Long-term Ecological Research in Row-crop Agriculture

The first 25 years – What have we learned?

KBS LTER 25th Anniversary Symposium

April 15-16, 2015

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

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MICHIGAN STATE UNIVERSITY

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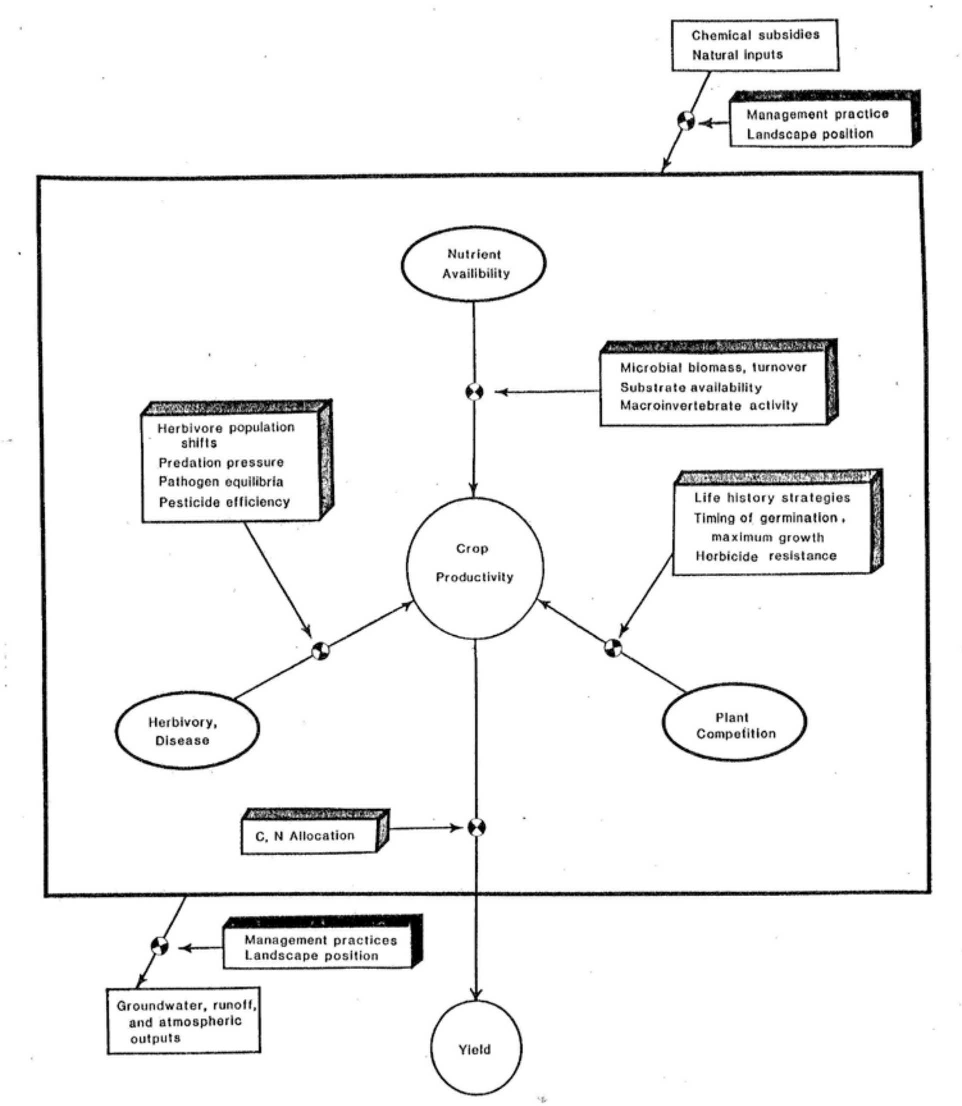
What's been learned

