The Marsden Farm experiment

Can cropping system diversification and crop-livestock integration reduce reliance on purchased inputs while supporting productivity, profitability, and environmental health?

Matt Liebman, Iowa State University (emeritus)
Marshall McDaniel, Iowa State University
Steven Hall, University of Wisconsin–Madison

2-year rotation: corn-soybean

3-year rotation: corn-soybean-oat/red clover + manure

4-year rotation: corn-soybean-oat/alfalfa-alfalfa + manure

Plots are 60’ x 275’ each, all phases of each rotation present every year

2001 and 2002: base-line sampling / 2003-2005: start-up period

2006-present: mature period

LEOPOLD CENTER

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Expanding Opportunities. Delivering Results.

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

Mean annual mineral N fertilizer and herbicide use, 2008-2019

	N fertilizer			Herbicides		
Rotation	2-year	3-year	4-year	2-year	3-year	4-year
	lb N/acre			lb a.i./acre		
Corn	159	42	35	0.83	0.83	0.83
Soybean	4	4	4	1.37	1.37	1.37
Oat	--	4	4	--	0	0
Alfalfa	--	--	5	--	--	0
Rotation av.	82	17	12	1.10	0.73	0.55
Reduction		-79%	-85%		-33%	-50%

Herbicide regimes that reduce the mass of active ingredients applied by 97% have also been used effectively.

Mean yields, 2008-2019

Hunt et al. (2020), doi:10.1021/acs.est.9b06929 and unpublished data

	Yield, bu/acre or tons/acre			
Rotation	Corn	Soybean	Oat	Alfalfa
2-year	191 b	48 c	---	---
3-year	201 a	55 b	87 b	
4-year	202 a	58 a	94 a	4.2

Cropping system diversification reduced incidence and severity of soybean sudden death syndrome and increased yield.

Leandro et al. (2018), doi:10.1094/PDIS-`11-16-1660-RE

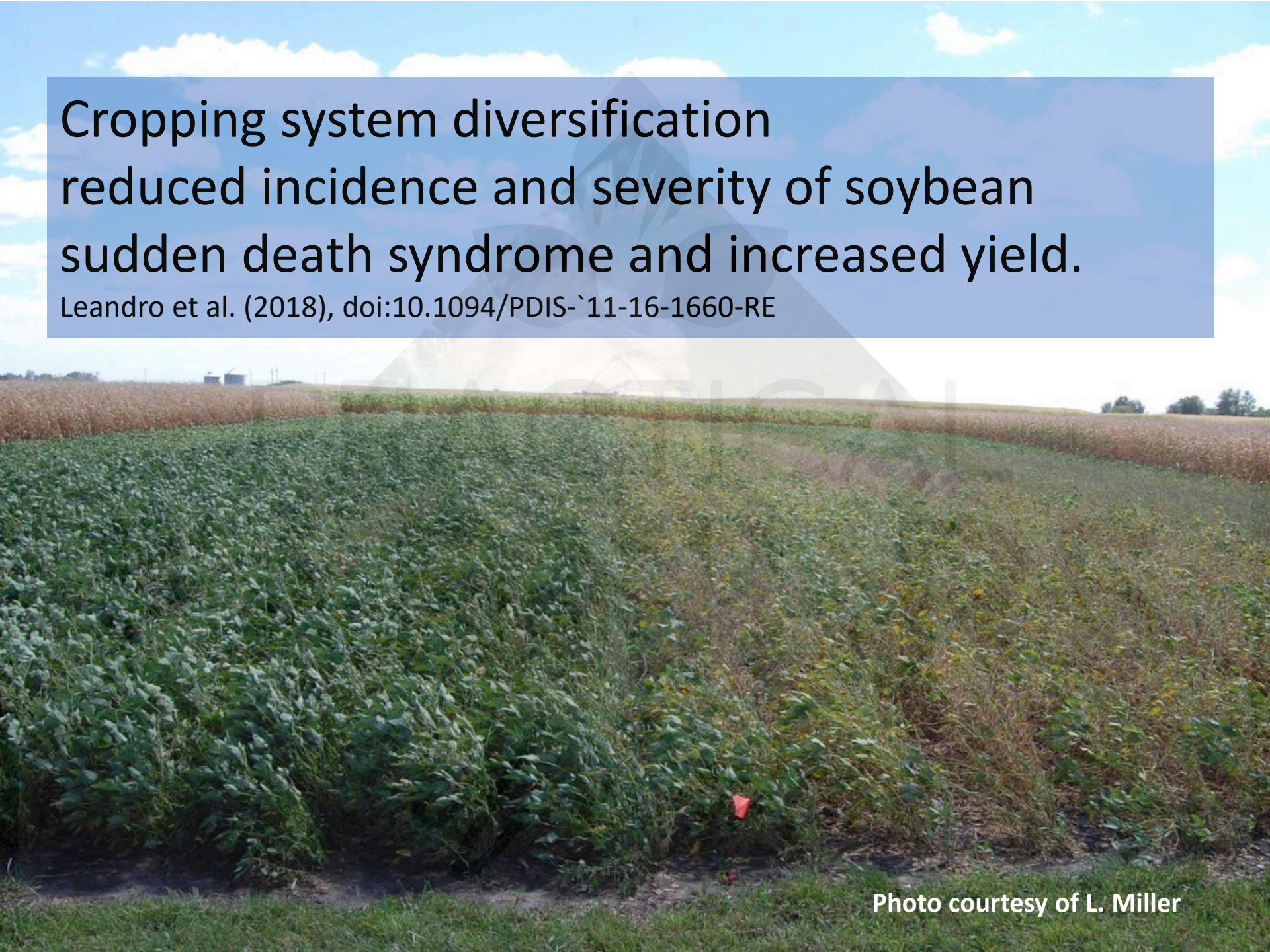


Photo courtesy of L. Miller

Economic performance, 2008-2019

	Rotation system		
	2-year	3-year	4-year
Gross returns ($/acre)	657 a	588 b	612 b
Costs of production (including labor, but not land, $/acre)	352 a	282 b	298 b
Profits (returns to land and management, $/acre)	305 a	306 a	314 a

Diversity → lower gross returns, lower costs, similar profits

Hunt et al. (2020), doi:10.1021/acs.est.9b06929 and unpublished data

Net returns to land and management, by crop and rotation, 2008-2019

	Rotation		
	2-year	3-year	4-year
	—— $/acre ——		
Corn	384	466	459
Soybean	227	314	334
Oat		137	123
Alfalfa			342
Rotation average	305	306	314

