Long-term Ecological Research in Row-crop Agriculture

# The first 25 years – What have we learned?

KBS LTER 25<sup>th</sup> Anniversary Symposium April 15-16, 2015

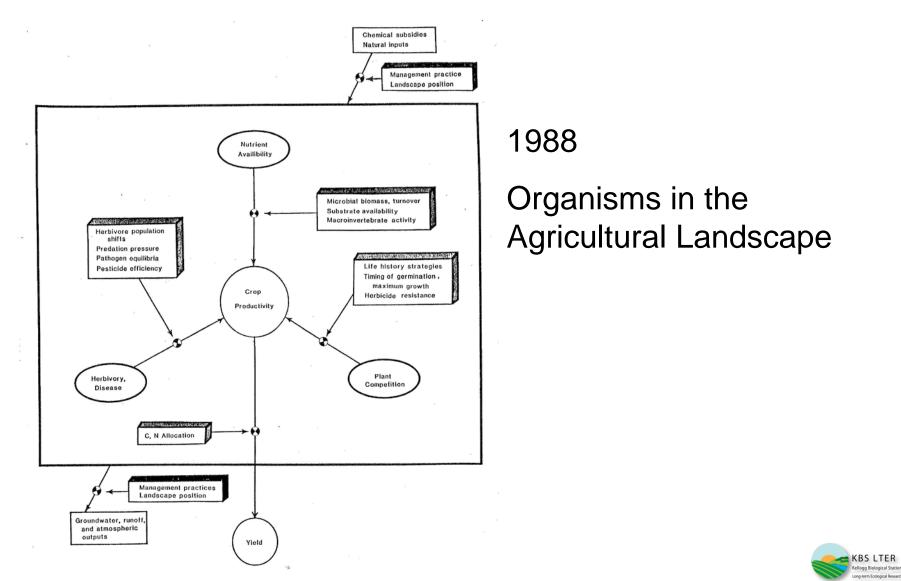
Phil Robertson Dept. of Plant, Soil, and Microbial Sciences and W.K. Kellogg Biological Station Michigan State University

robert30@msu.edu

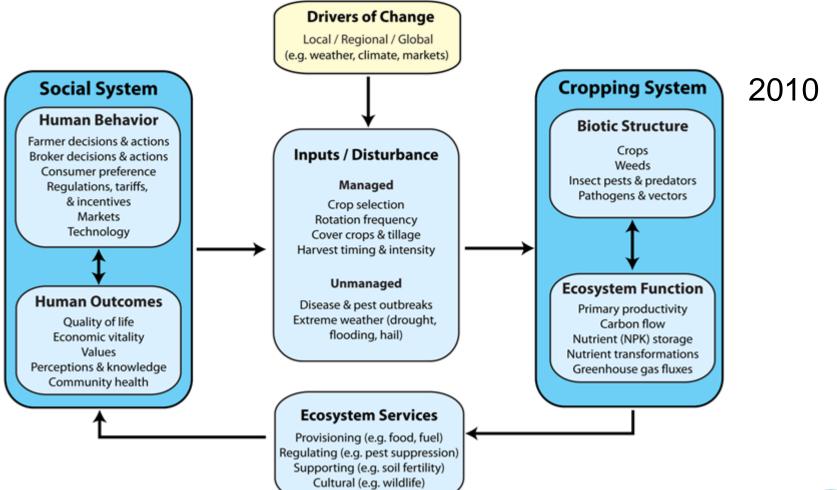




1. We've learned how to make better conceptual models



### 1. We've learned how to make better conceptual models





#### 2. We've learned how to work together in more complex teams

## 1988 3 Pls: Robertson, Paul, Klug

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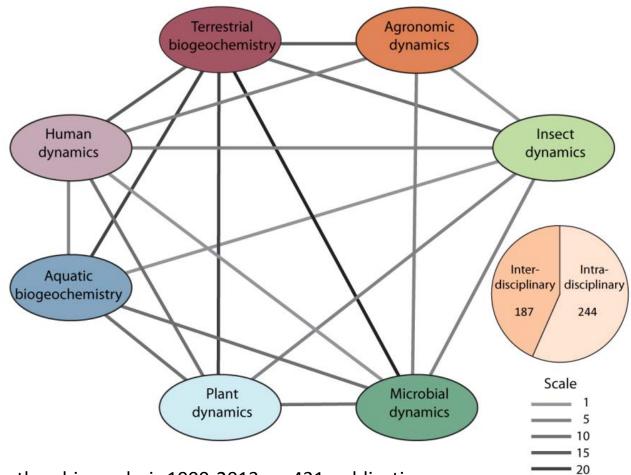
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2. We've learned how to work together in more complex teams

