Learning from farmers: Diversifying crop rotations to make farms more resilient

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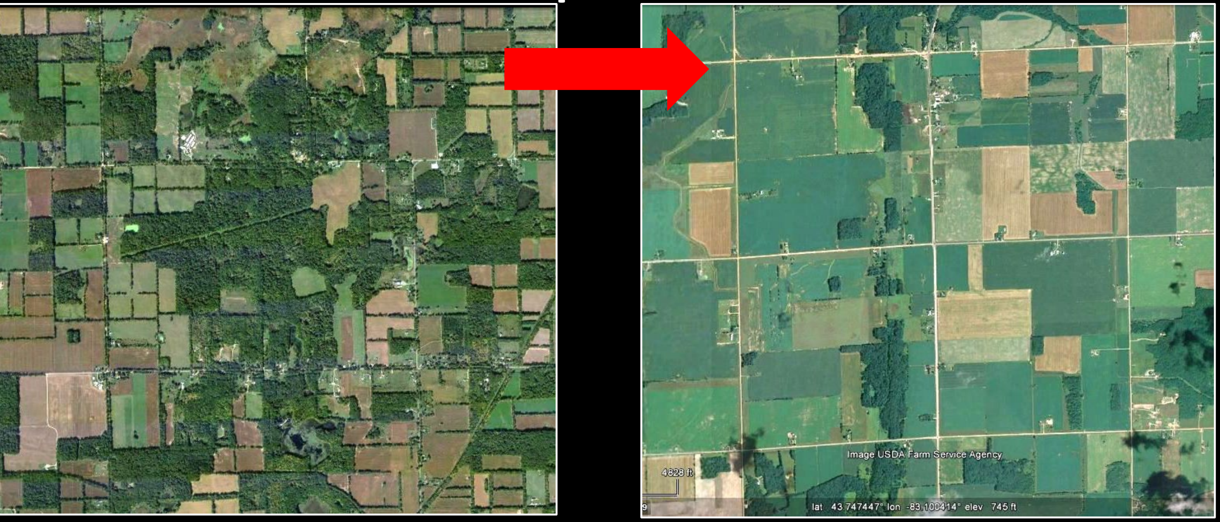
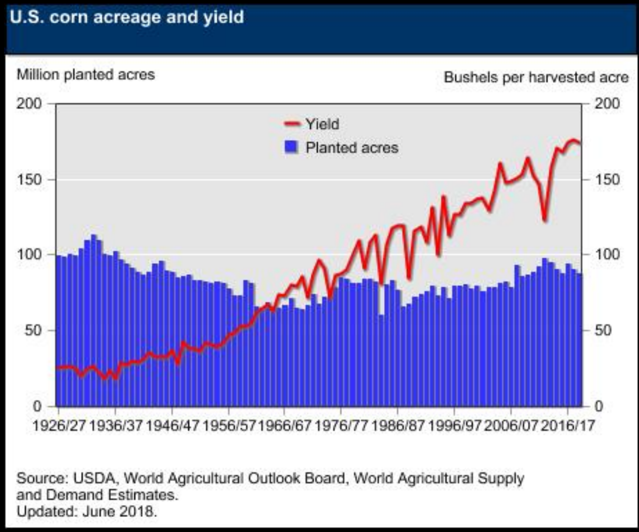
Consolidated agricultural landscapes

- Policies support yield but neglect other goals
- Inputs of agricultural chemicals have replaced species functions, and allowed for simplified rotations…

…with many unintended consequences

Simplification

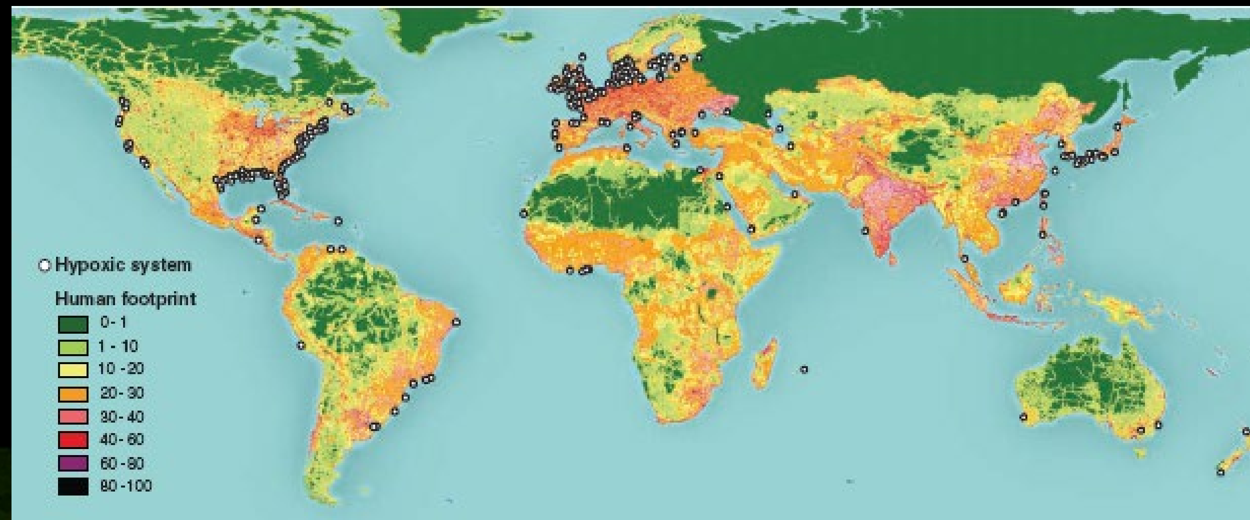


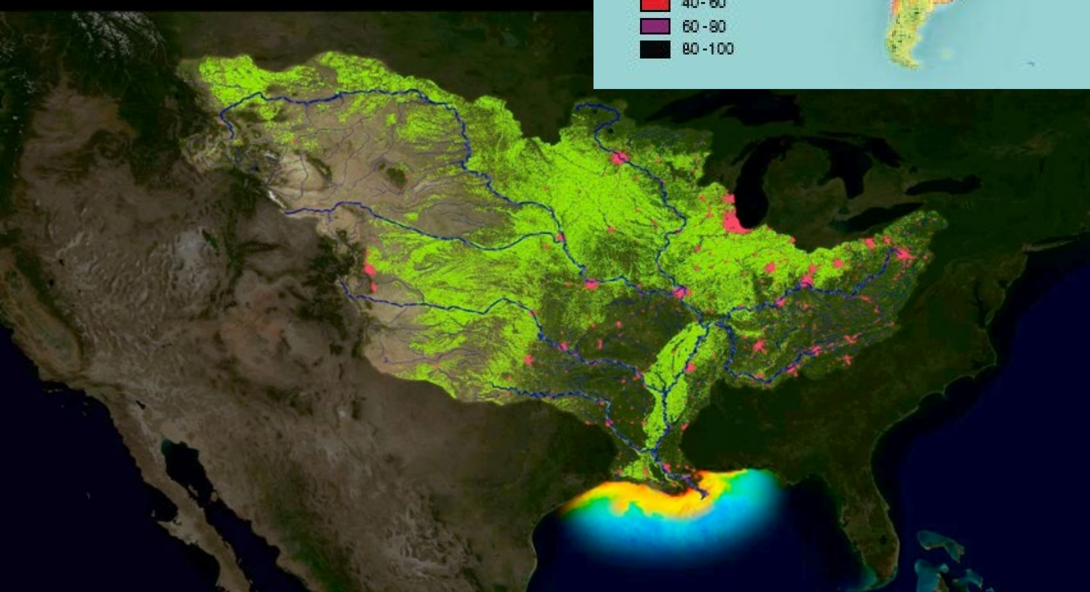


Images courtesy of Doug Landis, MSU

Consequences: dead zones and harmful algal blooms

> 400 “Dead zones”

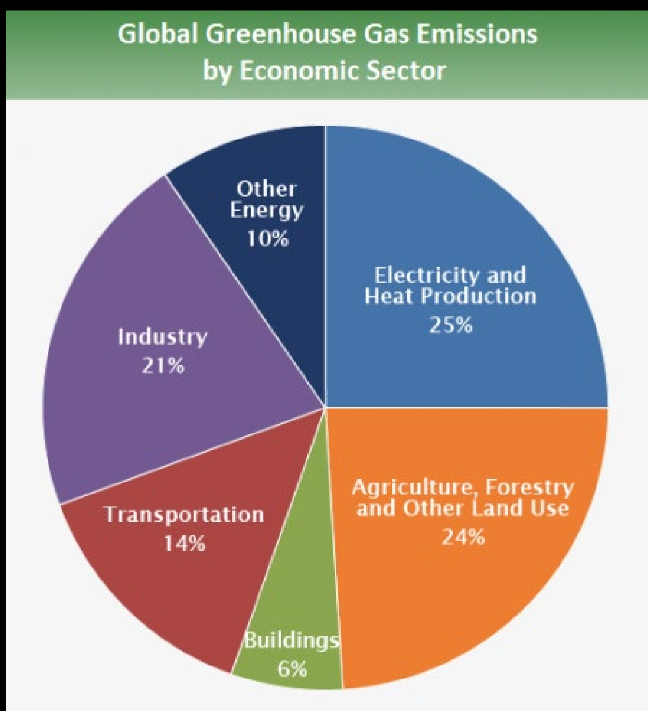




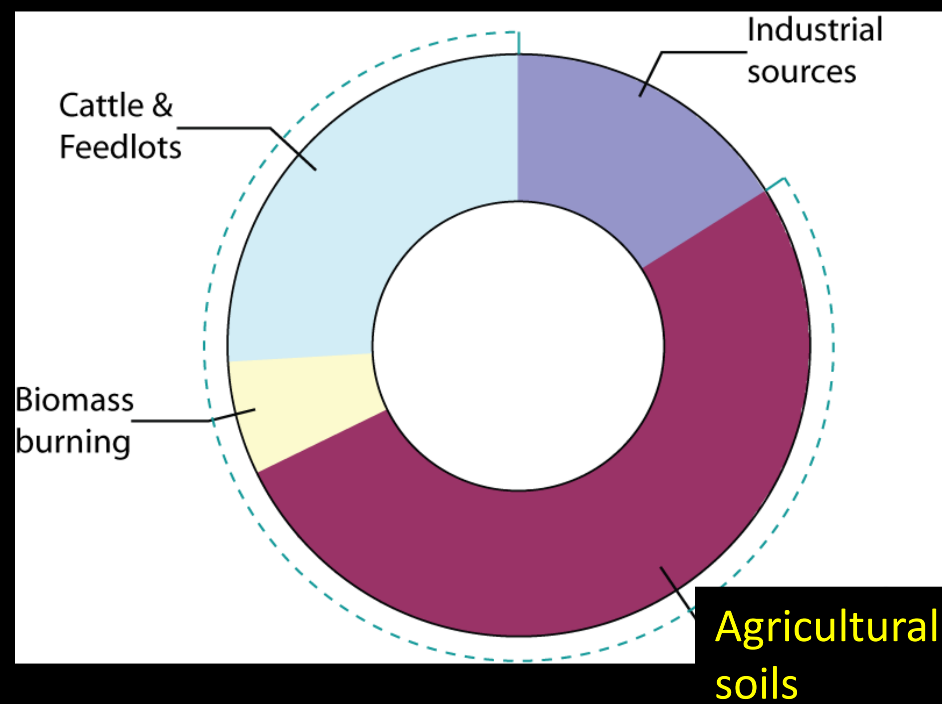
http://oceantoday.noaa.gov/happnowdeadzone/
http://oceanservice.noaa.gov/news/weeklynews/june11/deadzone.html
Diaz and Rosenberg 2008, *Science*;

