Can we sequester carbon in agricultural soils?

Randy Jackson, Professor of Grassland Ecology
Department of Agronomy, University of Wisconsin-Madison

Gregg Sanford

Anna Cates

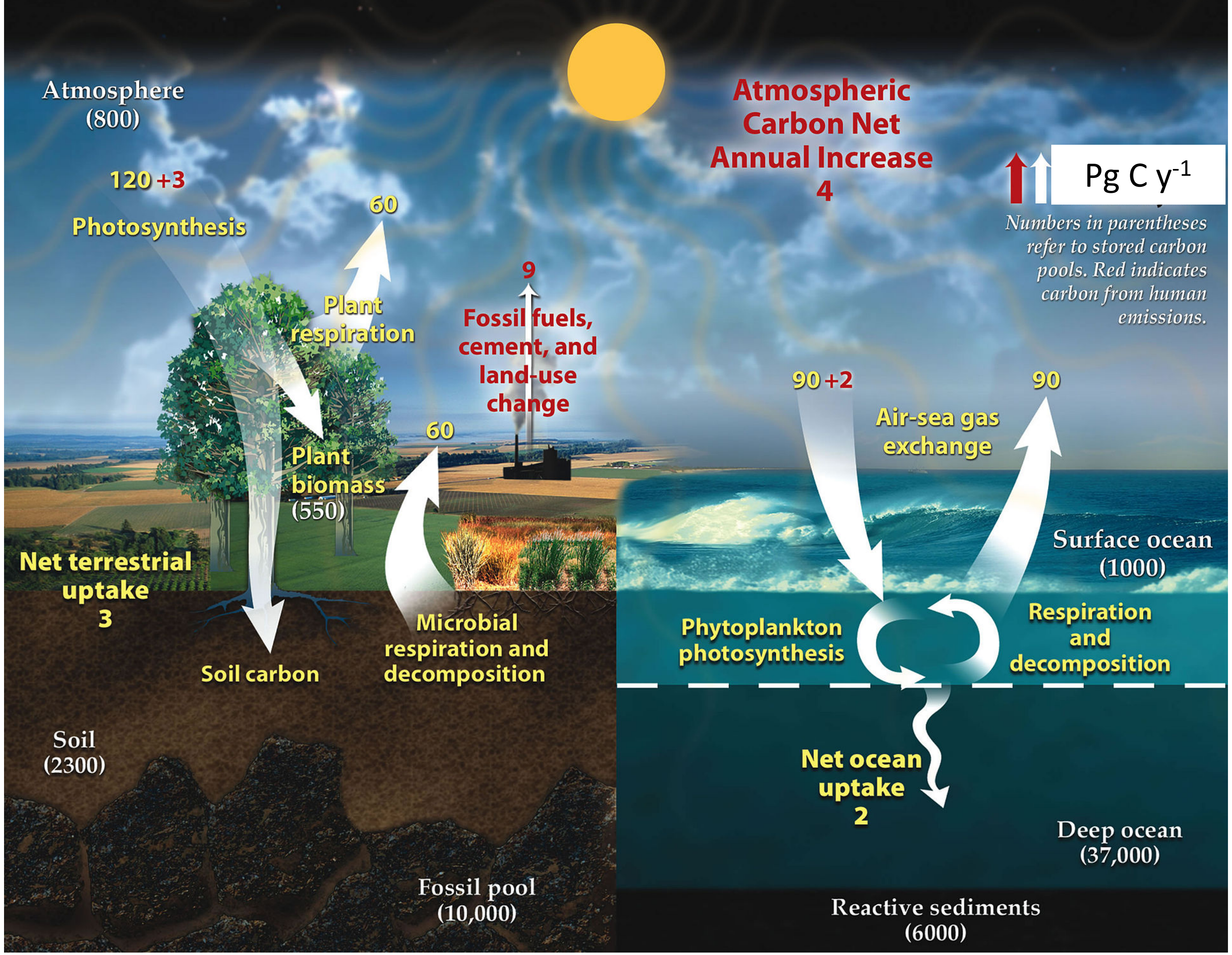
UW-MADISON CENTER for INTEGRATED AGRICULTURAL SYSTEMS collaborative research on sustainability

MICHAEL FIELDS AGRICULTURAL INSTITUTE

USDA United States Department of Agriculture National Institute of Food and Agriculture

COLLEGE OF AGRICULTURAL & LIFE SCIENCES University of Wisconsin-Madison

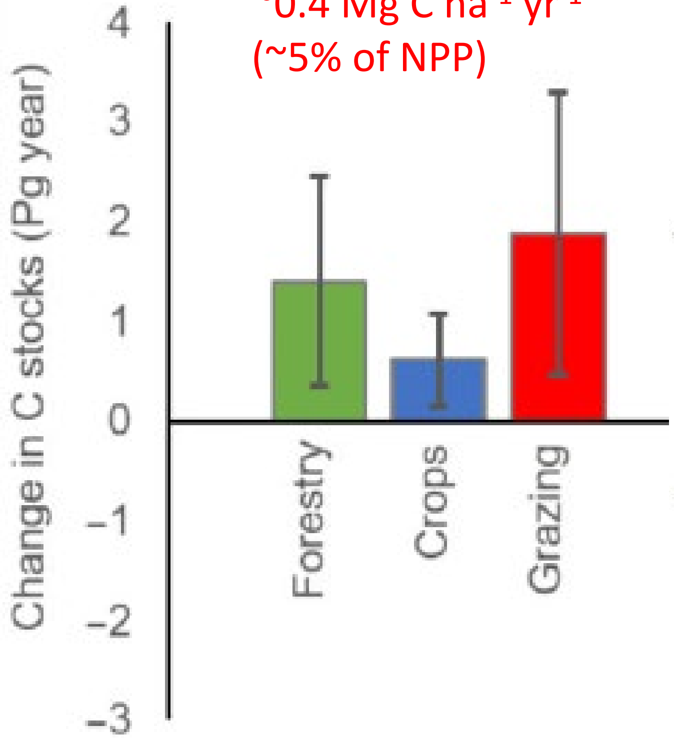
Climate stabilization?



adapted from U.S. DOE, Biological and Environmental Research Information System
http://earthobservatory.nasa.gov/Features/CarbonCycle/

Climate stabilization?

assumes gains of
~0.4 Mg C ha^{-1} yr^{-1}
(~5% of NPP)



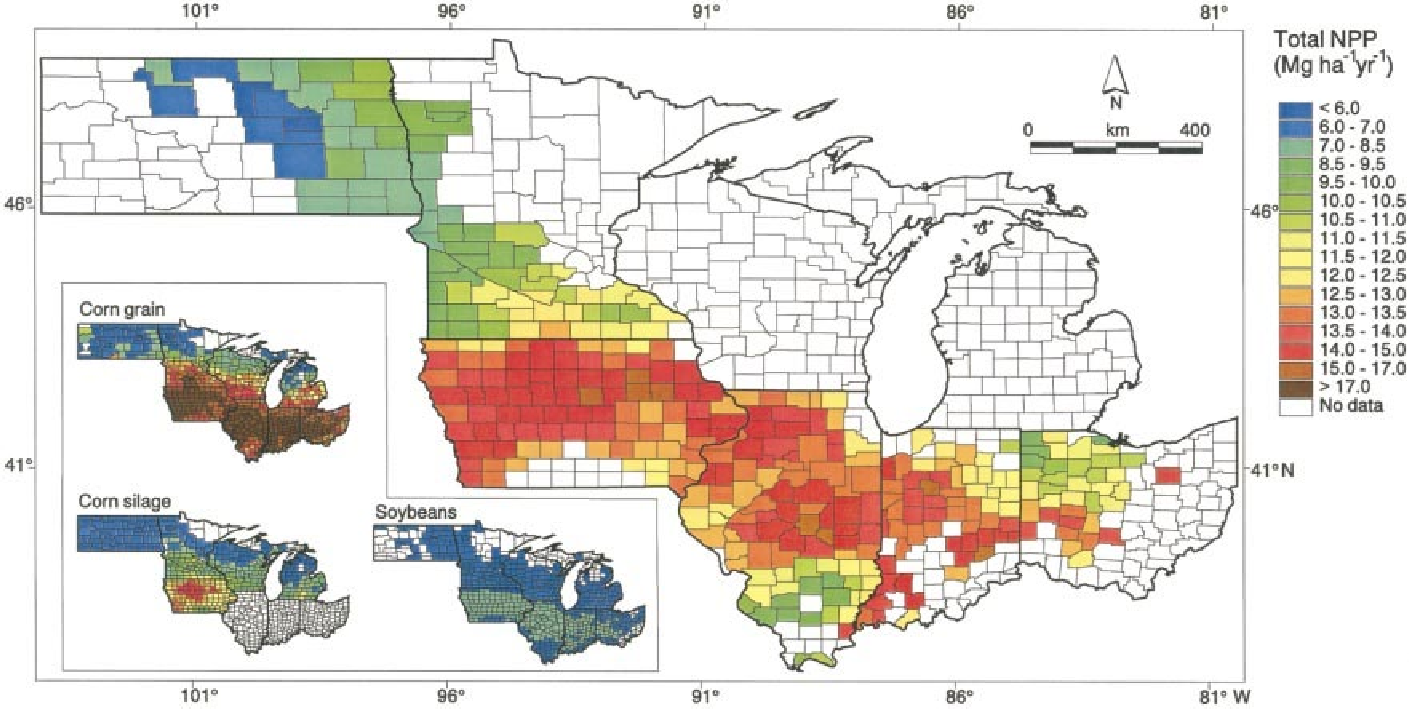
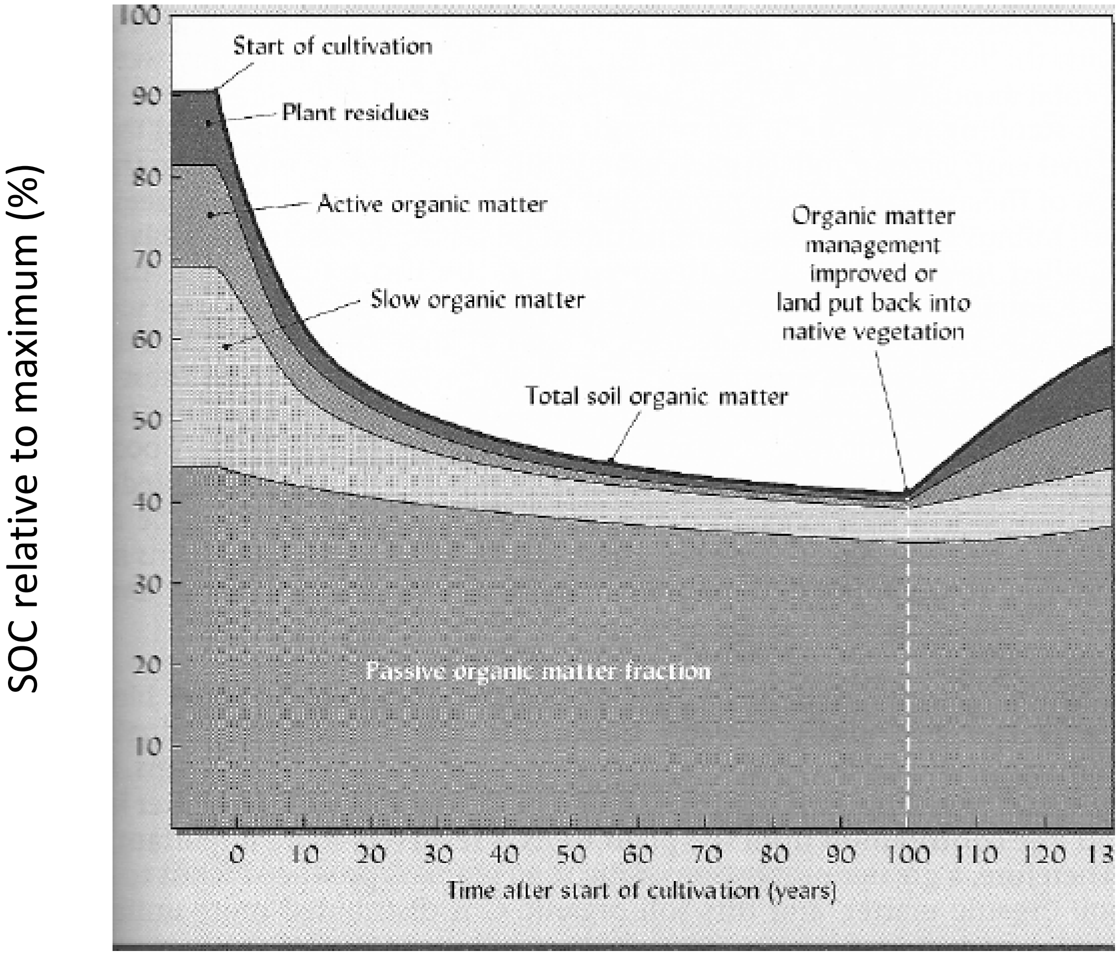


Figure 1. Total annual net primary production (NPP) in 1992 for U.S. Midwest counties, estimated from National Agricultural Statistics Service (NASS) harvest yield and literature values of crop harvest index and below-ground allocation.