**Cross-disciplinary Publications** 

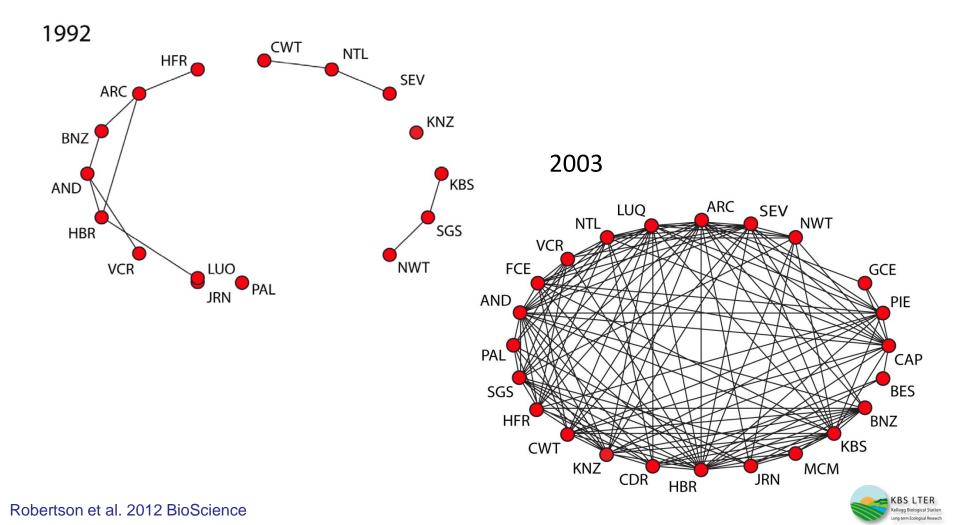




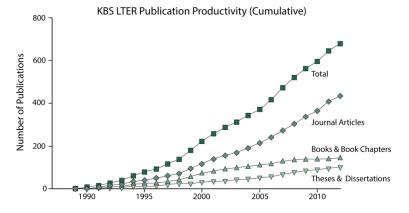
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Based on co-authorship analysis 1999-2013; n=431 publications

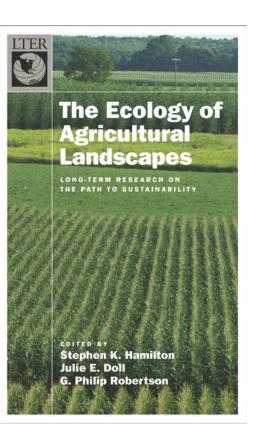
# 3. We've learned the importance of an open site and an even more open data catalog



- 4. We've learned lots of practical things
  - How to leverage funding
  - How to encourage grad and postdoctoral scientists



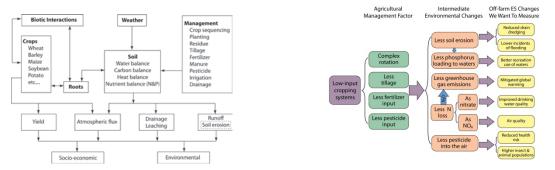
- How to throw a party (!)
- How to write a book!



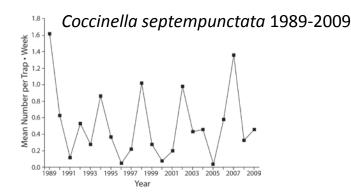


# But the two biggest lessons

- 1. Importance of taking a systems approach at multiple scales
  - Reveals connections not otherwise recognized
  - Informs the potential for trade-offs and synergies

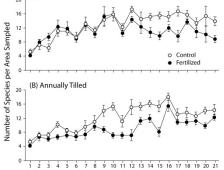


- 2. The surprising importance of long-term observations
  - Allows discovery of unrecognized patterns
  - Allows retrospective analyses of new questions



