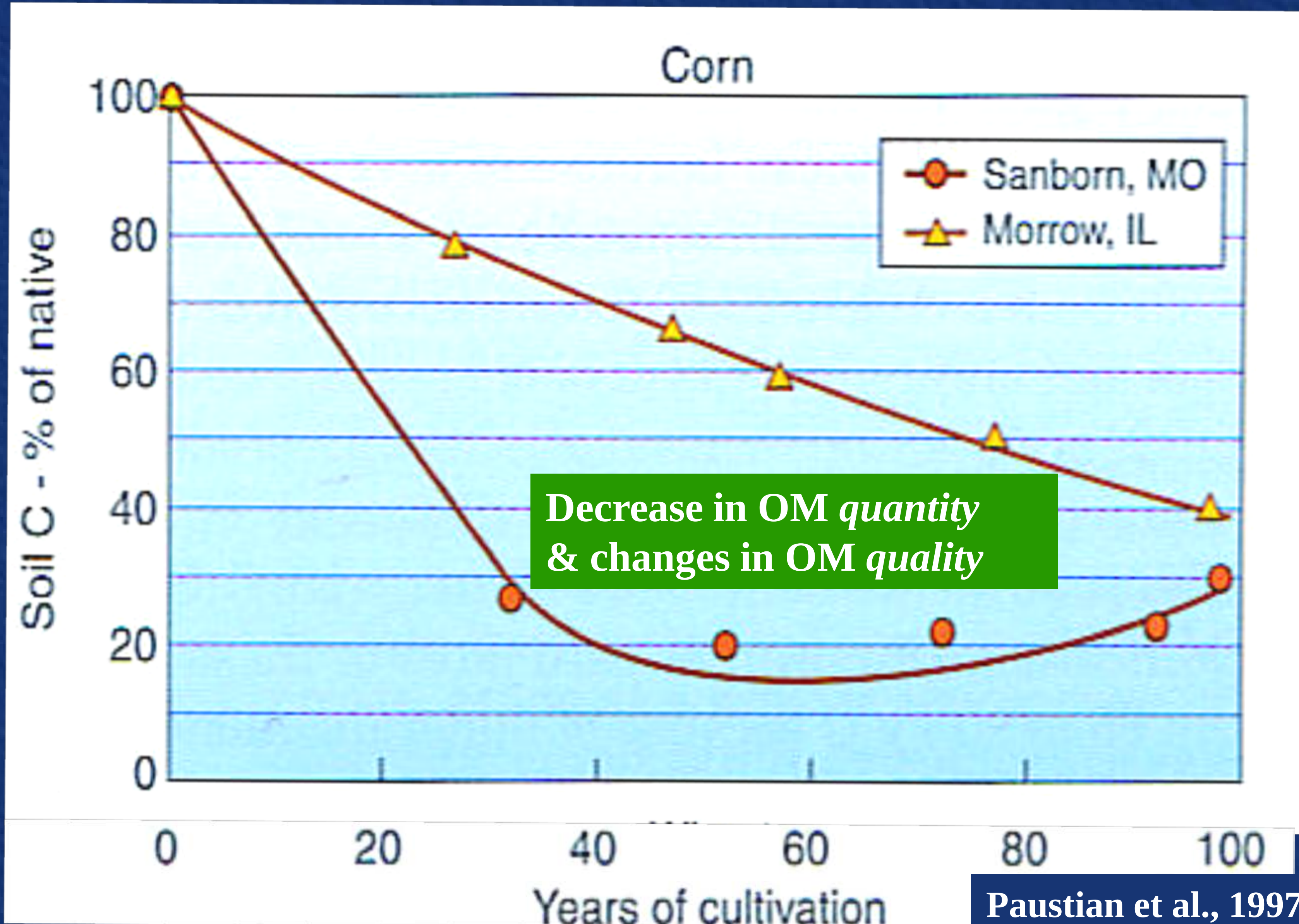
- Formative Change: Ecological time
  - Amount of SOM in a given soil is related to the texture and mineralogy of that soil
- Dynamic Change: Human Time
  - SOM is dynamic soil characteristic that can change with land-use and management

Dynamic equilibrium



Characteristics of a sustainable ecosystem…

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



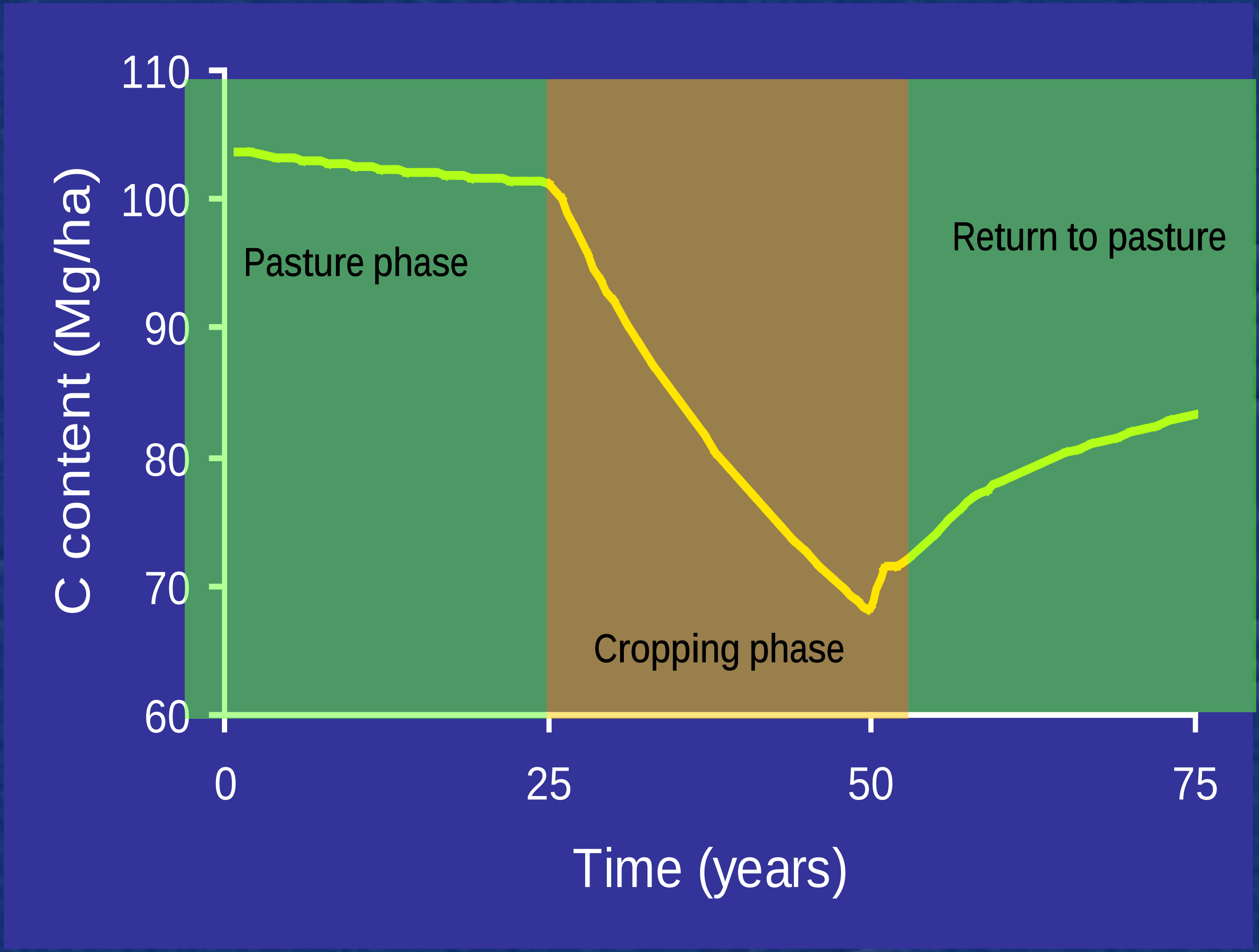
Paustian et al., 1997

Midwestern soils have lost >1/2 of their native carbon
and are still losing C

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

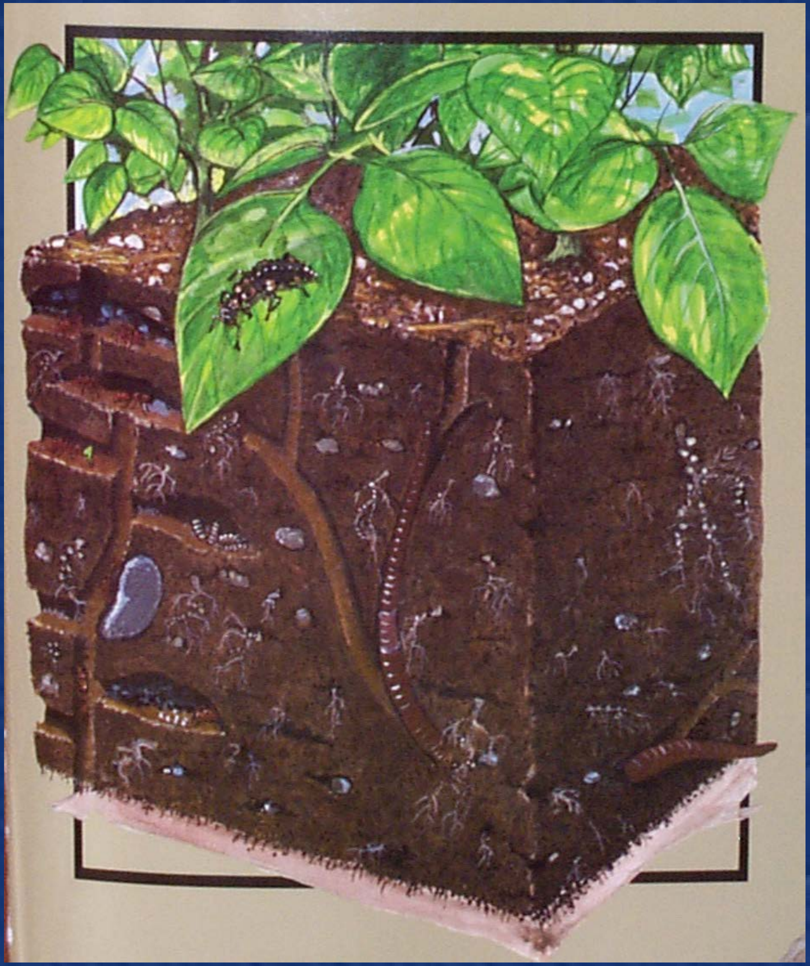

Agricultural Sustainability
depends on the system maintaining
functional resilience
in the face of repeated disturbance

Soil Quality

"…capacity of soil ecosystem to function …"

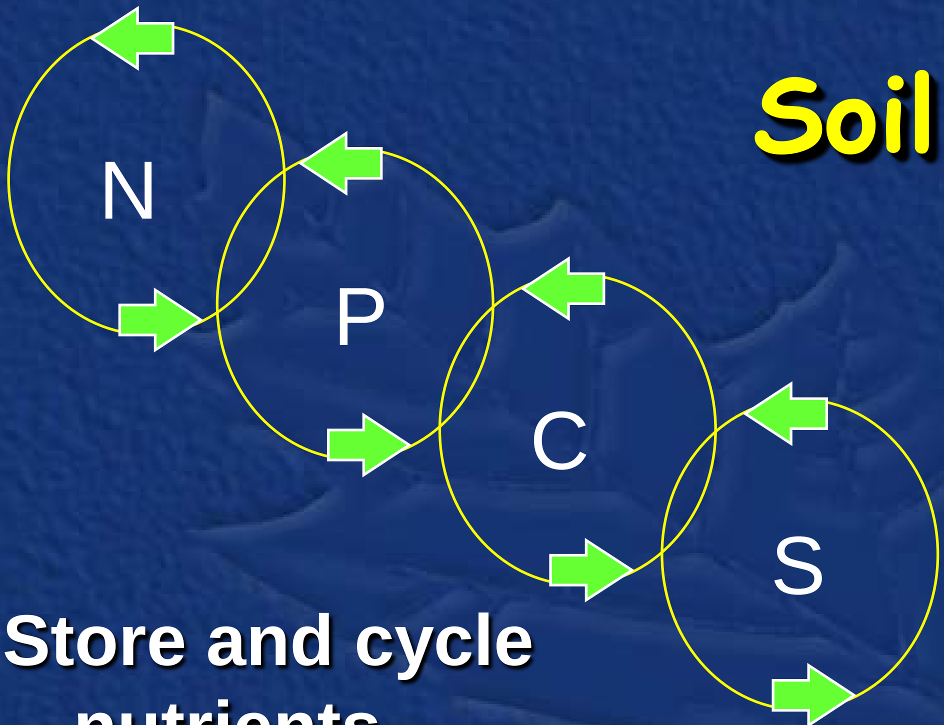
Maintain productivity & biodiversity
Store and cycle nutrients
Regulate & partition water flow
Filter, buffer & detoxify