Hunt et al. (2020), doi:10.1021/acs.est.9b06929 and unpublished data

Diversification improved environmental performance

Performance indicator	Units (per year)	4-year rotation, C-SB-O/A-A	3-year rotation, C-SB-O/RCl	2-year rotation, C-SB
Fossil energy use	GJ/ha	3.4	4.1	9.5
GHG emissions	kg CO_2-eq/ha	281	359	783
Herbicide aquatic toxicity	CTUe/ha	2363	3151	4727
Soil sediment loss	Mg/ha	1.0	1.7	2.6
N discharge in run-off	kg/ha	6.2	6.5	10.0
P discharge in run-off	kg/ha	1.6	1.6	2.3
$PM_{2.5}$-related health damage	$/ha	298	401	688
Ground beetle diversity	no. of species	11.1	---	8.3

Hunt et al. (2017) doi:10.1021/acs.est.6b04086; Hunt et al. (2019) doi:10.1021/acs.est.8b02193; Hunt et al. (2020) doi:10.1021/acs.est.9b06929, O'Rourke et al. (2008) doi:10.1603/0046-225X(2008)37[121:GBCCAI]2.0.CO;2


Soils

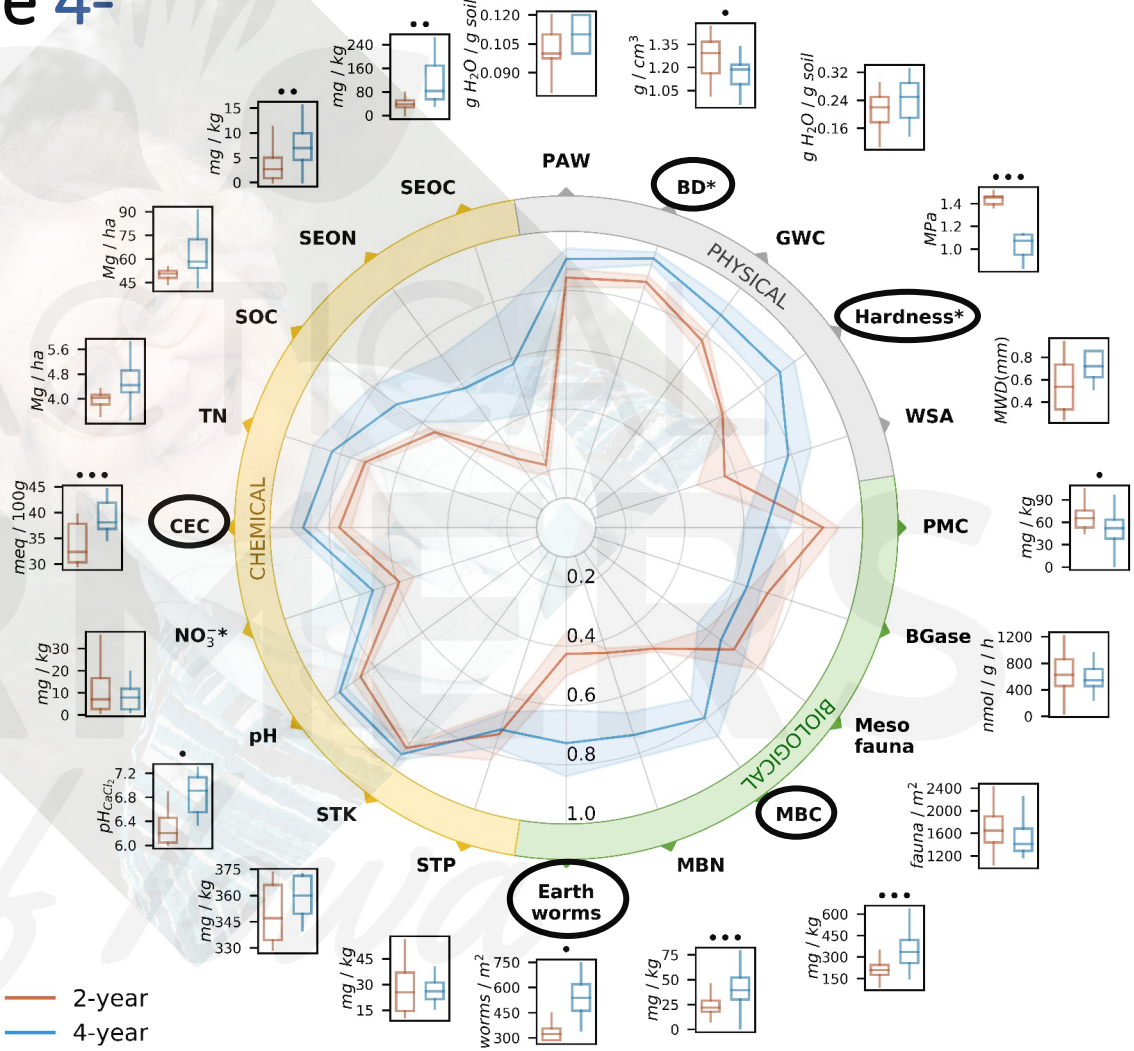
Soil Health (2017-2018) – 15 years later

Soil Health Benefits in the 4-year rotation (0-12”) are Bountiful…

A few of the highlights:

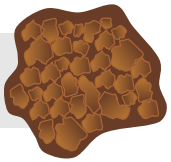
1. Soil hardness (penetration resistance)
2. Bulk density
3. Water infiltration
4. Earthworms
5. Particulate organic carbon
6. Soil microbial biomass