modified from Harden et al. 2017. Global Change Biology



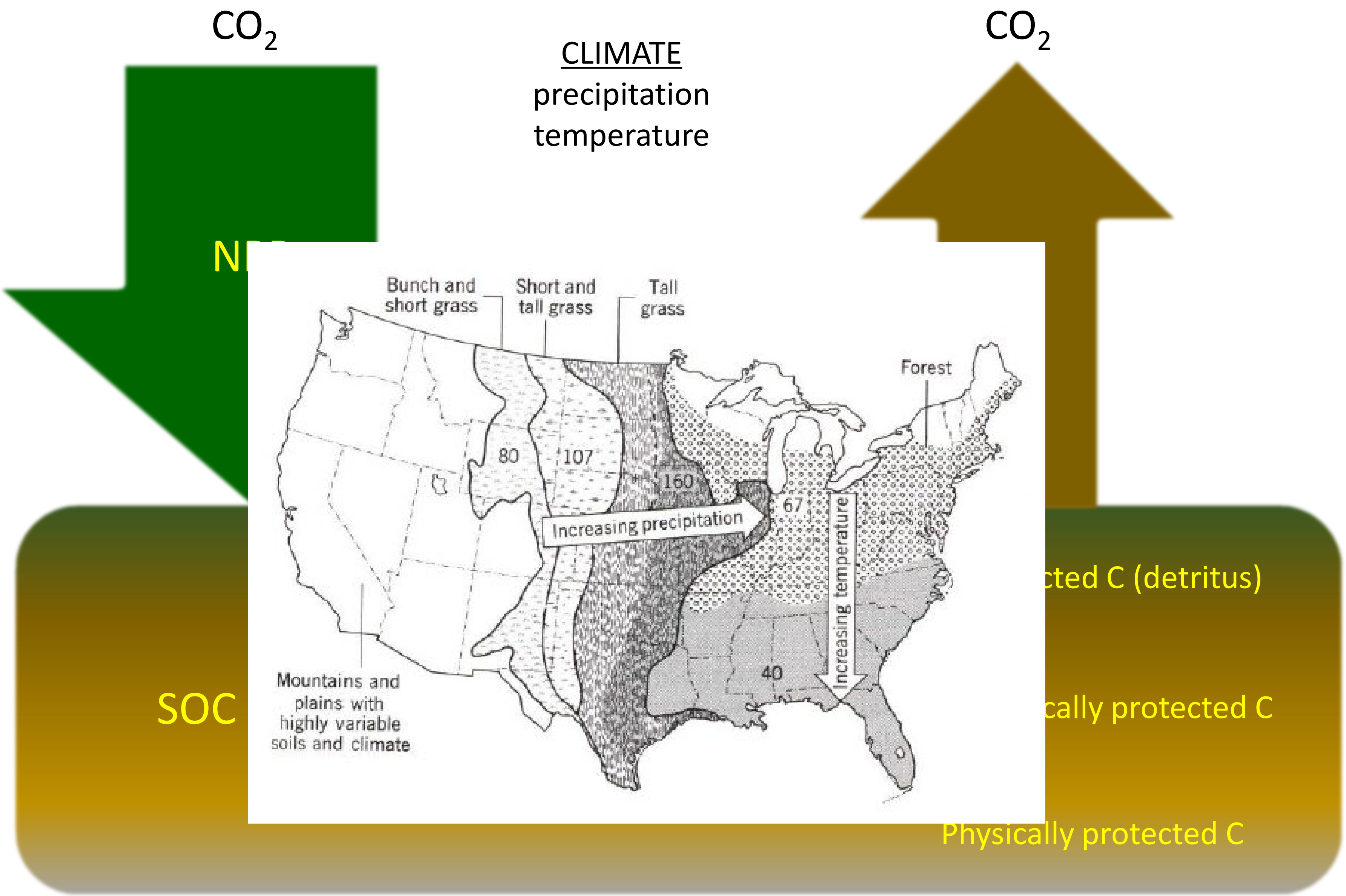
SOC relative to maximum (%)
Start of cultivation
Plant residues
Active organic matter
Slow organic matter
Organic matter management improved or land put back into native vegetation
Total soil organic matter
Passive organic matter fraction
Time after start of cultivation (years)

Building organic matter in the agroecosystem is known to

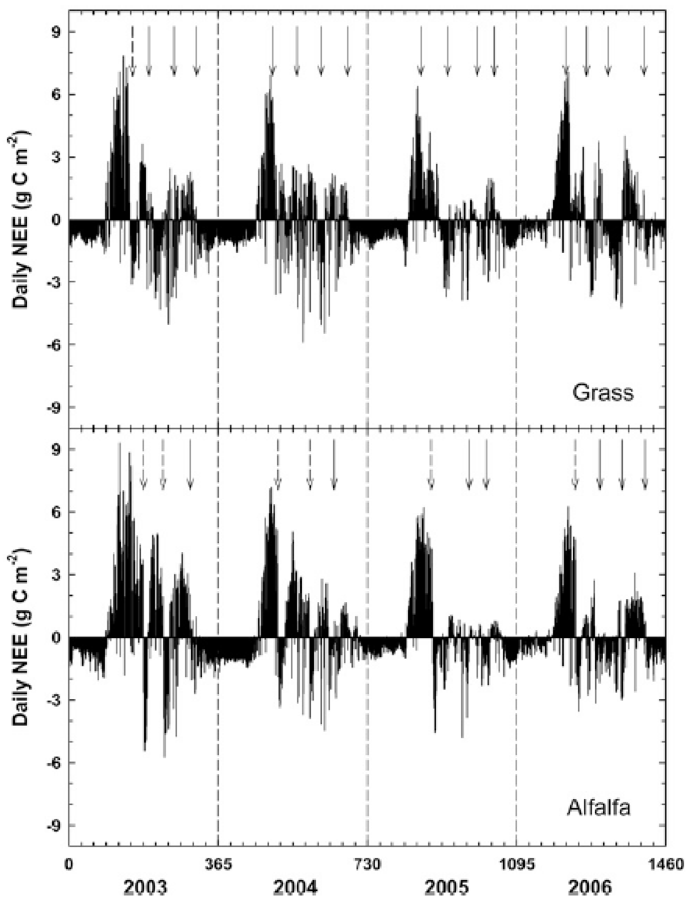
1. Improve crop yields
2. Reduce soil erosion
3. Increase water infiltration
4. Retain nutrients

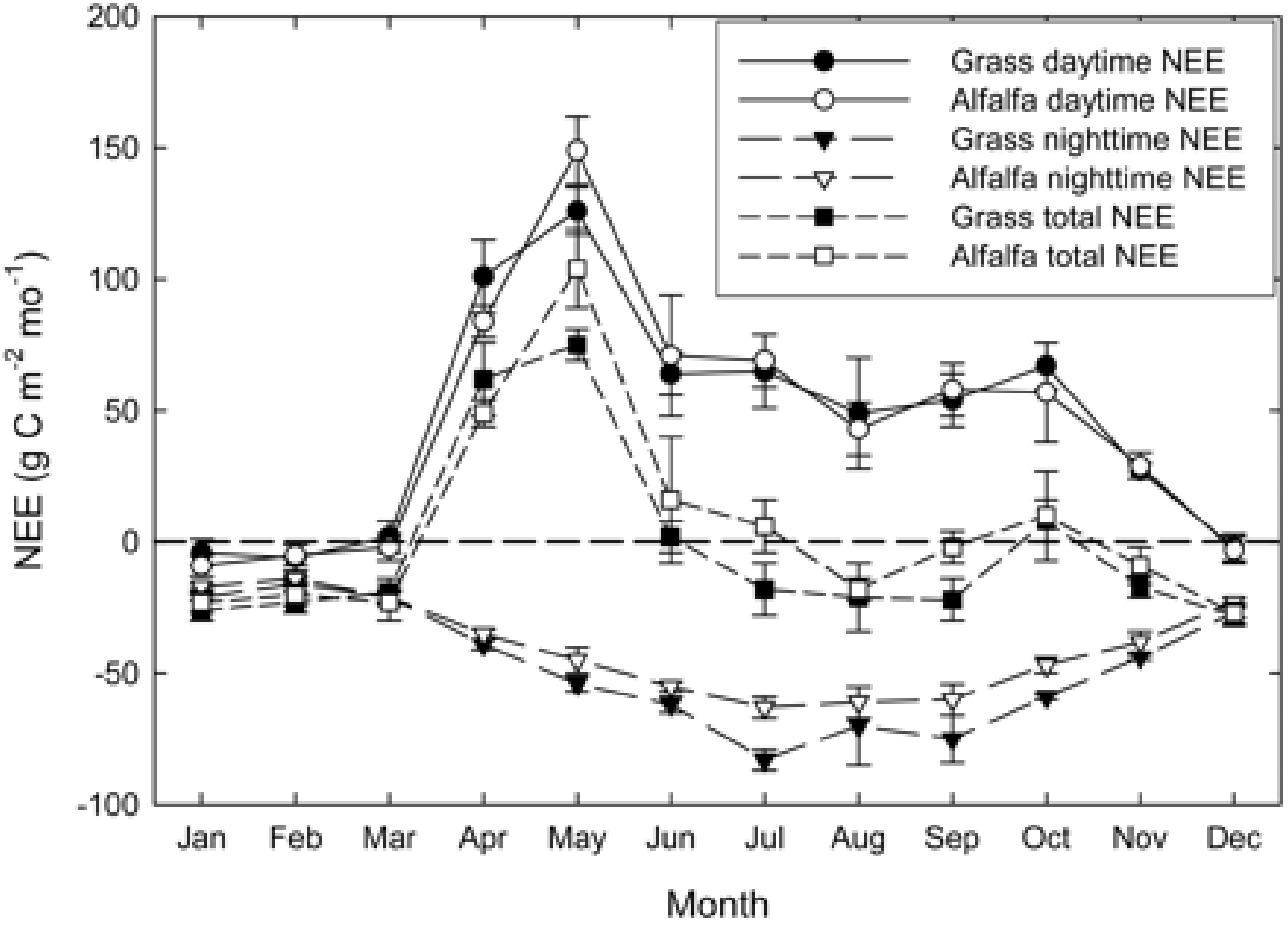
Agricultural practices promoted for C accumulation

1. Reducing tillage intensity/frequency (Sanford et al. 2012 *Ag Ecosys Env*)
2. Applying manure (Sanford et al. 2012 *Ag Ecosys Env*)
3. Using cover crops (Cates & Jackson 2018 *Agron J*)
4. Optimizing fertilizer application (Collier et al. 2017 *SSSAJ*)
5. Planting perennials (Sanford 2014, unpublished data)
6. Increasing plant diversity (Spiesman et al. 2018 *Oecologia*)
7. Improving grazing management (Oates et al. 2014 *Rangeland Ecol Mgmt*)


CO2
CLIMATE
precipitation
temperature
CO2
SOC
cted C (detritus)
cally protected C
Physically protected C
Bunch and short grass
Short and tall grass
Tall grass
Forest
80
107
160
67
40
Increasing precipitation
Increasing temperature
Mountains and plains with highly variable soils and climate

Opportunities for accumulating C are precarious





Skinner. 2008. Journal of Environmental Quality

Wisconsin Integrated Cropping Systems Trial (WICST)

Established in 1990

Two locations

- (ARL) Arlington, WI – 1990 to present
- (LAC) Elkhorn, WI – 1990 to 2002

Large plots

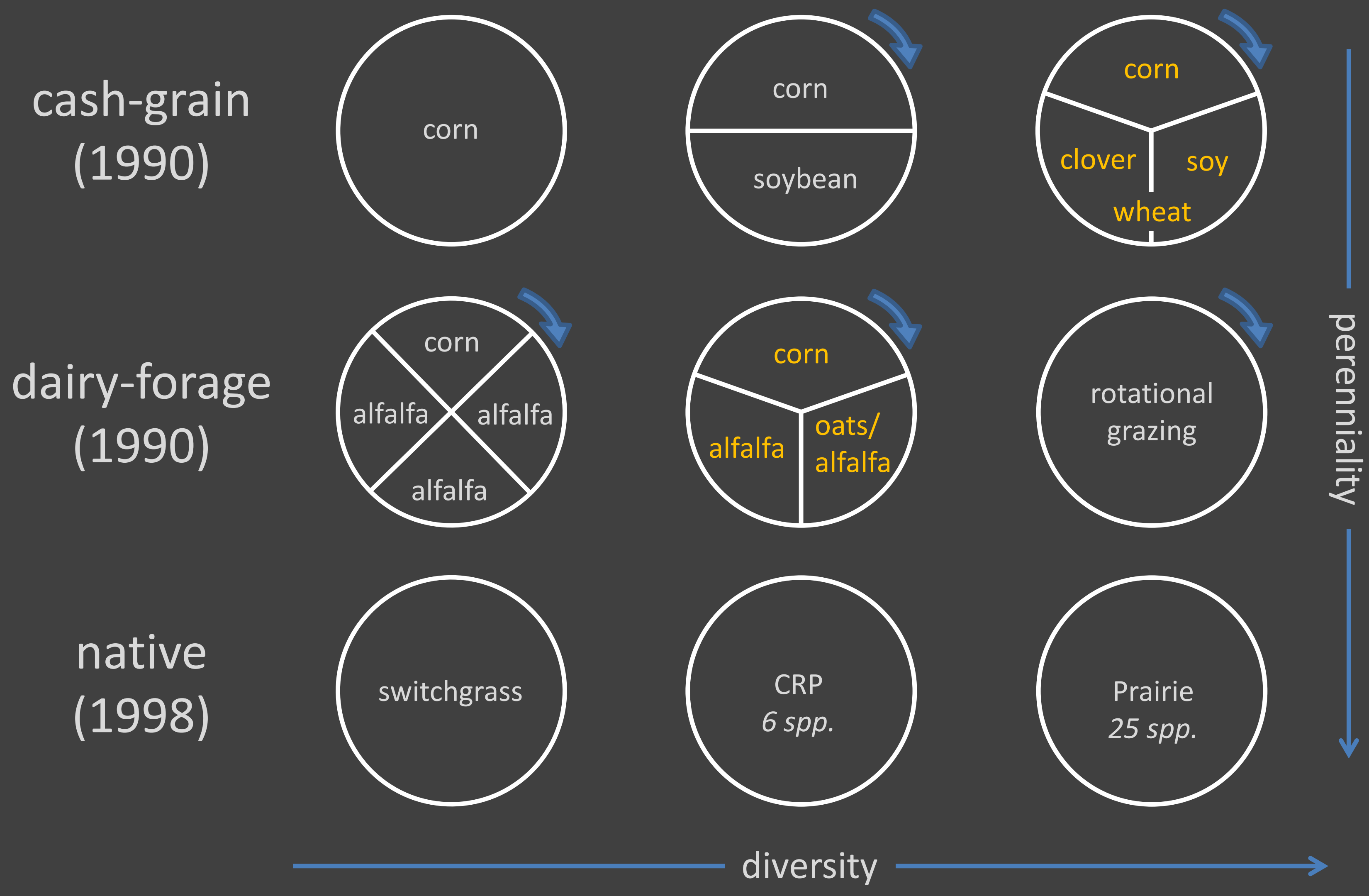
- Plot size = 0.7 ac
- Field-scale equipment