Soil Functions



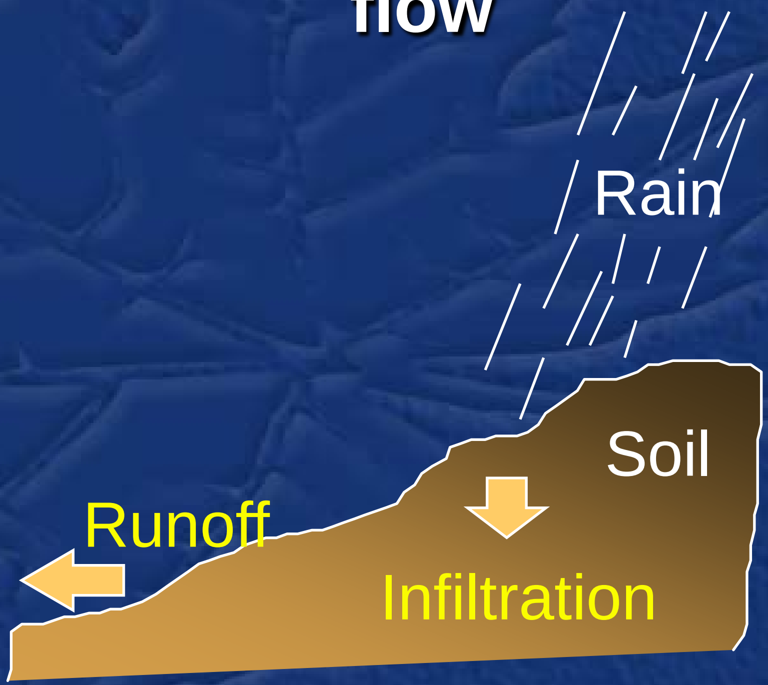
Maintain productivity and biodiversity

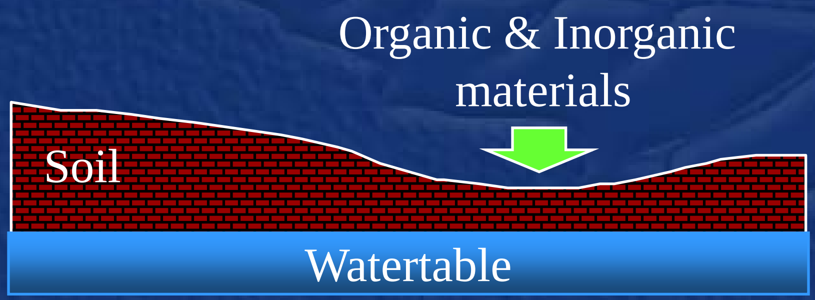
Soil Functions



Store and cycle nutrients

Regulate and partition water flow



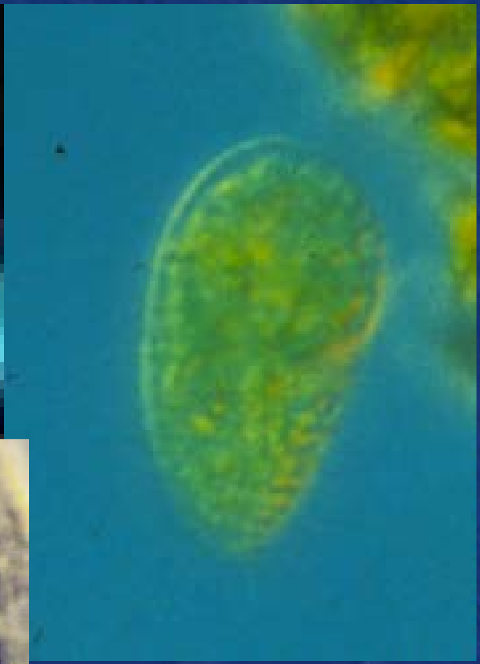


Filter, buffer and detoxify

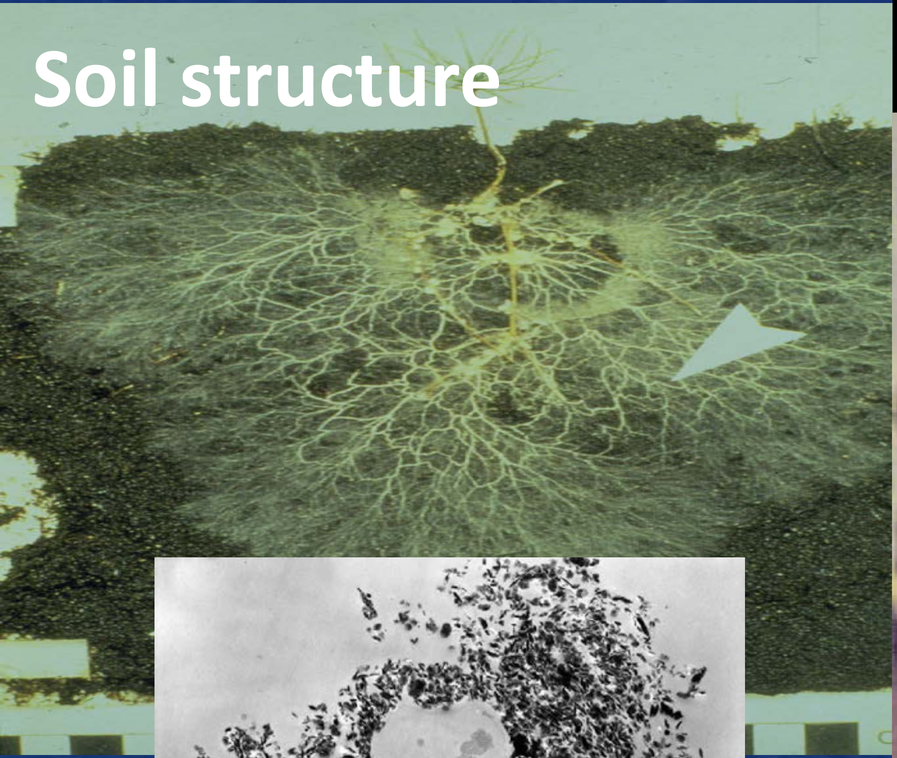
Soil is one of the most diverse habitats on earth and is one of earth's most complex ecosystems

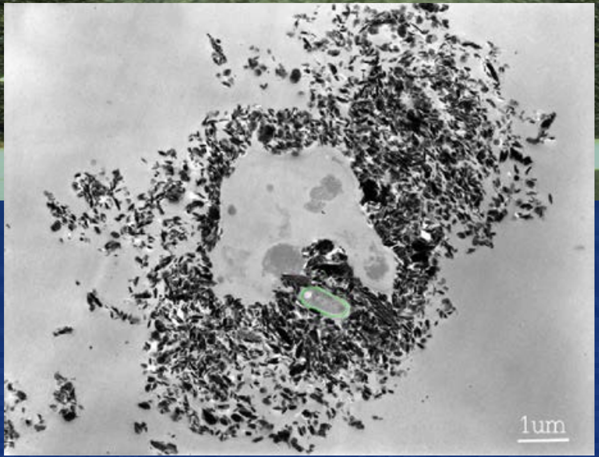
Earthworms
Termites
Ants

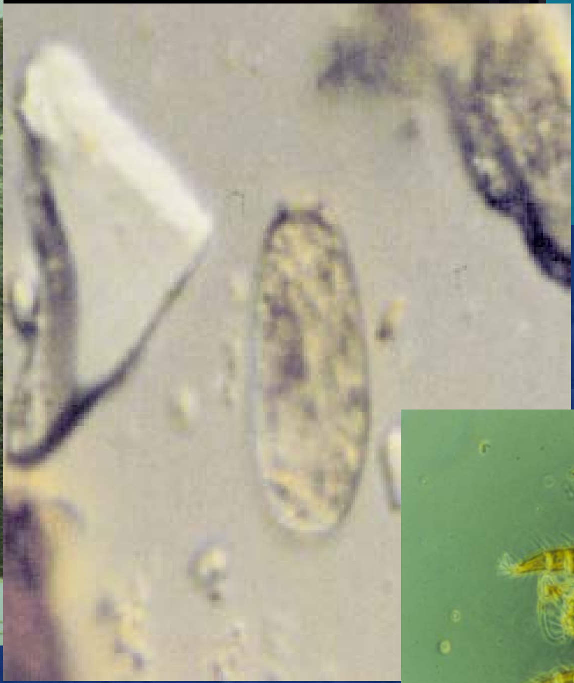
Bacteria, Fungi
Protozoa, Nematodes
Micro-arthropods



Soil structure

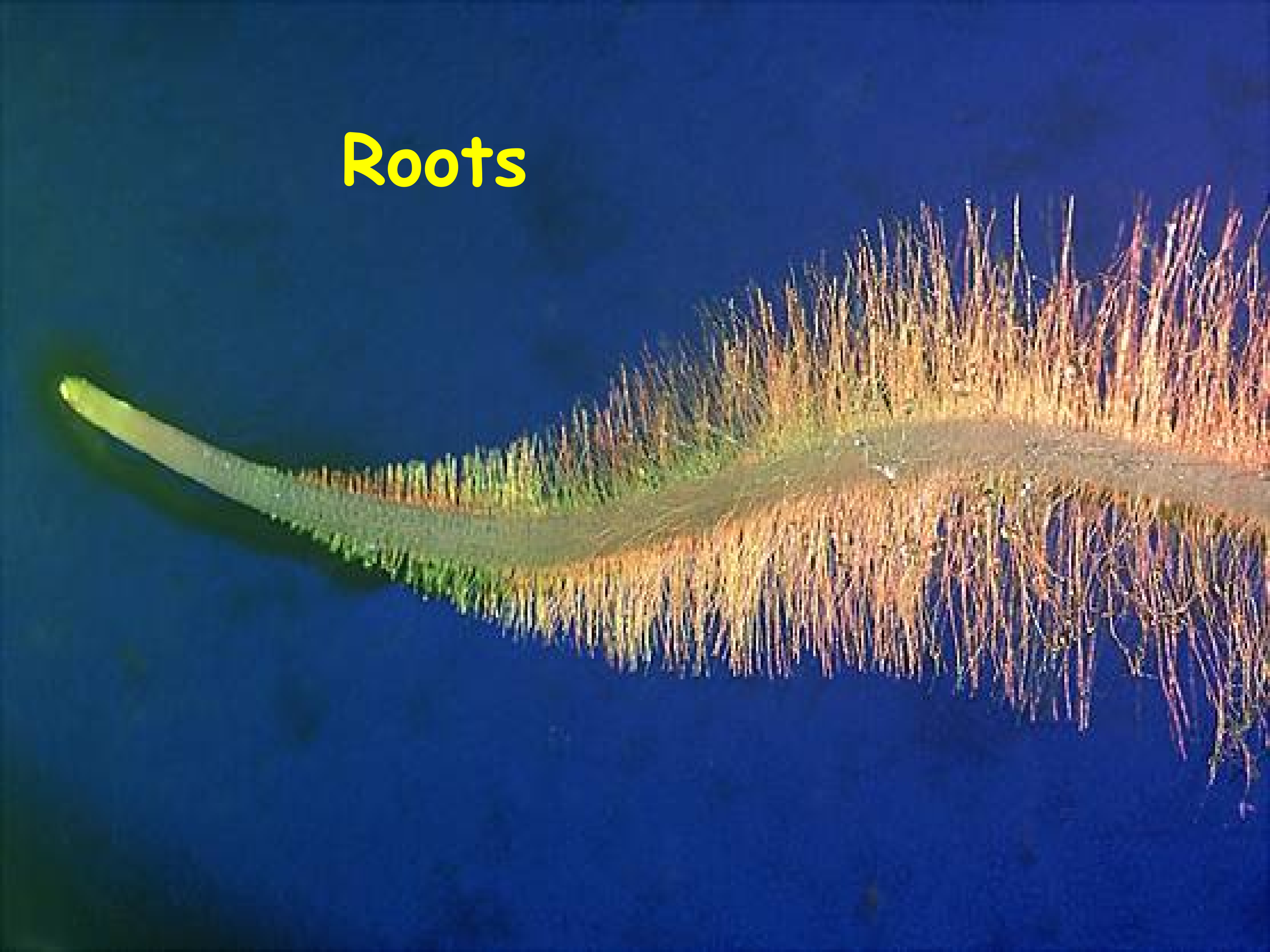




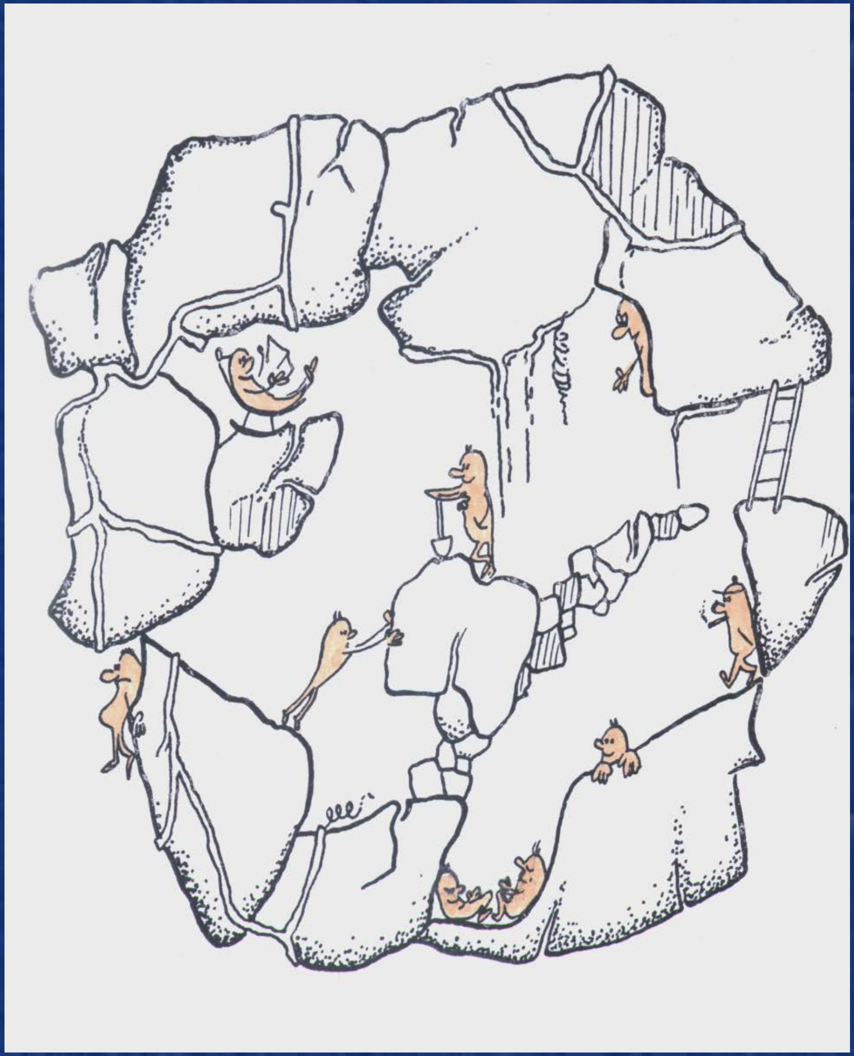


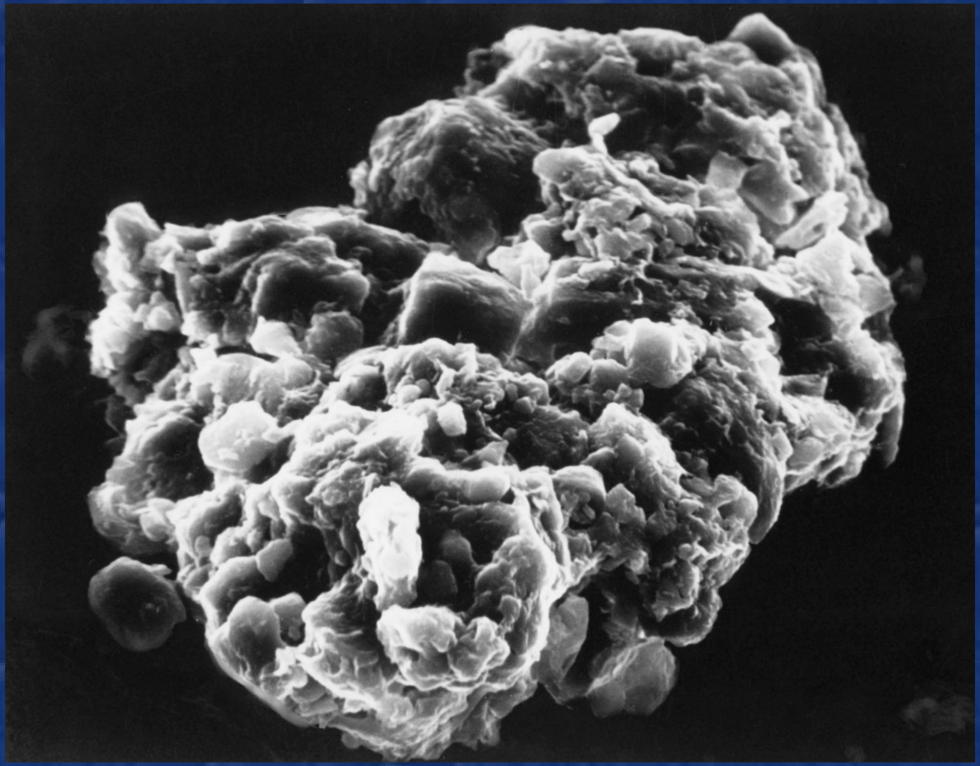
OM cycling

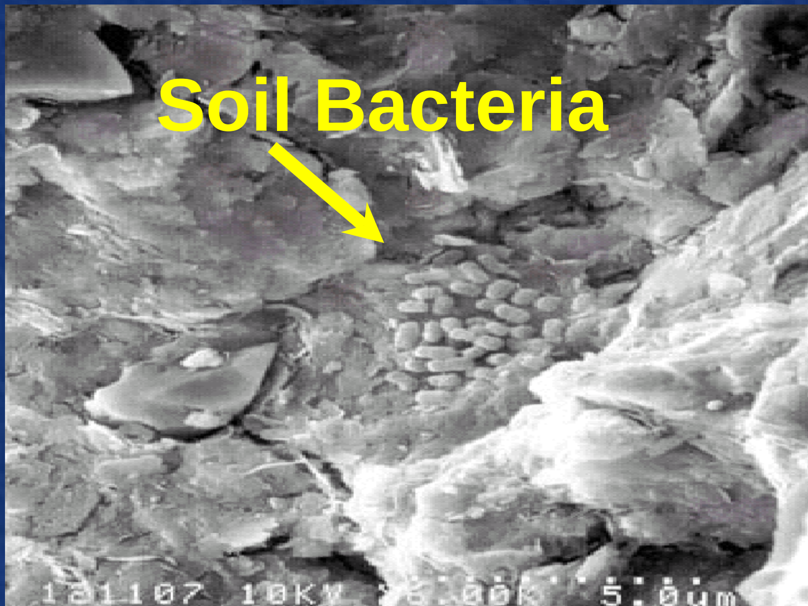
Nutrient cycling

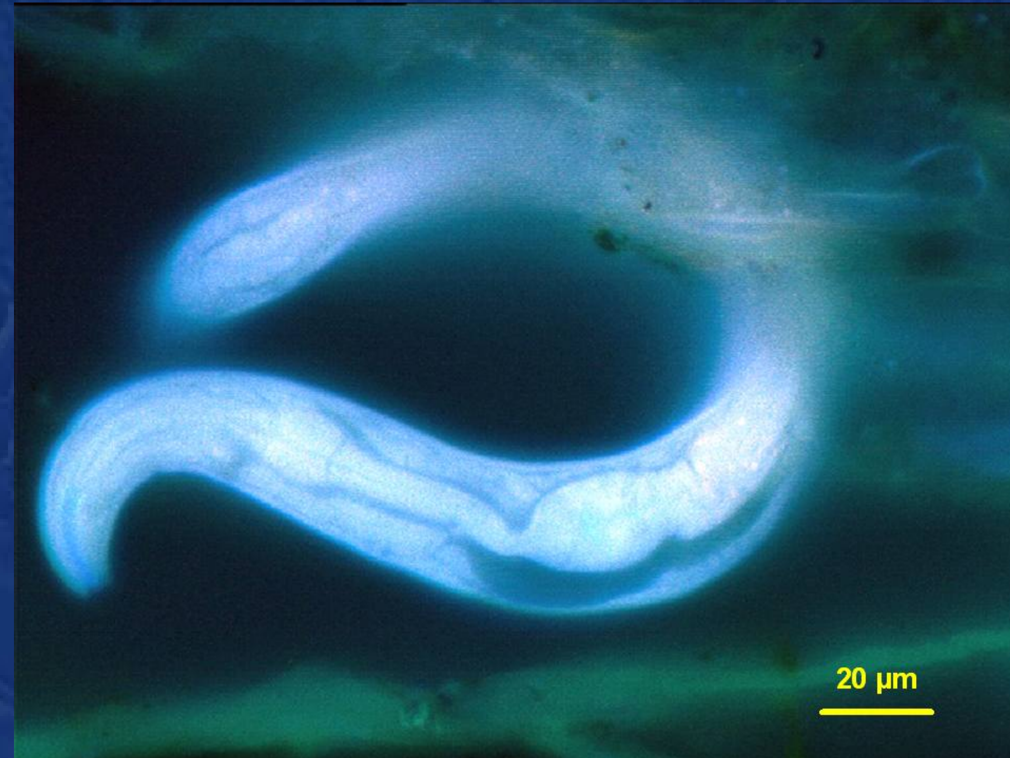

Roots

Where do populations of soil organisms live in the soil?