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

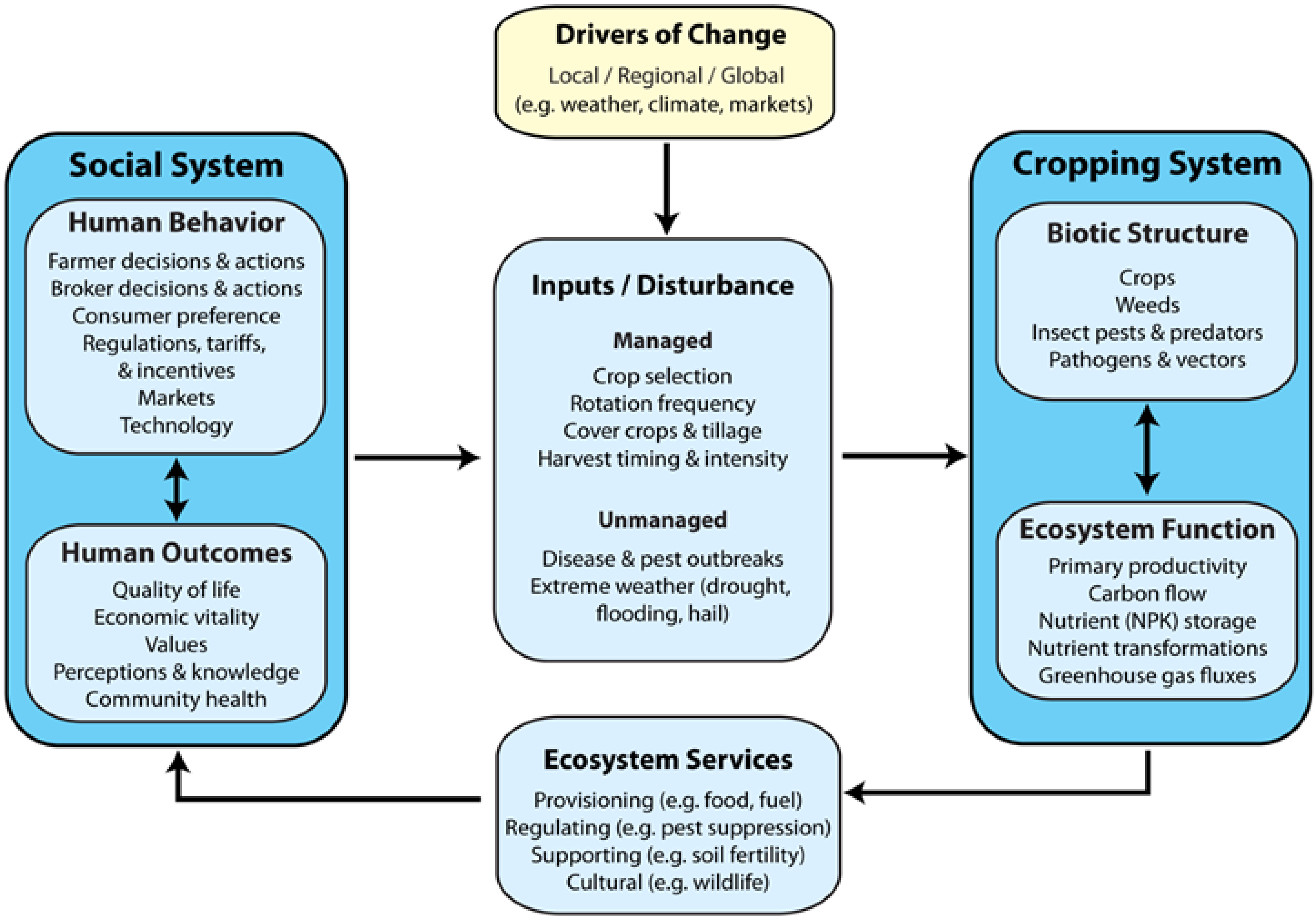


1988

Organisms in the Agricultural Landscape

What's been learned

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



2010

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What's been learned

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

1988

3 PIs:
Robertson, Paul, Klug

PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION
Cover Page

FOR CONSIDERATION BY NSF ORGANIZATIONAL UNIT (Indicate the most specific unit known, i.e. program, division, etc.)
LTER Program

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PROGRAM ANNOUNCEMENT/SOLICITATION NO.:

CLOSING DATE (IF ANY): November 3, 1986

NAME OF SUBMITTING ORGANIZATION TO WHICH AWARD SHOULD BE MADE (INCLUDE BRANCH/CAMPUS/OTHER COMPONENTS)
Michigan State University

ADDRESS OF ORGANIZATION (INCLUDE ZIP CODE)
East Lansing, Michigan 48824

TITLE OF PROPOSED PROJECT
Organisms in the Agricultural Landscape: Long Term Ecological Research

REQUESTED AMOUNT	PROPOSED DURATION	DESIRED STARTING DATE
$2,000,000	5 years	January 1, 1988

PI/PD DEPARTMENT	PI/PD ORGANIZATION	PI/PD PHONE NO.
W.K. Kellogg Biol. Station	Michigan State University	616/671-2267

PI/PD NAME	SOCIAL SECURITY NO.*	SIGNATURE	MALE*	FEMALE*
G. Philip Robertson		below	X	
ADDITIONAL PI/PD: Eldor A. Paul			X	
ADDITIONAL PI/PD: Michael J. Klug			X	
ADDITIONAL PI/PD				
ADDITIONAL PI/PD				

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SUBMITTING ORGANIZATION IS: ☐ For-Profit Organization; ☐ Small Business; ☐ Minority Business; ☐ Women-Owned Business; (See cover page instructions, Page 3)

*Submission of social security numbers is voluntary and will not affect the organization's eligibility for an award. However, they are an integral part of the NSF information system and assist in processing the proposal. SSN solicited under NSF Act of 1950, as amended.

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☐ Animal Welfare ☐ Human Subjects ☐ National Environmental Policy Act
☐ Endangered Species ☐ Marine Mammal Protection ☐ Research Involving Recombinant DNA Molecules
☐ Historical Sites ☐ Pollution Control ☐ Proprietary and Privileged Information

	PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR	AUTHORIZED ORGANIZATIONAL REP.	OTHER ENDORSEMENT (optional)
NAME	G. Philip Robertson		George H. Lauff
SIGNATURE			
TITLE	Asst. Professor		Director for Education & Biol. Sci. Pgm, KBS
DATE	10/31/86		10/31/86
TELEPHONE NO. Area Code:	616/671-2267		616/67-5117

20

2010

7 PIs:
Robertson, Gross, Hamilton, Landis, Schmidt, Snapp, Swinton

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 10-1
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DEB - Long-Term Ecological Research

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
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IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE
Michigan State University

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
CONTRACT AND GRANT ADMINISTRATIO
301 ADMINISTRATION BUILDING
EAST LANSING, MI 48824-1046

AWARDEE ORGANIZATION CODE (IF KNOWN)
0022905000

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE

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PERFORMING ORGANIZATION CODE (IF KNOWN)

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions) ☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS ☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT The KBS LTER Project: Long-term Ecological Research in Row-crop Agriculture

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 5,640,000	72 months	12/01/10	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
☐ BEGINNING INVESTIGATOR (GPG I.G.2)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date ______
PHS Animal Welfare Assurance Number ______
☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number ______
Exemption Subsection ______ or IRB App. Date ______
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