Performance metrics:

- Productivity
- Profitability
- Environment

WICST

4 reps
each phase every year



Agriculture, Ecosystems and Environment 162 (2012) 68–76

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Soil carbon lost from Mollisols of the North Central U.S.A. with 20 years of agricultural best management practices

Gregg R. Sanford[a,*], Joshua L. Posner[a], Randall D. Jackson[a], Christopher J. Kucharik[a,b], Janet L. Hedtcke[a], Ting-Li Lin[c]

1. Reducing tillage
2. Applying manure
3. Using cover crops
5. Planting perennials

Table 3
SOC mean values by year and depth for WICST overall and by system.[a]

Type	Label	Depth	g C kg soil^{-1} 1989	2009	Δ	pr > |t|[b]
Grain systems	CS1 (Corn) Cons. Tillage	0–15 cm	28.8	23.8	–5.0	**
		15–30 cm	20.3	15.6	–4.8	*
		30–60 cm	10.9	6.8	–4.1	†
		60–90 cm	6.2	4.3	–1.9	ns
		Average of Δ conc.			*–3.9*	*0.01*
	CS2 (Corn, Soybean) Min. Tillage	0–15 cm	23.8	21.4	–2.4	†
		15–30 cm	19.3	14.5	–4.8	***
		30–60 cm	8.6	7.3	–1.3	ns
		60–90 cm	4.9	3.8	–1.1	ns
		Average of Δ conc.			*–2.4*	*0.03*
	CS3 (Corn, Clover, Soy, Wheat) Organic	0–15 cm	25.0	23.3	–1.7	*
		15–30 cm	18.6	16.0	–2.6	**
		30–60 cm	8.1	7.3	–0.7	ns
		60–90 cm	4.8	3.4	–1.4	ns
		Average of Δ conc.			*–1.6*	*0.03*
Forage systems	CS4 (Corn, Alfalfa, Alfalfa, Alfalfa) Conventional	0–15 cm	27.3	26.8	–0.5	ns
		15–30 cm	19.3	18.1	–1.2	**
		30–60 cm	9.6	9.1	–0.5	ns
		60–90 cm	5.2	4.4	–0.8	ns
		Average of Δ conc.			*–0.8*	*ns*
	CS5 (Corn, Oats/Alfalfa, Alfalfa) Organic	0–15 cm	25.1	24.0	–1.1	ns
		15–30 cm	16.9	16.9	–0.1	†
		30–60 cm	8.8	7.5	–1.3	ns
		60–90 cm	5.4	4.0	–1.4	ns
		Average of Δ conc.			*–1.0*	*0.09*
	CS6 (Managed Grazing) Rotation	0–15 cm	27.1	31.1	4.0	*
		15–30 cm	22.0	19.7	–2.3	ns
		30–60 cm	10.1	9.0	–1.1	ns
		60–90 cm	5.4	4.5	–0.9	ns
		Average of Δ conc.			*–0.1*	*ns*

[a] All significance tests were calculated using comparison specific contrasts (ESTIMATE statements within PROC MIX
[b] Pr > |*t*|, ns = not significant at the $\alpha = 0.1$ level.
* $p \leq 0.05$.
** $p \leq 0.01$.
*** $p \leq 0.001$.
† $p \leq 0.1$.

Soil & Tillage Research 155 (2016) 371–380

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Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Long-term tillage, rotation and perennialization effects on particulate and aggregate soil organic matter

Anna M. Cates[a,*], Matthew D. Ruark[b], Janet L. Hedtcke[c], Joshua L. Posner[a]

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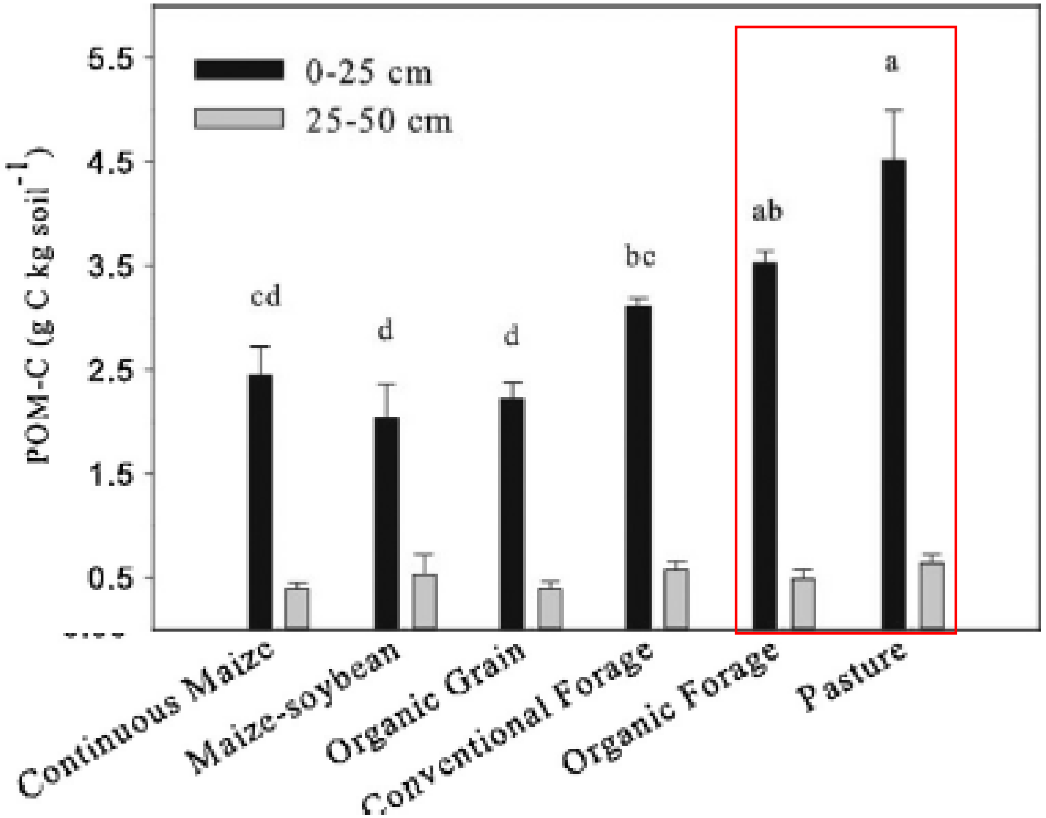

Soil Fertility & Plant Nutrition

Apparent Stability and Subtle Change in Surface and Subsurface Soil Carbon and Nitrogen under a Long-Term Fertilizer Gradient

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Michael D. Casler
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Madison, WI 53706

4. Optimizing fertilizer application

Table 3. Estimated C and N balances for long-term N rate treatments 1958 to 2010.

Treatment	Input†	Removed‡	Net
	Mg N ha^{-1}		
Low N	0.5	2.1	-1.6
Rec. N	7.3	5.2	2.1
High N	13.3	5.6	7.7
	Mg C ha^{-1}		
Low N	181	82	99
Rec. N	395	180	215
High N	414	188	226

† Based on fertilizer applications for N, and on stover, belowground biomass, and rhizodeposition for C, with estimates as follows: harvest index = 0.5, belowground biomass input to aboveground biomass production = 0.6, biomass C content = 0.45 (Hay, 1995; Vanotti et al., 1997; Sinclair, 1998; Amos and Walters, 2006; Johnson et al. 2006).

‡ Based on grain N and C content, with estimates as follows: grain C content = 0.45, grain N content = 0.0115, 0.013, and 0.0135 for Low N, Rec. N, and High N, respectively (Cerrato and Blackmer, 1990).

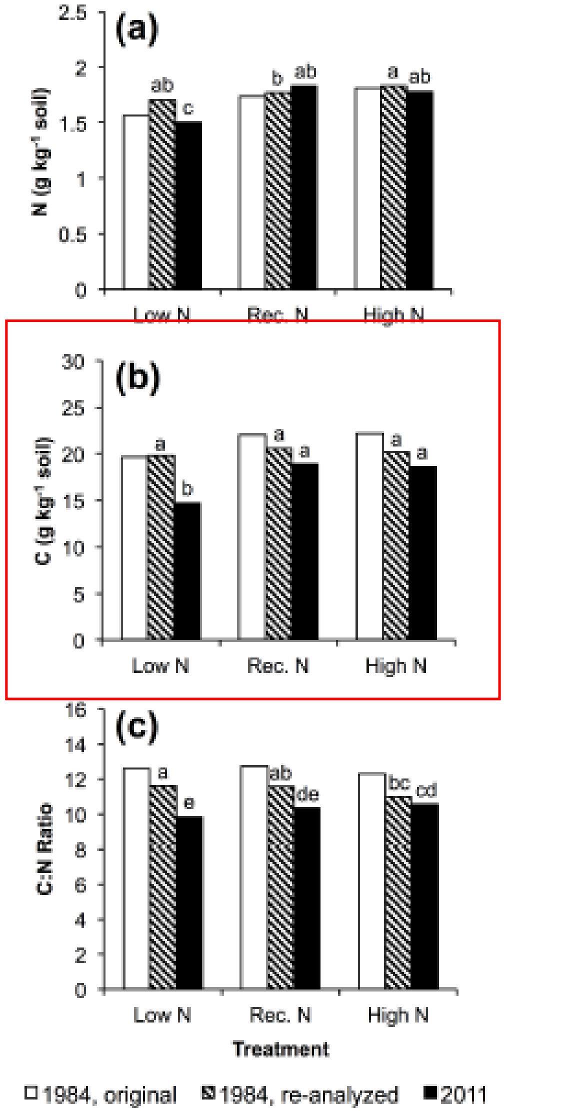

Fig. 4. Change in C and N content and C/N ratio over time (1984–2011). Original 1984 values are as reported by Vanotti et al. (1997) who found significant differences in N content (Low N < Rec. N = High N, a = 0.05); statistics were not reported for C. Re-analyzed 1984 values are from analysis of archived samples by dry combustion in 2013. Values for 2011 are from samples associated with the present study. Differing letters indicate significant differences at the a = 0.1 level (applied to 1984 re-analyzed and 2011 samples only).