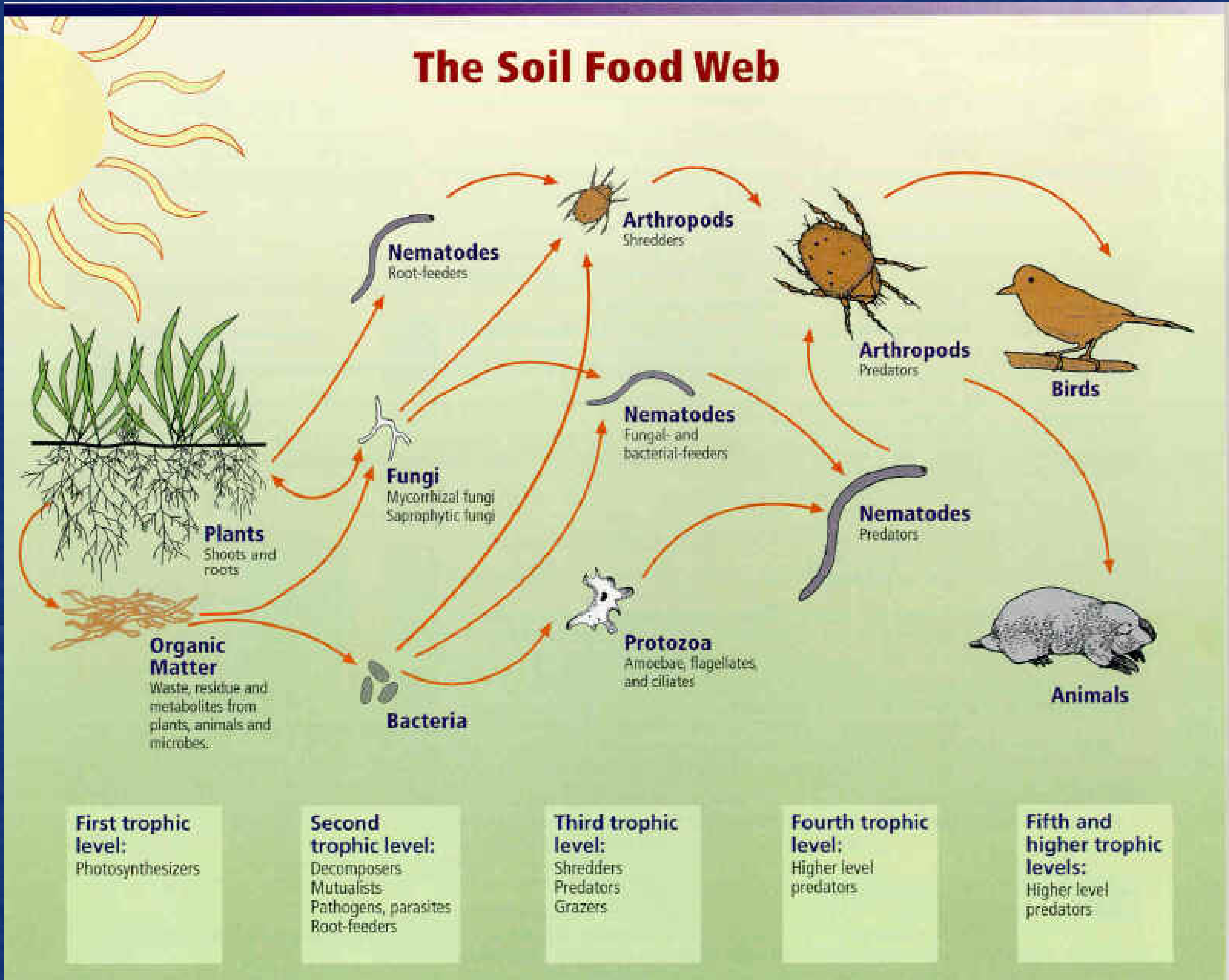


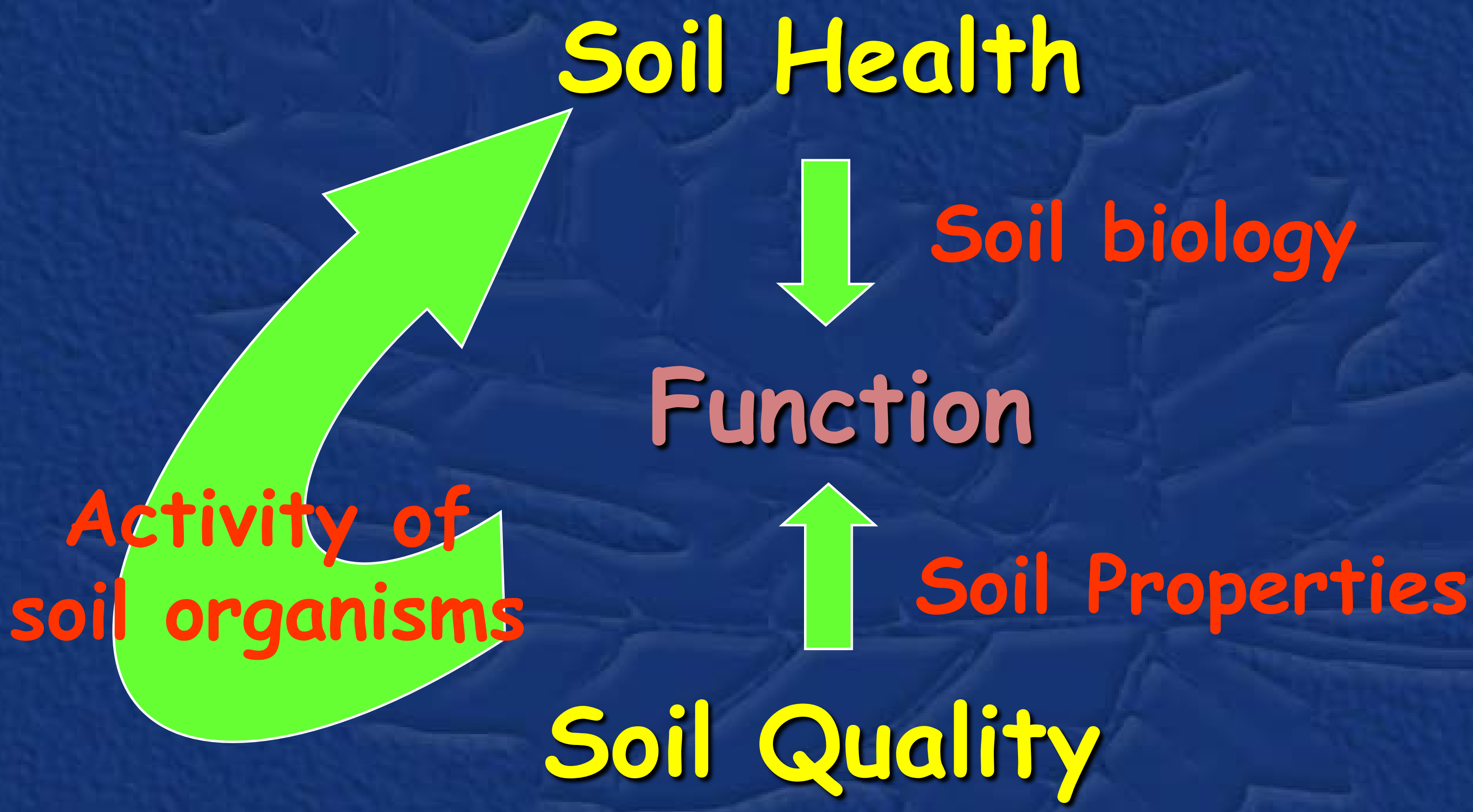




Nematode living in water-filled pore space

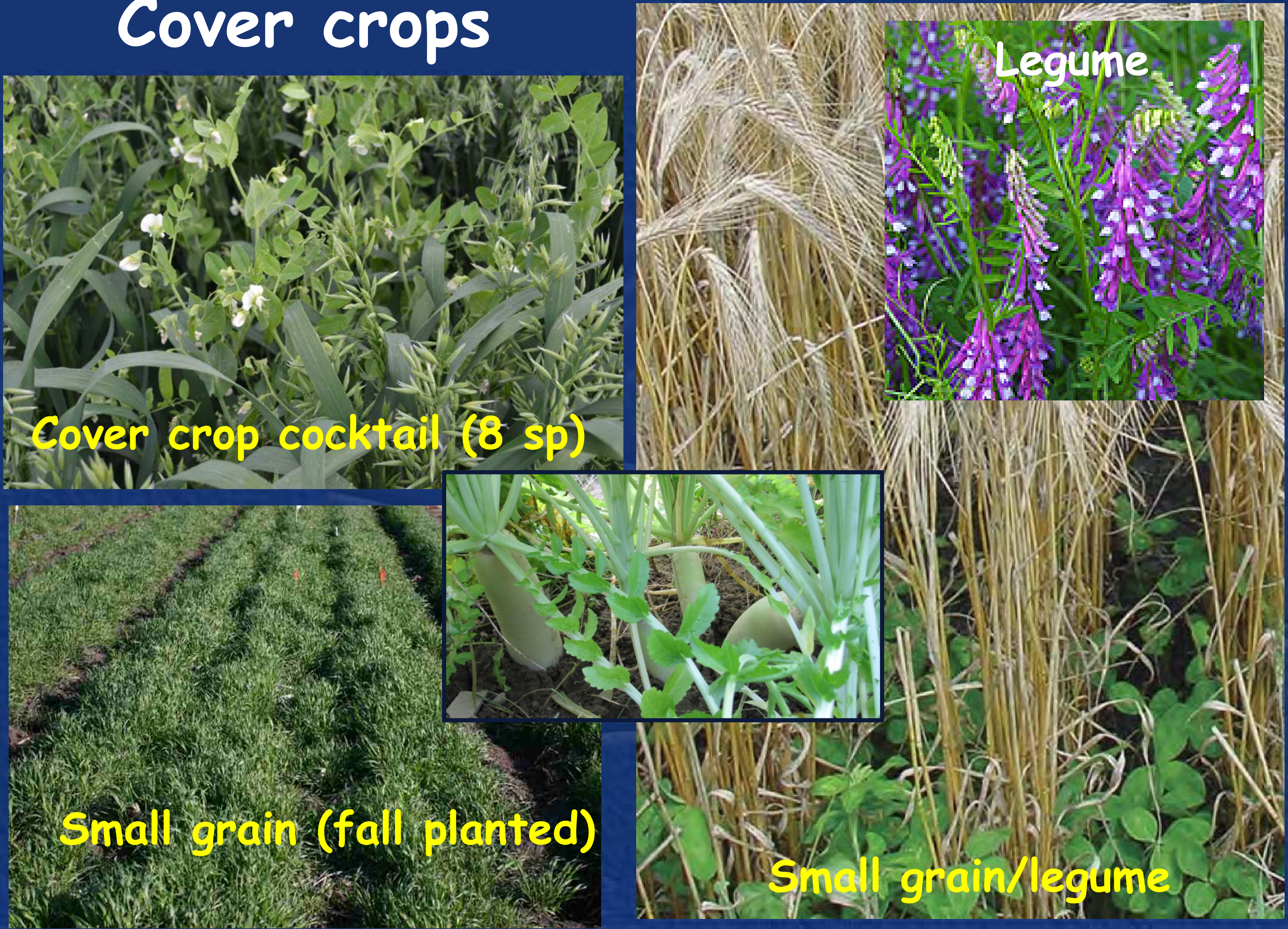
Saprophytic fungi living in air-filled pore space


The Soil Food Web
Nematodes
Root-feeders
Arthropods
Shredders
Arthropods
Predators
Birds
Plants
Shoots and roots
Fungi
Mycorrhizal fungi
Saprophytic fungi
Nematodes
Fungal- and bacterial-feeders
Nematodes
Predators
Organic Matter
Waste, residue and metabolites from plants, animals and microbes.
Bacteria
Protozoa
Amoebae, flagellates, and ciliates
Animals
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
Soil biology
Function
Activity of
soil organisms
Soil Properties
Soil Quality

Plant extended rotations, reduce tillage, diversify landscape

Cover crops

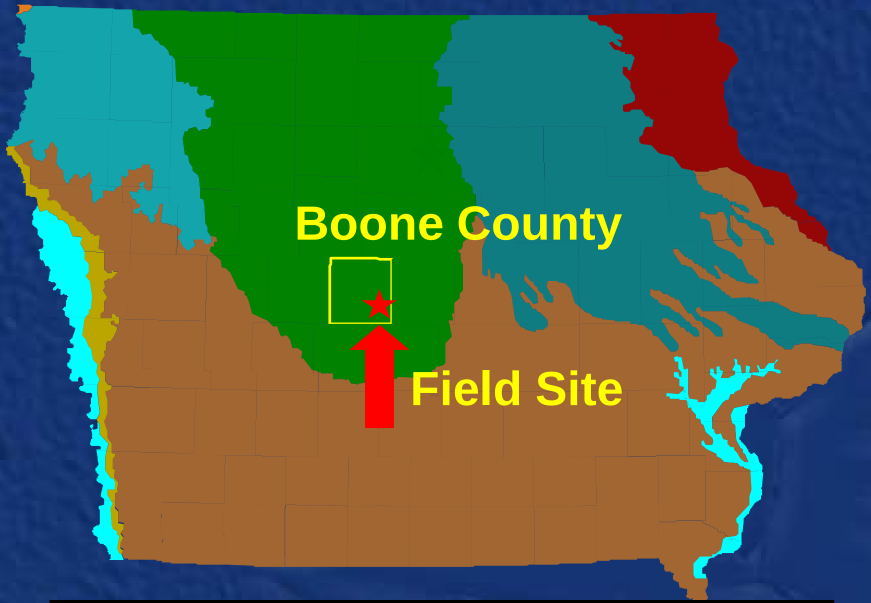

Legume
Cover crop cocktail (8 sp)
Small grain (fall planted)
Small grain/legume


Retain residue, add manure, compost and green manures

ECOSYSTEM SERVICES

Millennium Ecosystem Assessment

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

USDA NIFA

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

Fall 2011	Reduced Tillage	Conventional Tillage
SOC (g/kg)*	31.10a	31.93a
TN (g/kg)	2.84a	2.75a
POMC (g/kg)	5.74a	3.92a
MBC (mg/kg)	533a	406b
PotMinN (mg/kg)	55.0a	46.2b
pH	6.66a	6.44a
Macroaggs (%)	40.2a	41.3a
Bulk Density	1.22a	1.16a

*** Depth 0-15 cm**

Means followed by same letter within a row are not different at 95%

Fall 2011	Reduced Tillage	Conventional Tillage
MBC (mg/kg)		
Iowa	533a	406b
Michigan	318a	282a
Minnesota	579a	503a
Pennsylvania	418a	358b
Wisconsin	748a	518a