#### Swinton et al. 2015; Basso and Ritchie 2015; Landis and Gage 2015; Gross et al. 2015

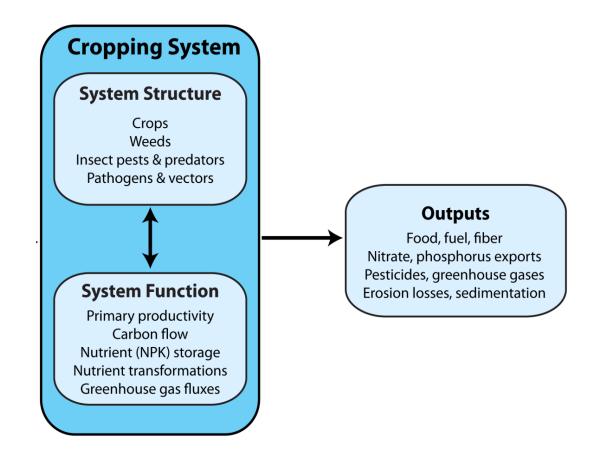




Years after Abandonment

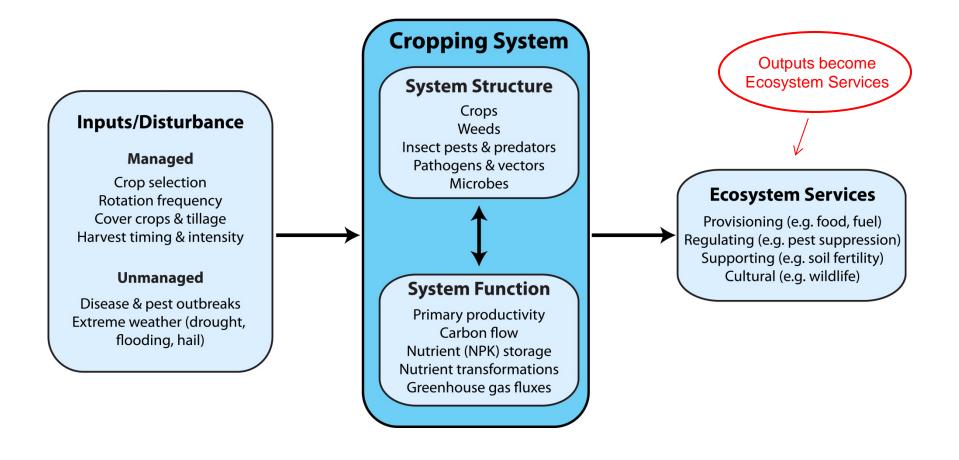


# How we conceptualize the row-crop ecosystem



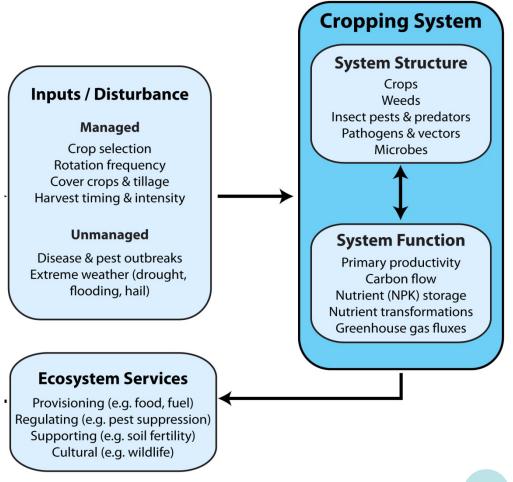


# How we conceptualize the row-crop ecosystem





# How we conceptualize the row-crop ecosystem





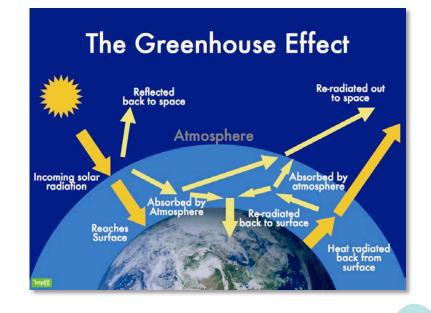
#### How we conceptualize the row-crop ecosystem Added a Social system **Social System Cropping System Human Behavior System Structure** Farmer decisions & actions Crops Inputs / Disturbance Broker decisions & actions Weeds Consumer preference Insect pests & predators Regulations, tariffs, Managed Pathogens & vectors & incentives **Crop** selection Microbes Labor & technology **Rotation frequency** Markets Cover crops & tillage Harvest timing & intensity Unmanaged **System Function Human Outcomes Disease & pest outbreaks** Primary productivity Quality of life Extreme weather (drought, Carbon flow flooding, hail) **Economic vitality** Nutrient (NPK) storage Values Nutrient transformations Perceptions & knowledge Greenhouse gas fluxes Community health **Ecosystem Services** Provisioning (e.g. food, fuel) Regulating (e.g. pest suppression) Supporting (e.g. soil fertility) Cultural (e.g. wildlife)