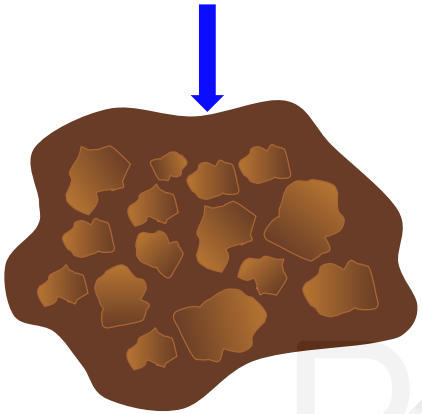
Rebecca Baldwin-Kordick



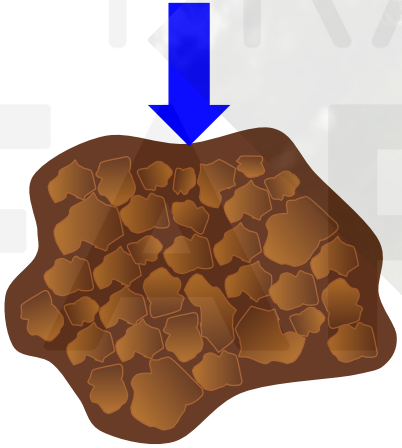
Baldwin-Kordick et al. 2022, doi:10.1080/21683565.2021.2019167

PHYSICAL



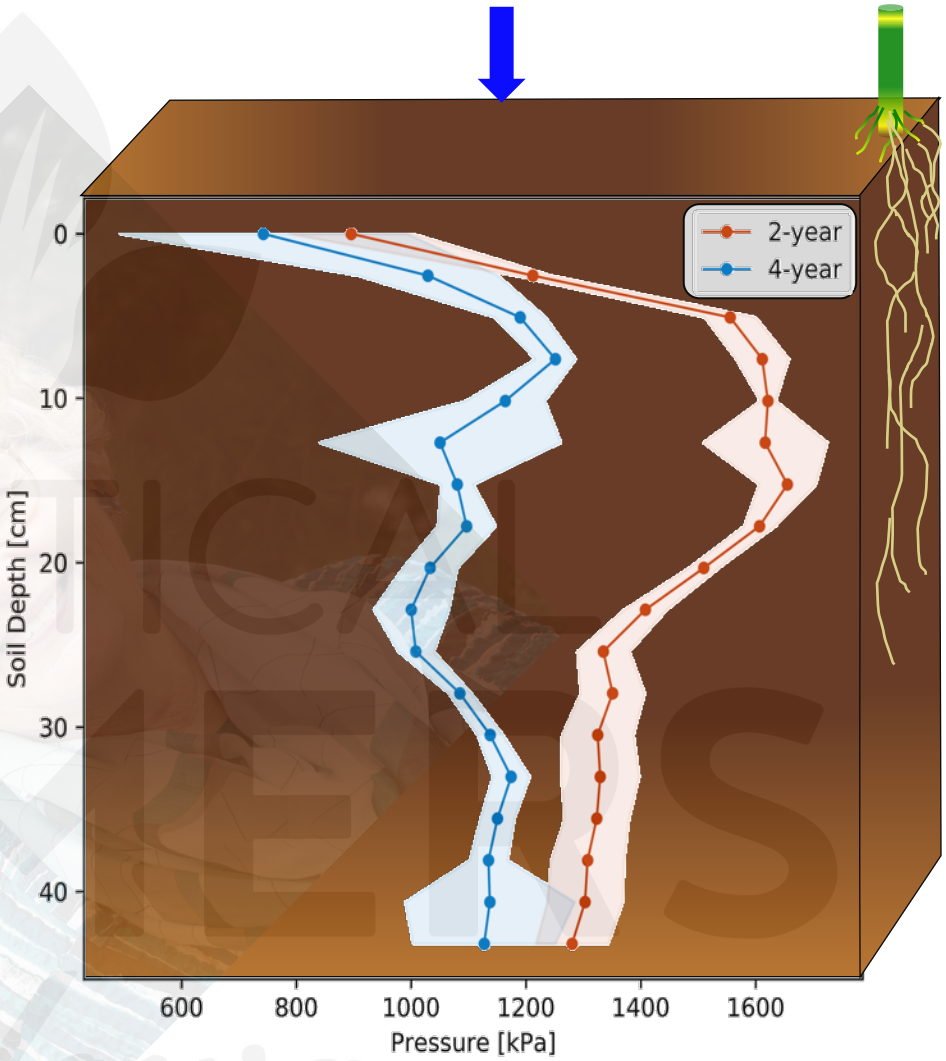


4-year



2-year

Soil resistance to penetration



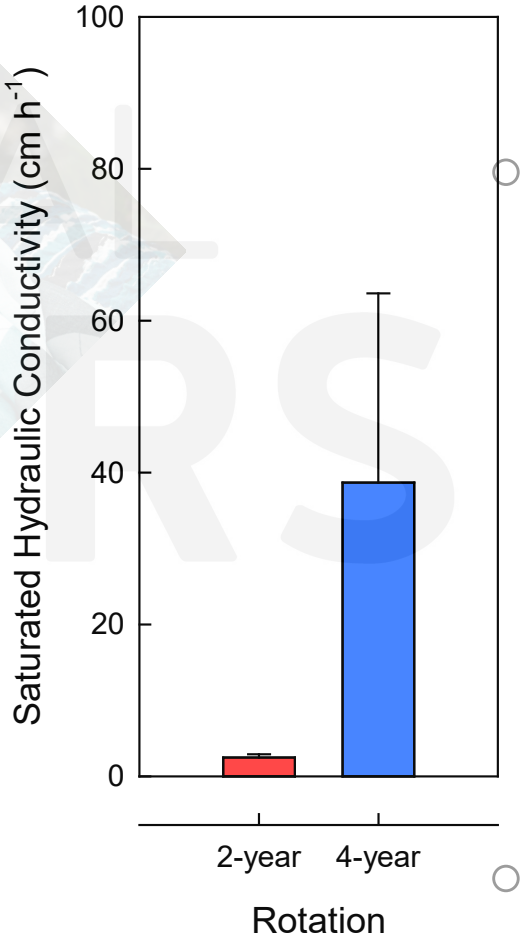
Diversification reduced soil bulk density by 8% and resistance to root penetration by 26%