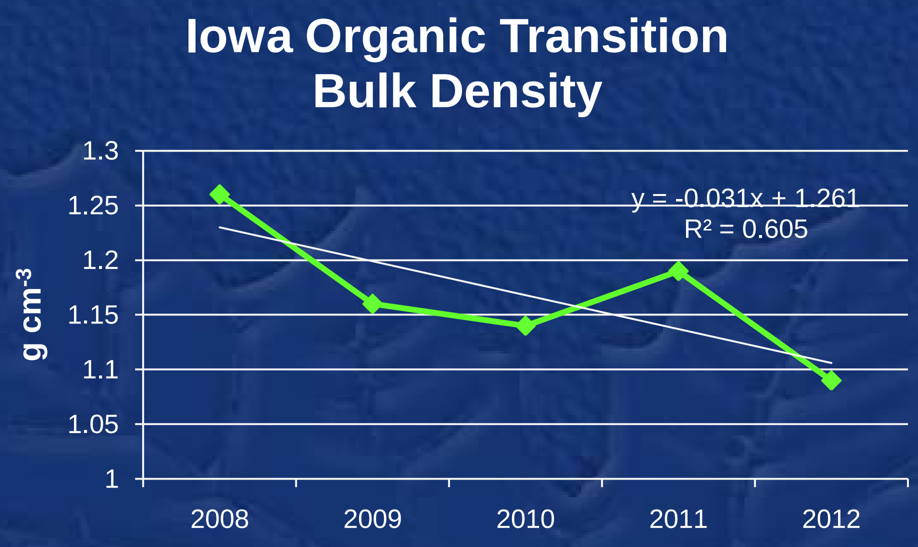
Depth 0-15 cm

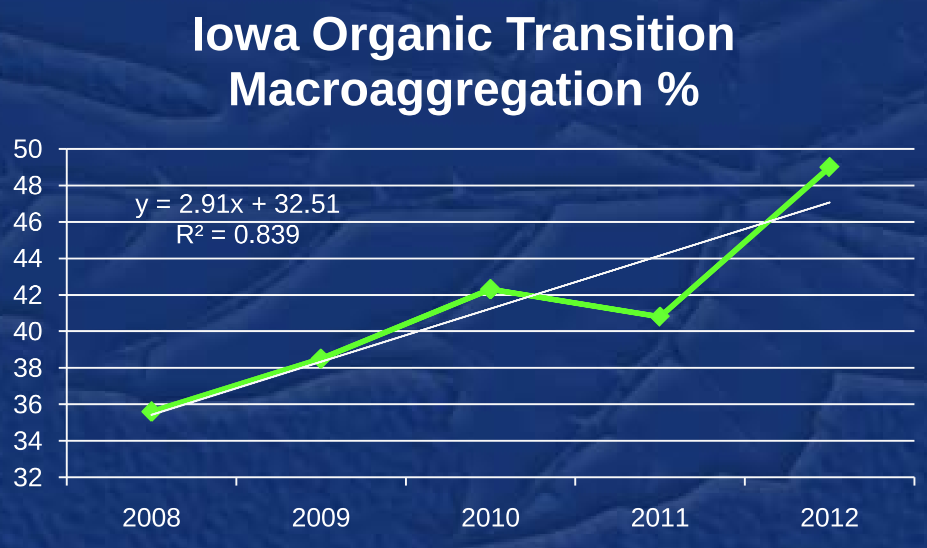
Means followed by same letter within a row are not different at 95%

Fall 2011	Reduced Tillage	Conventional Tillage
PotMinN (mg/kg)		
Iowa	55a	46b
Michigan	44a	30b
Minnesota	44a	39a
Pennsylvania	74a	67a
Wisconsin	79a	68b

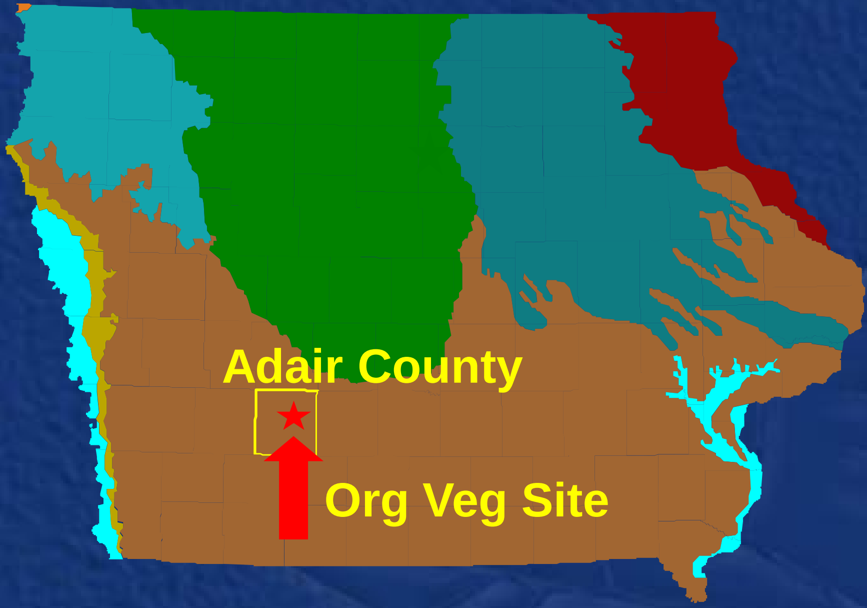
Depth 0-15 cm

Means followed by same letter within a row are not different at 95%


Iowa Organic Transition
Bulk Density
g cm-3
1.3
1.25
1.2
1.15
1.1
1.05
1
2008
2009
2010
2011
2012
y = -0.031x + 1.261
R² = 0.605


Iowa Organic Transition
Macroaggregation %
50
48
46
44
42
40
38
36
34
32
2008
2009
2010
2011
2012
y = 2.91x + 32.51
R² = 0.839

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

USDA
NIFA

Tomato-Sweet Corn- Pepper Rotations

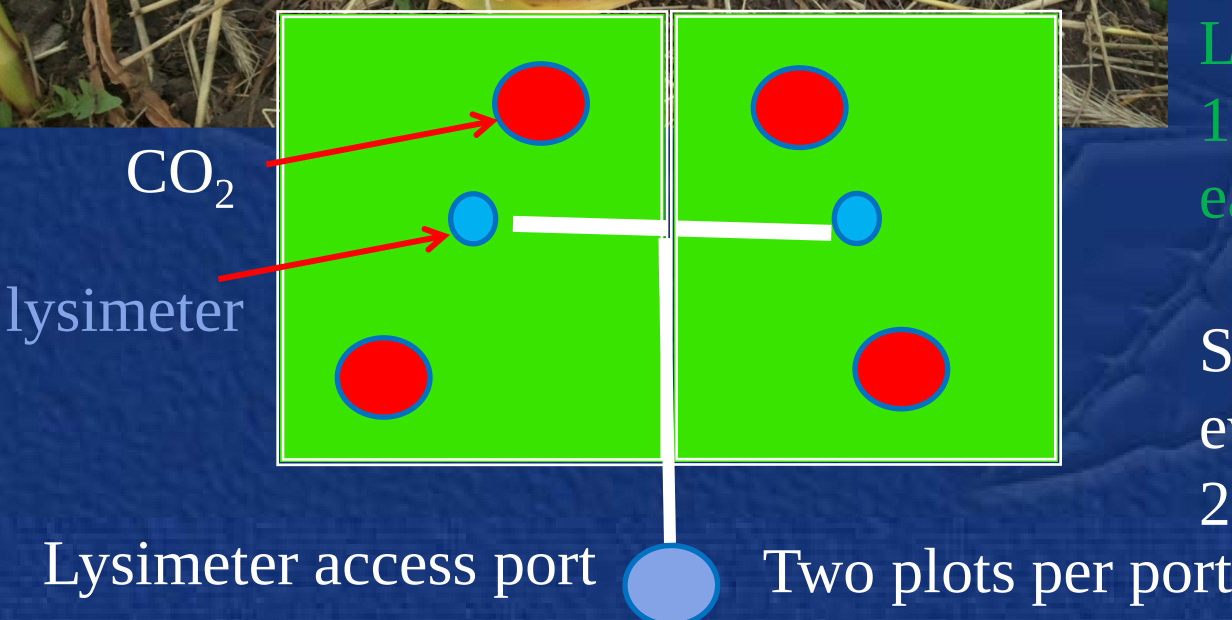
Randomized Block Design
4 replicates

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 CO_2 collars per plot
-close to plant
-max dist from plant

CO_2 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

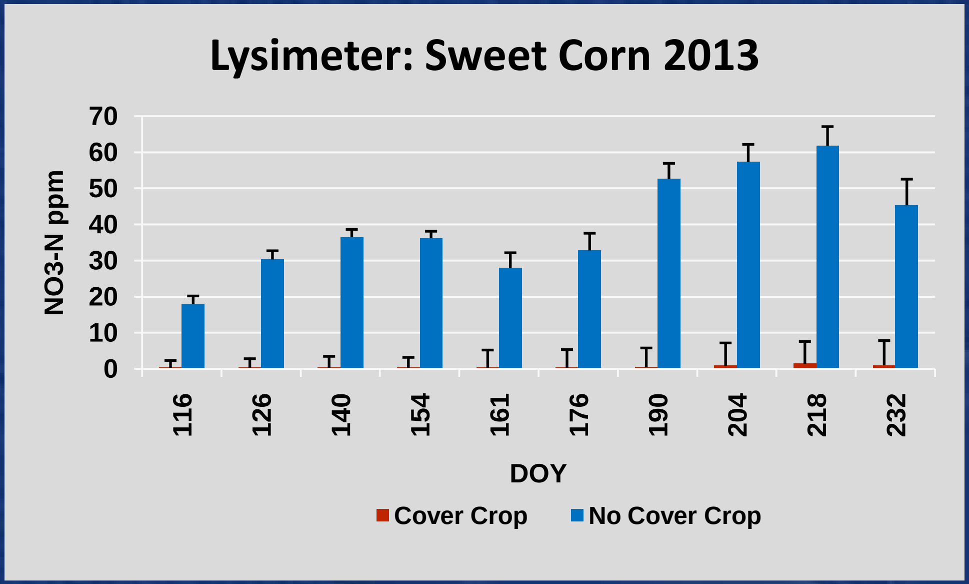
Fall 2014*	NCC_T	CC_NT	CC_T
SOC (g/kg)*	26.8c	30.7a	29.0ab
TN (g/kg)	2.7bc	3.0a	2.9ab
POMC (g/kg)	3.8b	5.7a	6.0a
MBC (mg/kg)	220b	283a	286a
PotMinN (mg/kg)	54.3b	70.4a	70.2a
Macroaggs (%)	15.0c	27.0a	21.4b

* after peppers

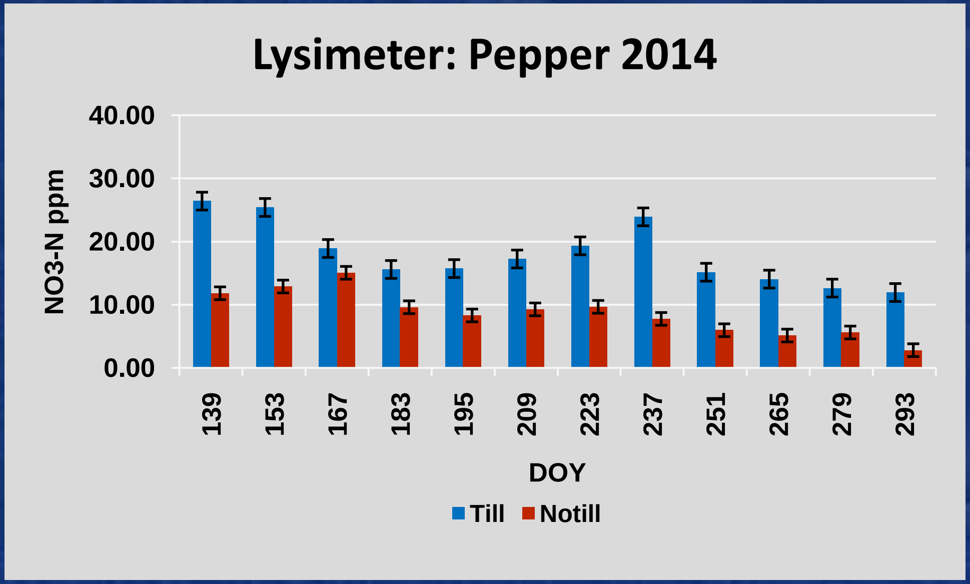
NCC_T = No Cover Crop, Till
CC_NT = Cover Crop, No-Till
CC_T = Cover Crop, Till

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

Lysimeter NO_3-N to estimate N leaching potential

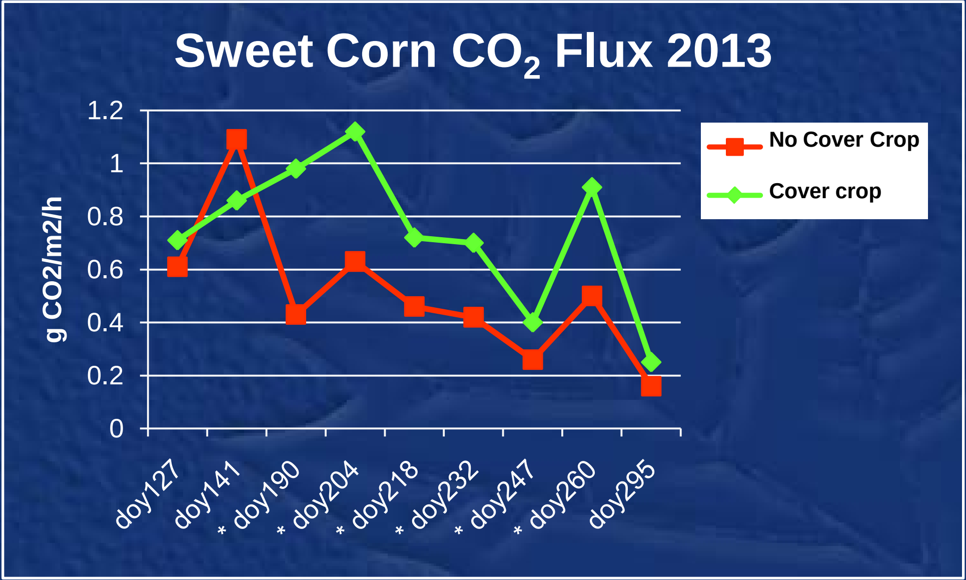


NO_3-N lower with cover crops in all crops in all years



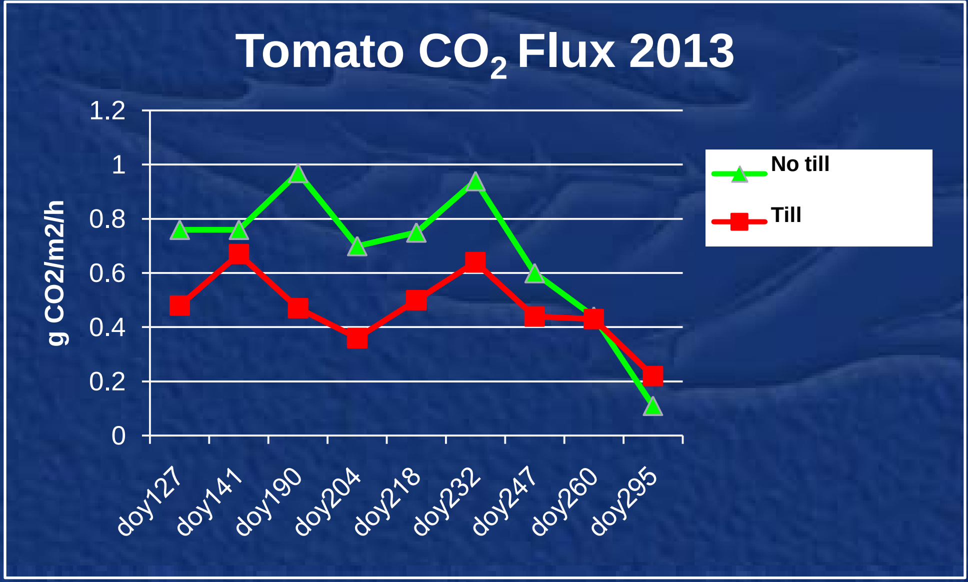
NO_3-N lower under no-till in all crops in all years