Wisconsin Integrated Cropping Systems Trial (WICST)

Chapter 29
Perennial Grasslands Are Essential for Long Term SOC Storage in the Mollisols of the North Central USA

Gregg R. Sanford

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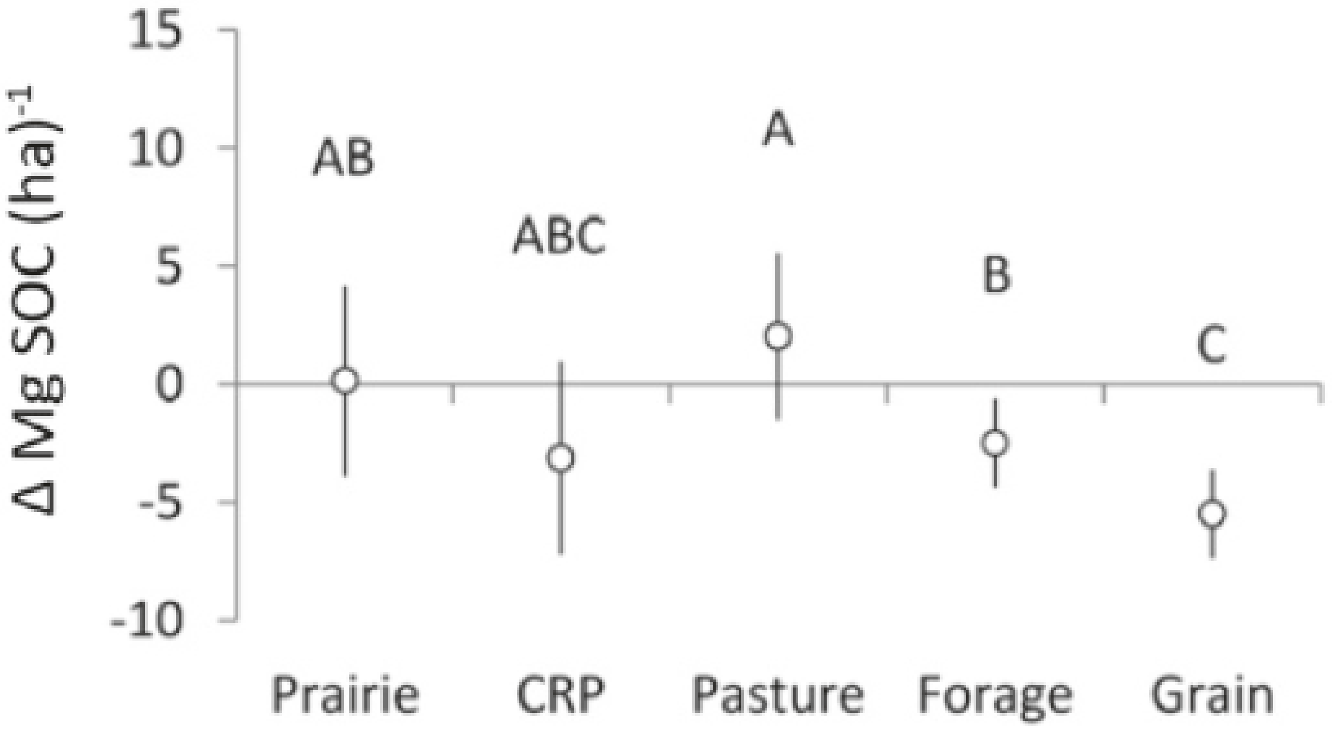
A.E. Hartemink and K. McSweeney (eds.), *Soil Carbon*. Progress in Soil Science, DOI 10.1007/978-3-319-04084-4_29, © Springer International Publishing Switzerland 2014