Baldwin-Kordick et al. 2022, doi:10.1080/21683565.2021.2019167

PHYSICAL

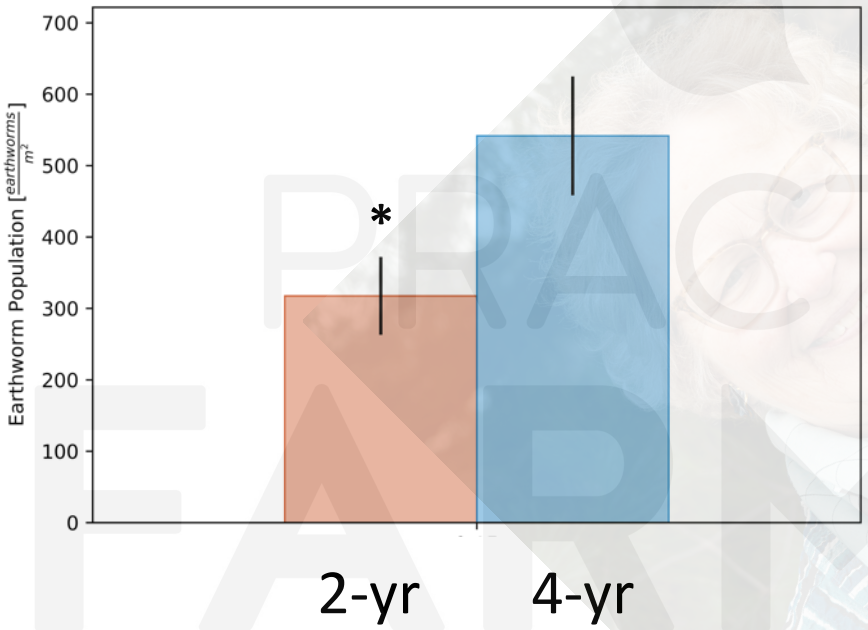
4-year rotation increased infiltration by > 15× (or 1400%)!!!

Liz Rieke
(Soil Health Institute)



Biological

Earthworm abundance



4-year system had 71% more earthworms.

Baldwin-Kordick et al. 2022, doi:10.1080/21683565.2021.2019167

Chemical

Biological

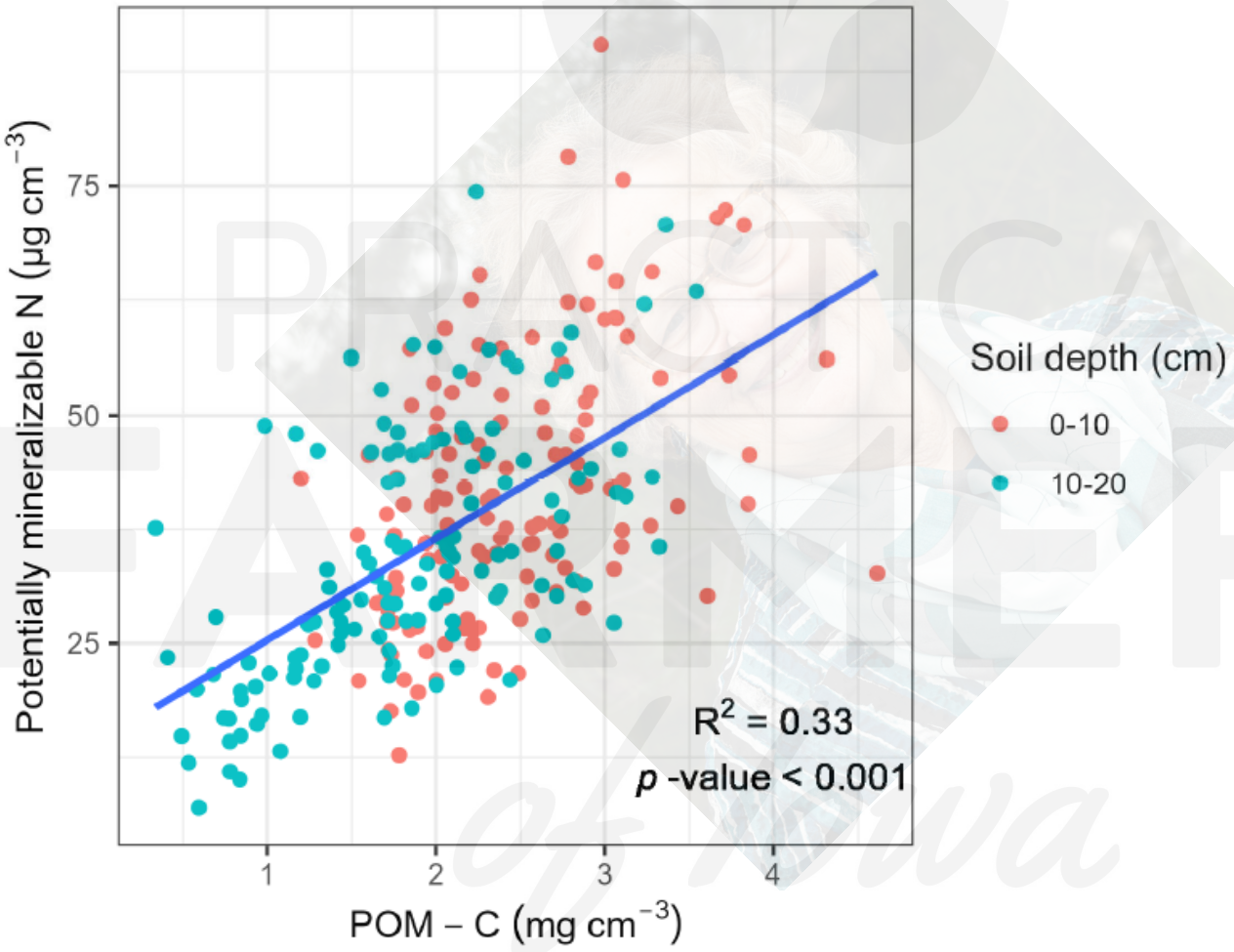
Diversification increased soil particulate organic matter and microbial biomass carbon

Rotation	Particulate organic matter carbon	Microbial biomass carbon
	mg POM-C cm^{-3} soil	µg C g^{-1} soil
2-year	1.86 b	312.6 b
4-year	2.38 a	472.2 a
	+28%	+51%

Measurements made in corn phase, 8” (20 cm) depth.

Lazicki et al. 2016, doi:10.1371/journal.pone.0164209;
King & Hofmockel 2017, doi:10.1016/j.agee.2017.01.040.