Consequences: greenhouse gas emissions

Agriculture is responsible for 10-14% of global GHG emissions



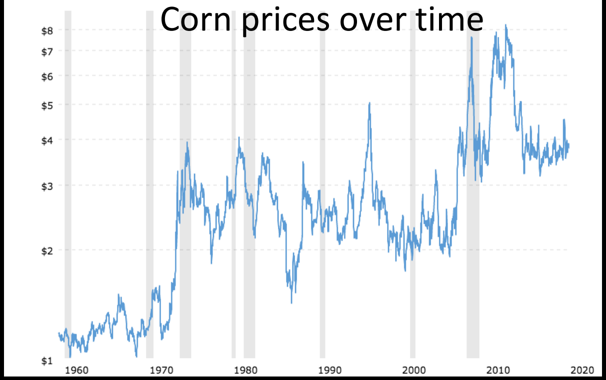
Nitrous Oxide (N_2O)

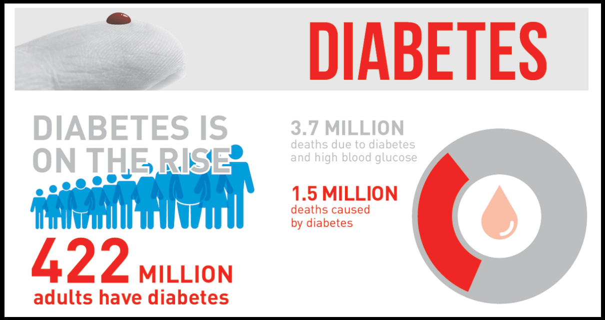


IPCC 2007; US EPA adapted from IPCC 2014

Other consequences

- Soil degradation and erosion
- Pesticide and fertilizer “treadmills”
- Increased vulnerability to market and weather variability
- Antibiotic resistance
- Human health problems from diet-related chronic diseases
- Decline of rural communities



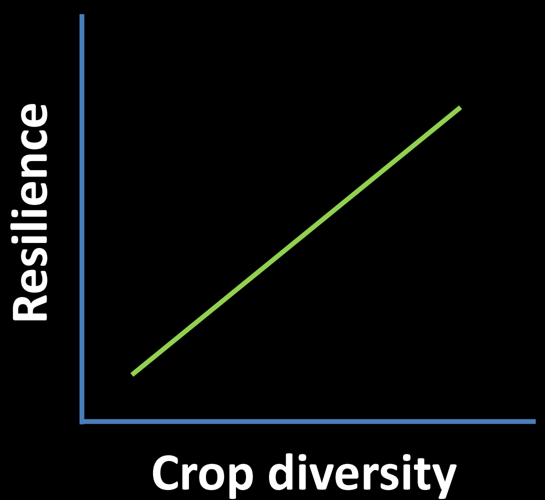


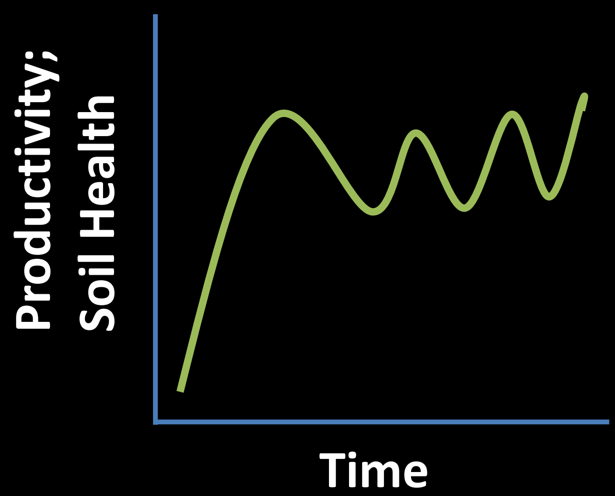
https://www.macrotrends.net/2532/corn-prices-historical-chart-data

Resilience

- Ecology: ability of an ecosystem to experience disturbance and maintain its basic structure and functions

Cropping system resilience





Holling, 1973; Gunderson and Holling, 2002; Schipanski et al. 2016

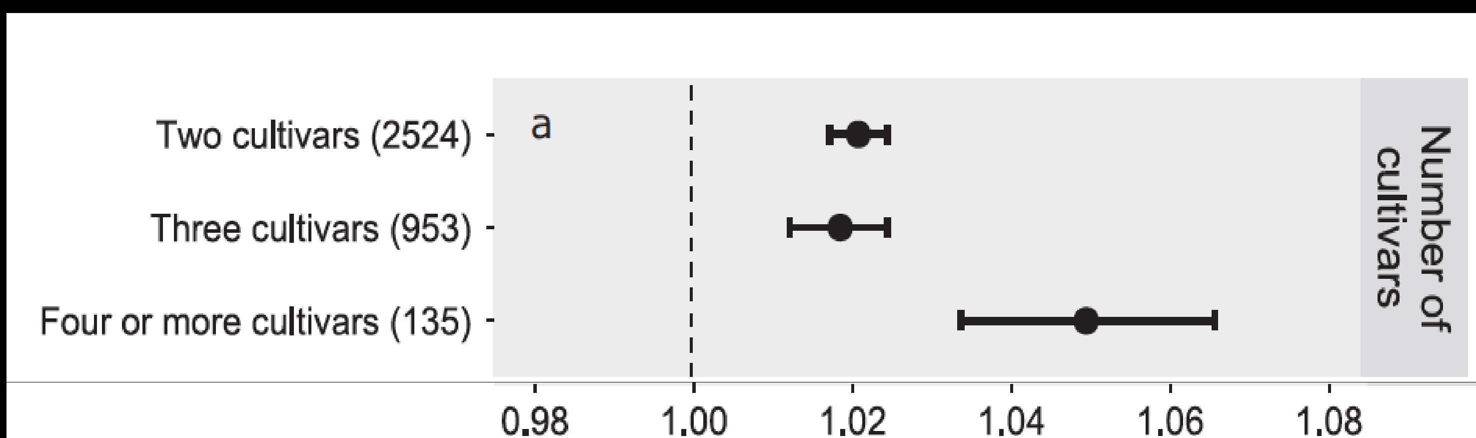
Food System Resilience

- Food systems: capacity to produce and access nutritious food in the face of uncertainty, without diminishing other vital ecosystem services
- Ecological science can inform more resilient farming systems, by *determining how to increase the diversity of farms and watersheds* to reduce both non-renewable inputs and environmental impacts

(Holling, 1973; Gunderson and Holling, 2002; Schipanski et al. 2016)

Diversified crop rotations

- In agriculture, small increases in biodiversity can have large benefits
- Example: varietal diversity and resilience



Relative Crop Yield

Reiss and Drinkwater, 2018, *Ecological Applications*

Diversified crop rotations

- Crop "functional diversity" is the key
  - Rotate or mix crops with traits that complement each other
    - Legumes and grasses; annuals and perennials
    - Harvested and non-harvested crops
  - Promotes species interactions that can increase overall resource use, crop productivity, and soil health