5. Planting perennials

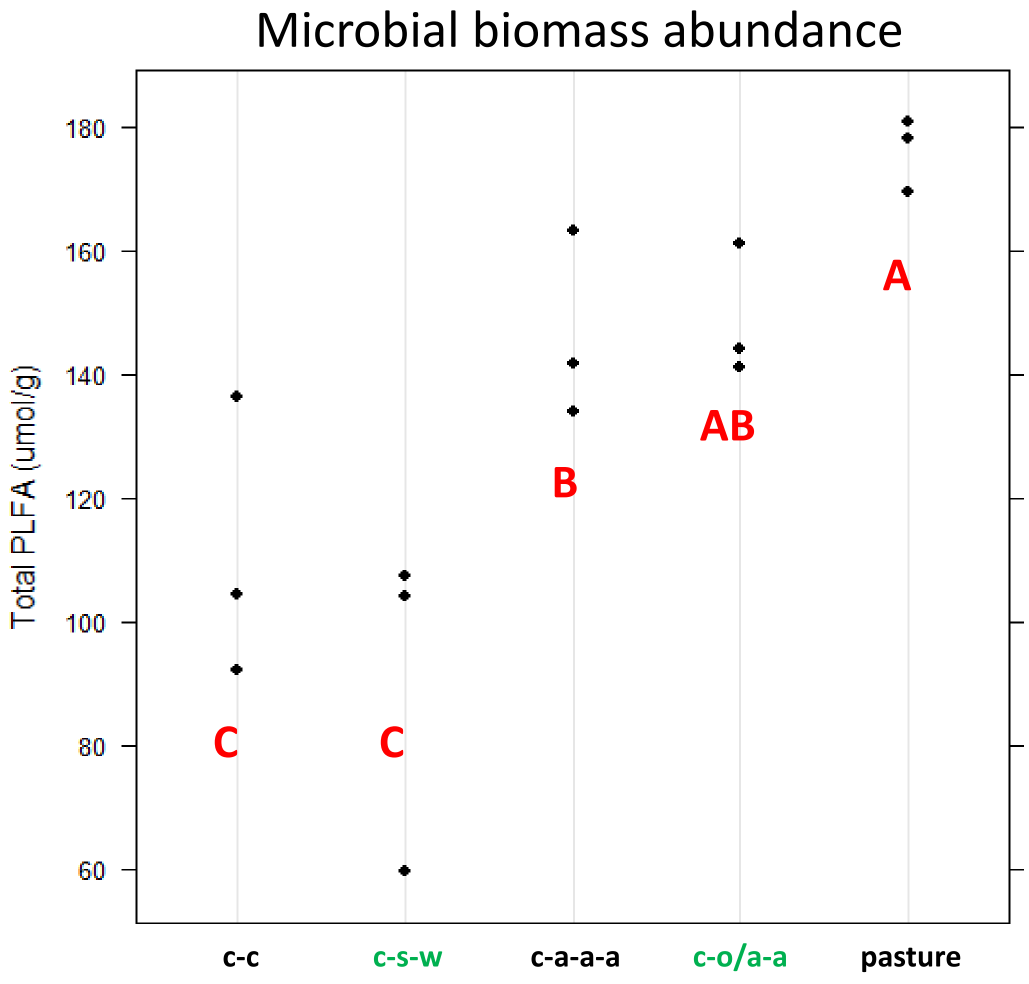


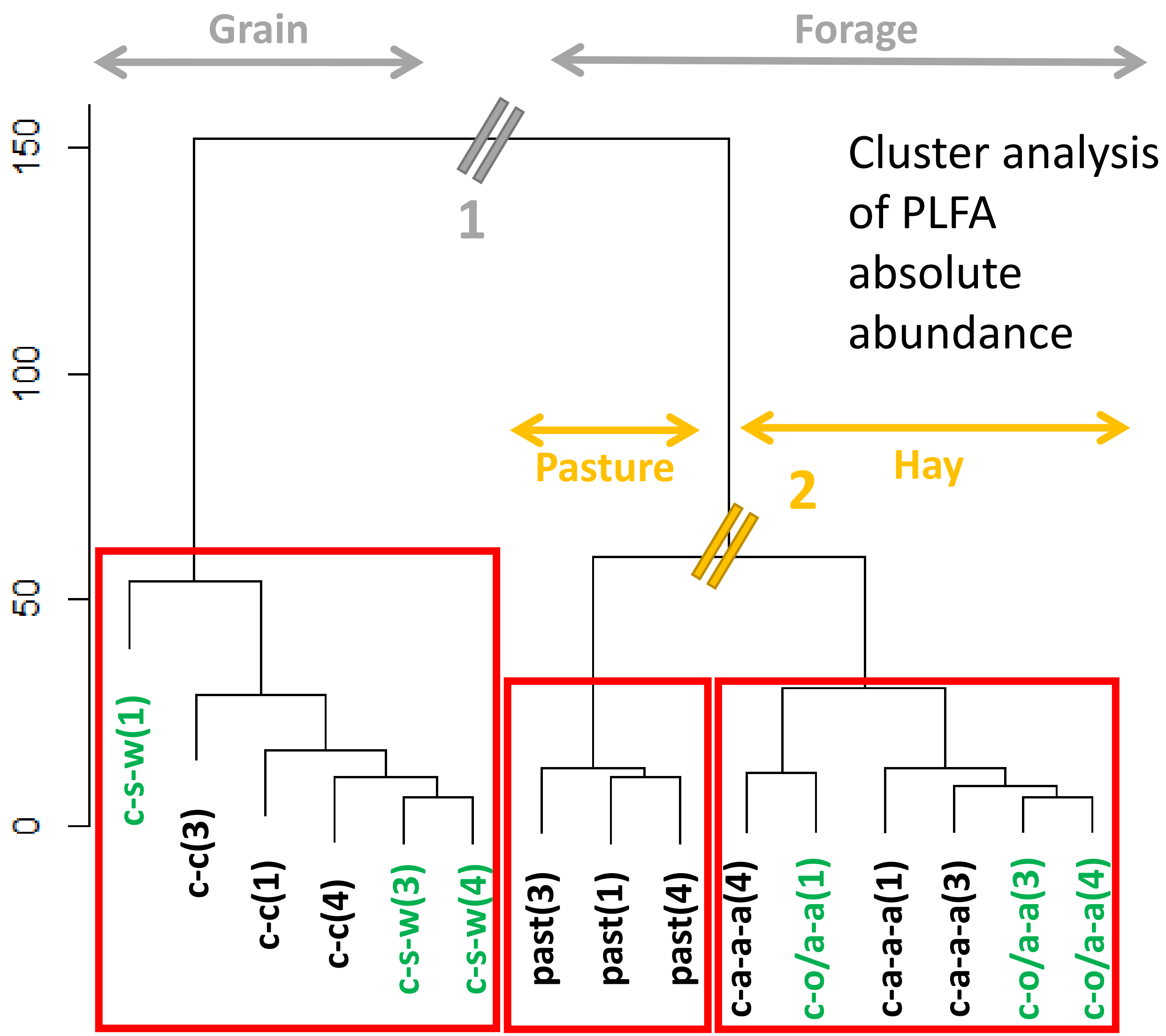
10-y restored grasslands

20-y cropping systems

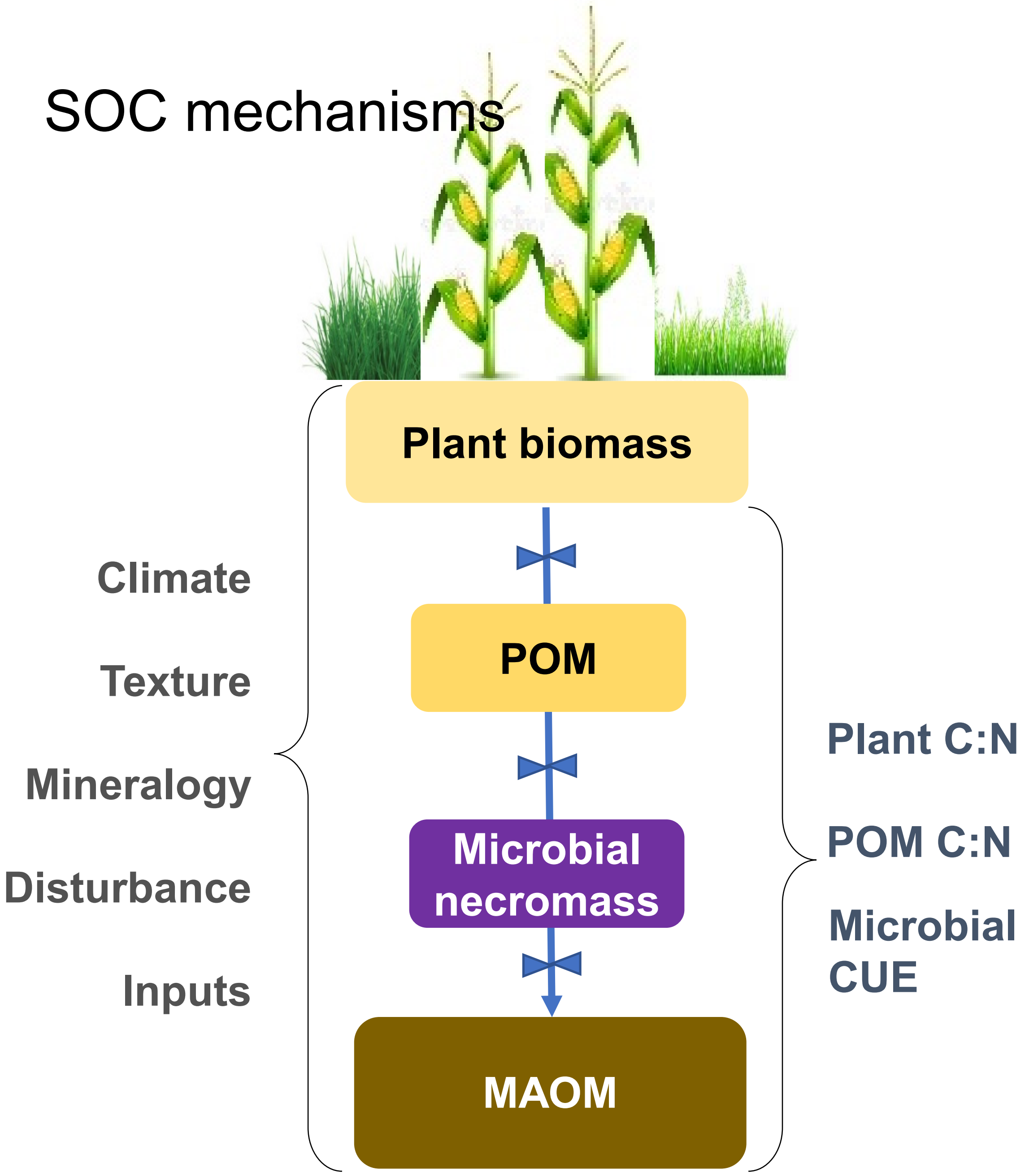
southern WI

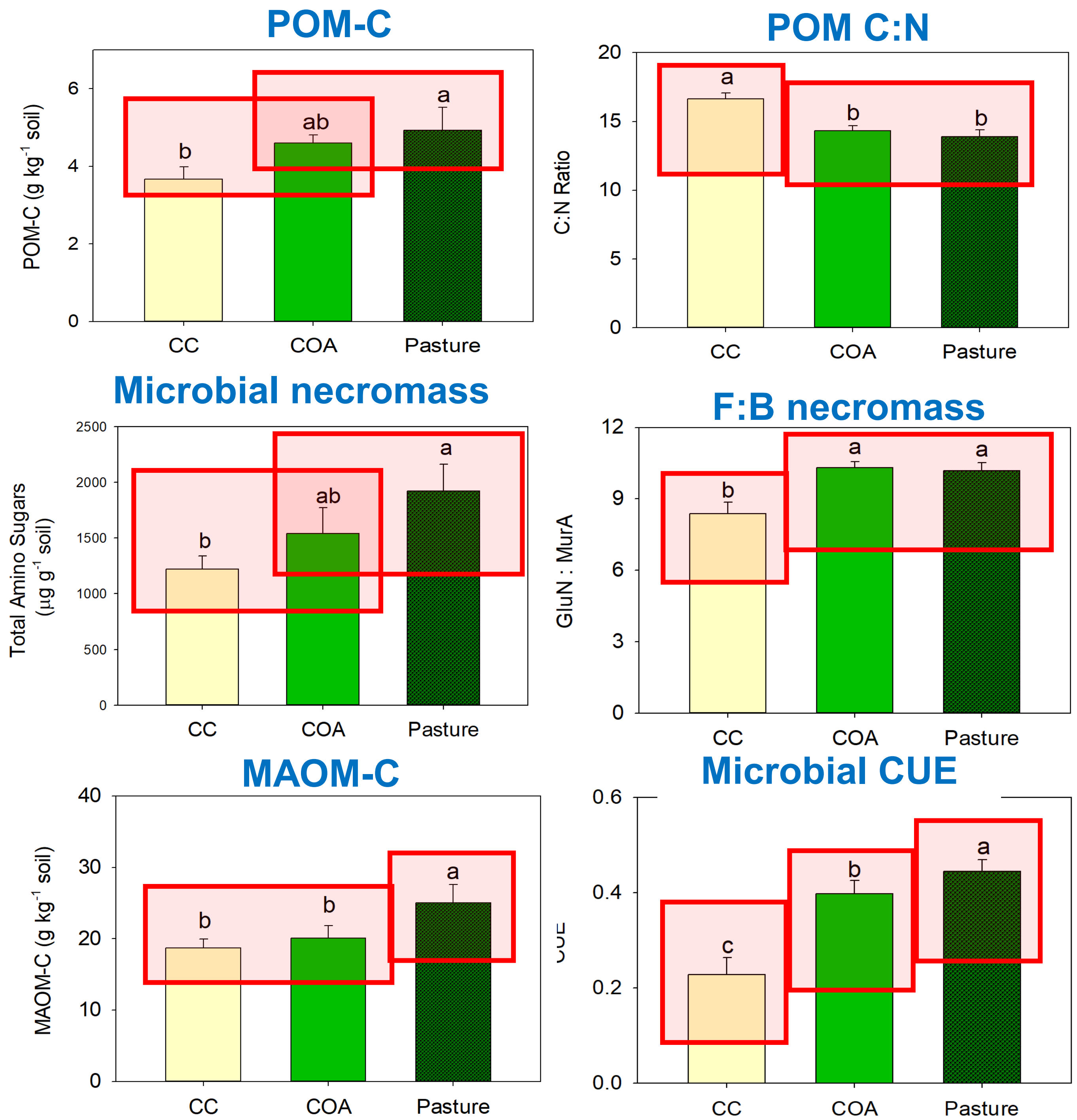
Microbial composition differs by cropping system





SOC mechanisms



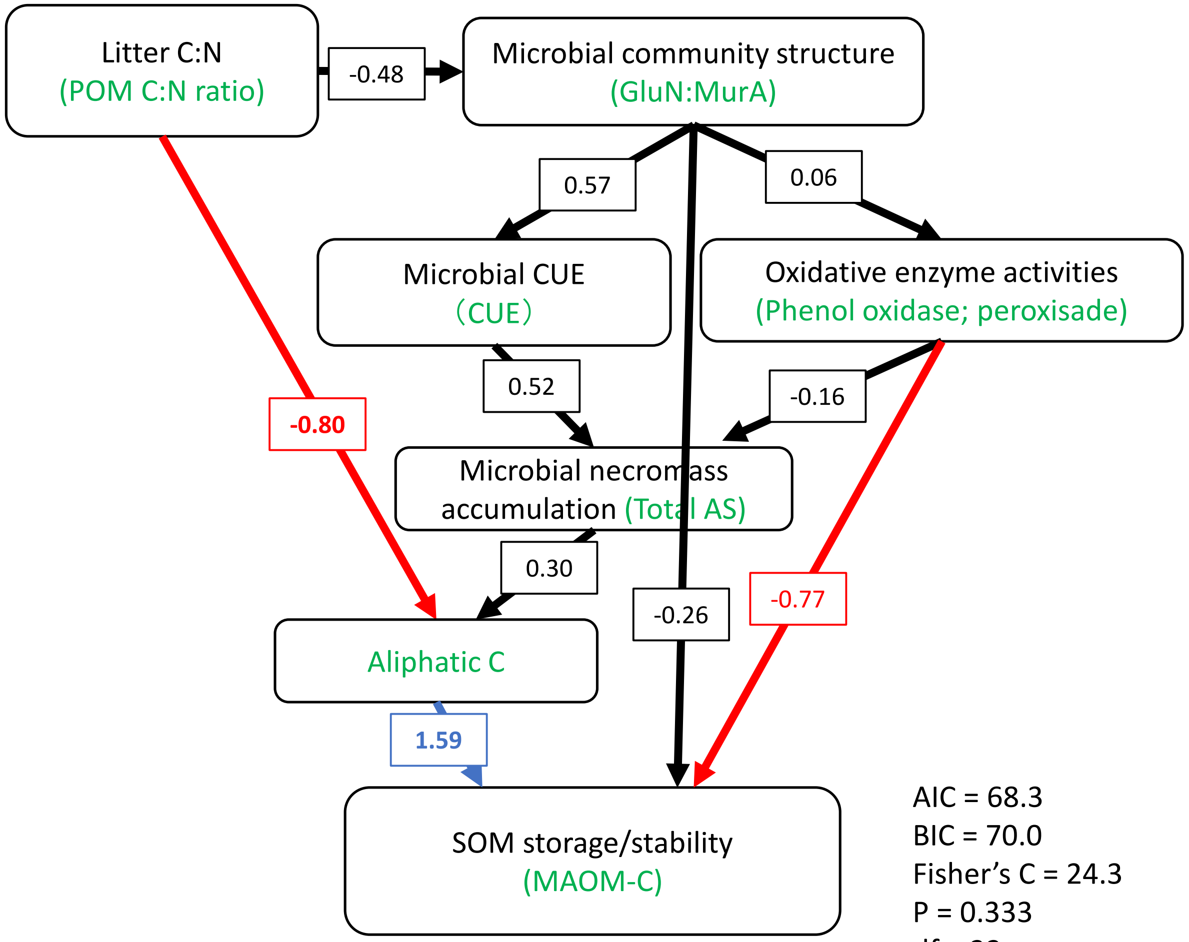


Rui, in prep

Structural equation models predicting SOM storage (Rui, Spiesman, et al., in prep)

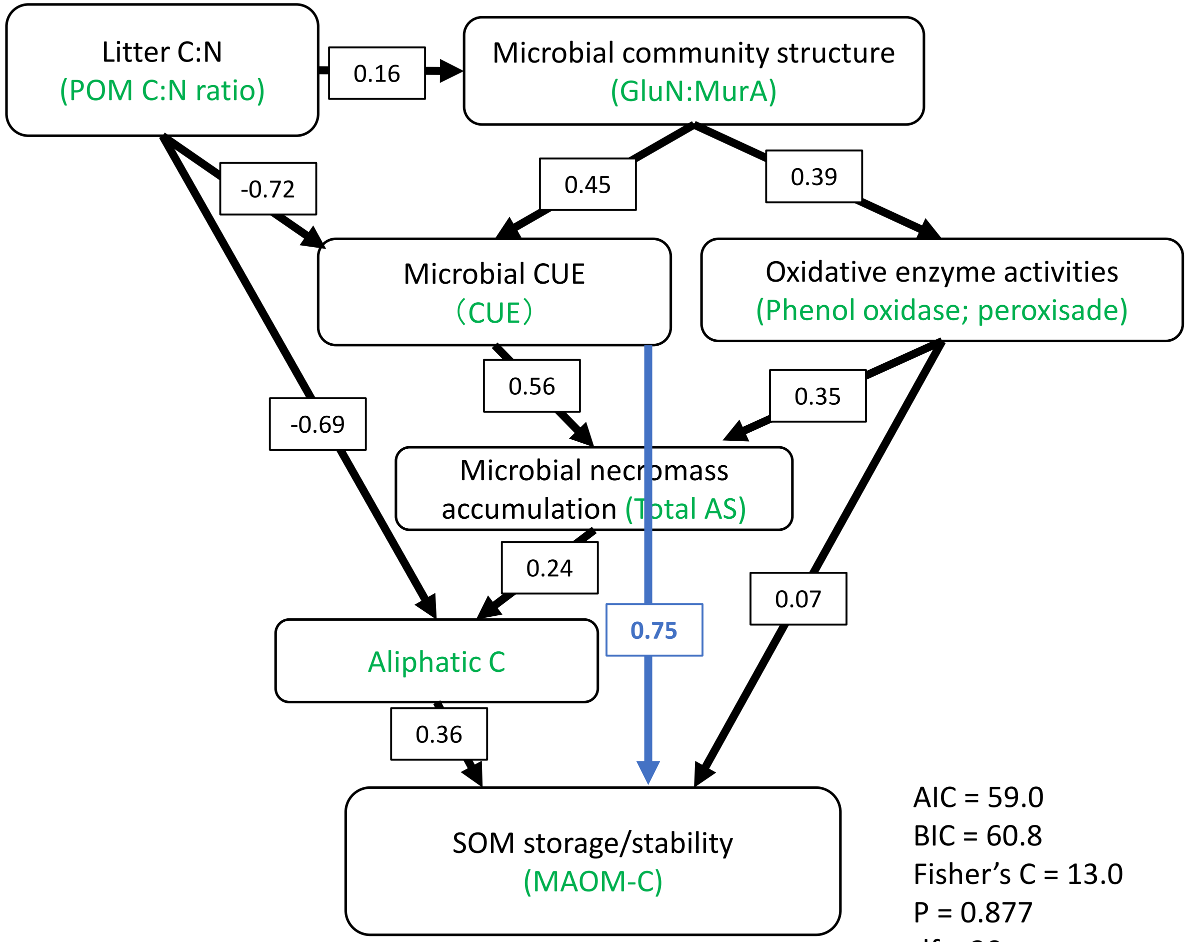
Non-sig
Significant negative
Significant positive
Values over arrows are the standardized estimates, or the strength of the direct effect