All signs point to greater N-supplying power in the 4-year crop rotation

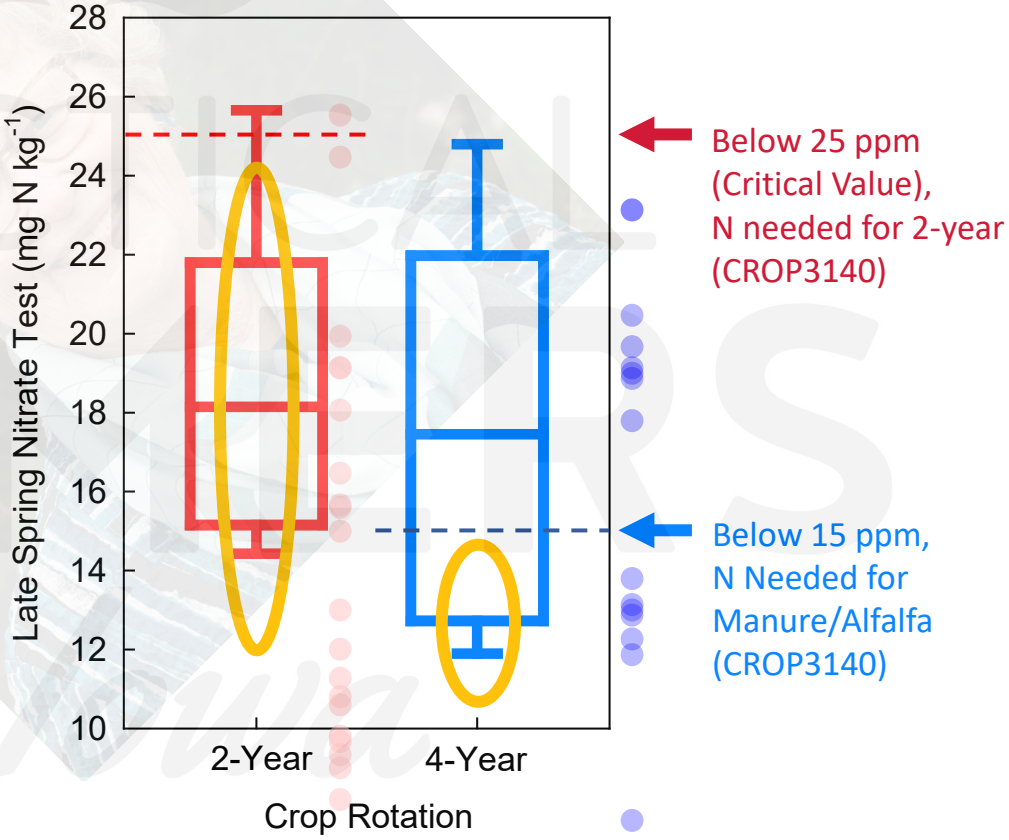


Lazicki et al. 2016, doi:10.1371/journal.pone.0164209;
Jordahl et al. 2023, doi:10.3390/land12081630

Less need to add N fertilizer to corn in June

- **2-year** gets pre-plant N (100 lbsN/ac) and sidedress N based on LSNT (18/20 years)
- **4-year** *sometimes* gets sidedress N based on LSNT (5/20 years)

Sawyer 2017_CROP3140



How did the diversified rotations impact total soil carbon and nitrogen?

- The diversified rotations received greater root carbon and carbon from manure
- Therefore, we might expect greater soil organic carbon (SOC) stocks in those rotations
- We collected soil cores to 1 m depth (3.3 feet) from all plots in fall 2021
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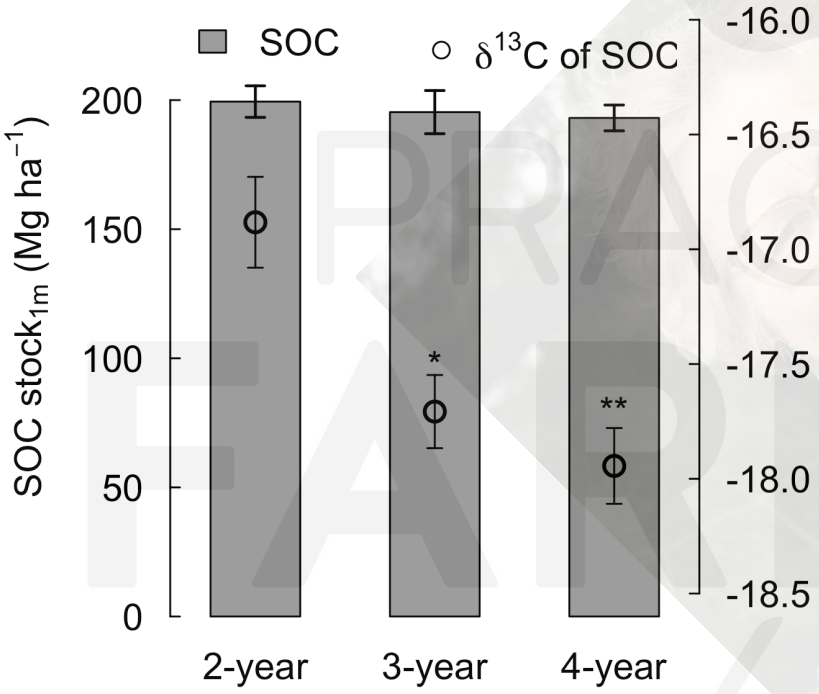