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Electronic Signature

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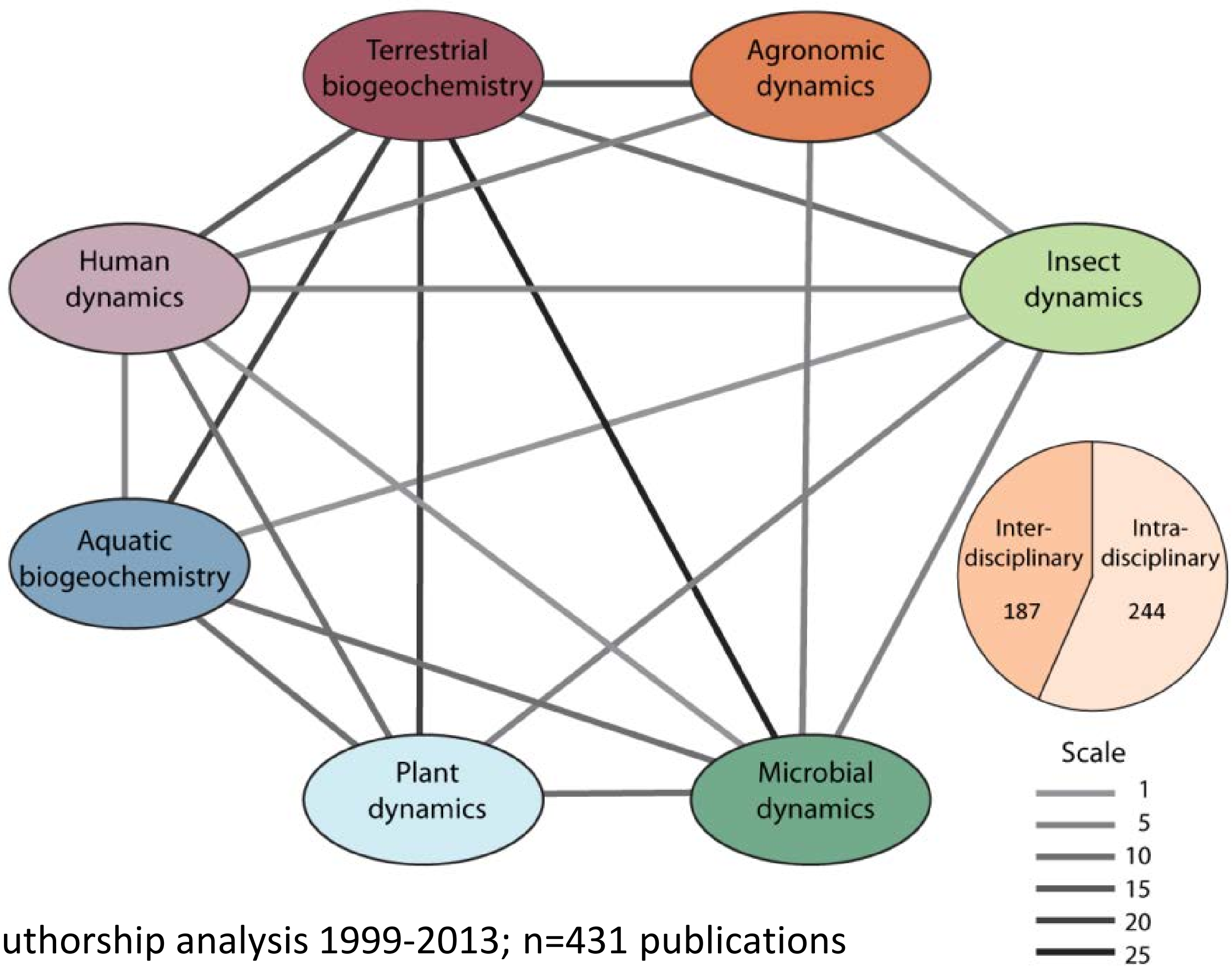
What's been learned