Soil Respiration as an estimate of Microbial Activity



Average growing season CO_2 flux higher with cover crops in both rotations in all years

Cover crop: 0.74 g $CO_2/m^2/h$
No cover crop: 0.51 g $CO_2/m^2/h$

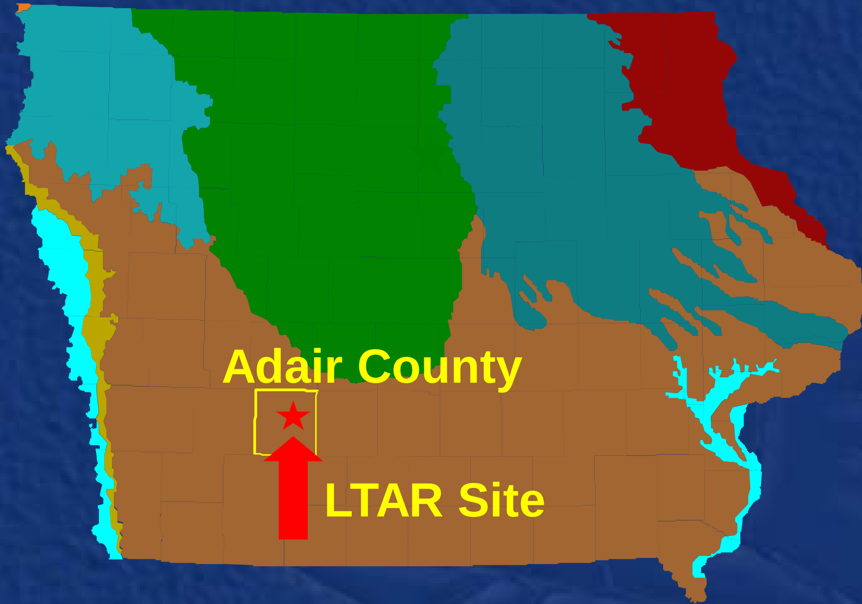


Average growing season CO_2 flux higher under no-till in both rotations in all years

Till: 0.47 g $CO_2/m^2/h$
No-till: 0.67 g $CO_2/m^2/h$

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



Long-Term Agroecological Research (LTAR) Site Neely-Kinyon Research Farm, Greenfield IA

Southern IA Drift Plain

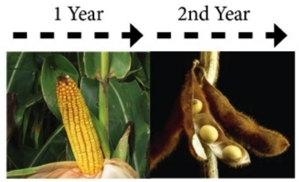
Started in 1998
Kathleen Delate, ISU, PI
Cindy Cambardella, ARS, co-PI

LEOPOLD CENTER FOR SUSTAINABLE AGRICULTURE

Neely-Kinyon LTAR

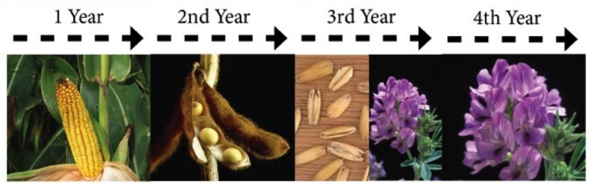
Treatments

8 Plots
Conventional C - SB

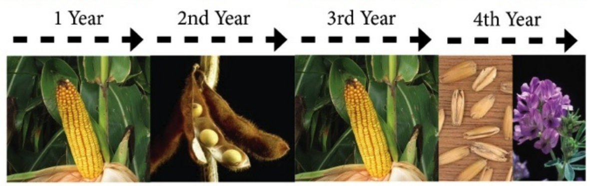


12 Plots
Organic C - SB - O/A

16 Plots
Organic C - SB - O/A - A



8 Plots
Organic C - SB - C - O/A
(changed from SB-W/RC in 2010)

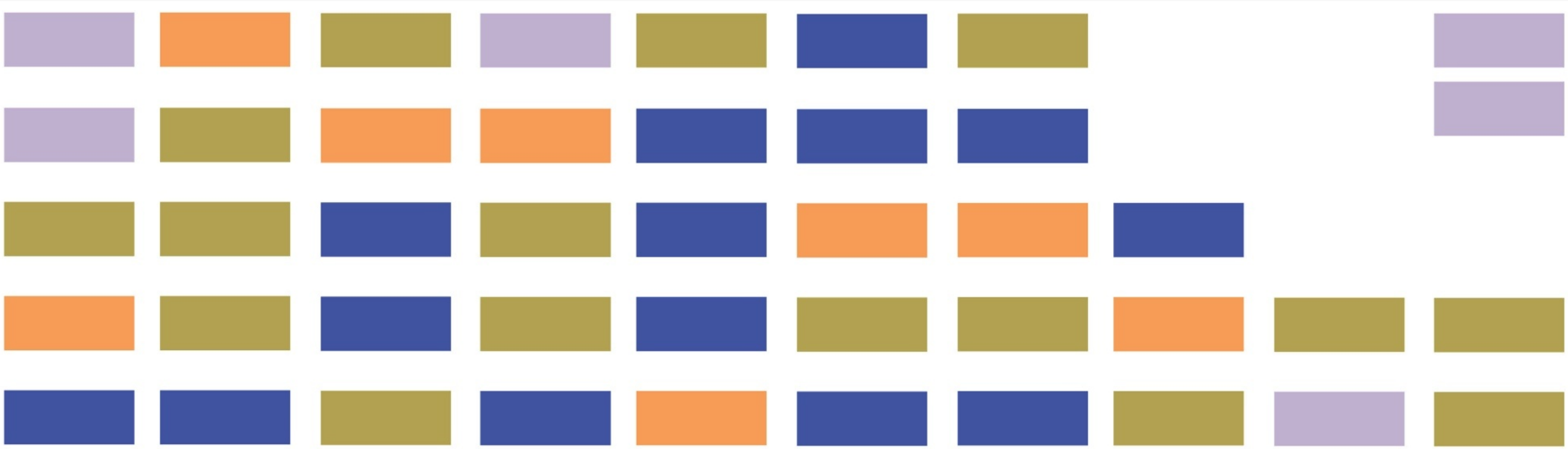


-44 plots total
-4 reps of each crop in each treatment
-70’ x 140’ plots
-30’ borders in each direction
-Completely randomized design based on uniform slope and soil type

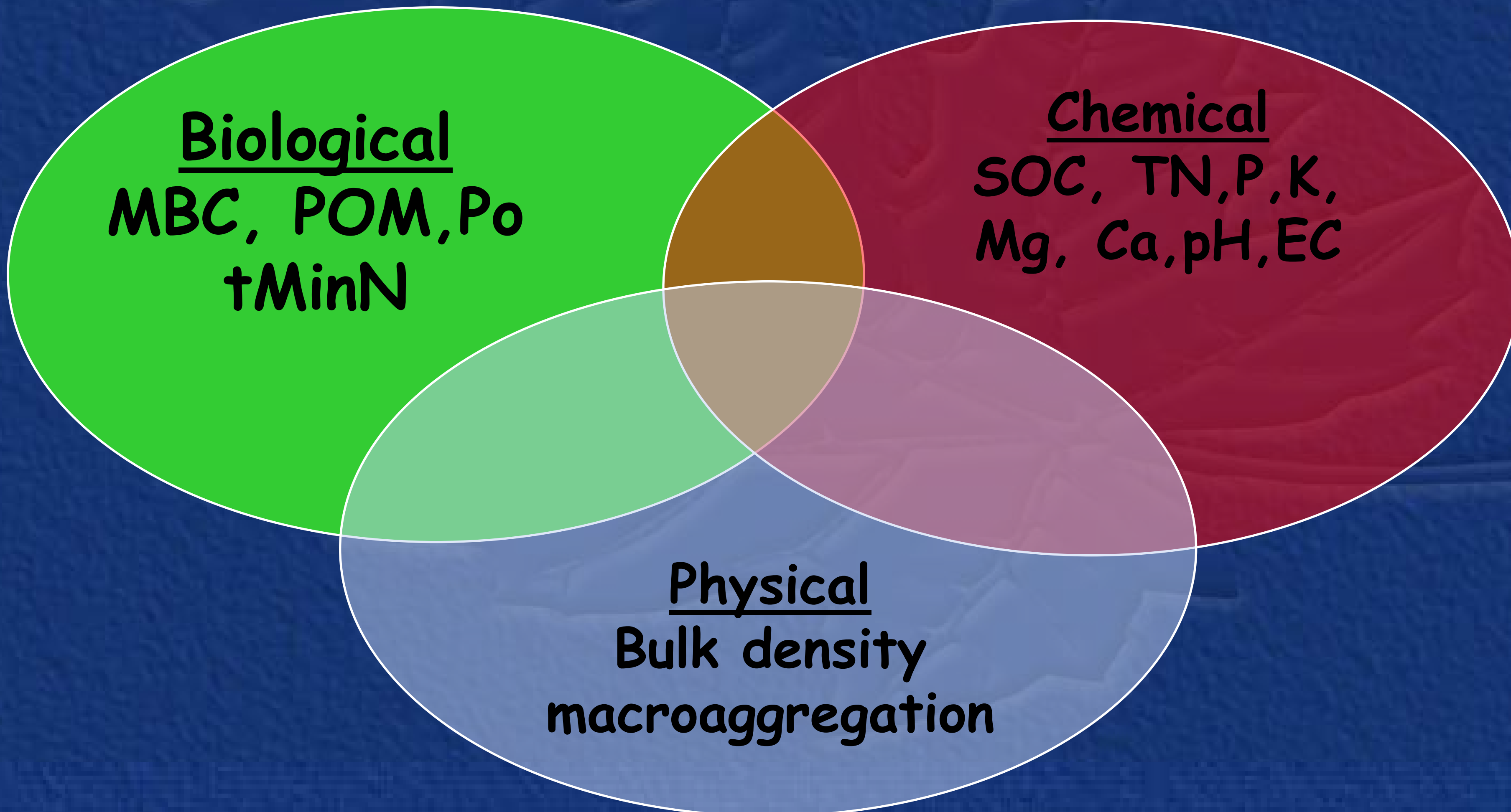
Composted animal manure organic corn and oats
28% Urea: conventional corn

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

Plot Plan



Soil Health Assessment



Uses of SQ Assessment

- **Adaptive management tool**

Fall 2014	Organic	Conventional
SOC (g/kg)*	24.6a	23.1b
TN (g/kg)	2.4a	2.3b
POMC (g/kg)	3.2a	2.4b
MBC (mg/kg)	452a	372b
PotMinN (mg/kg)	54a	43b
InorgN (mg/kg)	3.1a	3.2a
Macroaggs (%)	24a	22a

*** Depth 0-15 cm**

Means followed by same letter within a row are not different at 95%

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

*** Depth 0- 15 cm**

Means followed by same letter within a row are not different at 95%

Soil Health Summary
LTAR 1998-2014

Organic soils had

> total soil C & N

> biologically active soil C and N

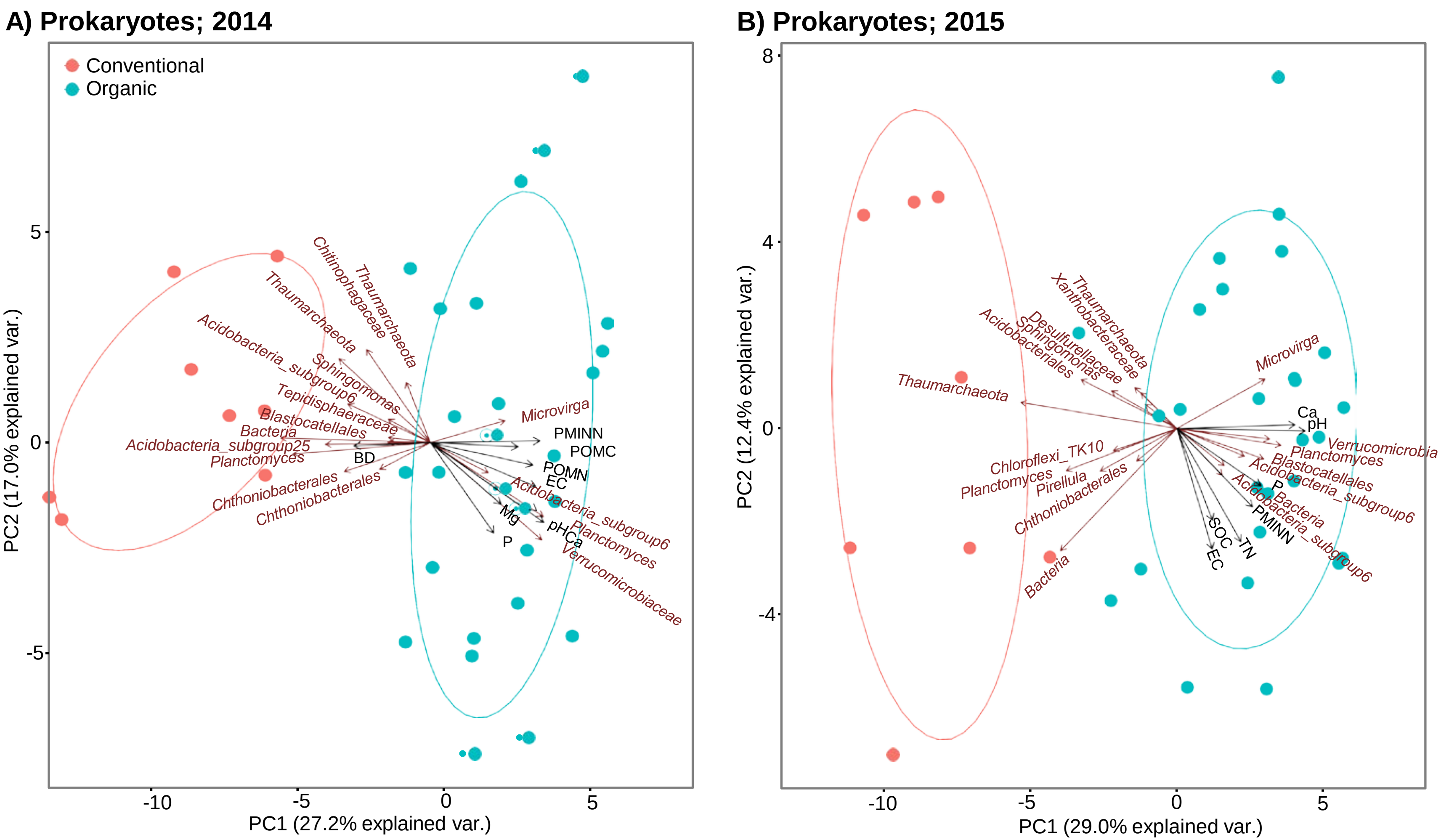
> plant nutrients (P,K,Mg)

< soil acidity

= aggregate stability

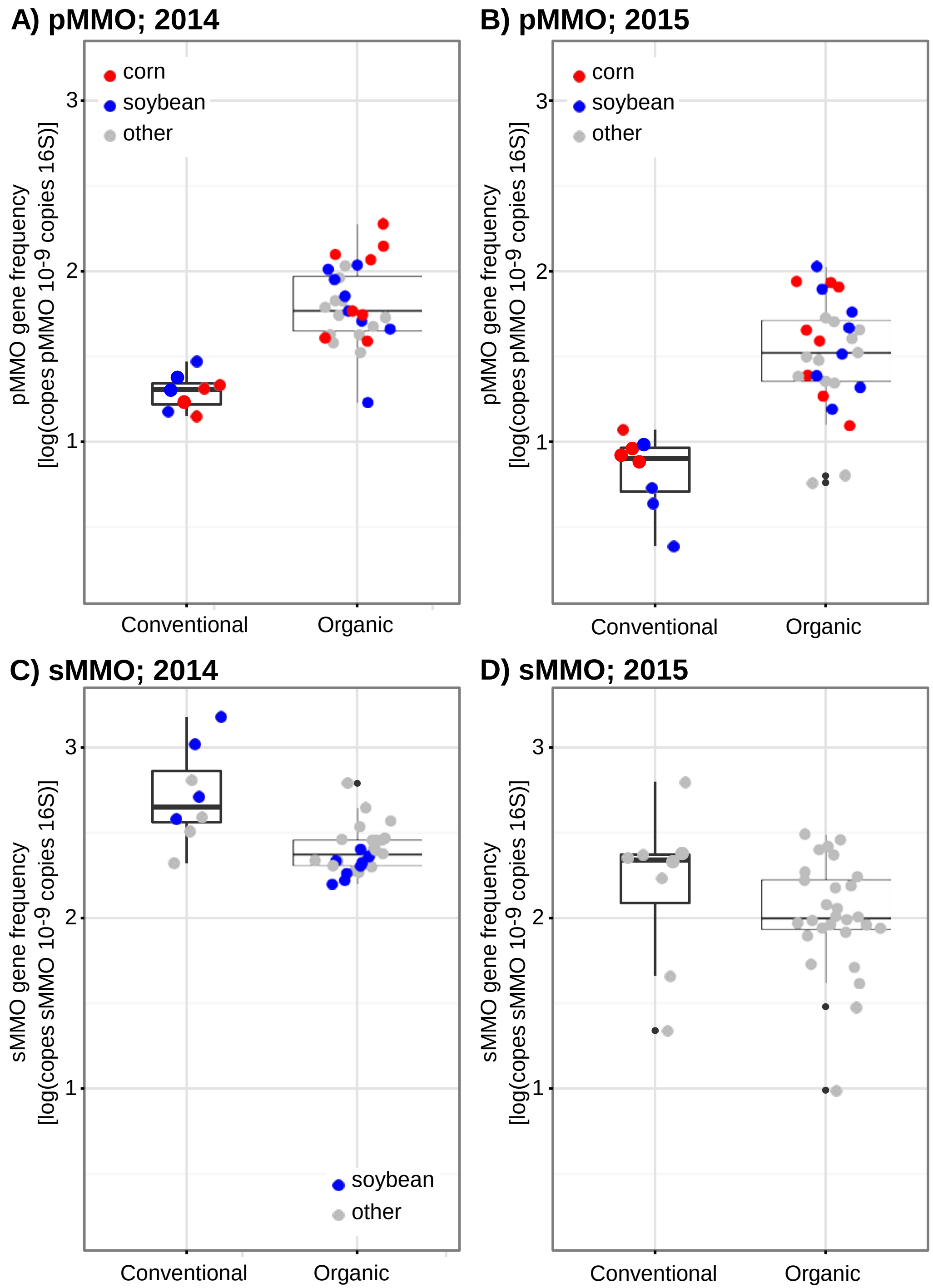
= bulk density

than conventional soils.