# Illustrate with a greenhouse gas story

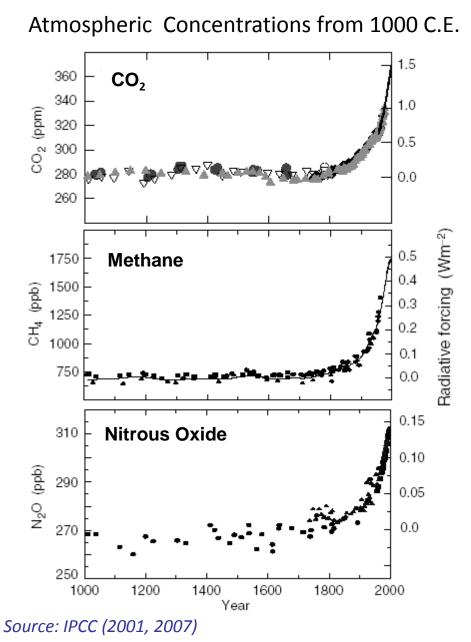
- 1) Systems approach
- 2) Retrospective analysis
- 3) Powered largely by grads and postdocs
- 4) Core findings baseline, leveraged external support
- 5) Broader impacts





KBS LT

# All 3 of the major biogenic greenhouse gases are affected



by agriculture (10-14% of total global GHG load)

 $CO_2 GWP = 1$ 

GWP = Global Warming Potential

 $CH_4 GWP = 23$ 

 $N_2O GWP = 296$ 



# Field crops influence global fluxes of all three gases

- CO<sub>2</sub>
  - Soil carbon change
  - Fuel use
  - Nitrogen fertilizer
  - Lime (carbonate) inputs
  - Pesticides, seeds, other inputs
- N<sub>2</sub>O
  - Soil microbes
- CH<sub>4</sub>
  - Microbial consumption





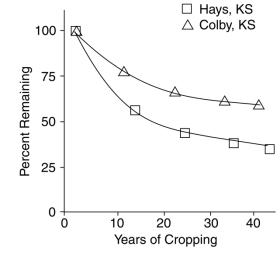
Soil carbon change

# Historical Soil Carbon Loss from Cropping Systems

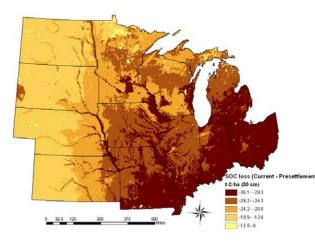
- locally 40-60% of original C lost after 40-60 years of cultivation in North America
- globally 54 Pg C from an original 222 Pg C (about 25%)

- potential for recovering  $0.3 0.5 \text{ Pg C y}^{-1}$ 
  - Increasing C inputs (crop residues, cover crops)
  - Slowing decomposition (no-till)

Source: Lal 1999, Smith 2004, IPCC 2002, Grace et al. 2006



Haas et al. 1957



#### A KBS greenhouse gas story

#### Soil carbon change

# How to Restore Soil Carbon?

- 1. Increase C inputs to soil
  - Cover crops
  - Rotations
  - Residue quantity

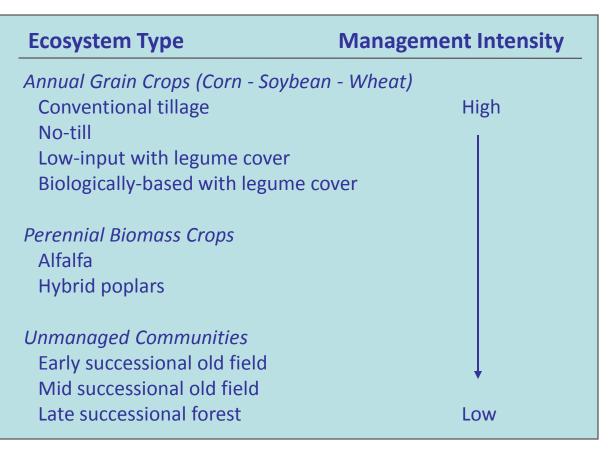


- 2. Decrease C loss from soil (slow decomposition)
  - Reduce tillage (e.g. no-till)
  - Residue quality