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

Cross-disciplinary Publications



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

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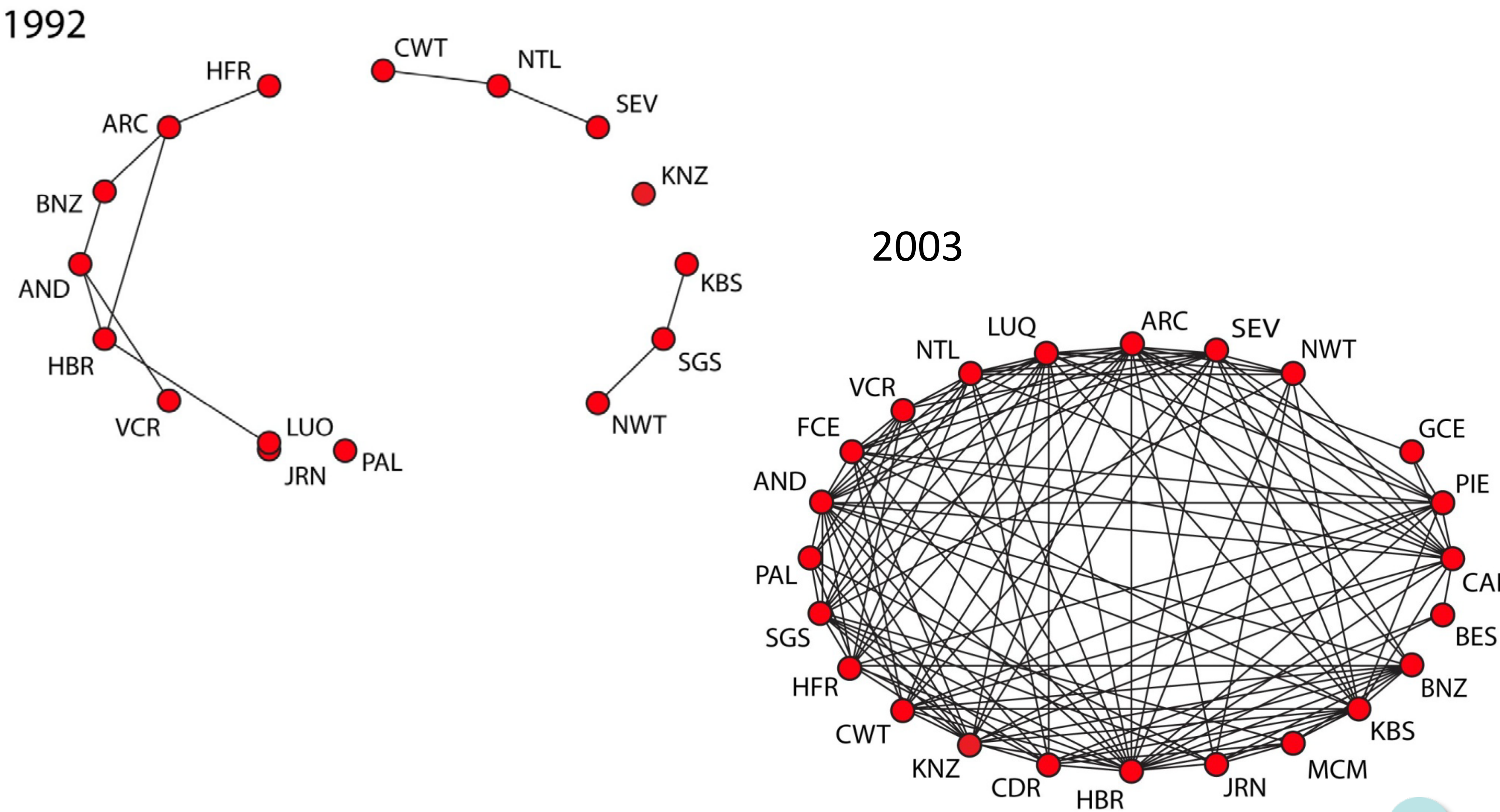
What’s been learned