Microbial community structure

Matt Bakker et al submitted



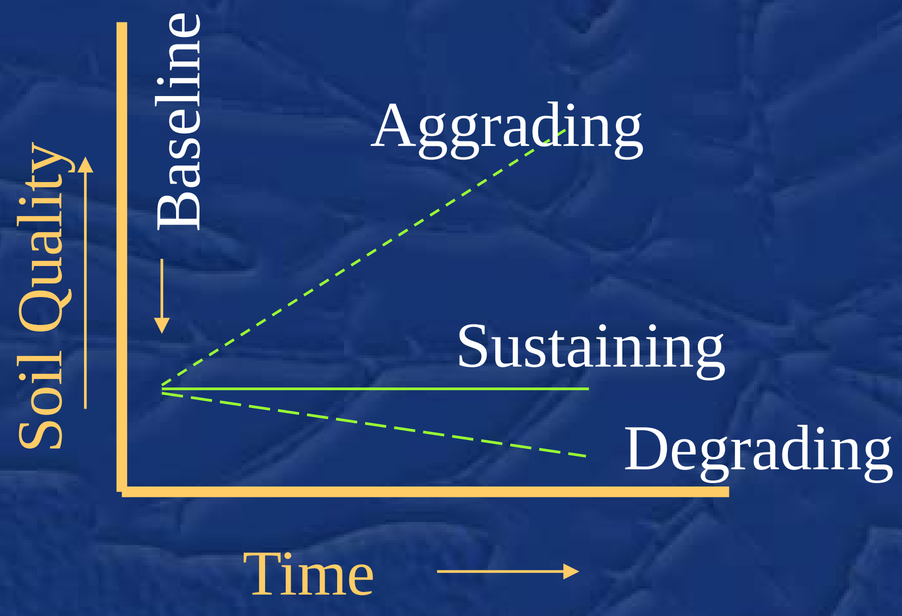
Microbial Community Function

Gene frequency (methane monooxygenase)

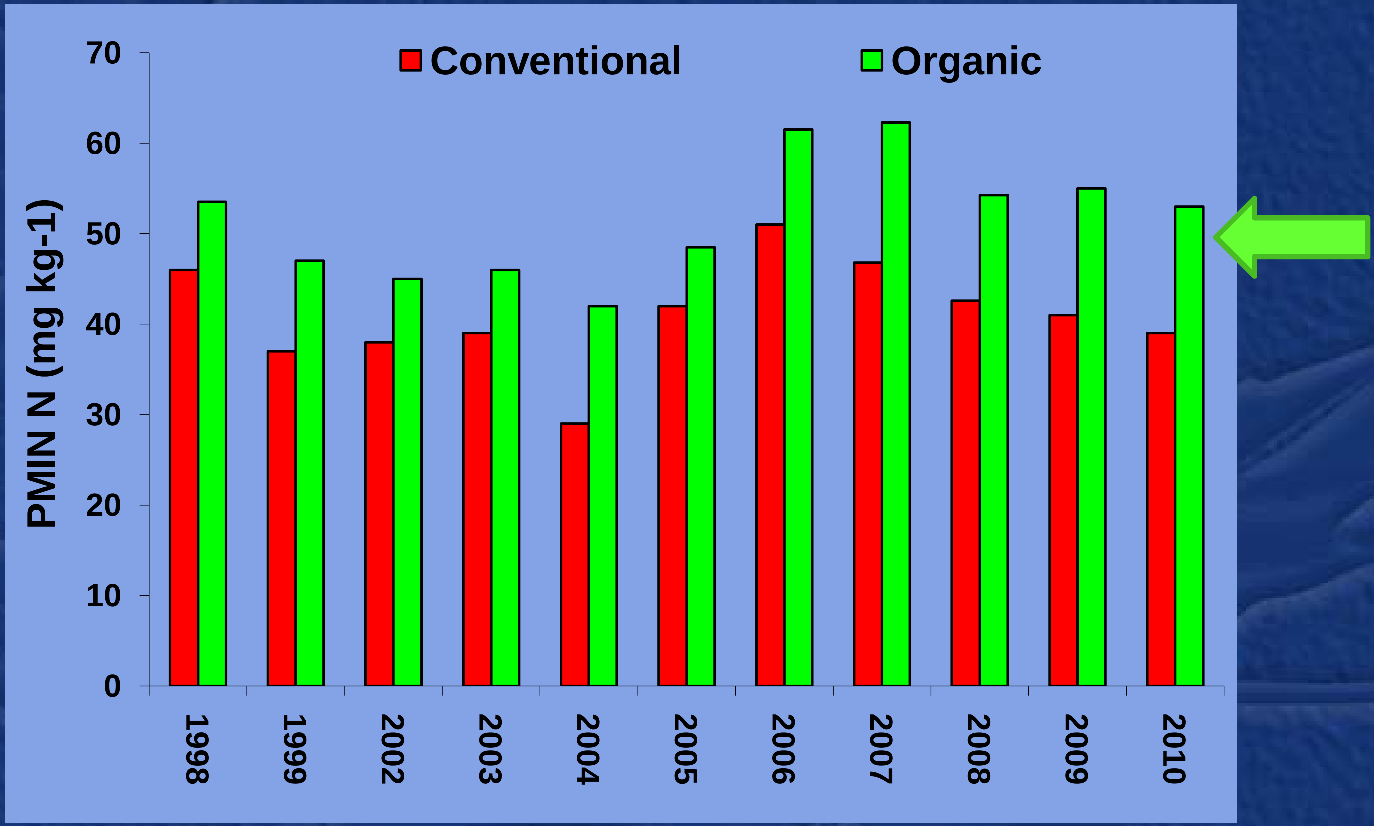
Matt Bakker et al submitted

Uses of SQ Assessment

- **Monitoring tool**



N Mineralization Potential



36% more biologically active N in organic surface soil in fall 2010

Summary II

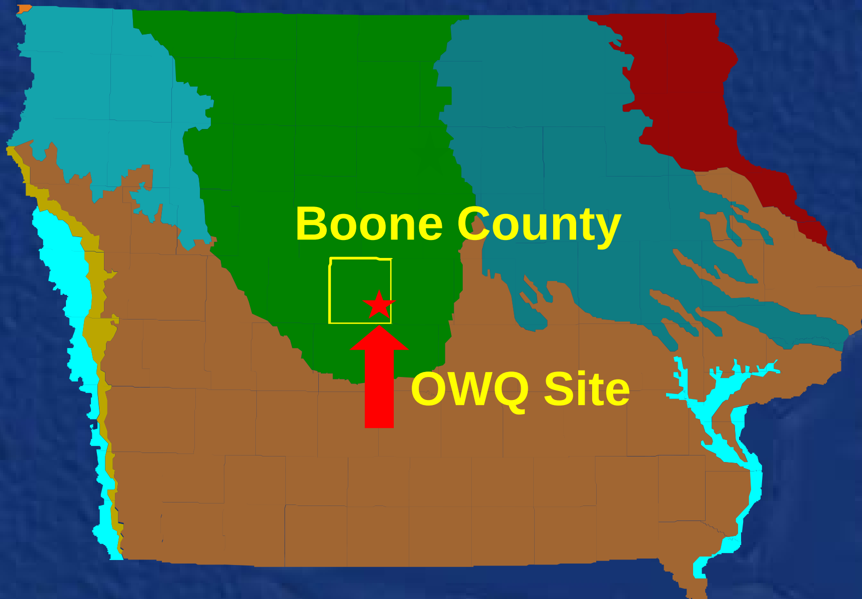
- Soil quality enhancement was particularly evident in:
  - labile soil N
    - critical to organic systems where N fertility is maintained through forage legumes and organic amendments
  - cation concentrations
    - related to CEC which controls nutrient availability other than N
- Nutrient cycling efficiency is an ecosystem function that is critical to the sustainability of organically managed crop rotations

Rotation	C-S-O/A	C-S-O/A-A	C-S
Residue C	41.5	41.1	58.5
Compost C	17.5	17.5	0
Total C inputs	59.0	58.6	58.5
SOC 1998	40.9	40.9	40.9
SOC 2007	43.6	46.2	40.7
ΔSOC 98-07	2.7	5.3	0
ΔSOC/ y	0.27	**0.53**	0

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

Des Moines Lobe

Experimental site managed by USDA-ARS-NLAE

Field History

No chemicals since 2006

Planted to oat/alfalfa 2006-2011

Pre-2006, conventional corn-soybean

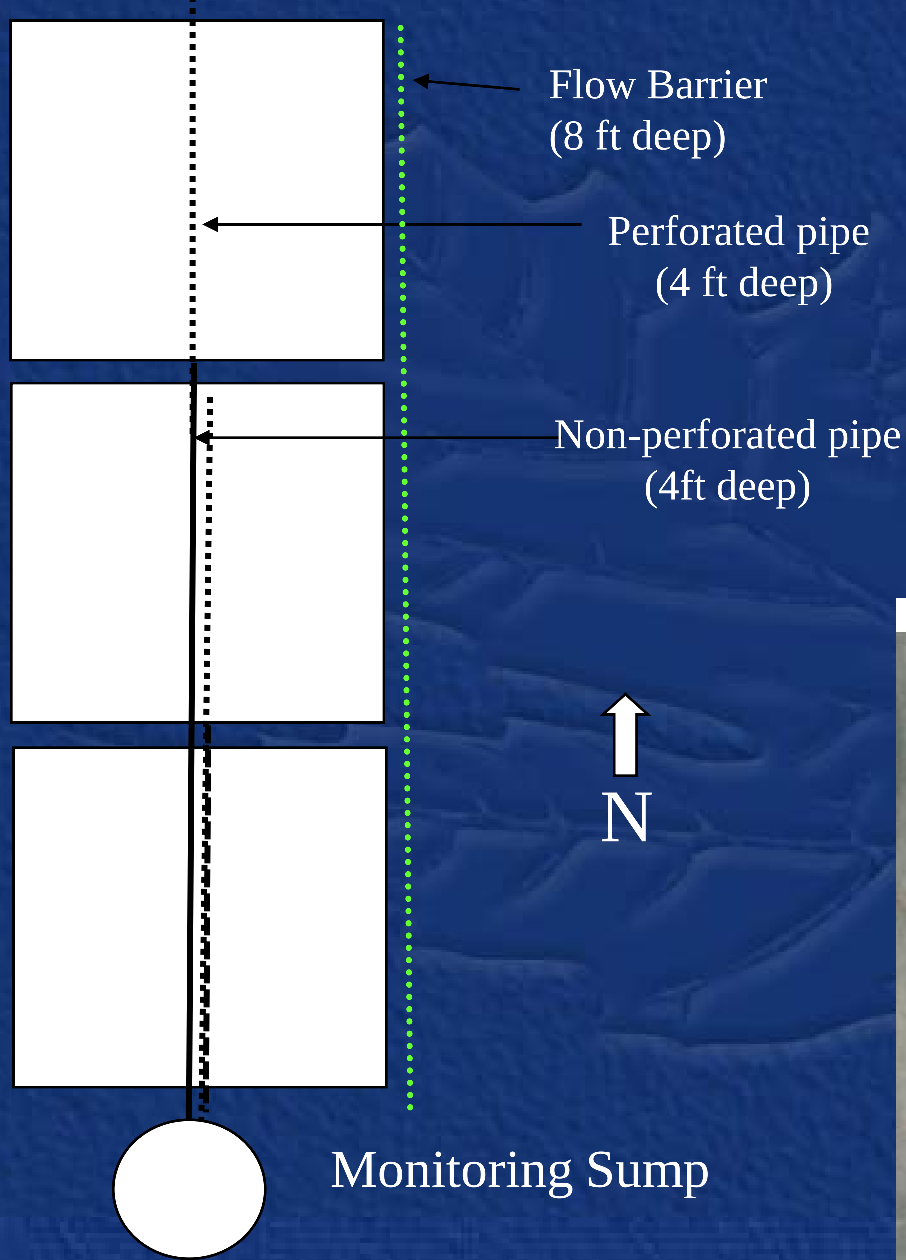
Soils

Clarion: moderately well drained, Typic Argiudoll

Canisteo: poorly drained, Typic Haplaquoll

Webster: poorly drained, Typic Haplaquoll

30 Plots (100 ft x 100 ft)



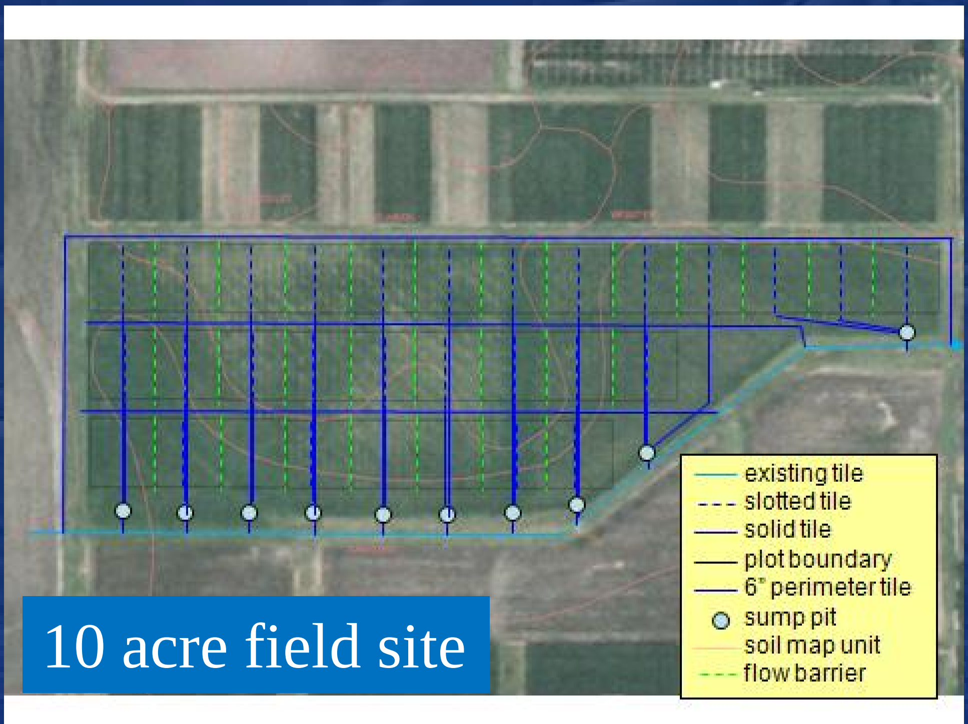
Isolate drainage from each plot

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



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 CO_2 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