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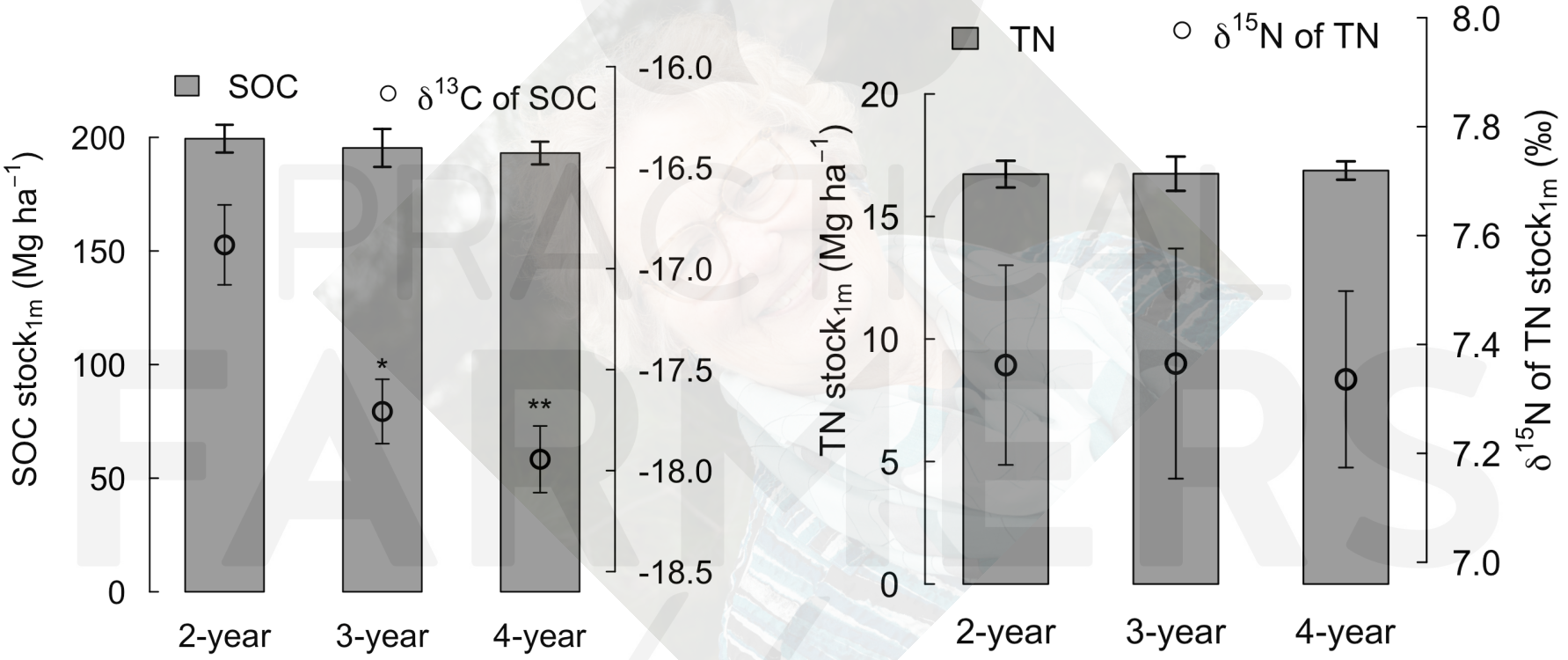
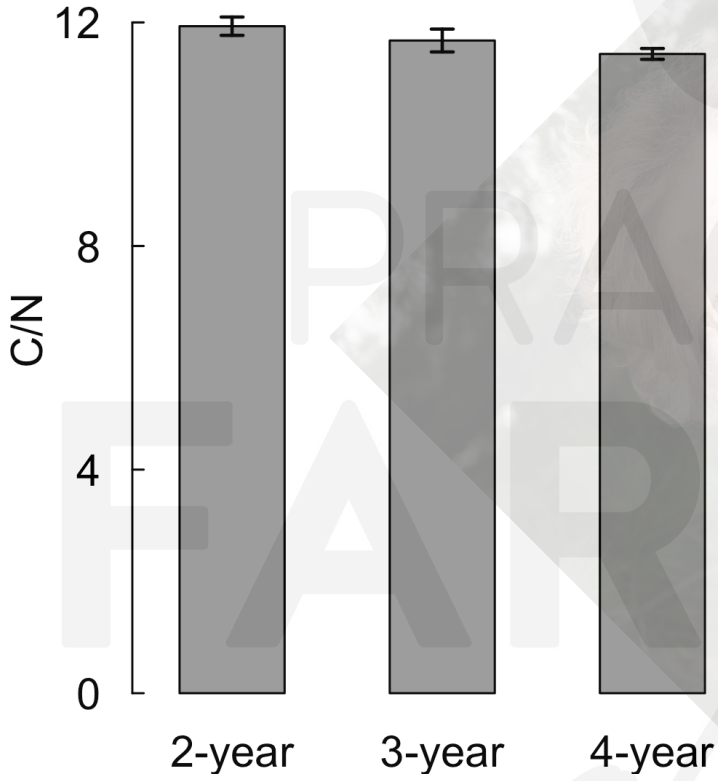


- **No significant difference in soil organic carbon stock among rotations**
  - On average, SOC was 7 Mg ha^{-1} lower in the 4-y than 2-y rotation
- **No significant difference in soil nitrogen stock among rotations**
  - On average, total N was 0.2 Mg ha^{-1} greater in the 4-y than 2-y rotation

How did the diversified rotations impact total soil carbon and nitrogen?



Significant decrease in soil C/N ratio

- 12.0 to 11.4 ($P < 0.05$) in the 4-y vs. 2-y rotation

What else might be changing with respect to carbon and nitrogen cycling in these soils?

How did the diversified rotations impact organic matter *decomposition*?

