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

Jennifer Blesh
Assistant Professor
School for Environment and Sustainability
University of Michigan
March 5, 2020
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

Images courtesy of Doug Landis, MSU

Simplification

U.S. corn acreage and yield

Consequences: dead zones and harmful algal blooms

> 400 “Dead zones”

http://oceantoday.noaa.gov/happnowdeadzone/
Diaz and Rosenberg 2008, Science;
Consequences: greenhouse gas emissions

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

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

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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

- Winter Pea
- Cereal Rye
- Red Clover
- Alfalfa
- Forage Radish
- Oats
- Hay and Pasture
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

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


does not apply

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-rye Mix
- Sole vetch

Fixed N in vetch shoots (lbs N/acre)

Vetch shoot biomass (lbs/ac)
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?
Significant increase in soil health after two years of rye/vetch

<table>
<thead>
<tr>
<th>Biological Indicators</th>
<th>Unit</th>
<th>Mean change</th>
<th>Significant change?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total SOM</td>
<td>%</td>
<td>0.04</td>
<td>N</td>
</tr>
<tr>
<td>Free POM</td>
<td>Mg ha(^{-1})</td>
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</tr>
<tr>
<td>Protected POM</td>
<td>g kg(^{-1})</td>
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<tr>
<td>N in Protected POM</td>
<td>kg ha(^{-1})</td>
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<tr>
<td>Mineralizable C</td>
<td>µg CO(_2) g(^{-1}) d(^{-1})</td>
<td>9.53</td>
<td>✓</td>
</tr>
<tr>
<td>Mineralizable N</td>
<td>mg kg(^{-1}) wk(^{-1})</td>
<td>1.91</td>
<td>✓</td>
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</table>

<table>
<thead>
<tr>
<th>Chemical Indicators</th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Bray-1 P</td>
<td>ppm</td>
<td>1.25</td>
<td>N</td>
</tr>
<tr>
<td>Nitrate + Ammonium</td>
<td>mg kg(^{-1})</td>
<td>0.10</td>
<td>N</td>
</tr>
</tbody>
</table>
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?

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

Crop diversity benefits the environment and communities

- Small-scale experiments
- Long-term cropping systems research
- Studies on real farms
- Meta-analyses
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;
How do farmers transition to diverse crop rotations in the U.S. Corn Belt?

Resources

On the farm
- Enterprise diversity
- Preventative thinking
- New skills, experience

Off the farm
- 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*;
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

Collaborators: Dan Brainard and Sieg Snapp (MSU)
Funding: The Ceres Trust, SEAS (UMich), USDA AFRI
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

Paterson et al. 2006
Perennials reduce N losses

Field-scale

Rotation Category

- A
- AA
- AP

Average annual N flux (kg N ha\(^{-1}\))

- Total N input
- Harvested N export
- N balance

County-scale

\(R^2=0.47\)

\(P<0.0001\)

\(N=355\)

Blesh and Drinkwater, 2013, *Ecological Applications*
Both environment and management determine SOM levels in a field

<table>
<thead>
<tr>
<th>Environment</th>
<th>Soil and Crop Management Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>Crop rotation</td>
</tr>
<tr>
<td>temperature</td>
<td>Residue inputs</td>
</tr>
<tr>
<td>rainfall</td>
<td>Tillage</td>
</tr>
<tr>
<td>Soil Texture</td>
<td>Organic amendments</td>
</tr>
<tr>
<td></td>
<td>(e.g., manure, compost)</td>
</tr>
<tr>
<td>Vegetation Type</td>
<td>Nutrient sources</td>
</tr>
</tbody>
</table>
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

\[ \text{Soluble inorganic N} \quad \text{NH}_4^+ \rightarrow \text{NO}_3^- \]

Gaseous losses

N fertilizer

leaching

Drinkwater and Snapp, 2007
“Ecological” nitrogen management

- **N input (organic)**
  - E.g., legume cover crop

- **Microbial biomass**

- **Particulate organic matter**

- **Stable organic matter**

- **Soluble inorganic N**
  - Ammonium $\rightarrow$ nitrate

- **N fertilizer**

- **Gaseous losses**

- **E.g., legume cover crop**

- **Leaching & run-off**

- **Stabilization of OM**

- **Supply**

- **Sink**

- **Mineralization**

- **Assimilation**

Drinkingwater 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.

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