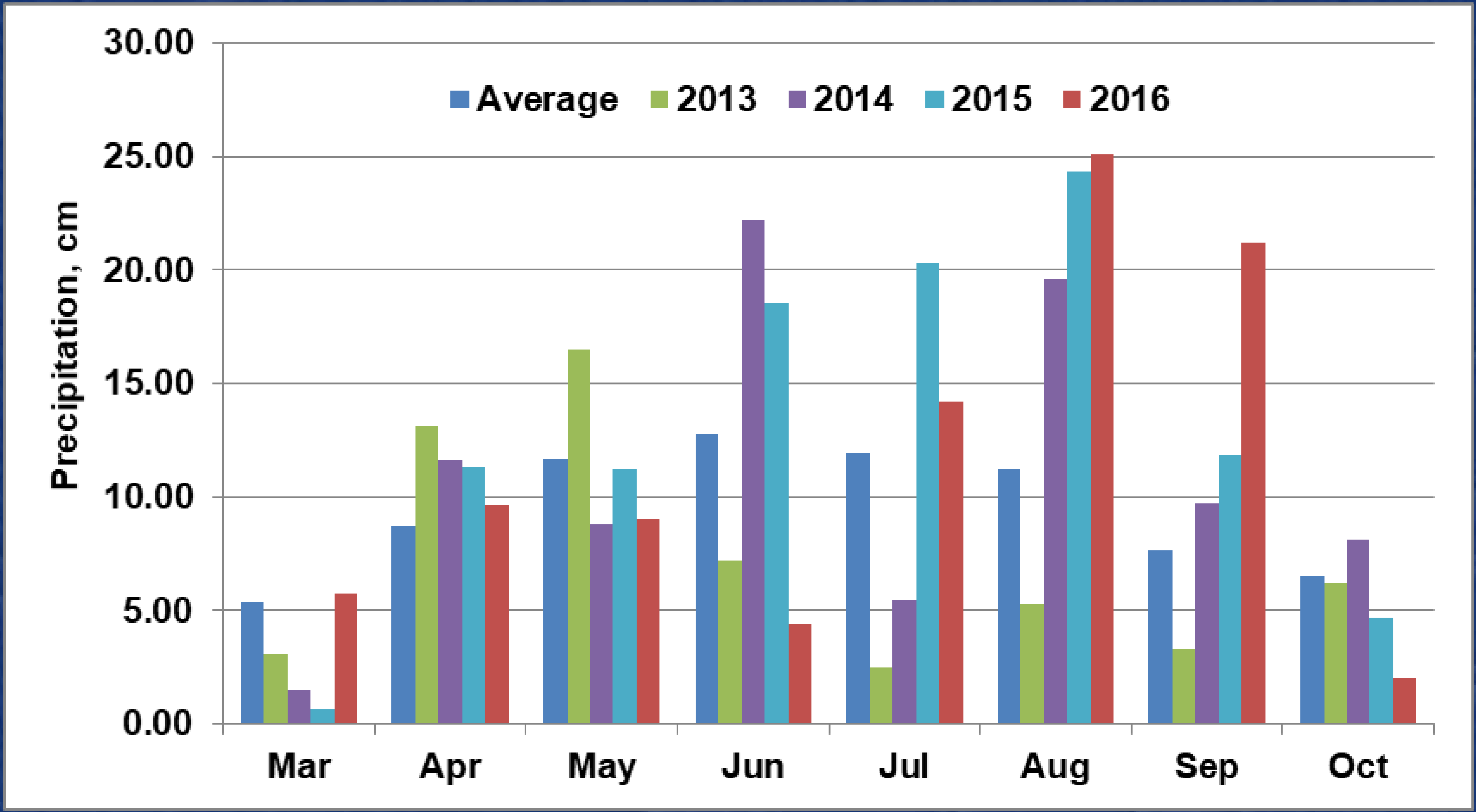
Total soil C&N; microbial biomass C&N; N mineralization potential; soil enzyme activity; inorganic N, P, K, Mg, Ca; aggregate stability; pH; EC; bulk density

microbial community structure and function

Plant Measurements

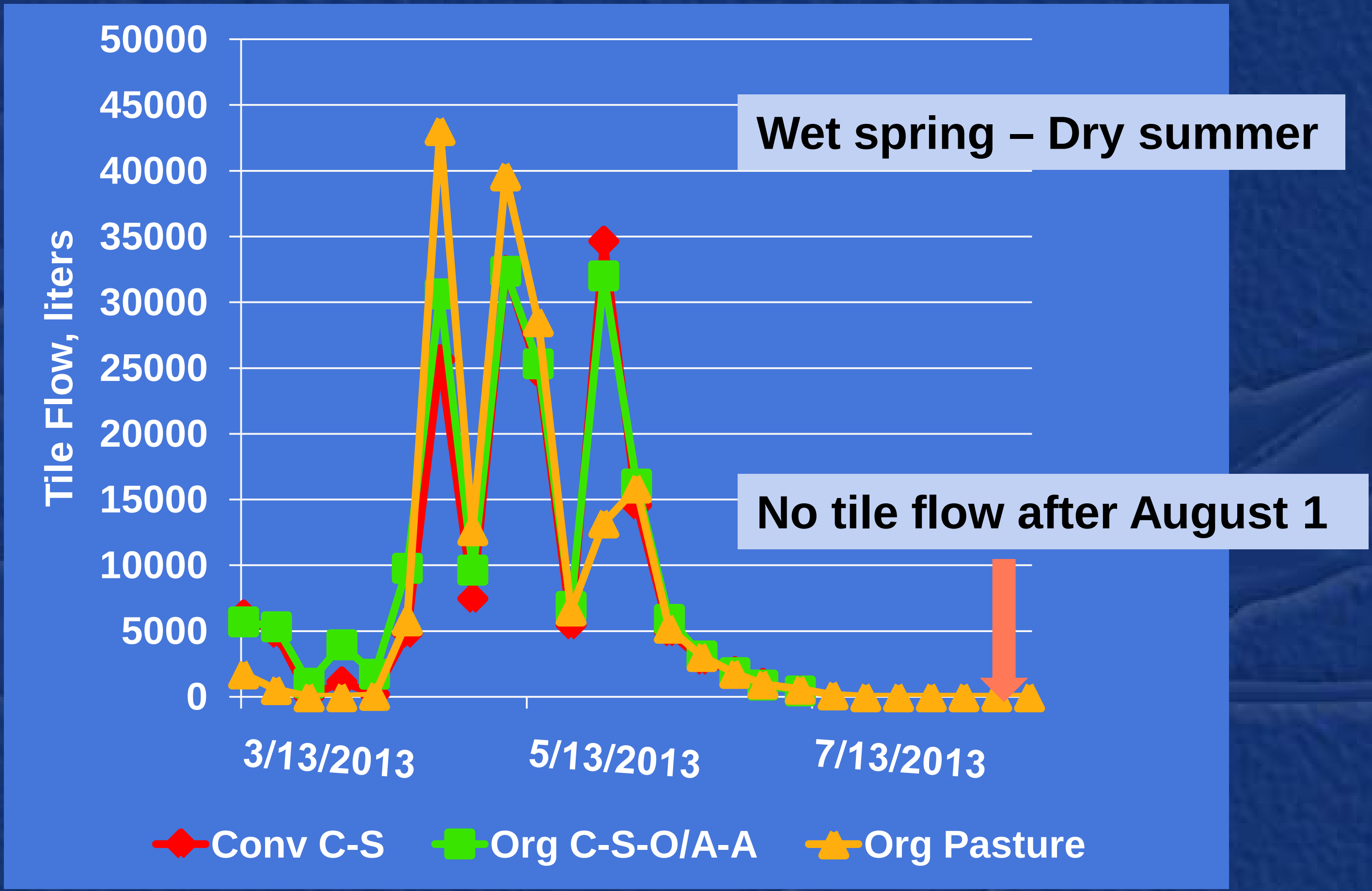
Yield; plant populations; total aboveground biomass C&N; weed density; insect pest and disease populations; stalk nitrate

Precipitation



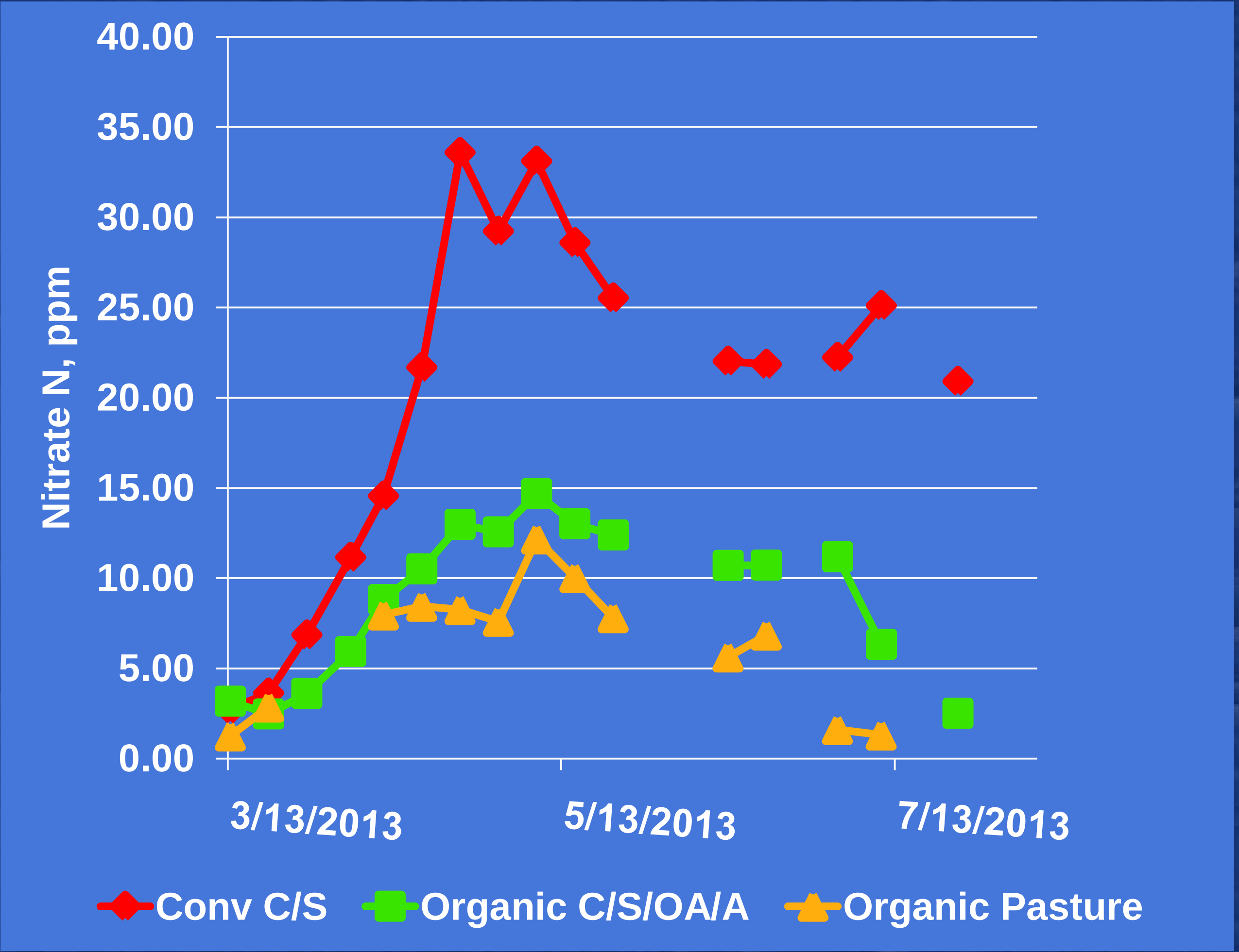
<u>2013:</u> wet spring – dry summer
<u>2014:</u> normal spring – wet summer
<u>2015</u>: wet spring – very wet summer
<u>2016</u>: normal spring – wet summer