# KBS LTER Main Cropping System Experiment (MCSE)









#### Soil carbon change

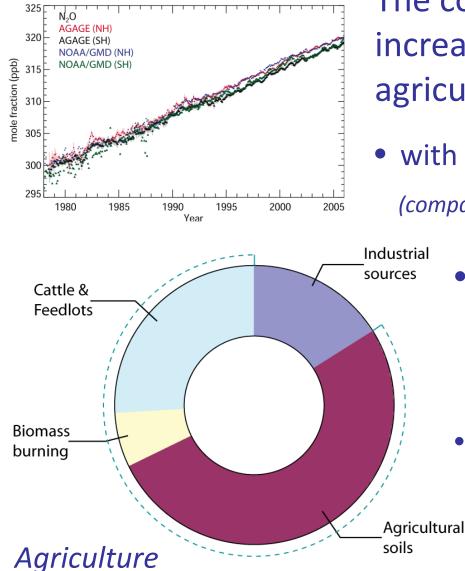
#### Soil carbon change in the first 10 years of KBS cropping

KBS System	Carbon					
	%C	kg/m <sup>2</sup>	g/m²/y*			
Annual Grain Crops (c-s-w)						
Conventional Tillage	1.00	.94	0			
No-Till	1.24	1.24	30			
Organic with cover	1.09	1.02	8			
Perennial Biomass Crops						
Alfalfa	1.30	1.38	44			
Poplar	1.40	1.26	32			
Successional (Unmanaged) Comm	nunities (CRP)					
Early Successional (<10y)	1.63	1.54	60			
Mid-Successional (50 y)	1.61	1.37	<11			
Late Successional	2.93	2.29	0			

\* Initial C = 1.0%



#### Atmospheric N<sub>2</sub>O from 1976



The contemporary N<sub>2</sub>O increase is largely due to agricultural intensification

• with a total annual impact ~ 1.2 Pg  $C_{equiv}$ 

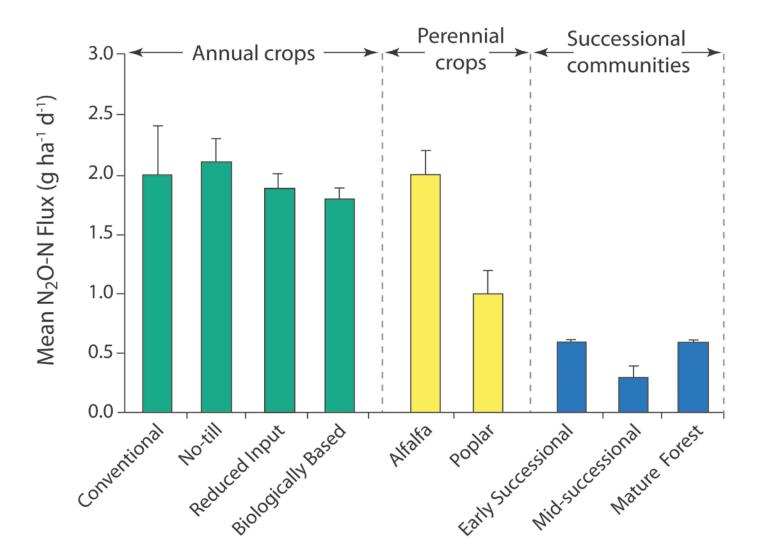
(compare to fossil fuel CO<sub>2</sub> loading = 4.1 Pg C per year)

- Industry is responsible for ~16% of the anthropogenic source
  - Agriculture for the remainder
- with most of the agricultural increase (~60%) from cropped soils



Source: IPCC 2001, 2007; Prinn 2004; Robertson 2004

# Nitrous Oxide Fluxes at KBS (1992-2010)







		Other							
	Soil-C	N-Fert	Fuel	Inputs	$N_2O$	CH <sub>4</sub>	Net		
		g CO <sub>2</sub> -equiv / m²/ y							
Annual Crops									
Conventional	0	33	13	19	37	-1	101		

NB

a. Soil C is at equilibrium (no annual change)
b. N<sub>2</sub>O is single largest source of GWP
c. Net impact >100 g CO<sub>2</sub>-equiv / m<sup>2</sup>/ y



	Other								
	Soil-C	N-Fert	Fuel	Inputs	N <sub>2</sub> O	$CH_4$	Net		
		g CO <sub>2</sub> -equiv / m²/ y							
Annual Crops									
Conventional	0	33	13	19	37	-1	101		
No-till	-122	33	9	28	39	-1	-14		

NB No-till

a. No-till C gain provides substantial mitigation

b. Other sources (including N<sub>2</sub>O) similar

c. Net impact is negative - mitigation



	Other								
	Soil-C	N-Fert	Fuel	Inputs	N <sub>2</sub> O	$CH_4$	Net		
		g CO <sub>2</sub> -equiv / m²/ y							
Annual Crops									
Conventional	0	33	13	19	37	-1	101		
No-till	-122	33	9	28	39	-1	-14		
<b>Biologically Based</b>	-183	0	20	8	32	-1	-124		