Hay and Pasture

Winter Pea

Red Clover

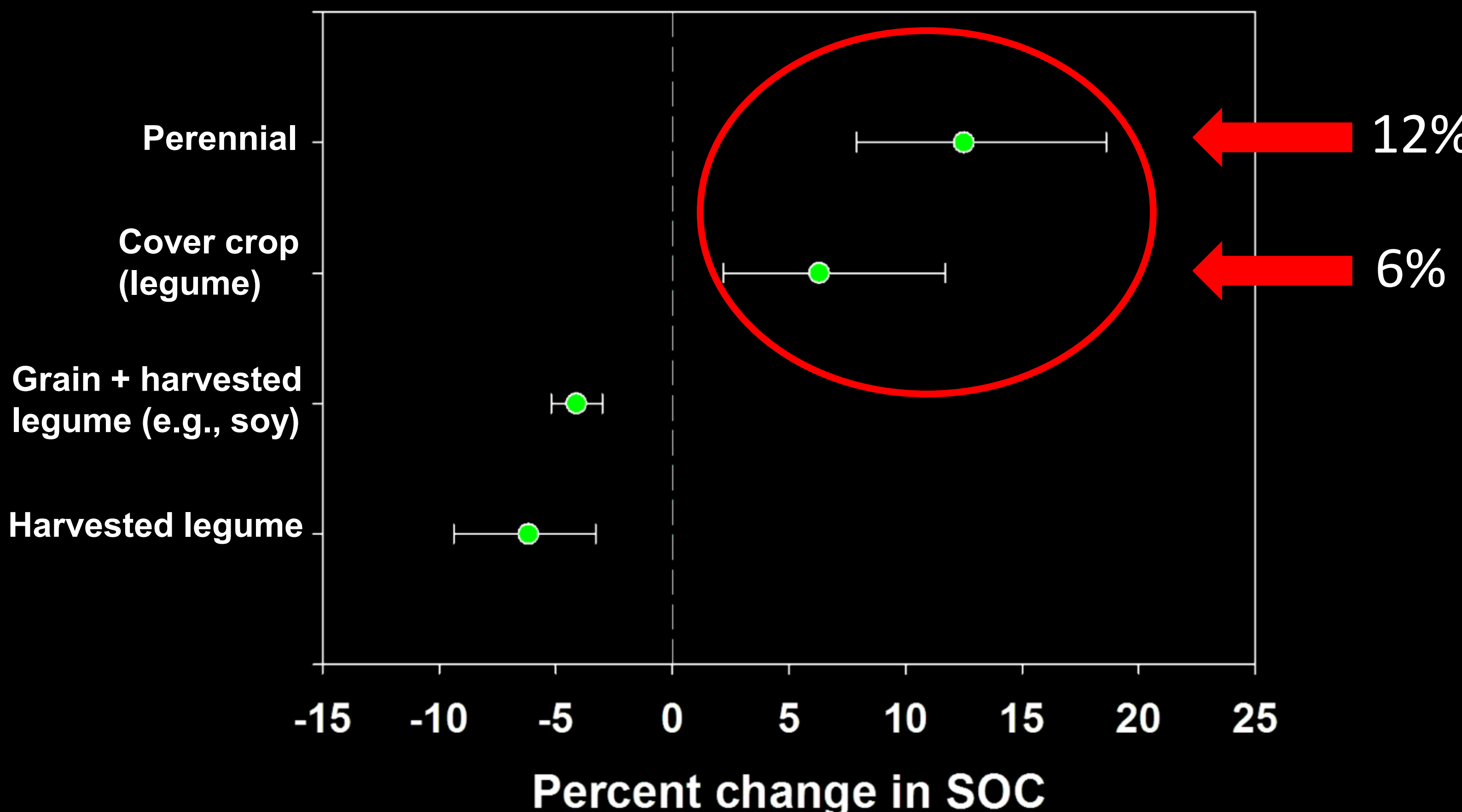
Cereal Rye

Alfalfa

Oats

Forage Radish

Functional diversity and soil carbon



Cover crops and perennials build soil organic C

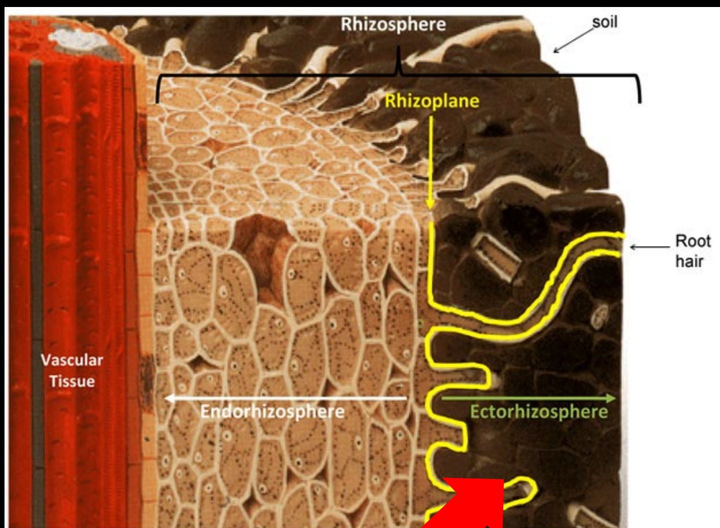
King and Blesh, 2018, *Ecological Applications*

Importance of vegetation: roots

Other ways to "perennialize" your rotation?

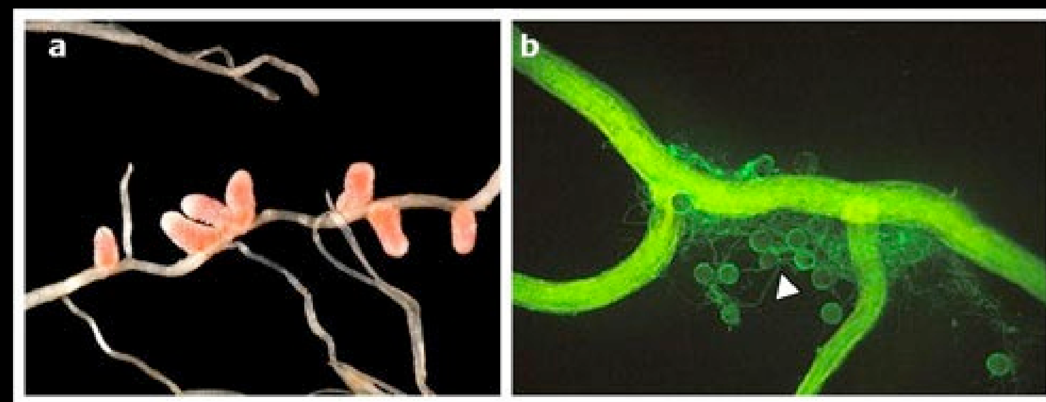
Image courtesy of the Land Institute: http://www.landinstitute.org/vnews/display

Knowledge frontiers: plant-microbe-soil interactions



"Rhizosphere": the gradient along plant roots where roots and soil organisms interact

Legume root with rhizobia Corn root with mycorrhizal fungi



http://www.nature.com/scitable/knowledge/library/the-rhizosphere-roots-soil-and-67500617

Blending farmer knowledge with ecological science

- How generalizable are these ecological principles?
- Do the results apply to my farm?

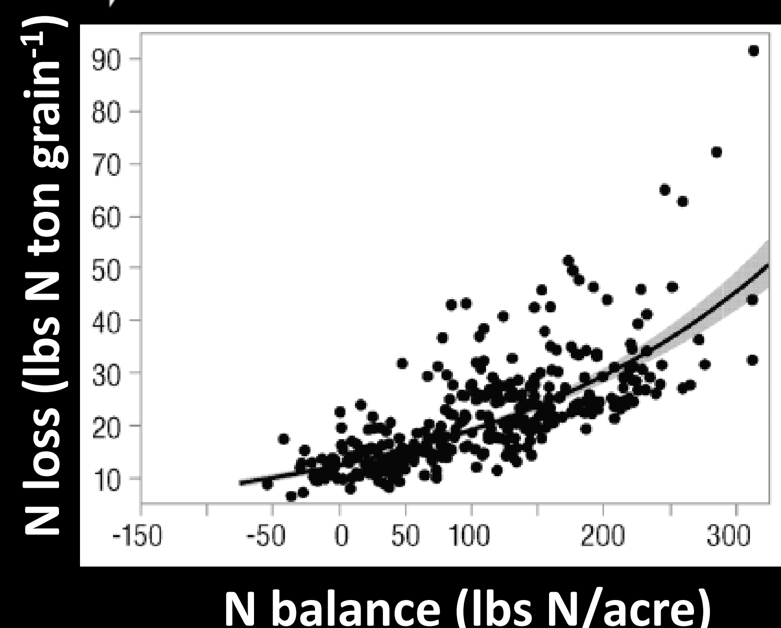
We can begin to answer both of these questions with on-farm research

Nitrogen balance: An indicator of field performance

N Inputs – Harvested N = N balance

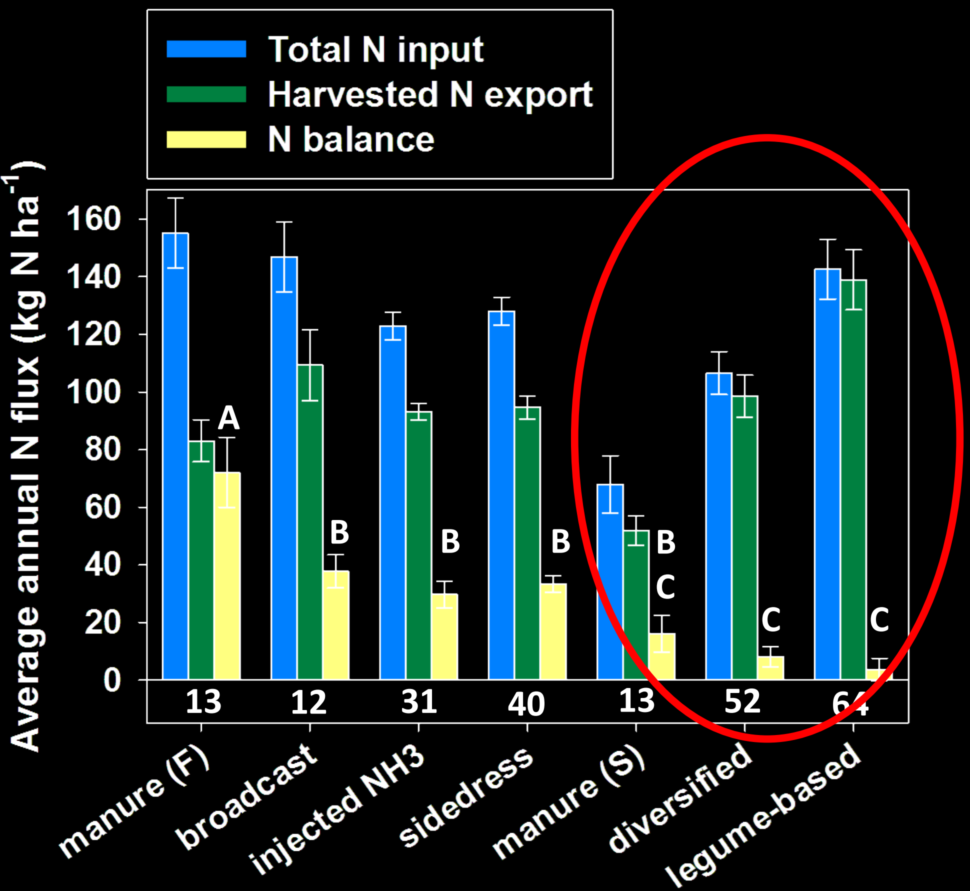
N “surplus” = potential for N loss

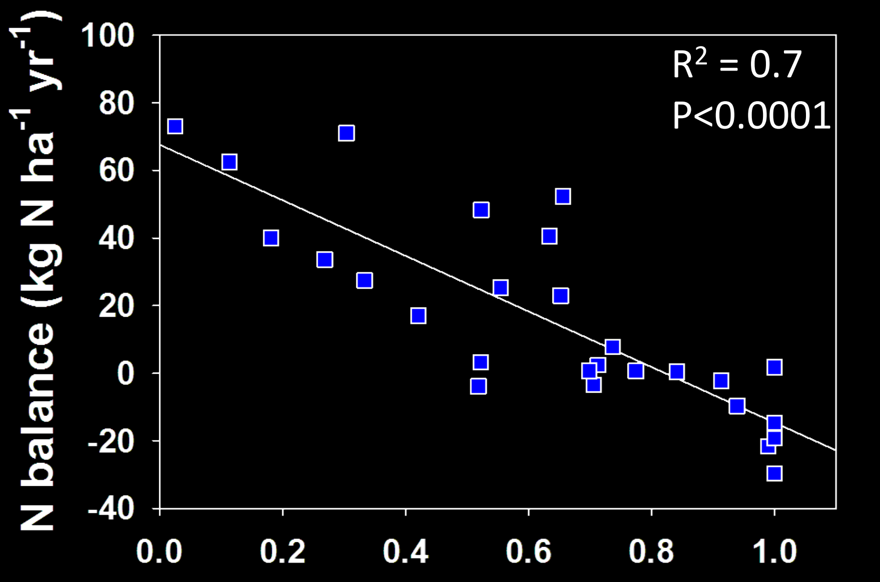
N “deficit” = potential depletion of soil N stocks