Tile Flow 2013

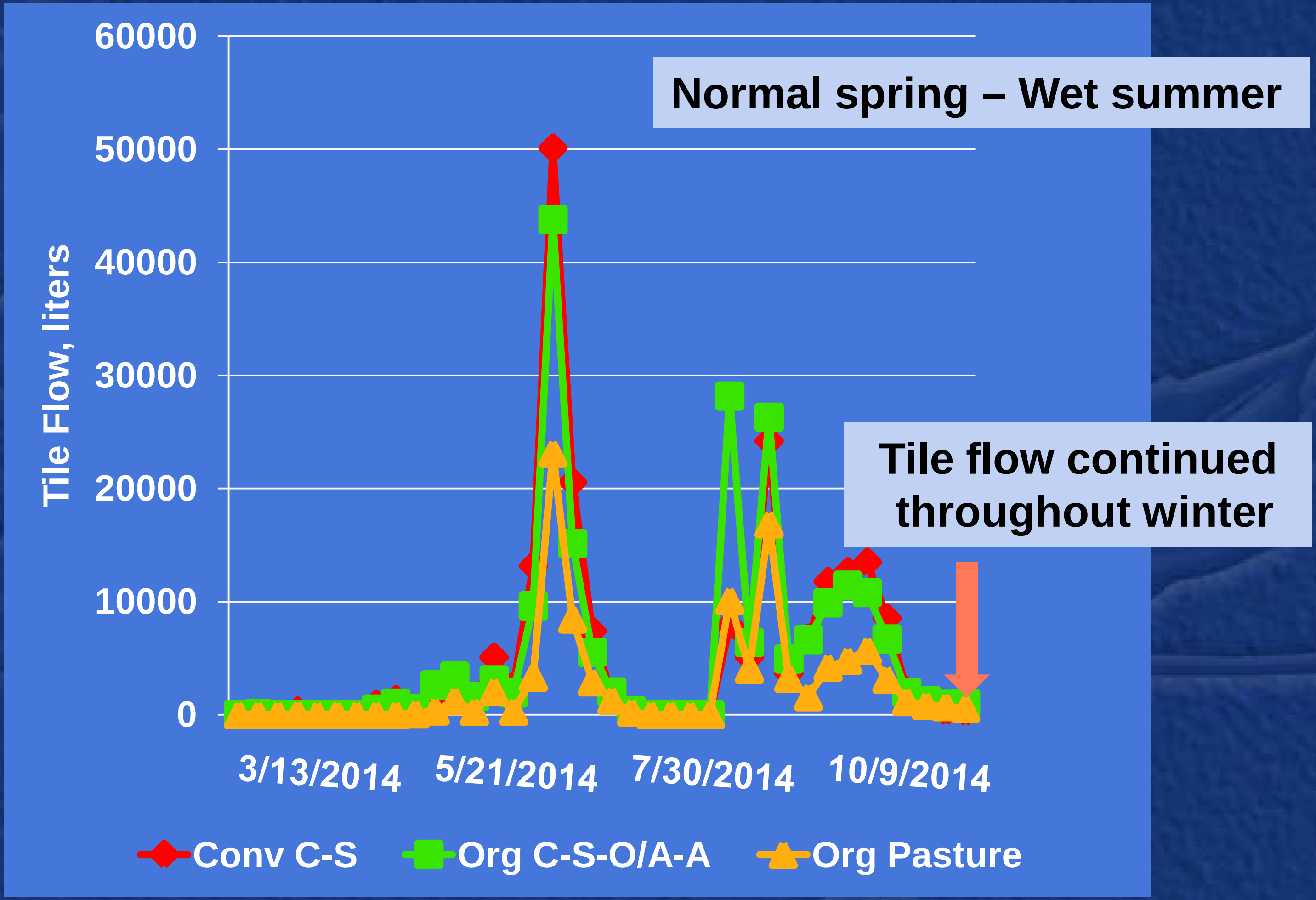


Peak tile flow correlated with rainfall
March-May rainfall 12.7 in

Tile Drainage Water Nitrate N 2013

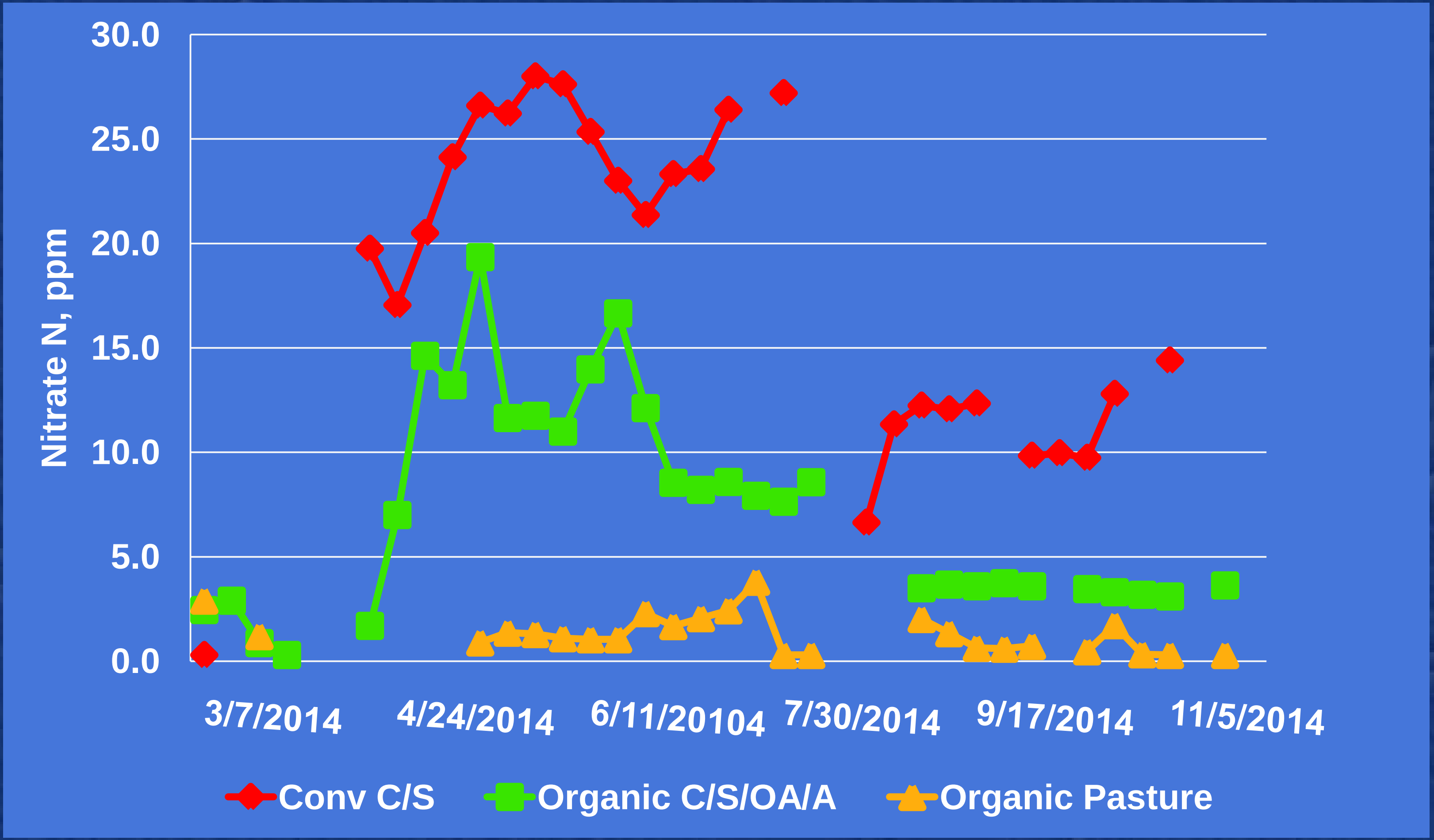


Tile Flow 2014

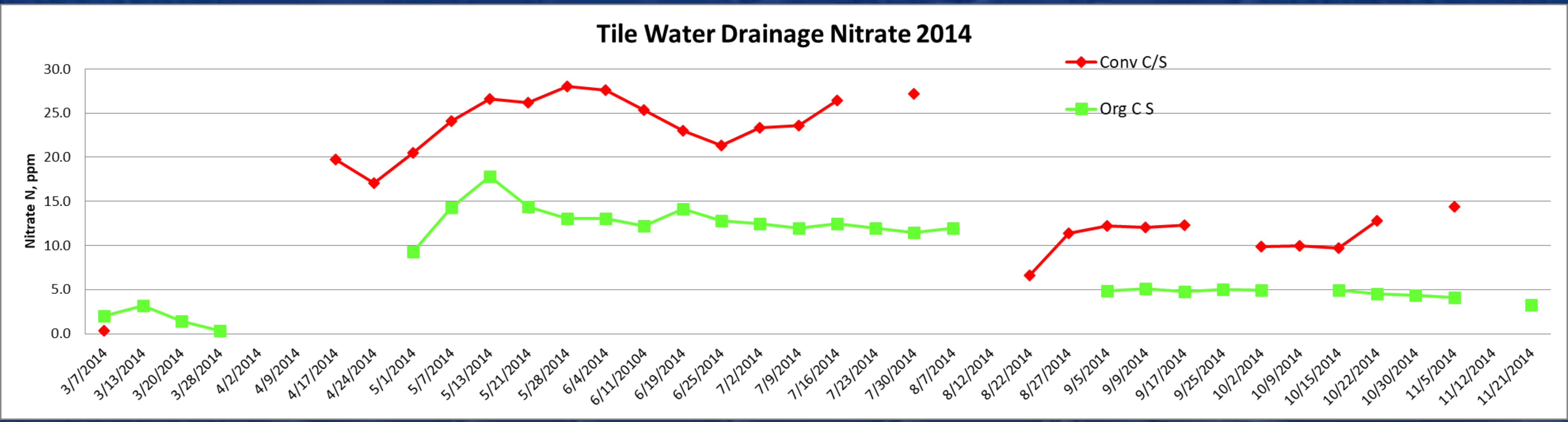


Tile flow peaked early July and late August, following 8.7 in of rain in June and 7.9 in of rain in August

Tile Drainage Water Nitrate N 2014



Overwinter Nitrate N concentrations from Nov 28, 2014 – Mar 25, 2015
Conventional C-S 13.0, Organic C-S-O/A-A 3.8, Organic Pasture 0.3 ppm



Tile Water Drainage Nitrate 2014
Conv C/S
Org C S
Nitrate N, ppm
30.0
25.0
20.0
15.0
10.0
5.0
0.0
3/7/2014
3/13/2014
3/20/2014
3/28/2014
4/2/2014
4/9/2014
4/17/2014
4/24/2014
5/1/2014
5/7/2014
5/13/2014
5/21/2014
5/28/2014
6/4/2014
6/11/20104
6/19/2014
6/25/2014
7/2/2014
7/9/2014
7/16/2014
7/23/2014
7/30/2014
8/7/2014
8/12/2014
8/22/2014
8/27/2014
9/5/2014
9/9/2014
9/17/2014
9/25/2014
10/2/2014
10/9/2014
10/15/2014
10/22/2014
10/30/2014
11/5/2014
11/12/2014
11/21/2014

Tile Flow 2015

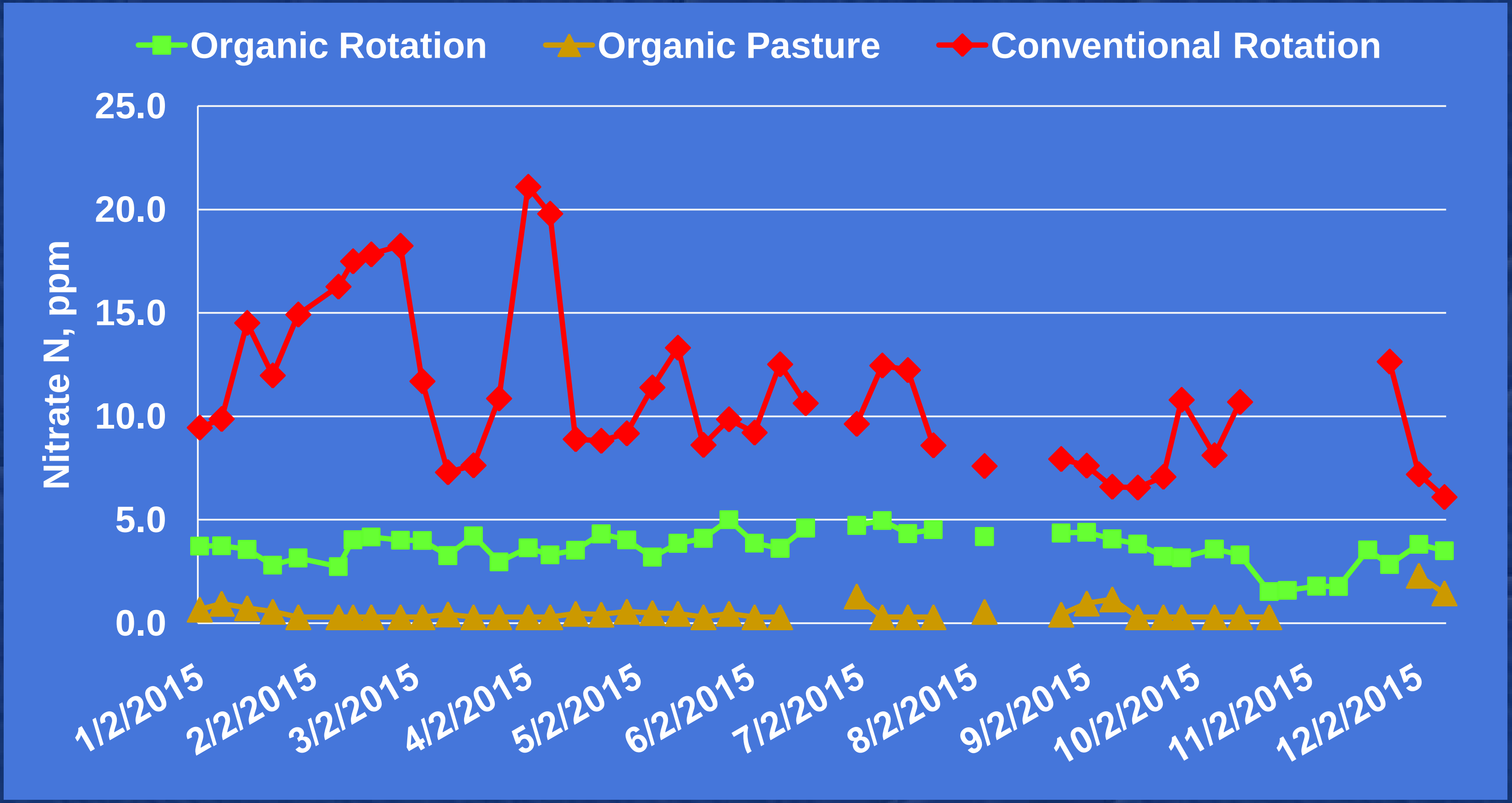
Wet spring – Very wet summer –Wet Fall

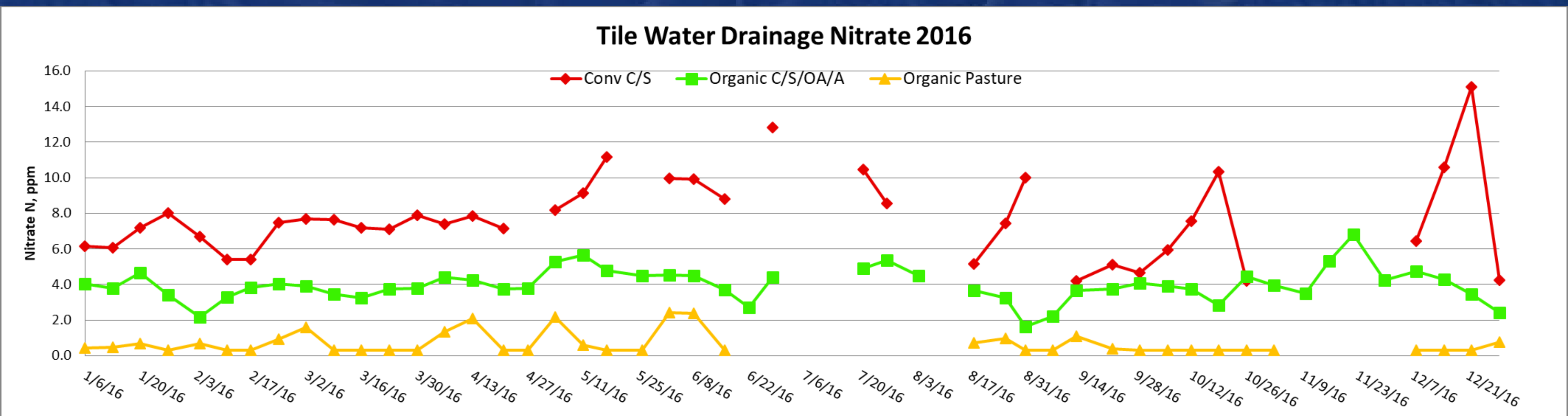
Site was flooded 8 times in 2015

June 24, July 29, August 10, 20 and 31, September 2 and 8, December 14

December 14, 2015 after 5.0 inches of rain

Tile Drainage Water Nitrate N 2015





Tile Water Drainage Nitrate 2016
Conv C/S
Organic C/S/OA/A
Organic Pasture
Nitrate N, ppm
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1/6/16
1/20/16
2/3/16
2/17/16
3/2/16
3/16/16
3/30/16
4/13/16
4/27/16
5/11/16
5/25/16
6/8/16
6/22/16
7/6/16
7/20/16
8/3/16
8/17/16
8/31/16
9/14/16
9/28/16
10/12/16
10/26/16
11/9/16
11/23/16
12/7/16
12/21/16

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**

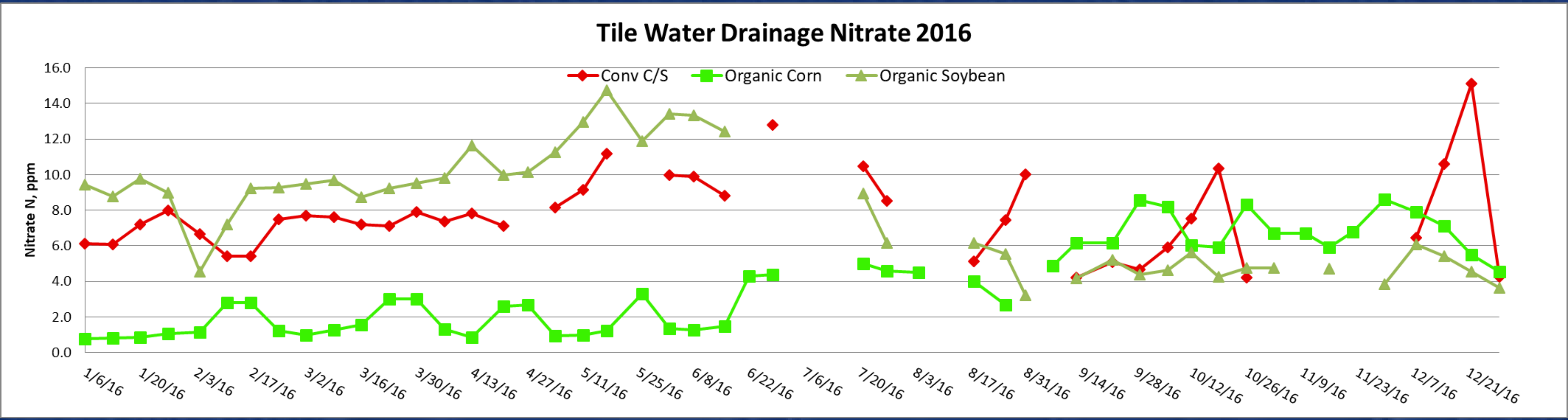
Nitrogen Loss (lb N/ac) to Tile Drainage Water

	2013	2014	2015	2016	∑ 2013-2016
Organic C-S-O/A-A	21.3	13.3	8.9	7.7	**51.2**
Conventional C-S	44.7	32.2	13.9	9.7	**100.5**
Organic Pasture	10.0	3.6	1.0	0.6	**15.2**

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

	2013	2014	2015	2016	∑ 2013-2016
Organic Alfalfa	12.6	12.2	5.74	2.35	**32.9**
Organic Corn	12.9	5.56	11.3	8.86	**38.6**
Organic Oat	32.3	13.3	9.14	3.41	**58.2**
Organic Soybean	27.2	22.4	9.35	13.1	**75.0**
Organic Corn/Soybean	20.1	14.0	10.3	12.5	**56.9**
Conventional Corn/Soybean	44.7	32.2	13.9	9.73	**100.5**
Organic C/S/O/A	21.3	13.4	8.89	7.68	**51.2**



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 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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