NB Biologically Based a. C gain even with more cultivation b. Gains from no inputs, but no N<sub>2</sub>O benefit c. Net impact is very negative – net mitigation



	Other								
	Soil-C	N-Fert	Fuel	Inputs	N <sub>2</sub> O	CH <sub>4</sub>	Net		
		g CO <sub>2</sub> -equiv / m²/ y							
Annual Crops									
Conventional	0	33	13	19	37	-1	101		
No-till	-122	33	9	28	39	-1	-14		
<b>Biologically Based</b>	-183	0	20	8	32	-1	-124		
Successional Communit	ies (Unmar	naged)							
Early Successional	-397	0	0	0	11	-1	-387		
Mid-successional	-214	0	0	0	16	-3	-201		
Deciduous Forest	0	0	0	0	12	-5	7		

**NB Successional** 

a. Huge soil C gain early in succession (only)

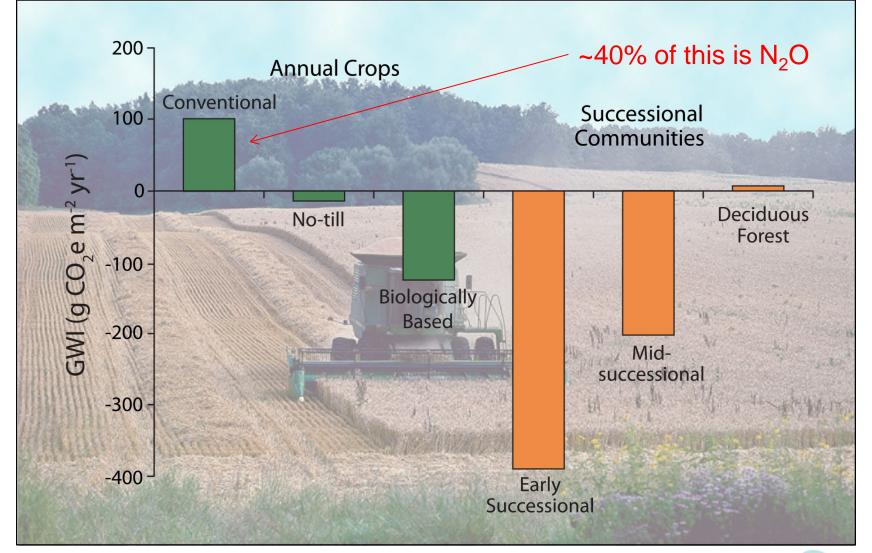
b. N<sub>2</sub>O fluxes low throughout (low nitrate availability)

c. Net impact high early, neutral late



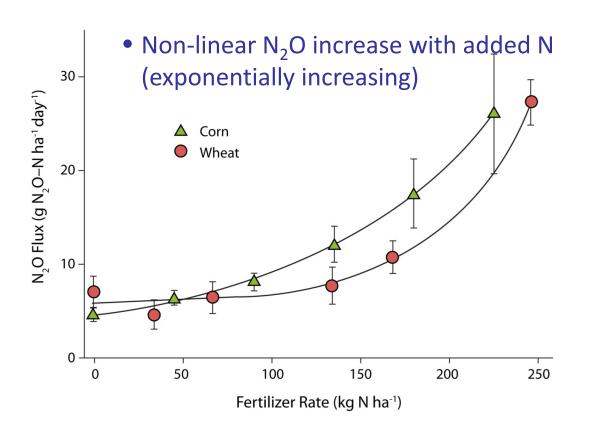
A KBS greenhouse gas story

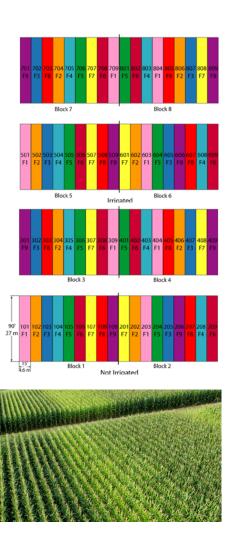
# Net Global Warming Impact of Cropped and Successional Ecosystems at KBS