Blesh and Drinkwater, 2013; McLellan et al. 2018; Zimnicki et al. 2020

Legume cover crops and perennials reduce N losses





Resilience: Reduced need to purchase N fertilizer inputs

Blesh and Drinkwater, 2013, *Ecological Applications*

Research on 10 Michigan farms

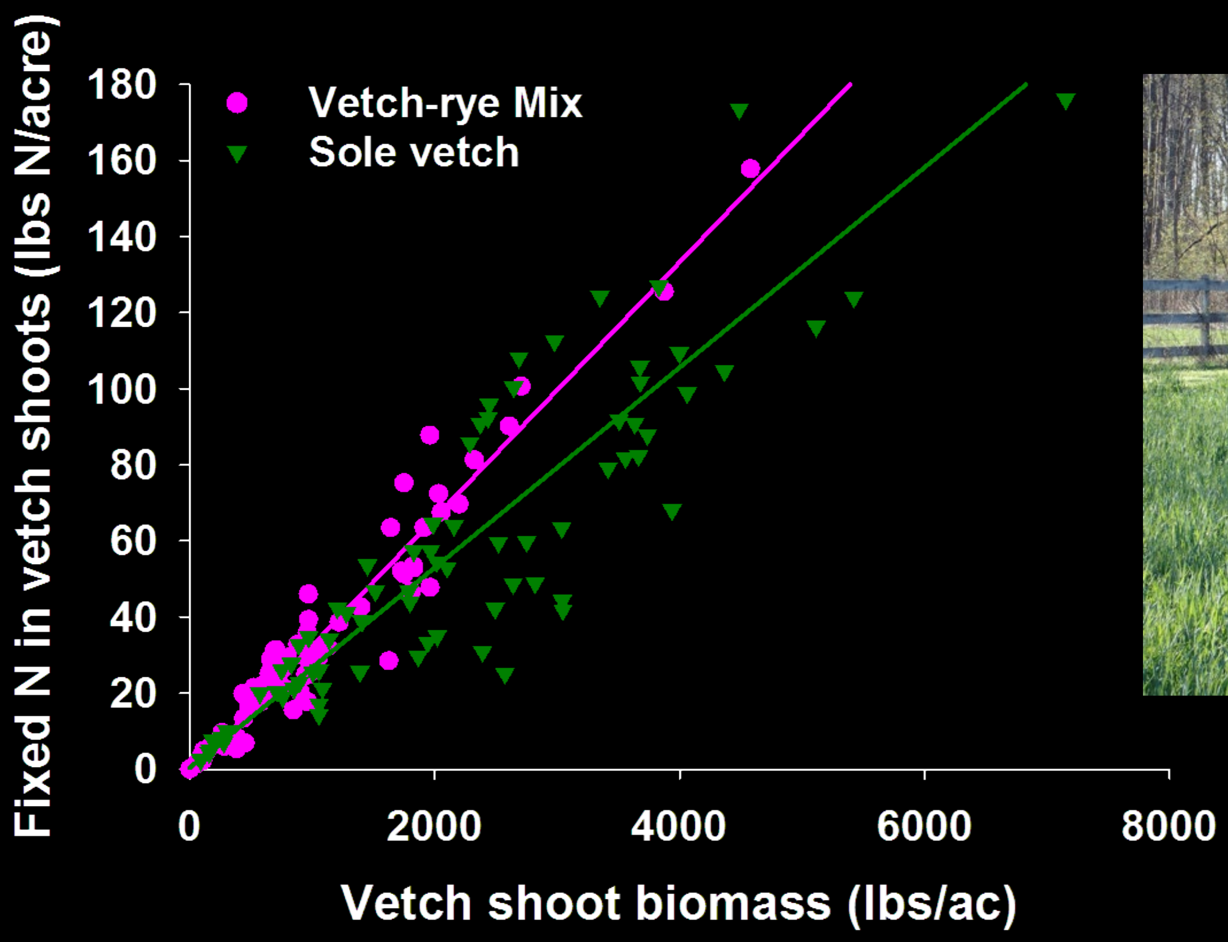
- How do legume cover crops affect soil health?
- How does soil fertility across farms affect legume nitrogen supply?
- 3 year, on-farm experiment with 2 seasons of an overwintering cover crop
- 3 treatments replicated 4 times:

Vetch

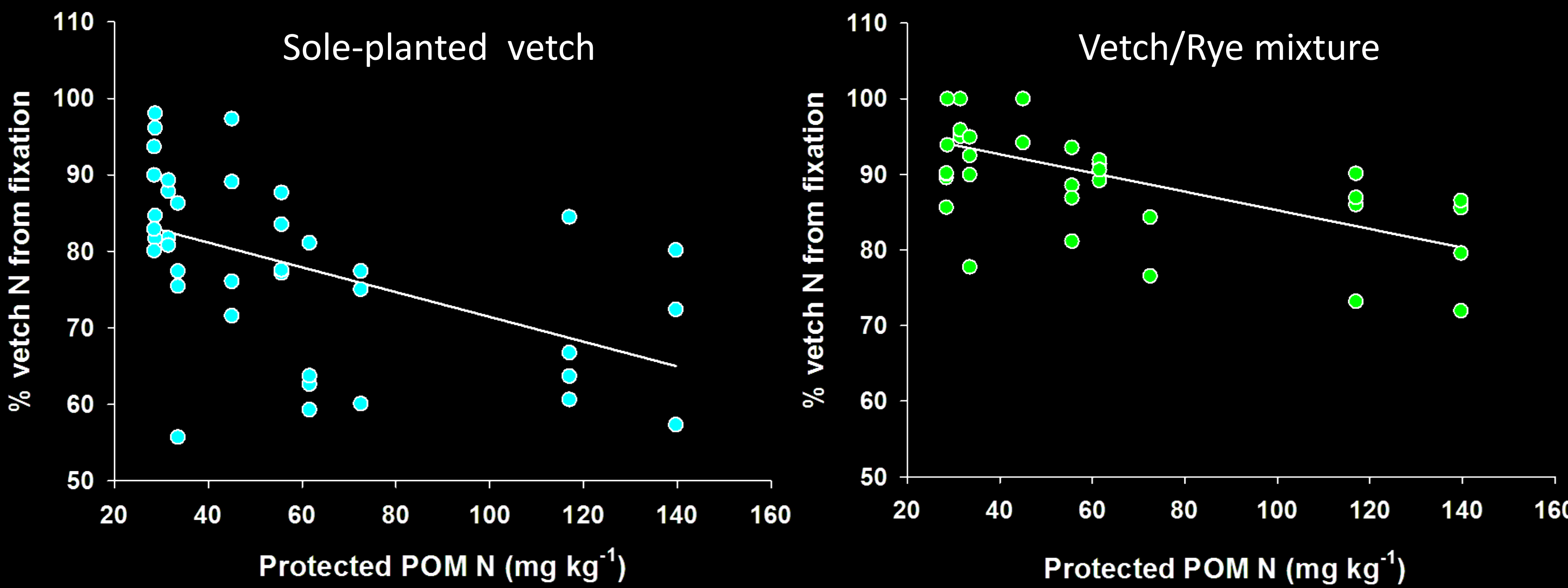
Vetch/Rye

Rye

Variation in vetch biomass and N fixation across farms



Vetch N fixation across the farm soil fertility gradient



As farmers build soil fertility (e.g., gains in particulate organic matter over 5 or more years), they can likely invest less in legume cover crop seed, and focus more on covers like grasses

Stabilizing feedbacks between soil fertility and legume N fixation

- Legumes self-regulate
- They invest less in the N fixation when soil N levels are high
- How can we take advantage of these remarkable traits of organisms?

photo by Meagan Schipanski

Pea root with fully developed, active nodules. The presence of leghemoglobin and thus nitrogen fixation is indicated by the pink coloration.

Significant increase in soil health after two years of rye/vetch

Biological Indicators	Unit	Mean change	Significant change?
Total SOM	%	0.04	N
Free POM	Mg ha^{-1}	3.71	✓
Protected POM	g kg^{-1}	3.28	✓
N in Protected POM	kg ha^{-1}	90.03	✓
Mineralizable C	µg CO_2 g^{-1} d^{-1}	9.53	✓
Mineralizable N	mg kg^{-1} wk^{-1}	1.91	✓
Chemical Indicators			
Bray-1 P	ppm	1.25	N
Nitrate + Ammonium	mg kg^{-1}	0.10	N

Cover crop mixtures

- Opportunity for planting species mixtures in grain fields
  - Especially after small grains
- Increase functional diversity in crop rotations
  - E.g., legume cover crops often grown in mixtures with grasses for both N supply and N retention (and other functions)


Winter Pea

Red Clover



Cereal Rye

Spring Wheat



Oats

Forage Radish


Martin and Isaac, 2015; Wood et al. 2015; Schipanski and Drinkwater, 2011; Blesh, 2017