- With respect to *crop production*, the total stock of soil carbon and nitrogen is perhaps not so important
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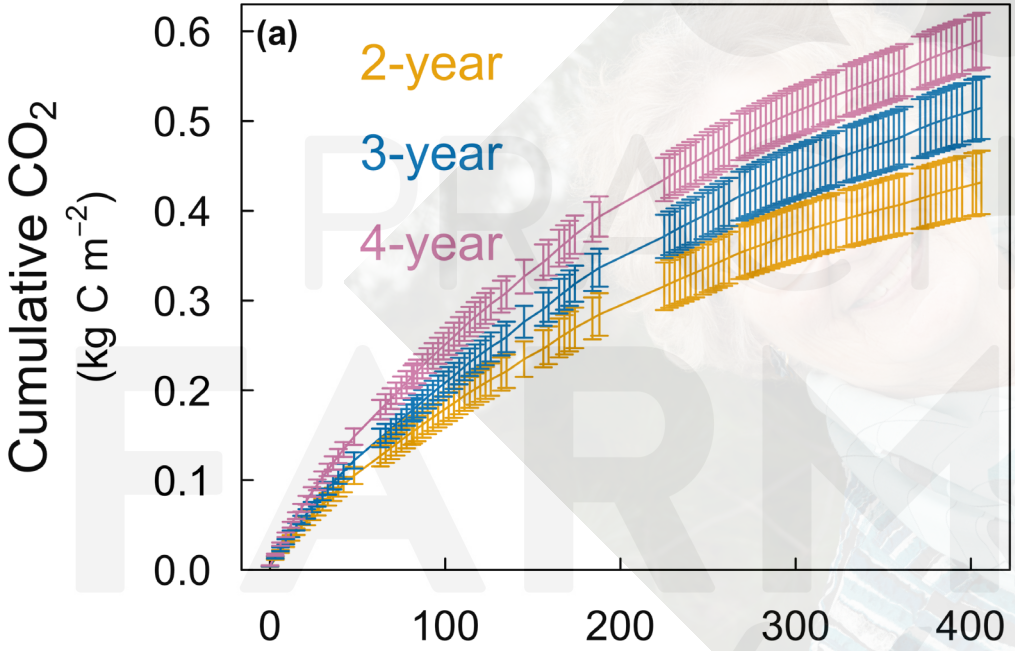
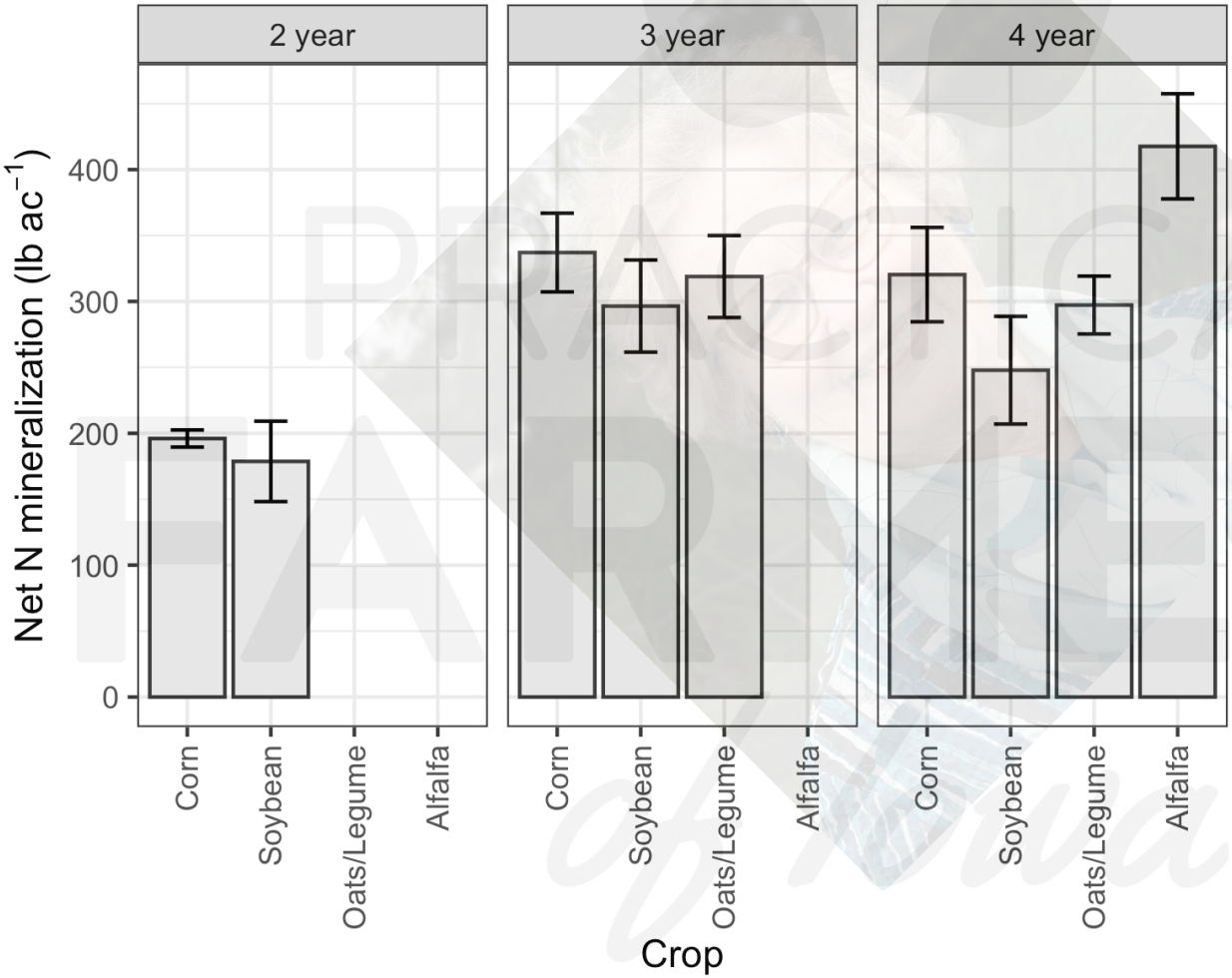


- With respect to *crop production*, the total stock of soil carbon and nitrogen is perhaps not so important
- We derive key agronomic benefits from soil organic matter when it **decomposes**
- Over a 1-y lab incubation, carbon dioxide (CO_2) release from organic matter decomposition was 43% greater in the 4-y than 2-y rotation