# N<sub>2</sub>O fluxes are strongly affected by nitrogen fertilizer inputs

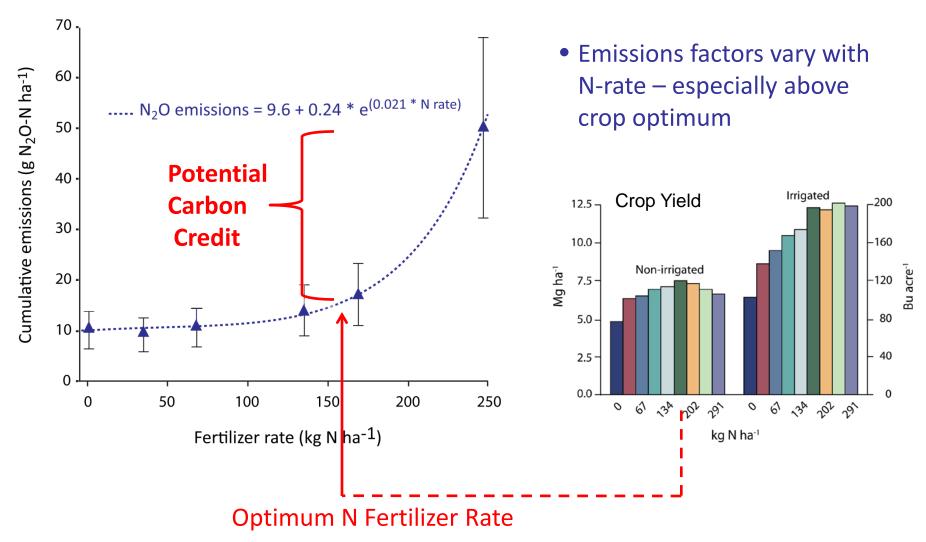






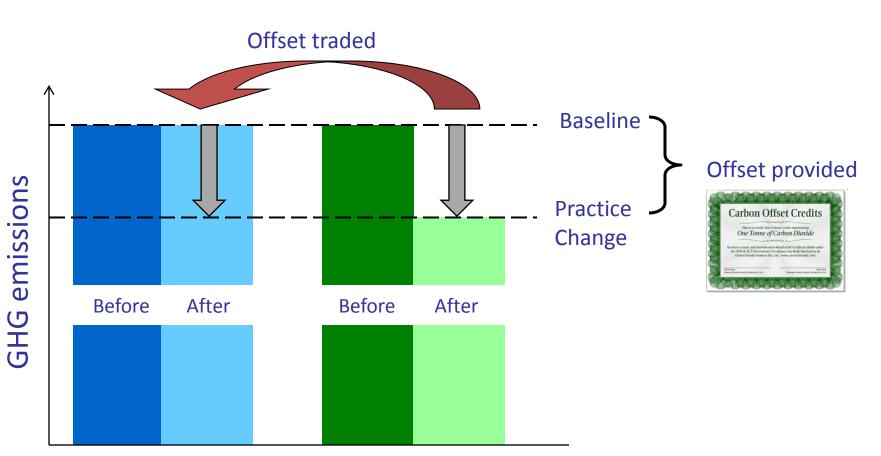


# Combined, this translates to a significant potential carbon credit





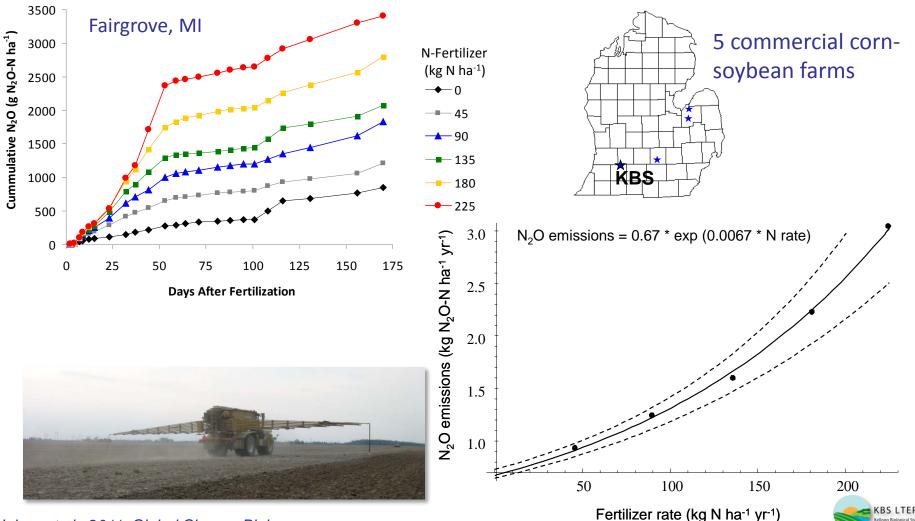
# **Carbon Trading and Offsets**



Regulated or Voluntary entity Electric Power Plant Green Retailer Offset provider Agriculture