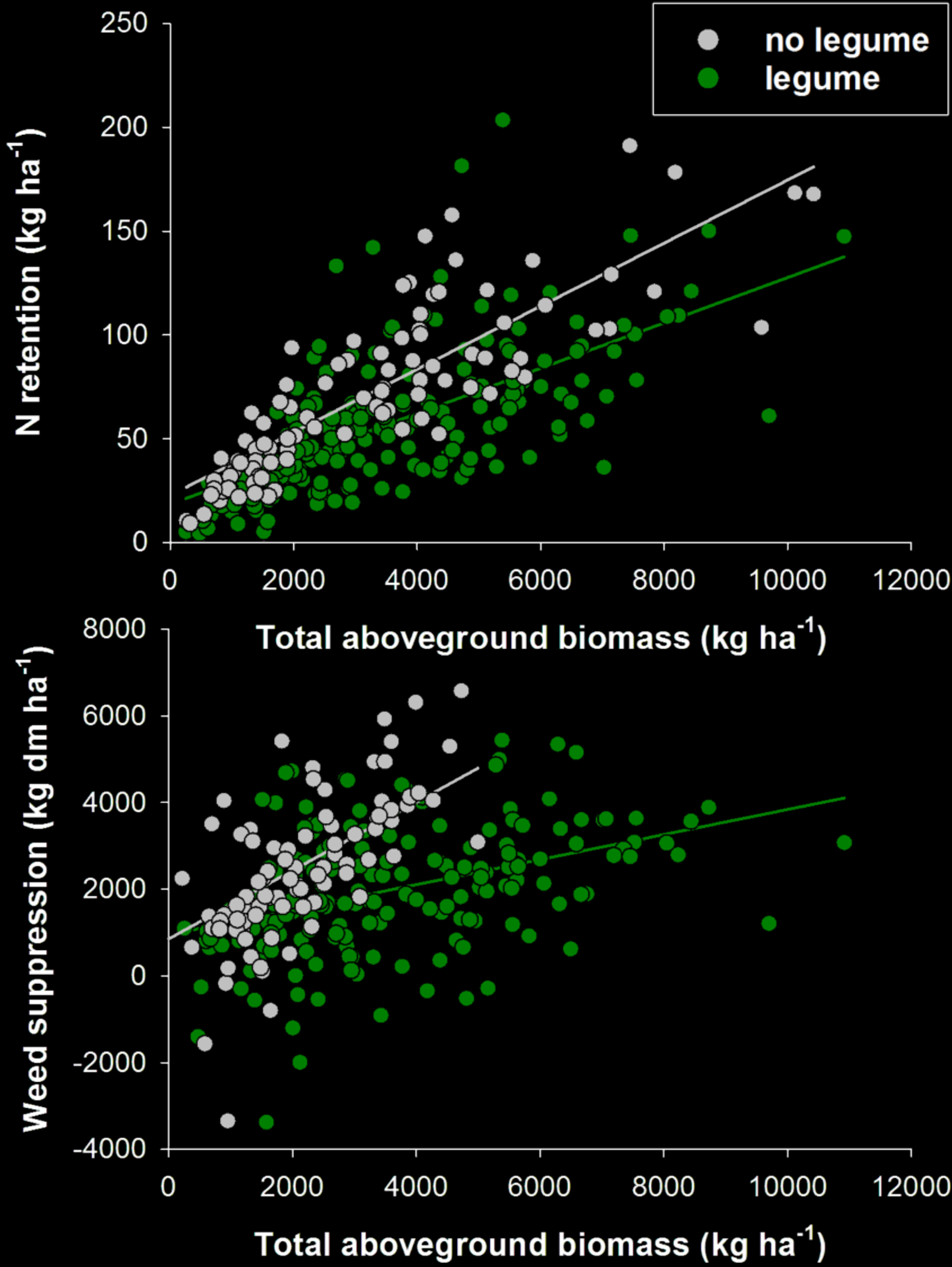
Cover crop mixtures

- Do they provide multiple benefits at once on working farms?
  - Treatments:
    - **Crimson clover/red clover/spring wheat**
    - **Winter pea/oat/daikon radish**
    - **Lentil/yellow mustard/oat**
    - **Red clover/spring wheat**
    - **Crimson clover/spring wheat**
    - **Cereal rye/chickling vetch**




Biomass drives outcomes of cover crops

- Grass covers are more reliable than legumes for N retention and weed suppression
- Legumes supply N
- Can mixtures of legumes and non-legumes increase multiple functions at once?

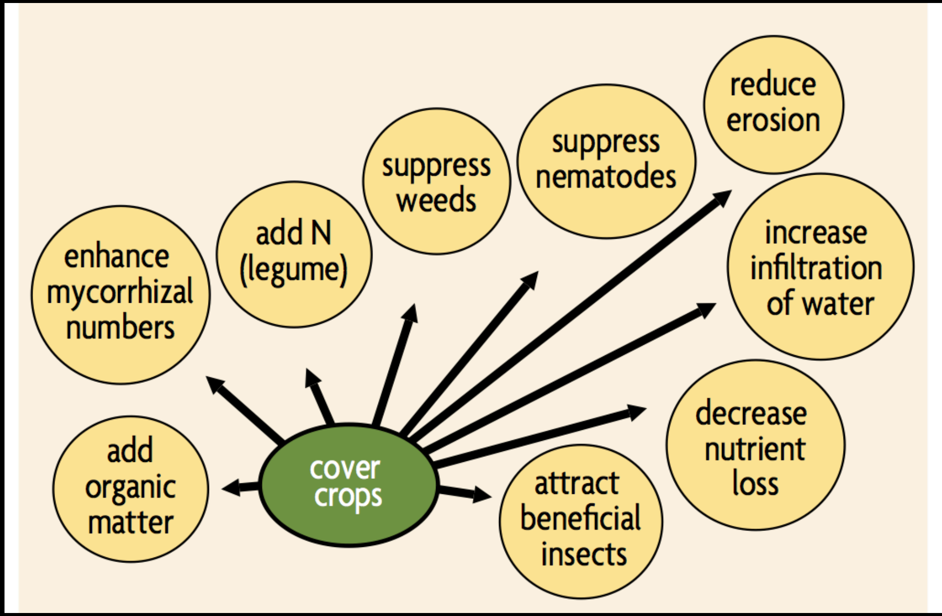


Blesh, 2017, *Journal of Applied Ecology*

Mixes were "multifunctional"

- Several cover crop mixtures increased multiple benefits at once across the farms:
  - Adding N, retaining nutrients (i.e., decreasing loss), and suppressing weeds

- Crimson clover/red clover/spring wheat
- Crimson clover/spring wheat
- Winter pea/oat/daikon radish



Blesh, 2017; Magdoff, F.R., and H.M. van Es. 2009. Building Soils for Better Crops: Sustainable Soil Management.

Crop diversity benefits the environment and communities

- Small-scale experiments
- Long-term cropping systems research
- Studies on real farms

- Meta-analyses

Ecological Applications, 19(8), 2009, pp. 2167–2184
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The fate of nitrogen in grain cropping systems: a meta-analysis of ^{15}N field experiments

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Abstract. Intensively managed grain farms are saturated with large inputs of nitrogen (N) fertilizer, leading to N losses and environmental degradation. Despite decades of research directed toward reducing N losses from agroecosystems, progress has been minimal, and the currently promoted best management practices are not necessarily the most effective. We investigated the fate of N additions to temperate grain agroecosystems using a meta-analysis of 217 field-scale studies that followed the stable isotope ^{15}N in crops and soil. We compared management practices that alter inorganic fertilizer additions, such as application timing or reduced N fertilizer rates, to practices that re-couple the biogeochemical cycles of carbon (C) and N, such as organic N sources and diversified crop rotations, and analyzed the following response variables: ^{15}N recovery in crops, total recovery of ^{15}N in crops and soil, and crop yield. More of the literature (94%) emphasized crop recovery of ^{15}N than total ^{15}N recovery in crops and soil (58%), though total recovery is a more ecologically appropriate indicator for assessing N losses. Findings show wide differences in the ability of management practices to improve N use efficiency. Practices that aimed to increase crop uptake of commercial fertilizer had a lower impact on total ^{15}N recovery (3–21% increase) than practices that re-coupled C and N cycling (30–42% increase). A majority of studies (66%) were only one growing season long, which poses a particular problem when organic N sources are used because crops recover N from these sources over several years. These short-term studies neglect significant ecological processes that occur over longer time scales. Field-scale mass balance calculations using the ^{15}N data set show that, on average, 43 kg $N \cdot ha^{-1} \cdot yr^{-1}$ was unaccounted for at the end of one growing season out of 114 kg $N \cdot ha^{-1} \cdot yr^{-1}$, representing ~38% of the total ^{15}N applied. This comprehensive assessment of stable-isotope research on agroecosystem N management can inform the development of policies to mitigate nonpoint source pollution. Nitrogen management practices that most effectively increase N retention are not currently being

How do farmers transition to diverse crop rotations in the U.S. Corn Belt?


Resources

__On the farm__

- Crop and livestock diversity
- Enterprise diversity
- Preventative thinking
- New skills, experience

Blesh and Wolf, 2014, *Agriculture and Human Values*;
Blesh and Galt, 2017, *Agroecological Practices for Sustainable Agriculture*

How do farmers transition to diverse crop rotations in the U.S. Corn Belt?


Resources

<u>On the farm</u>
- Enterprise diversity
- Preventative thinking
- New skills, experience

<u>Off the farm</u>
- Farmer networks (e.g., PFI)
- Professional organizations
- Technical assistance
- New market opportunities
- Farm Bill programs
  - EQIP
  - CSP

Blesh and Wolf, 2014, *Agriculture and Human Values*;
Blesh and Galt, 2017, *Agroecological Practices for Sustainable Agriculture*

Learning from farmers to guide policy change

- Michigan and Ohio cover croppers' policy recommendations:
  - Develop more programs at the local level (e.g., run by SWCD)
  - Longer contracts for practices like cover cropping

Blair and Blesh, In prep.

Learning from farmers to guide policy change

- Michigan and Ohio cover croppers' policy recommendations:
  - Develop more programs at the local level (e.g., run by SWCD)
  - Longer contracts for practices like cover cropping
  - Lower cost-share payments
  - Include soil testing or other monitoring as part of the programs

Blair and Blesh, In prep.

Farmer networks: Cover Crop Champions program

"…avoid language that would further the perception that cover crops and no-till are really risky because they're new. [We are] trying to change that norm to say: 'it's actually riskier to not do these practices, because we are going to continue to have extreme weather events in the future."