Continuous corn



AIC = 68.3
BIC = 70.0
Fisher's C = 24.3
P = 0.333
df = 22

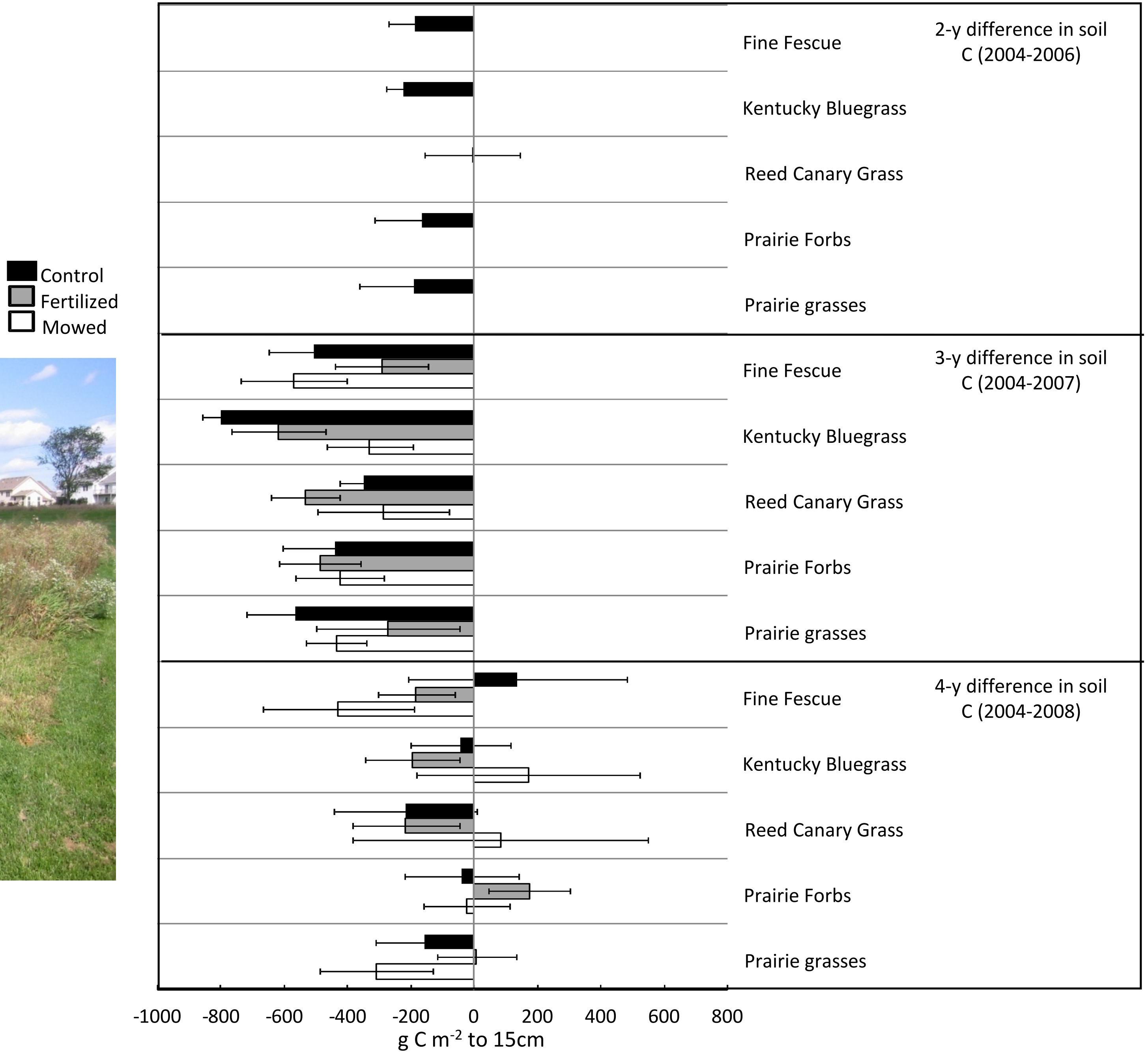
Grazed pasture



AIC = 59.0
BIC = 60.8
Fisher's C = 13.0
P = 0.877
df = 20

5. Planting perennials

Jackson & Stier, unpublished data



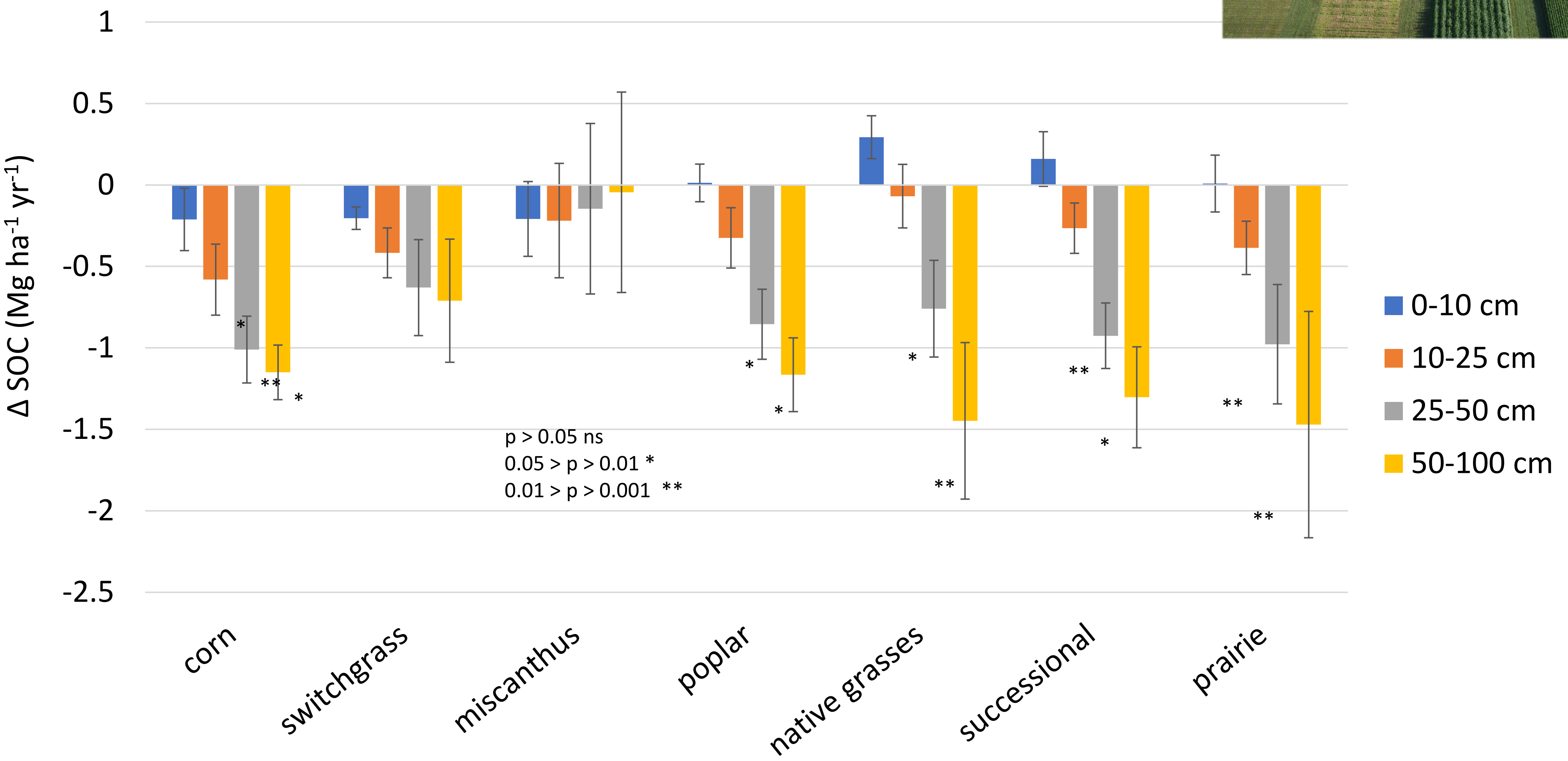
5. Planting perennials

6. Increasing diversity

Bioenergy cropping systems experiment

2008 – 2013

silt loam - southern Wisconsin



Soil Biology and Biochemistry 128 (2019) 35–44

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Soil Biology and Biochemistry

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5. Planting perennials

Conversion to bioenergy crops alters the amount and age of microbially-respired soil carbon

Laura M. Szymanski[a,*], Gregg R. Sanford[b,c], Katherine A. Heckman[d], Randall D. Jackson[b,c], Erika Marín-Spiotta[a]

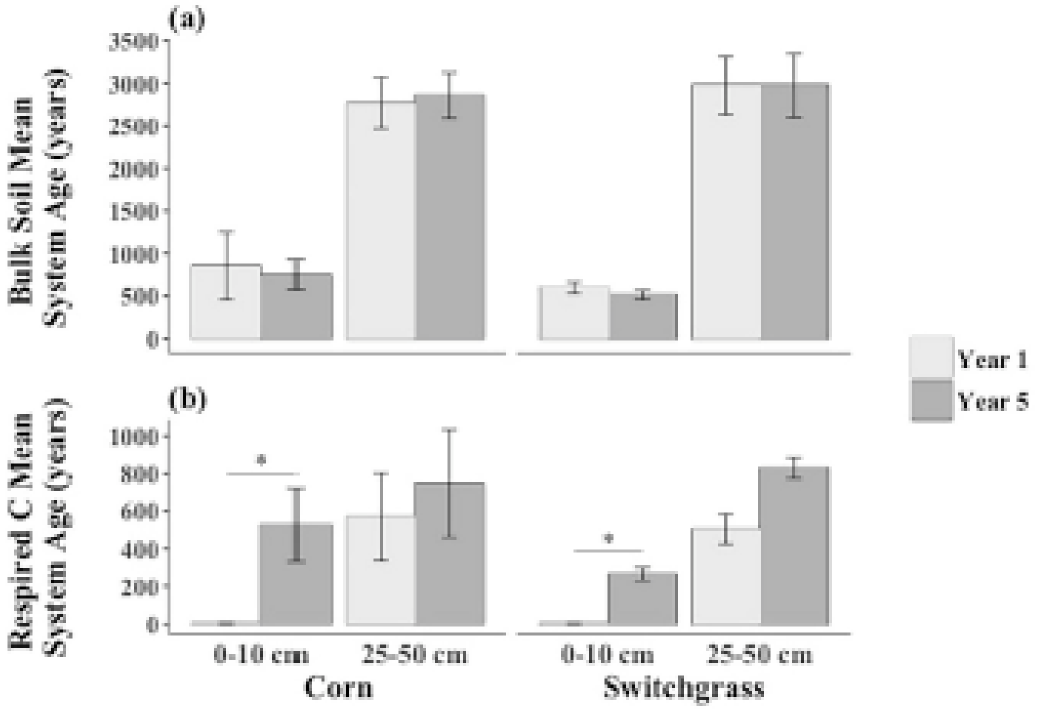


Fig. 3. Average radiocarbon-based modeled-mean system ages (years) of (a) respired CO_2 and (b) bulk soil collected from 0-10 cm and 25–50 cm under corn and switchgrass at Arlington Agricultural Research Station (ARL), WI in year 1 (2008) and year 5 (2013). Significant differences ($p < 0.05$) are indicated by an asterisk (*).

Oecologia (2018) 186:565–576
https://doi.org/10.1007/s00442-017-4036-8

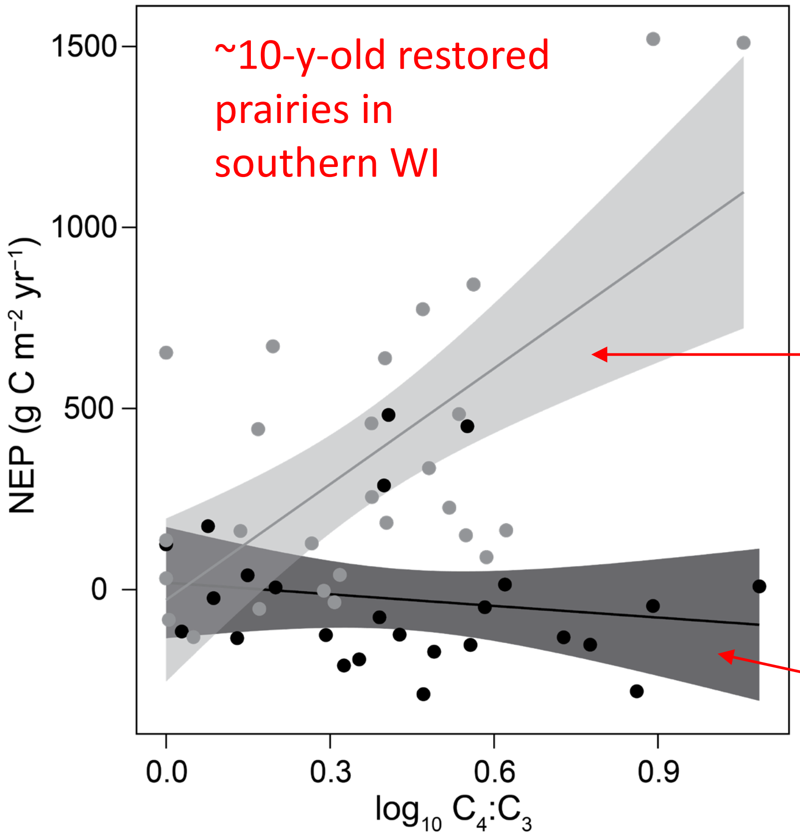
ECOSYSTEM ECOLOGY – ORIGINAL RESEARCH

5. Planting perennials

6. Increasing diversity

Carbon storage potential increases with increasing ratio of C_4 to C_3 grass cover and soil productivity in restored tallgrass prairies

Brian J. Spiesman[1,2] · Herika Kummel[3] · Randall D. Jackson[2,3]