# Cross-state test of non-linear N<sub>2</sub>O response to N-fertilizer



Hoben et al., 2011, Global Change Biology

A KBS greenhouse gas story

# **MSU-EPRI Nitrous Oxide Reduction Protocol**





American Carbon Registry® Trusted solutions for the carbon market



# Pays farmers for applying nitrogen fertilizer more precisely

- Reduces agricultural greenhouse gases
- Reduces reactive nitrogen in environment (including nitrate)
- Incentivizes conservation using current and new technology

#### **Current Status**

- Protocol now registered
- Being marketed by aggregators
- First credit issued June 2014 to Tuscola County farmer Marvin Ortner



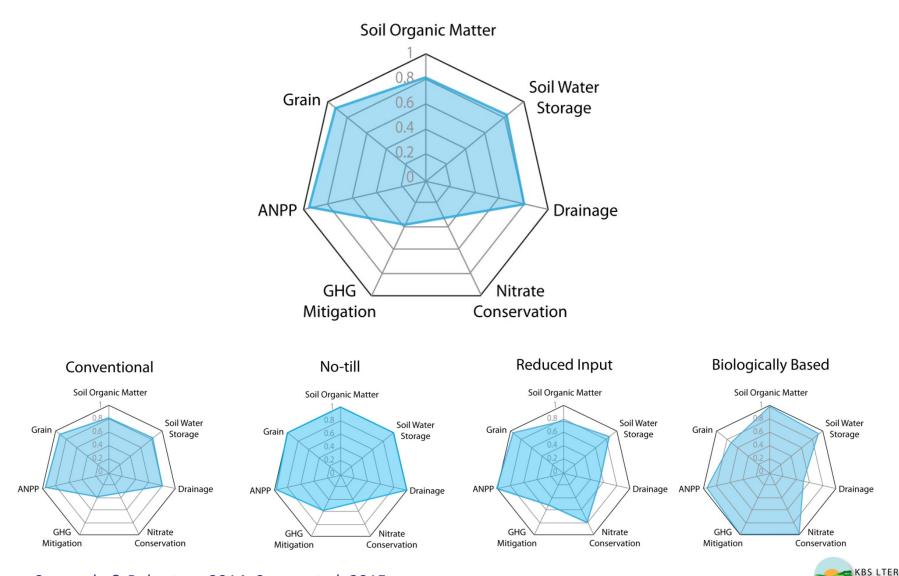


A KBS greenhouse gas story

Kellogg Biological Station

# Integrating Ecosystem Services to Optimize Systems

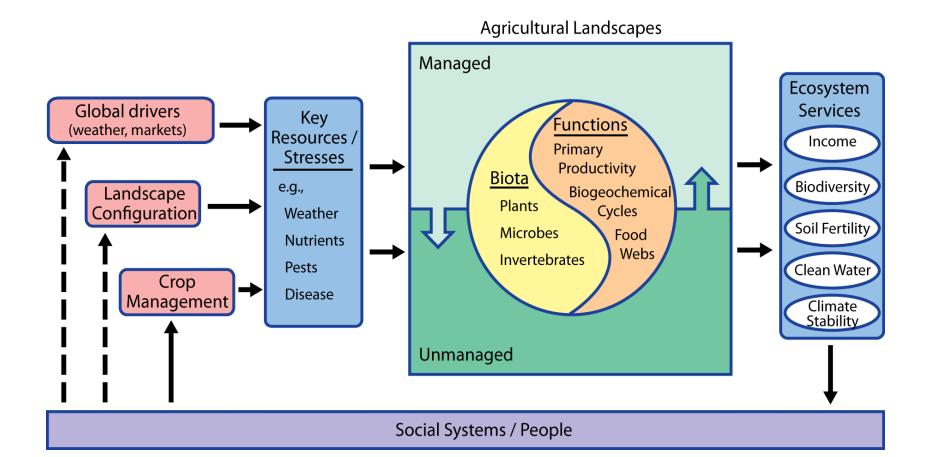




Source: Syswerda & Robertson 2014; Snapp et al. 2015

# Where we're headed

### A provisional conceptual model for the KBS LTER future





# Where ARE we headed?

# Crowd-sourcing the future: What are the most exciting questions that KBS LTER could pursue over the next 1-2 decades?

#### Breakout topic areas

- 1. Biological diversity and ecosystem functions in agricultural landscapes
- 2. Biogeochemical and hydrologic cycles
- 3. Productive, resilient cropping systems
- 4. Decision making for agricultural sustainability