- Program Participant

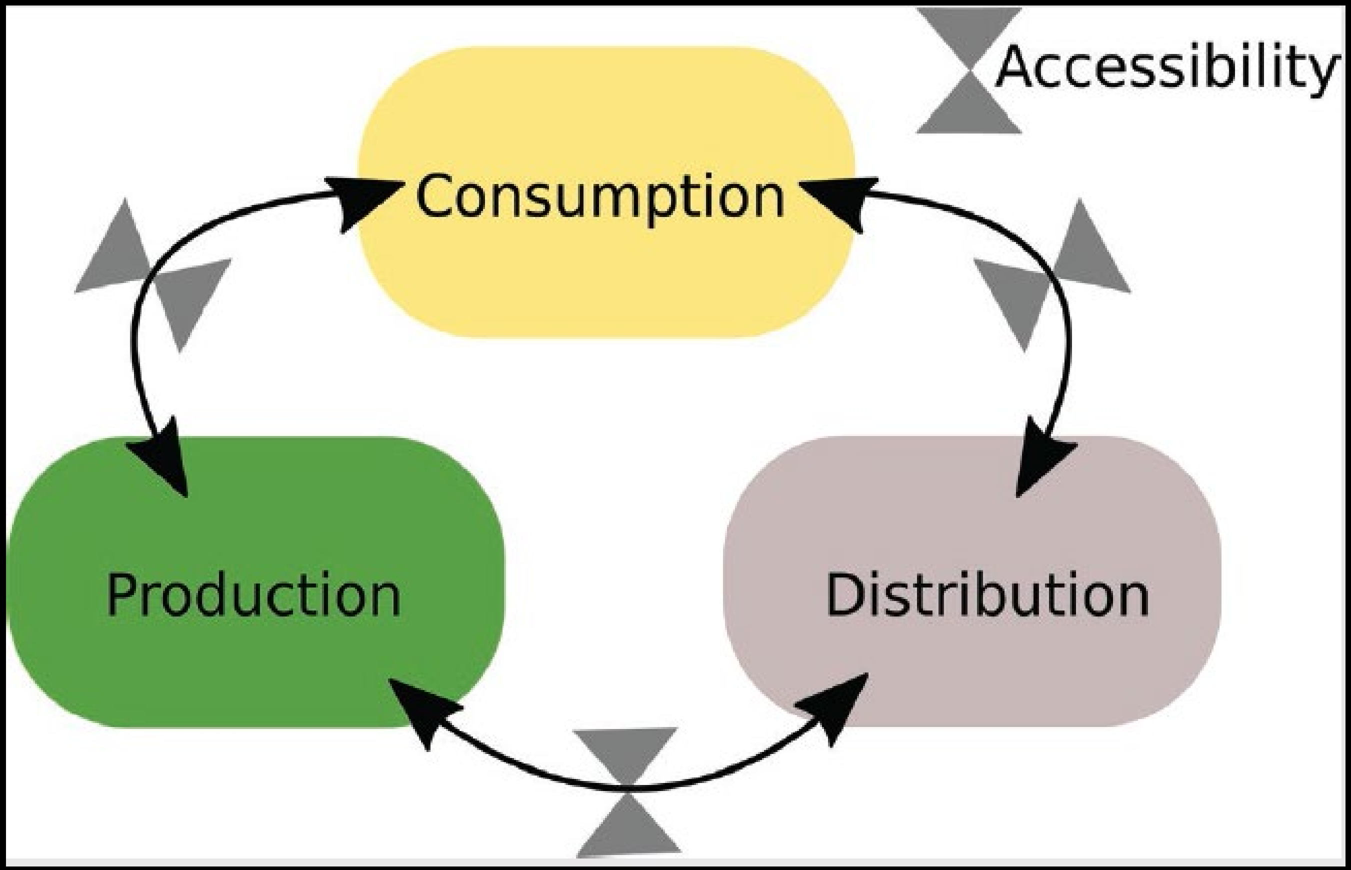
Bressler, Hoey, and Blesh, In prep.

Farmer networks: Cover Crop Champions program

"…[it's important to have] a resource person that someone new can call to say 'I have rye that's two feet tall and need to plant corn in two weeks. What do I do? Do I till it? Do I spray it? Do I plant in it?' Those questions that only a person that's had the experience can [answer]." - Farmer Champion

Bressler, Hoey, and Blesh, In prep.

Diversifying food systems



Schipanski et al. 2016, *BioScience*

Summary

- Crop diversity increases farm resilience
    - Especially functional diversity-- species with complementary traits, like legumes and grasses
- Cover crop mixtures are an opportunity to increase functional diversity in rotations with small grains
- Collaborations between researchers and farmers help to explain variability in results, and adapt practices for different locations and conditions
- Scaling diversity will require change at all levels-- from individual farms to major farm policies
    - Farmer networks are critical to success




Acknowledgements and team


Farmer partners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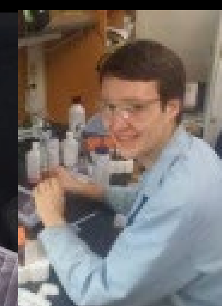
Tianyu Ying


Yili Luo


Santiago Bukovsky-Reyes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Ryan Nelson

University of Michigan Campus Farm

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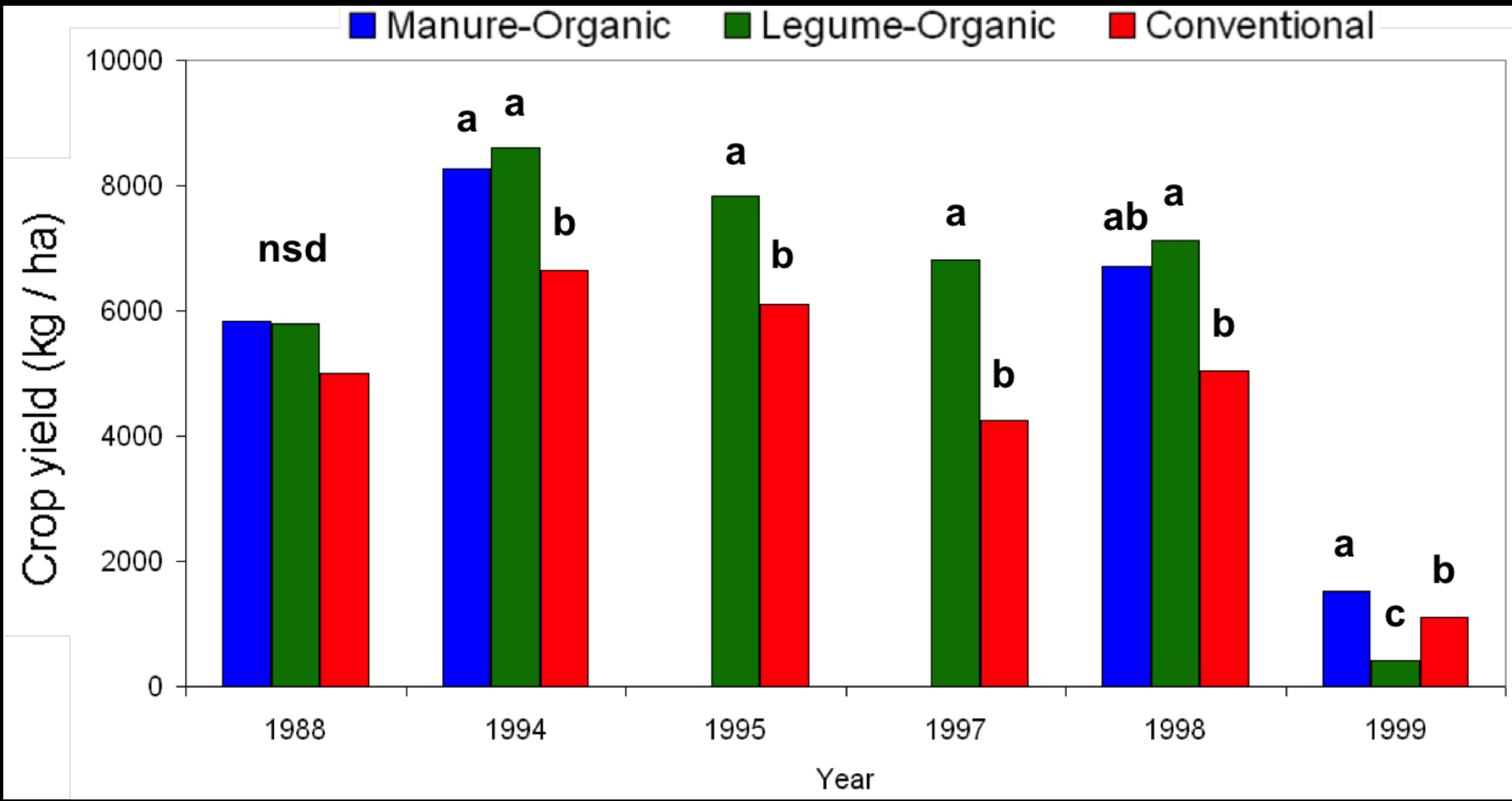
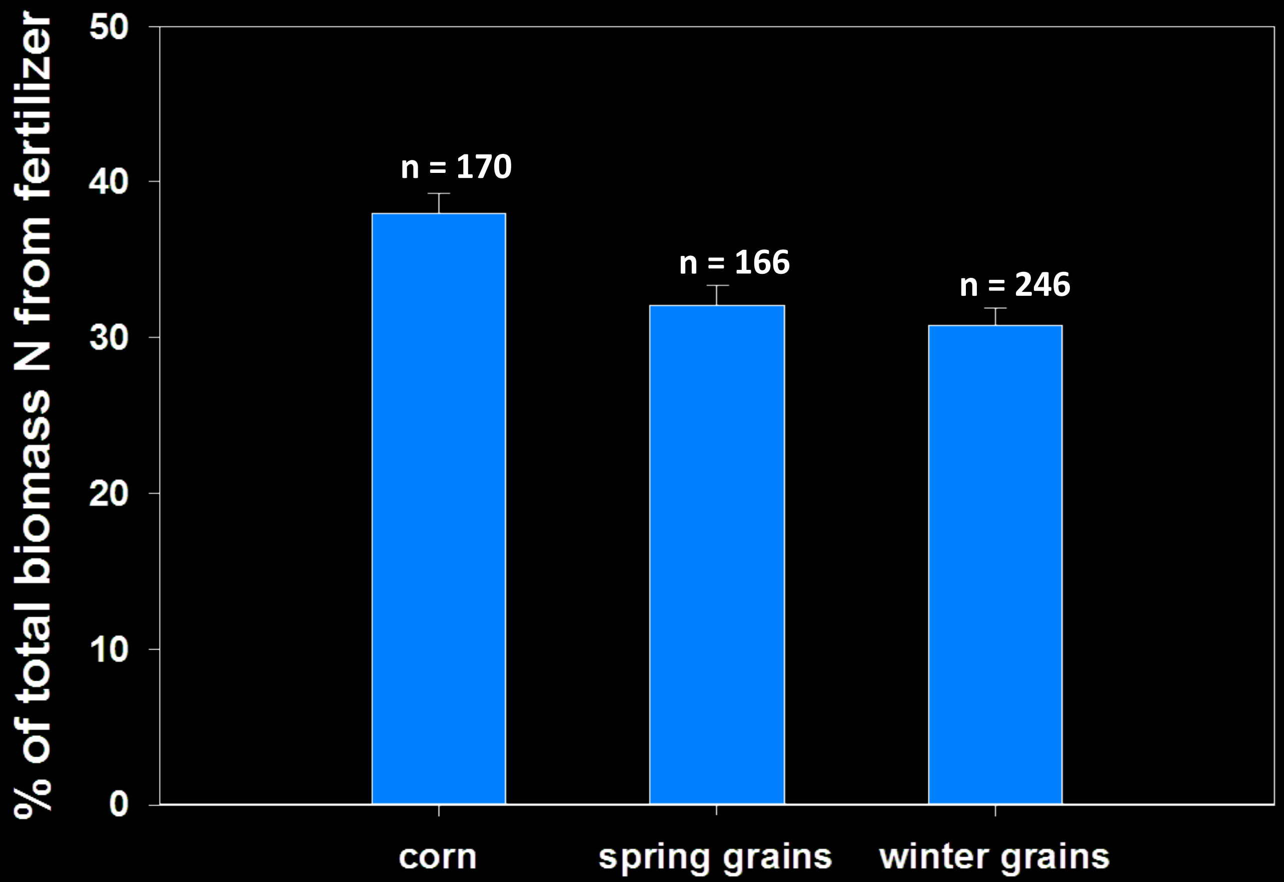


Manure-Organic
Legume-Organic
Conventional
Crop yield (kg / ha)
10000
8000
6000
4000
2000
0
nsd
a
a
b
a
b
a
b
ab
a
b
a
c
b
1988
1994
1995
1997
1998
1999
Year

What is agroecosystem multifunctionality?