Diversified rotations increased potential nitrogen mineralization



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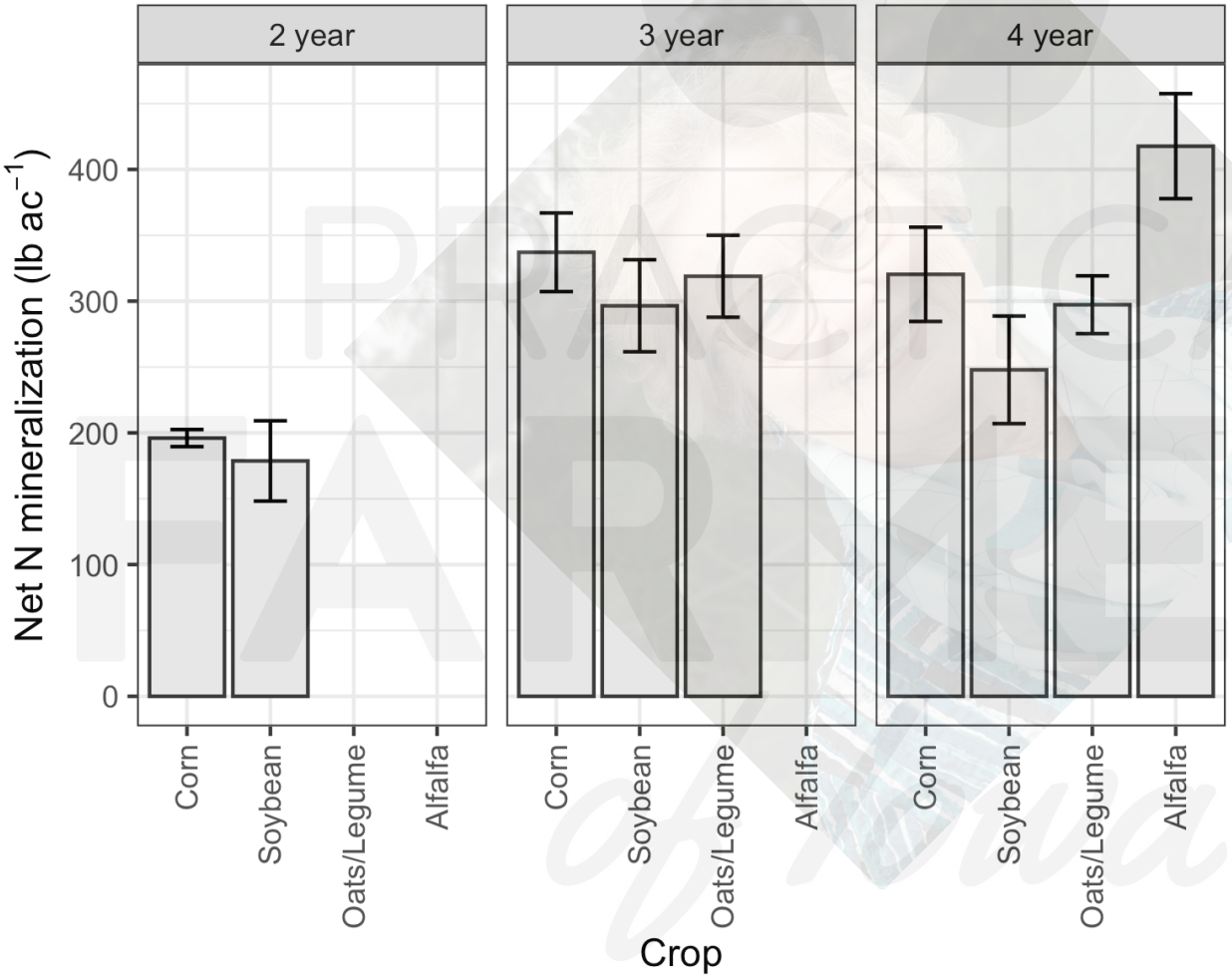

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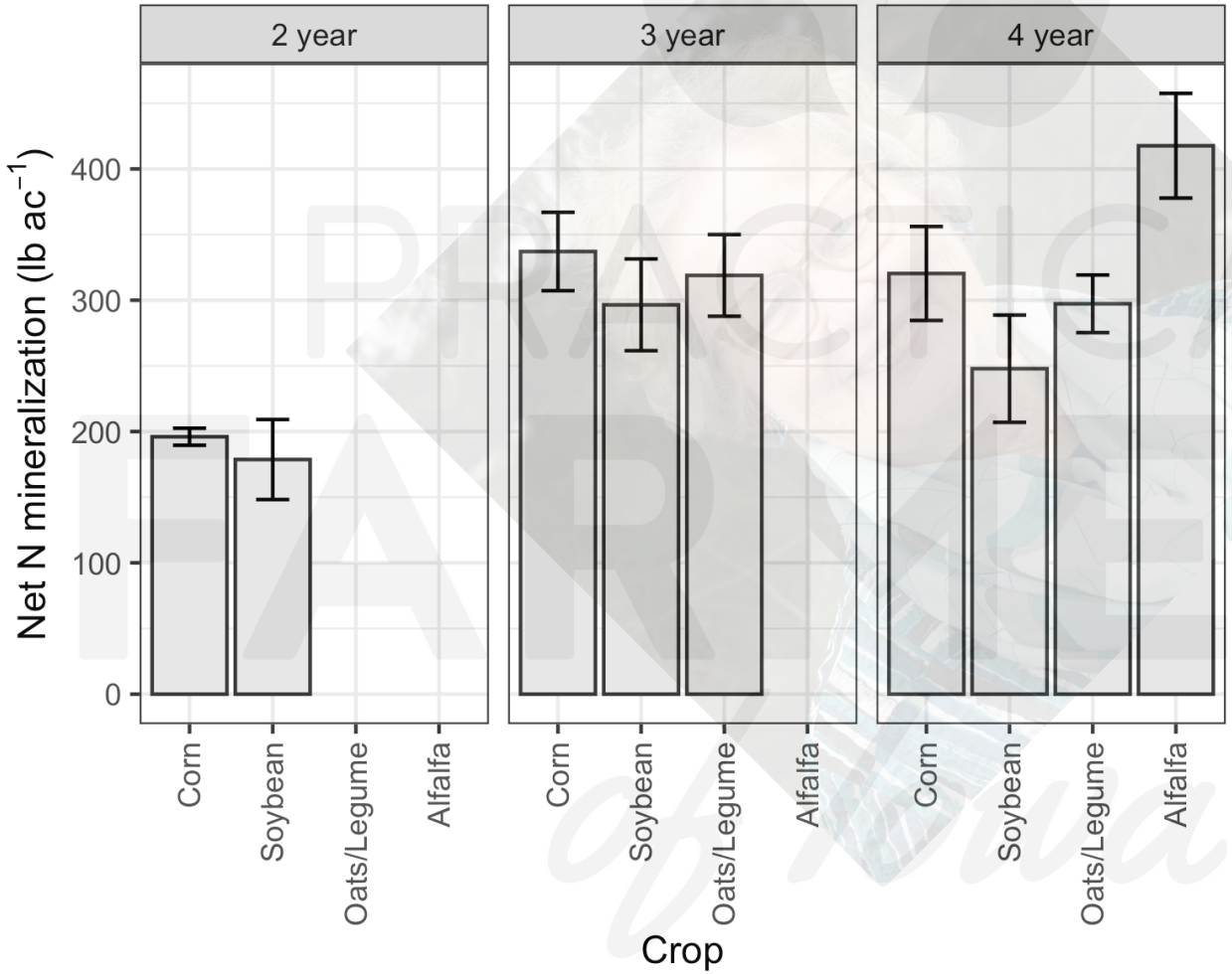
- After alfalfa in the 4-y rotation, N mineralization was **210 lb greater** than the 2-y rotation
- Roughly consistent with some Extension N-credit guidelines for grain following alfalfa

Take-home point: diversified crop rotations can greatly increase nitrogen *supply* even when they don't accumulate soil organic matter



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