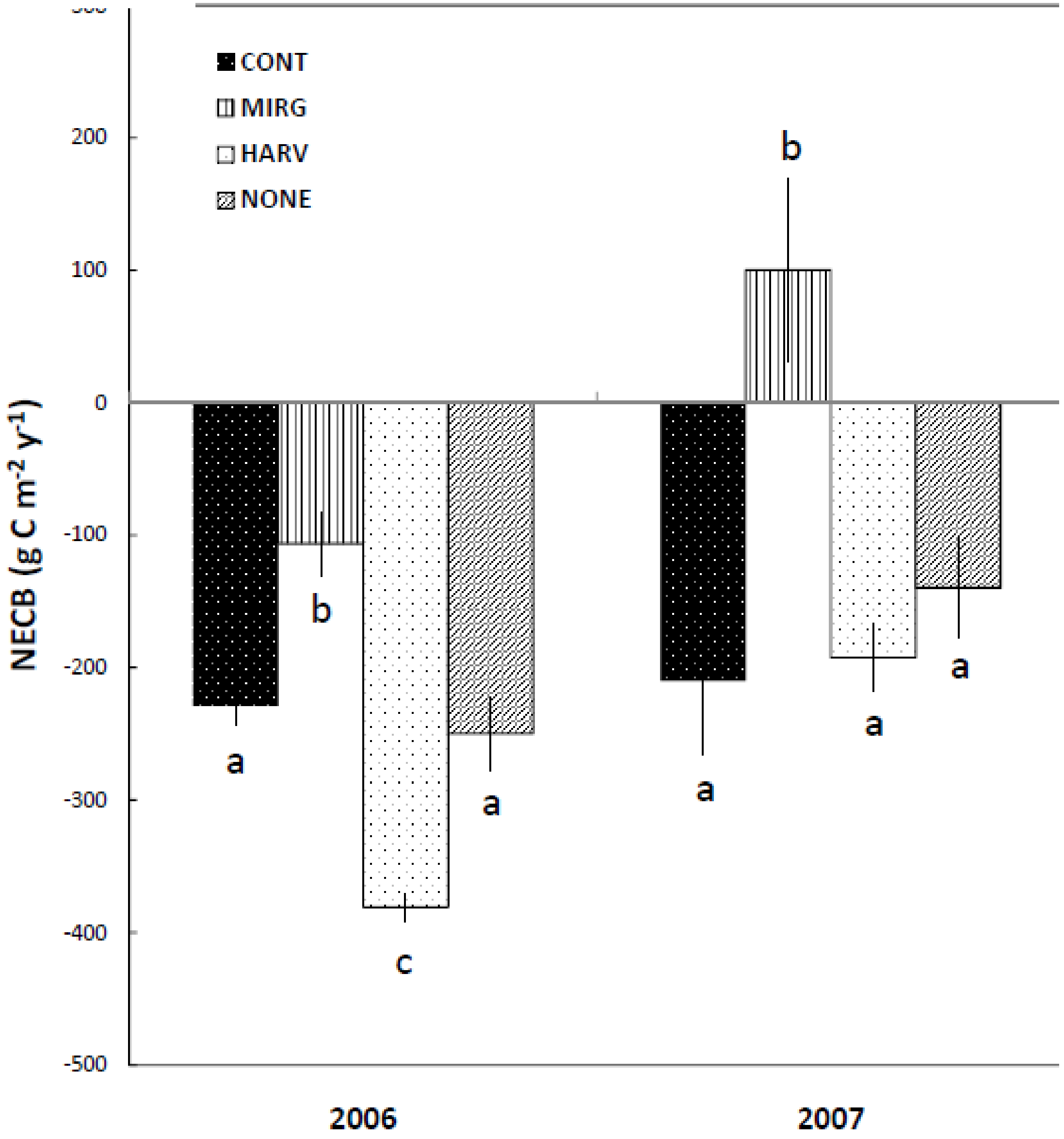


Rangeland Ecol Manage 67:19–29 | January 2014 | DOI: 10.2111/REM-D-12-00151.1

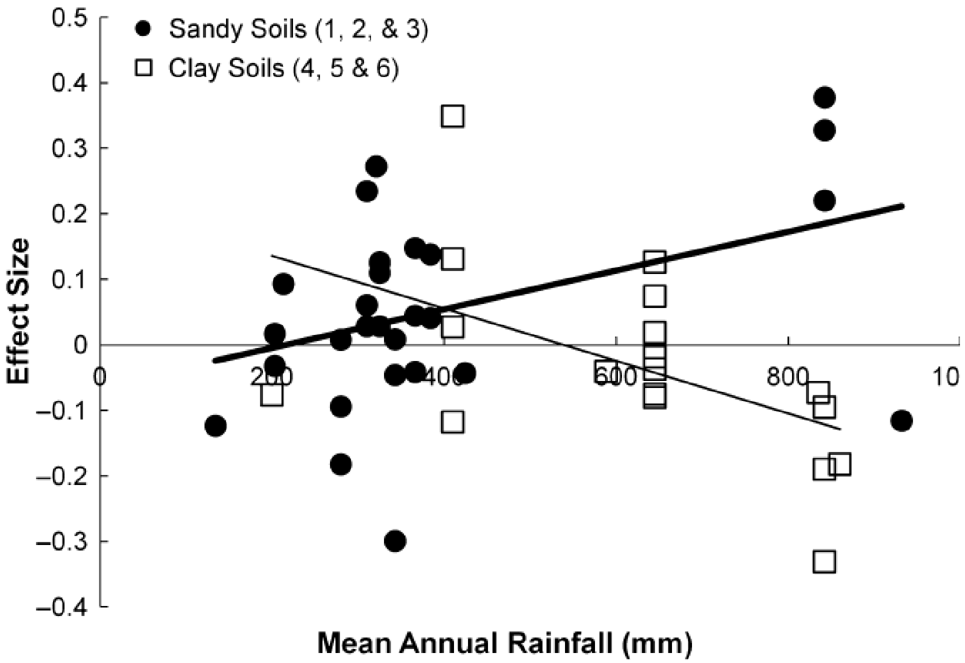
7. Improving grazing management

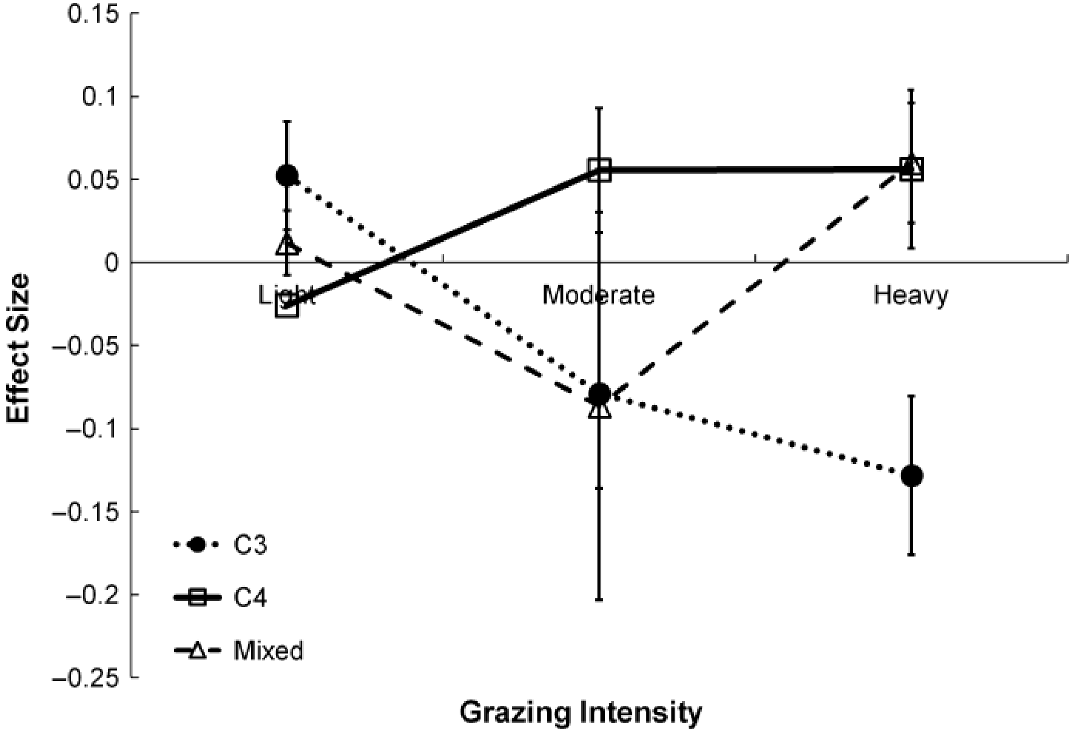
Livestock Management Strategy Affects Net Ecosystem Carbon Balance of Subhumid Pasture

Lawrence G. Oates[1] and Randall D. Jackson[2]



Climate, soils, and management interact!

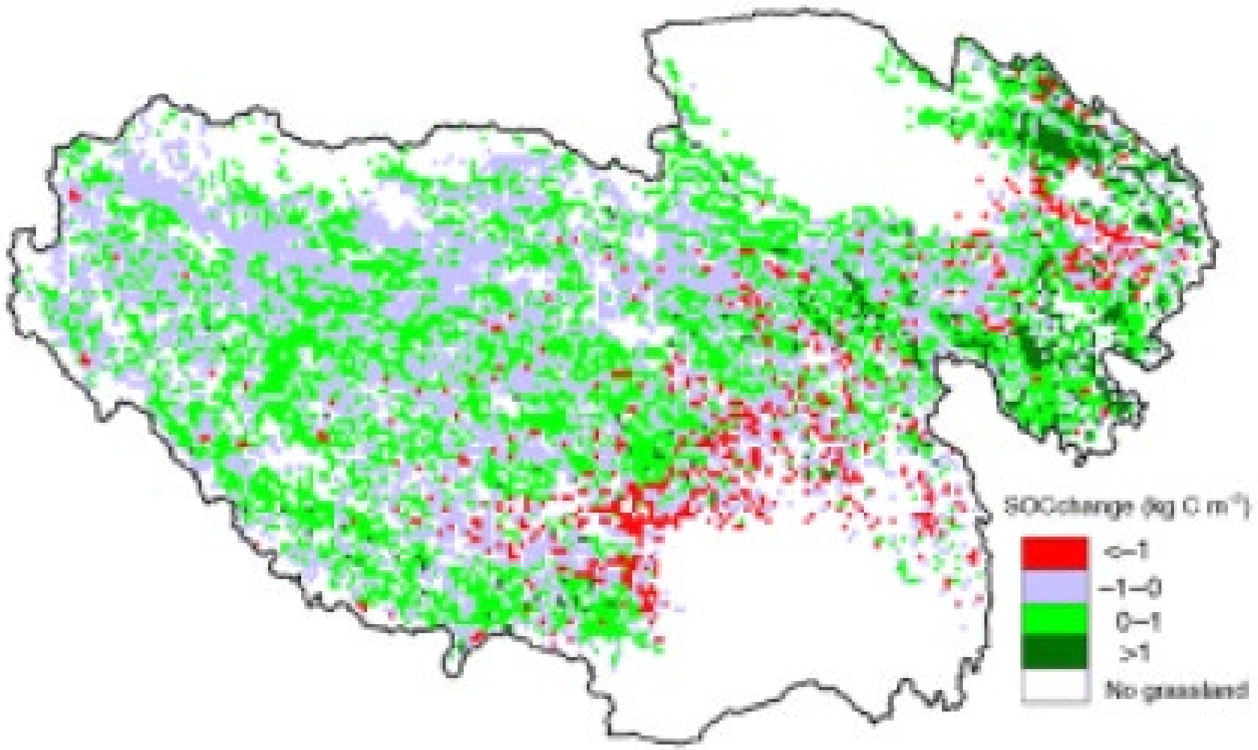




modified from McSherry & Ritchie 2013. Global Change Biology

What can we do to build SOC?

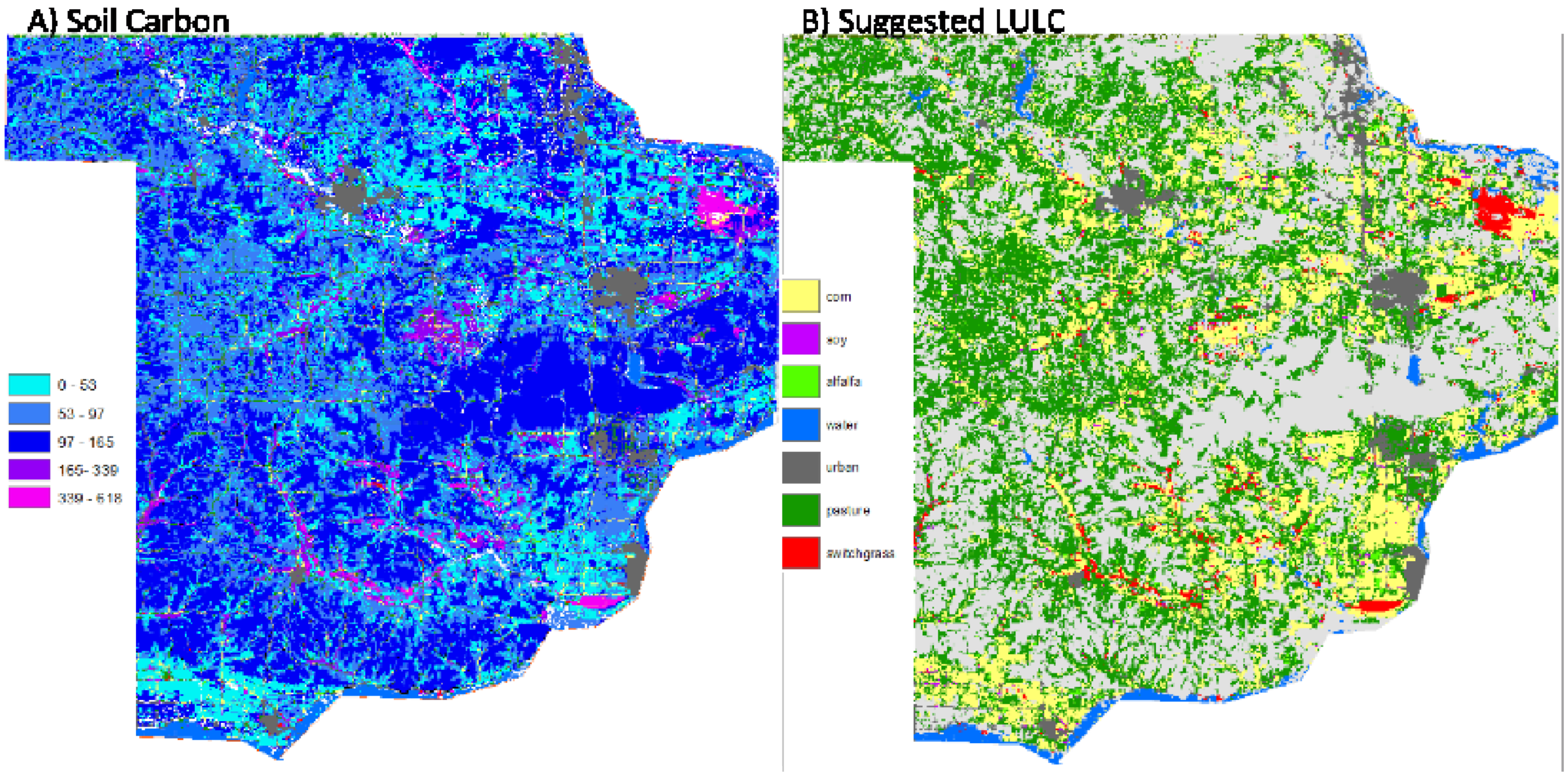
Some places do, some places don’t



SOC changes in the Tibetan grasslands over the last two decades.