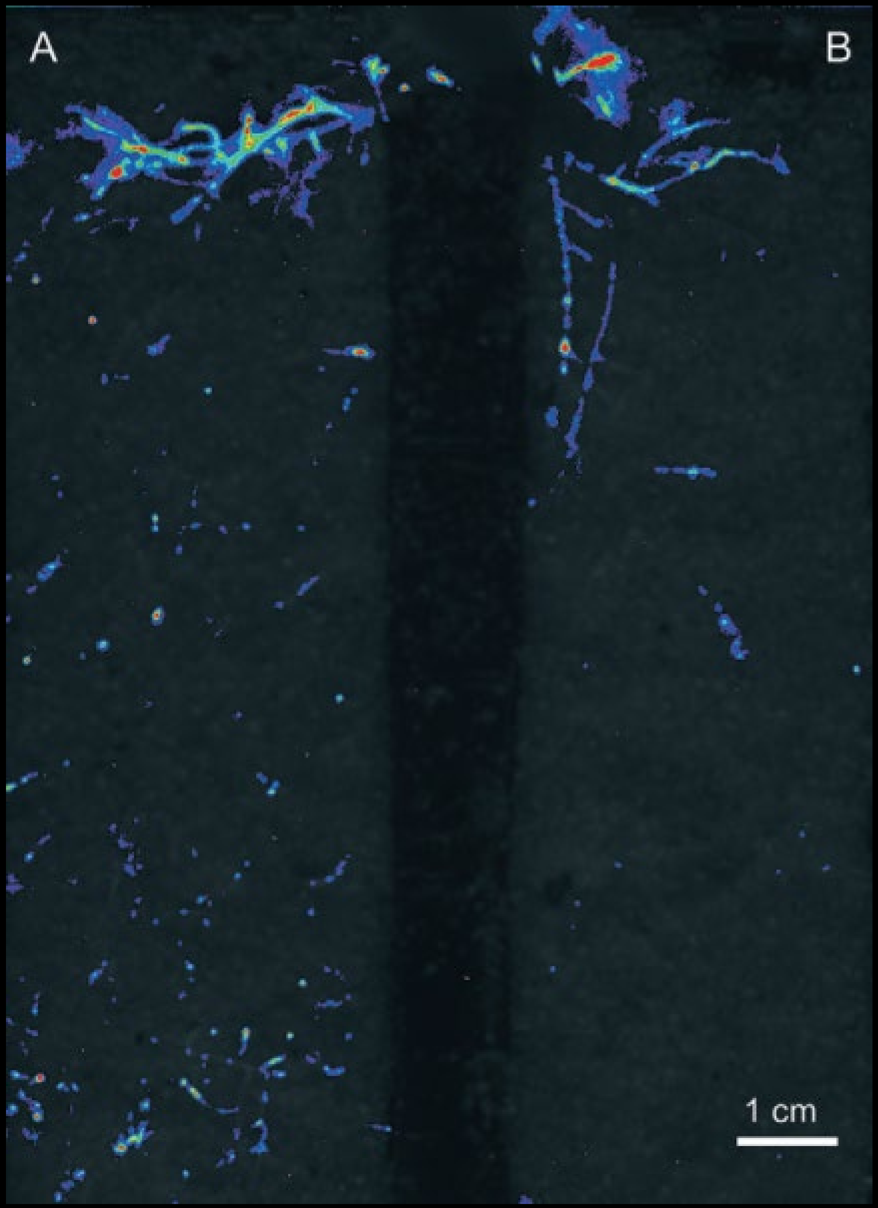
Jones, Hoey, Blesh et al. 2015, *Advances in Nutrition*

Crop N from fertilizer < 40%



Gardner (Blesh) and Drinkwater, 2009, *Ecological Applications*

Greenhouse experiments:
Plant root exudation increased in response to resource patches

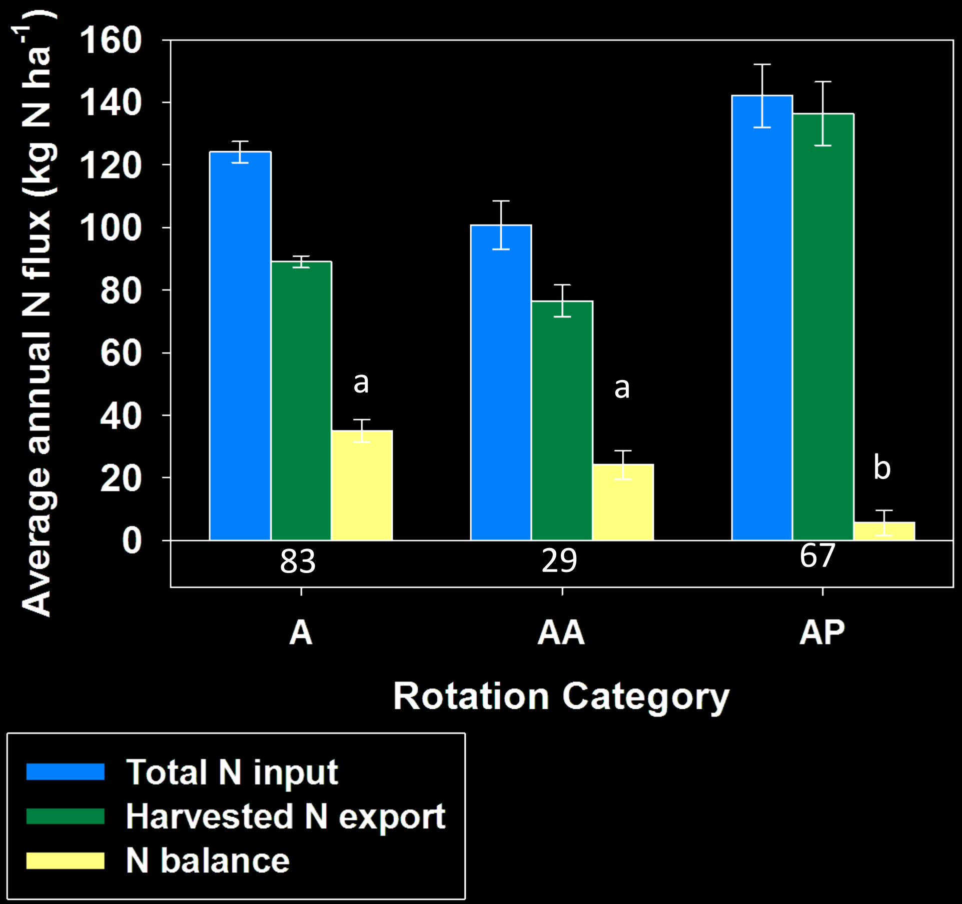


+N -N

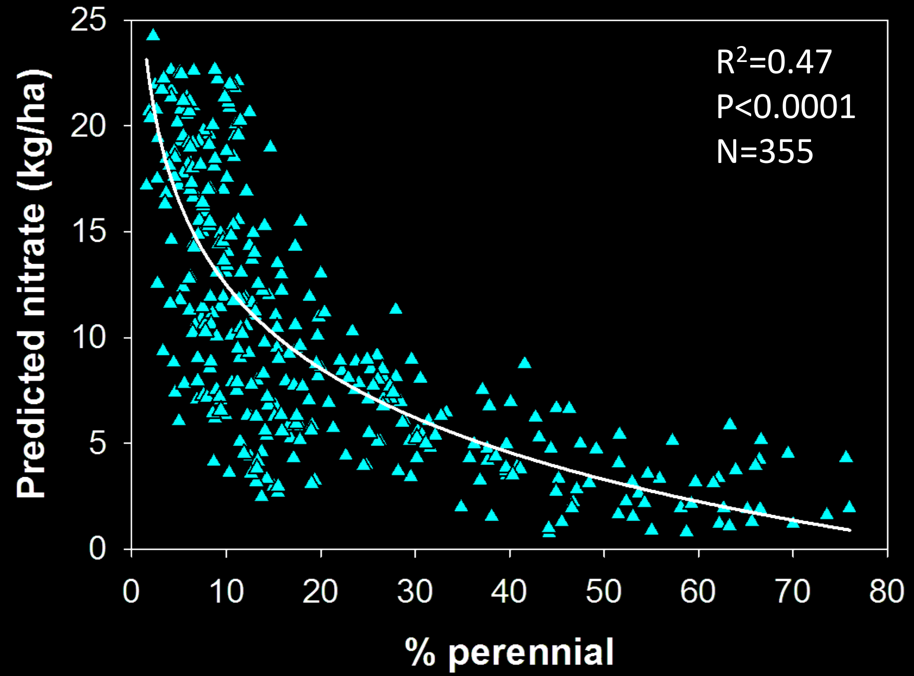
Paterson et al. 2006

Perennials reduce N losses

Field-scale



County-scale



Blesh and Drinkwater, 2013, *Ecological Applications*

Both environment and management determine SOM levels in a field

Environment

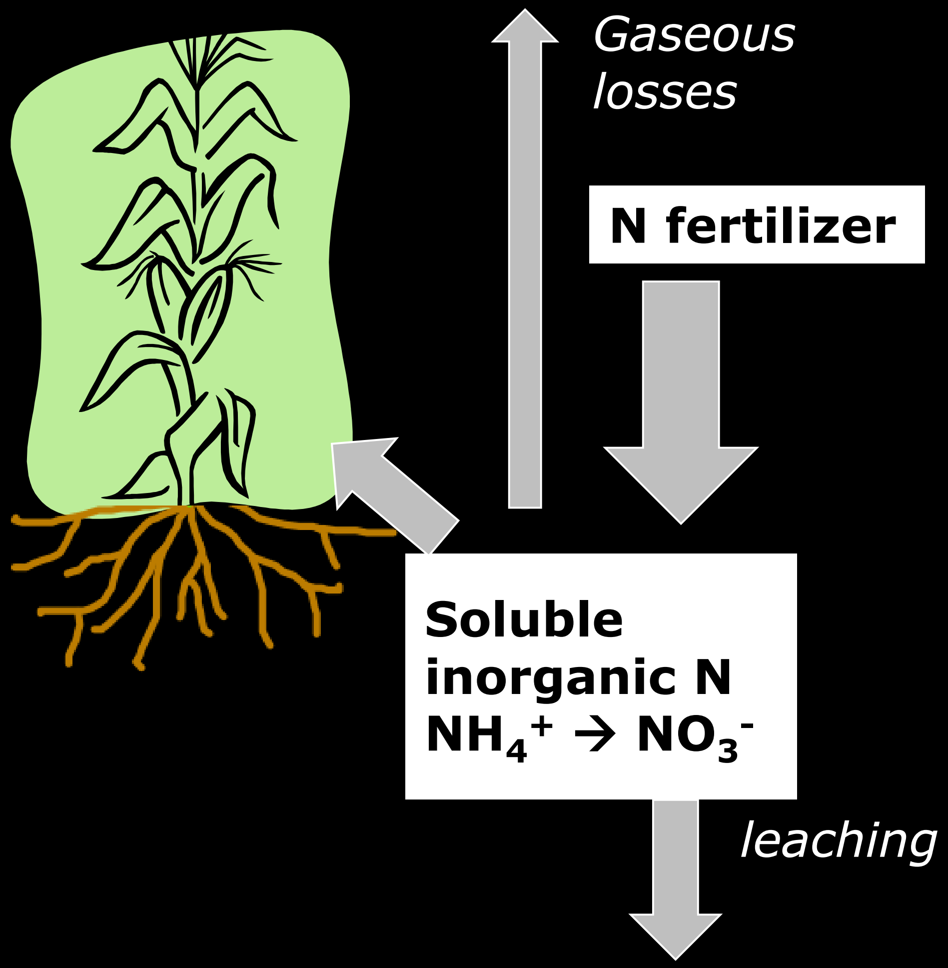
- Climate
  - temperature
  - rainfall
- Soil Texture
- Soil Drainage
- Vegetation Type

Soil and Crop Management Practices

- Crop rotation
- Residue inputs
- Tillage
- Organic amendments (e.g., manure, compost)
- Nutrient sources

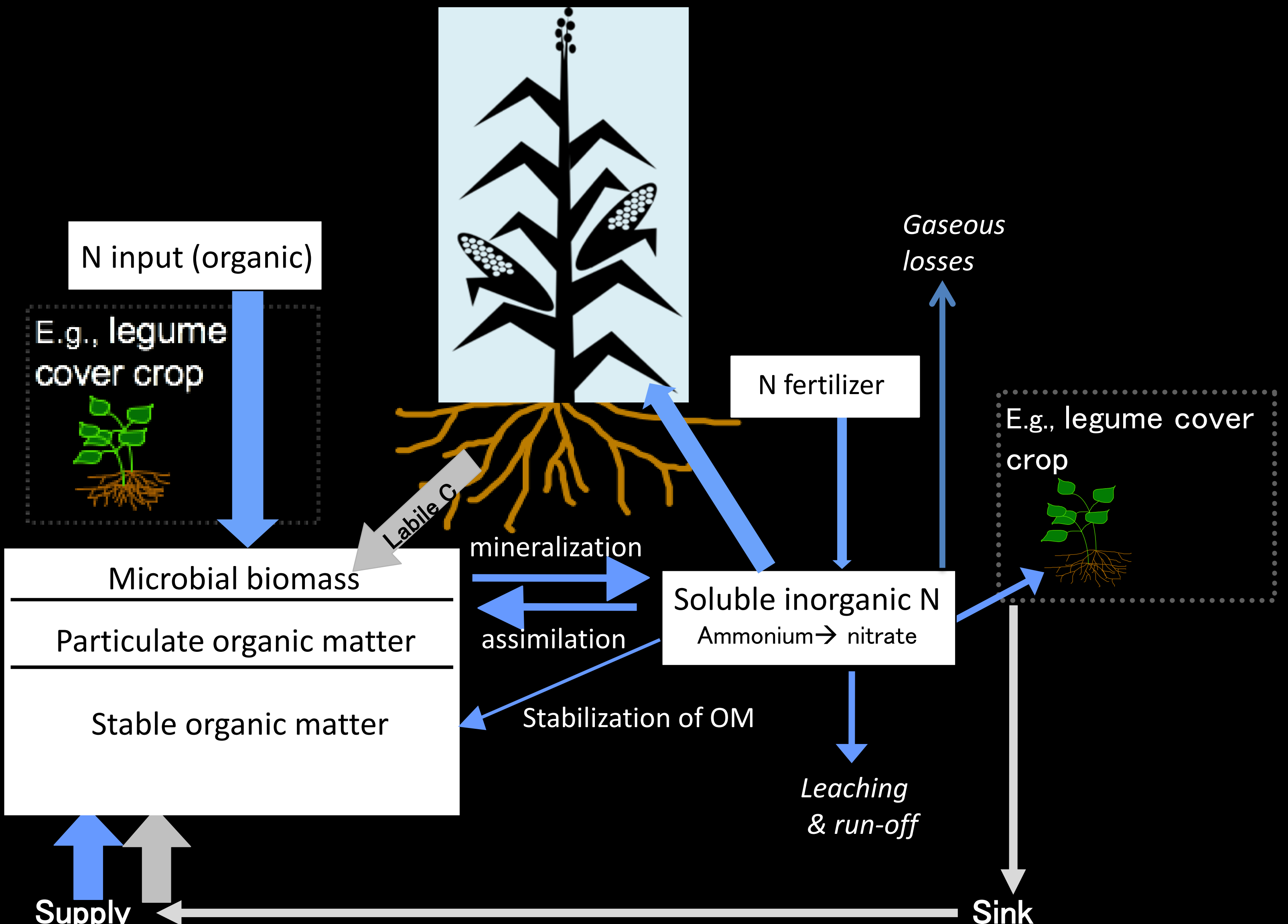
N Management: dominant paradigm

- Pulsed soluble N additions in fertilizer
- Not synchronized to plant demand
- Reduced SOM and disruption of soil biota result in inability to store inorganic N not taken up by crops



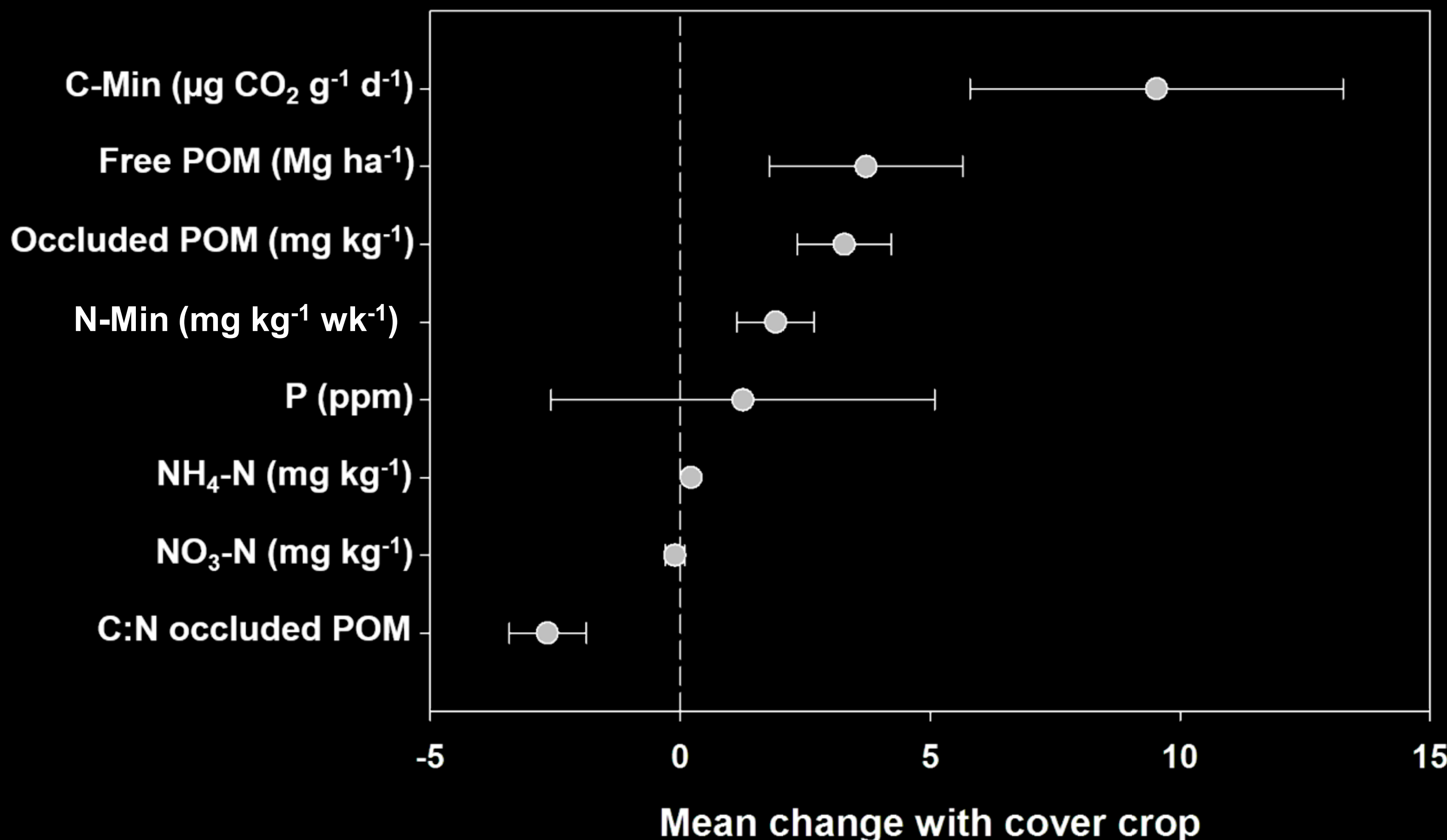
Drinkwater and Snapp, 2007

“Ecological” nitrogen management



Drinkwater and Snapp, 2007

Significant changes in labile SOM pools following two years of rye/vetch



Calculated as difference between cover crop vs. fallow control for two years; shown with 95% CI.