Yang et al. 2009 Global Change Biology

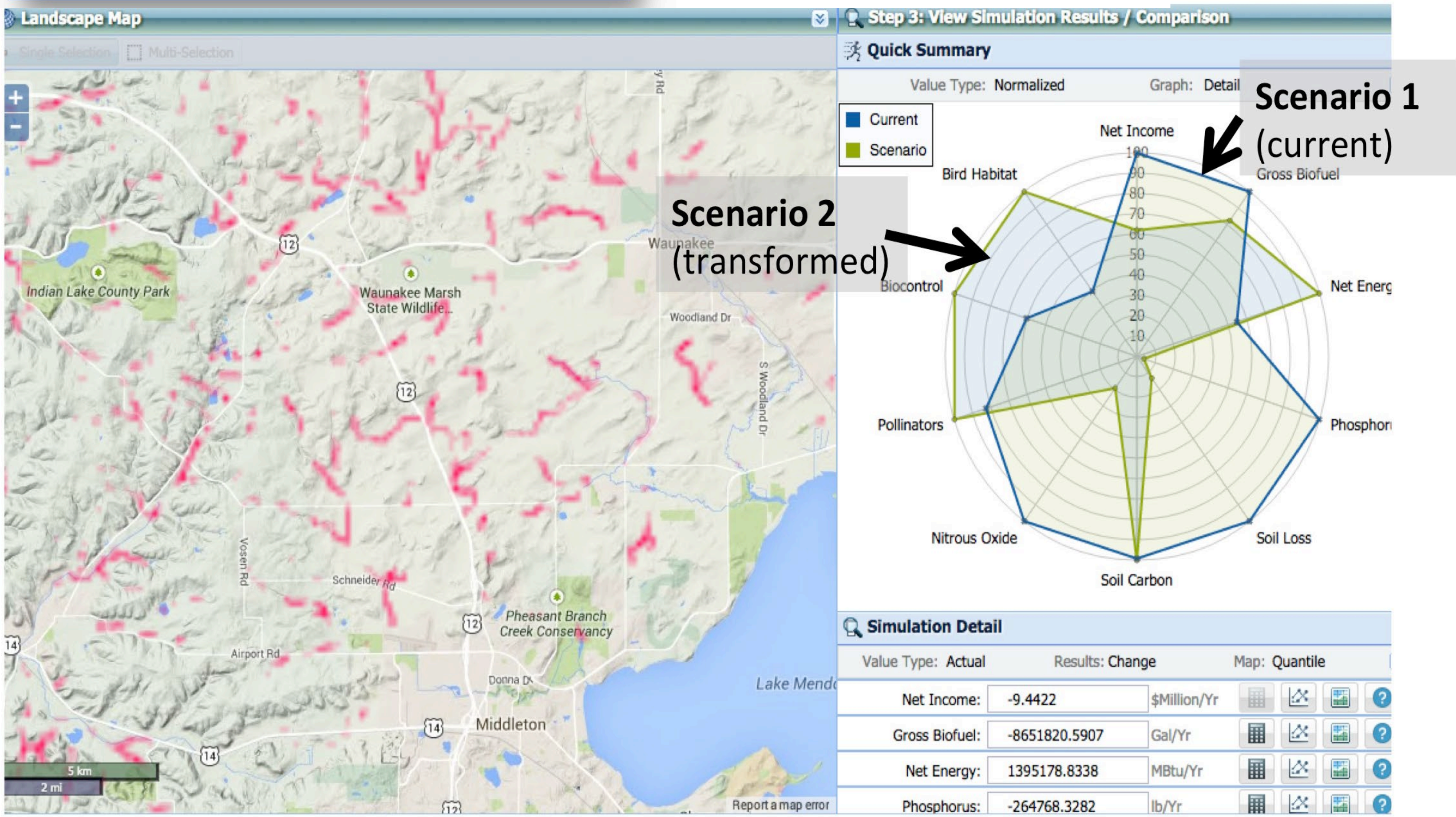
Identifying SOC hotspots requires good data & good models



Diehl et al., unpublished data

SmartScape decision support system

URL: http://**dss.wei.wisc.edu**



Tayyebi et al. 2016. Computers and Electronics in Ag

Summary & conclusions

1. Fine-tuning annual cropping systems not likely to build SOC
2. Perennialization offers best hope, but C balance still precarious
3. Much C "accumulation" may be ephemeral…so understanding SOM dynamics is key!
4. Best approaches focus on landscape designs that identify hotspots for protection AND possibly accumulation

Questions? Discussion?

Why do some studies predict SOC accumulation?

1. Use of chronosequences rather than time series SOC data
2. Extrapolating change in C concentrations to represent carbon loss or gain
3. Sampling depth too shallow
4. Sampling periods too short
5. Highly variable SOC

Why is soil C lost when it is predicted to increase?

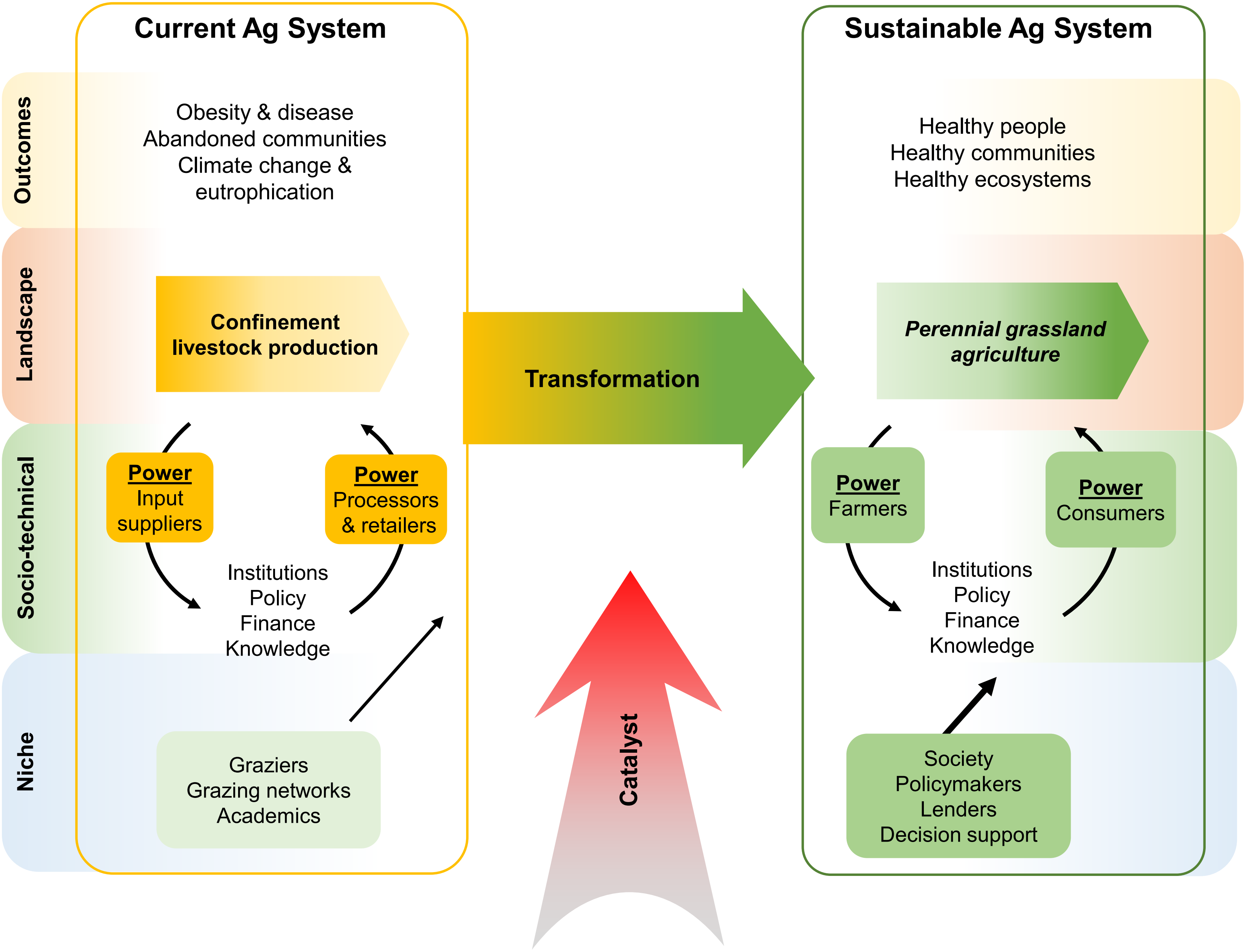
1. Soils still responding to initial soil plow-up
2. Soil biota not building SOC (C use efficiency)
3. Arbuscular mycorrhizal fungi (AMF) loss reducing aggregation
4. Climate change driving directional SOC change

Solutions

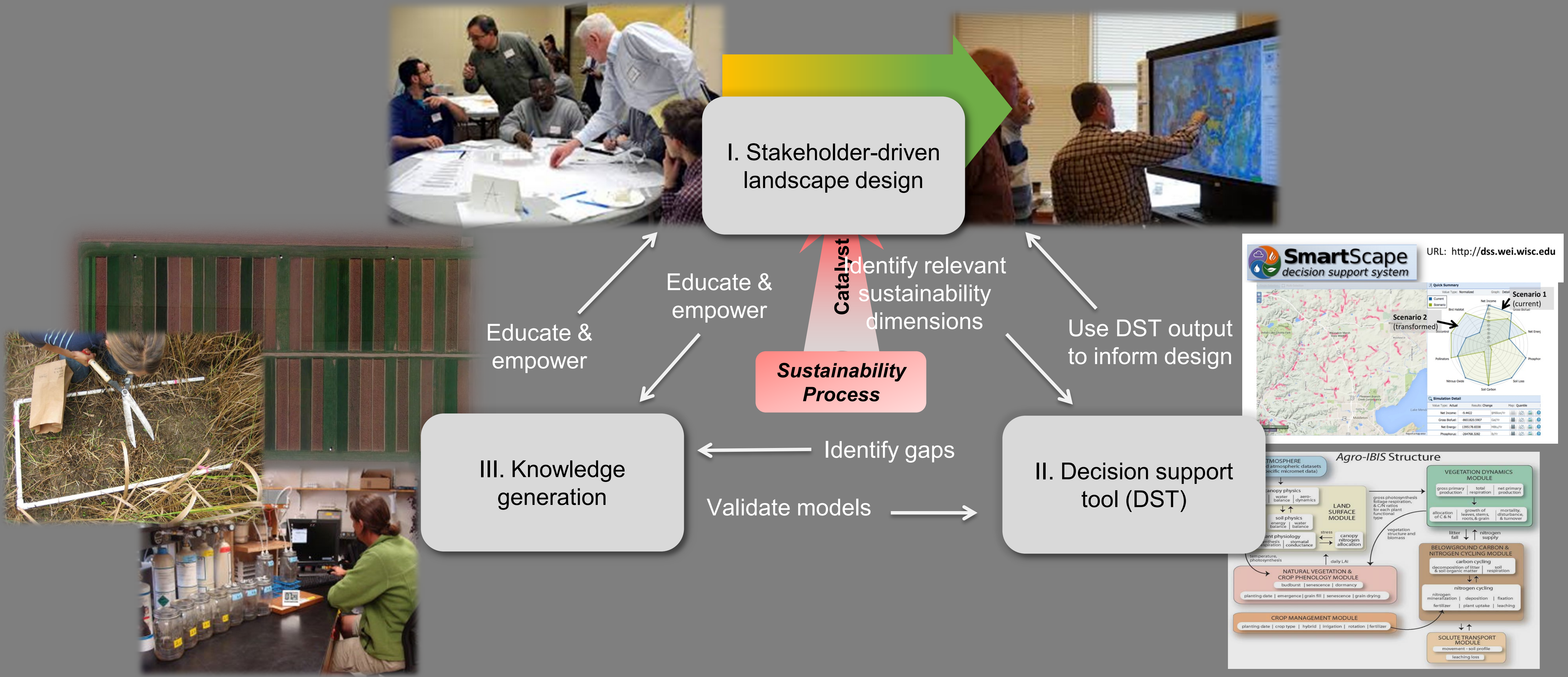
destabilizing climate change
polluting lakes & streams
reducing biodiversity

stabilizing climate
purifying water
mitigating floods
providing habitat

Solutions



Current Ag System
Sustainable Ag System
Outcomes
Landscape
Socio-technical
Niche
Obesity & disease
Abandoned communities
Climate change &
eutrophication
Confinement livestock production
Power
Input suppliers
Power
Processors & retailers
Institutions
Policy
Finance
Knowledge
Graziers
Grazing networks
Academics
Transformation
Catalyst
Healthy people
Healthy communities
Healthy ecosystems
Perennial grassland agriculture
Power
Farmers
Power
Consumers
Institutions
Policy
Finance
Knowledge
Society
Policymakers
Lenders
Decision support


I. Stakeholder-driven landscape design
Catalyst
Identify relevant sustainability dimensions
Educate & empower
Educate & empower
Use DST output to inform design
Sustainability Process
III. Knowledge generation
Identify gaps
Validate models
II. Decision support tool (DST)
SmartScape
decision support system
URL: http://dss.wei.wisc.edu
Scenario 1 (current)
Scenario 2 (transformed)
Agro-IBIS Structure
VEGETATION DYNAMICS MODULE
LAND SURFACE MODULE
NATURAL VEGETATION & CROP PHENOLOGY MODULE
BELOWGROUND CARBON & NITROGEN CYCLING MODULE
CROP MANAGEMENT MODULE
SOLUTE TRANSPORT MODULE

Grassland 2.0!