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



Robertson et al. 2012 BioScience

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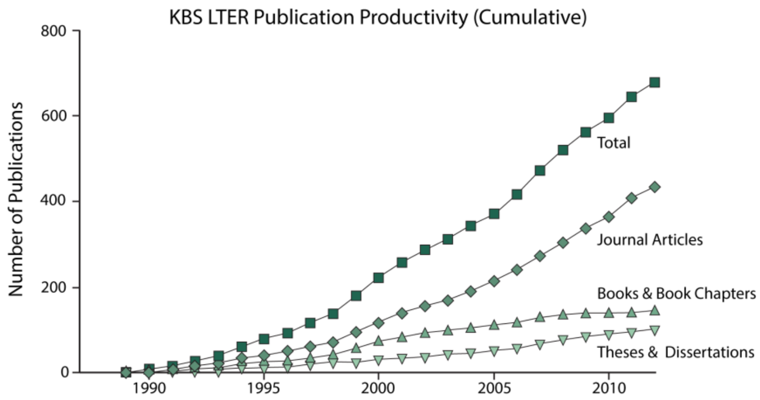
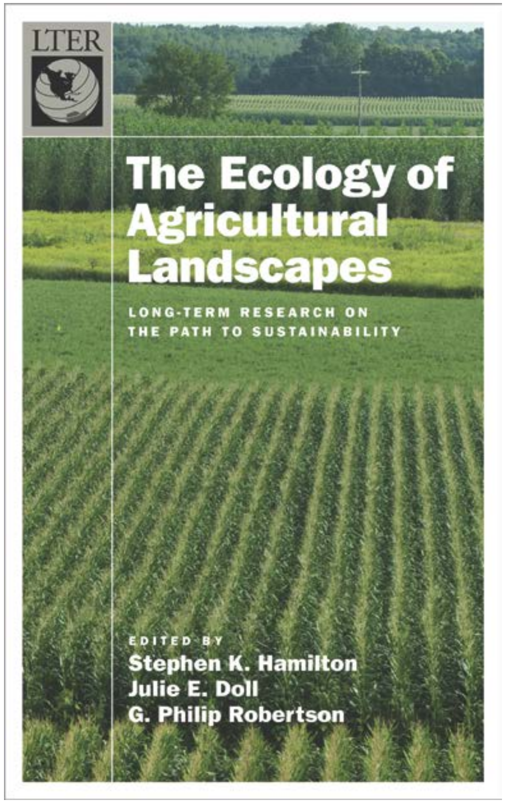
What’s been learned

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!



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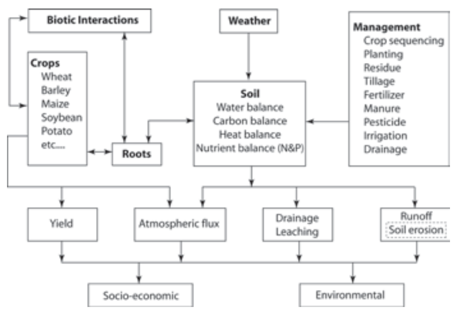
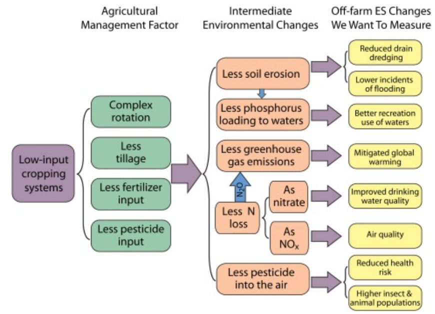
But the two biggest lessons

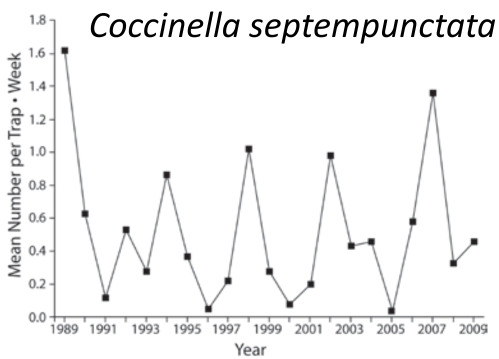
1. Importance of taking a systems approach at multiple scales
   - Reveals connections not otherwise recognized
   - Informs the potential for trade-offs and synergies



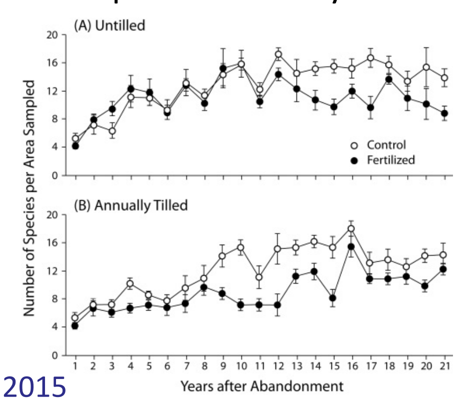


2. The surprising importance of long-term observations
   - Allows discovery of unrecognized patterns
   - Allows retrospective analyses of new questions

Coccinella septempunctata 1989-2009



Plant species diversity over 20y in early succession



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

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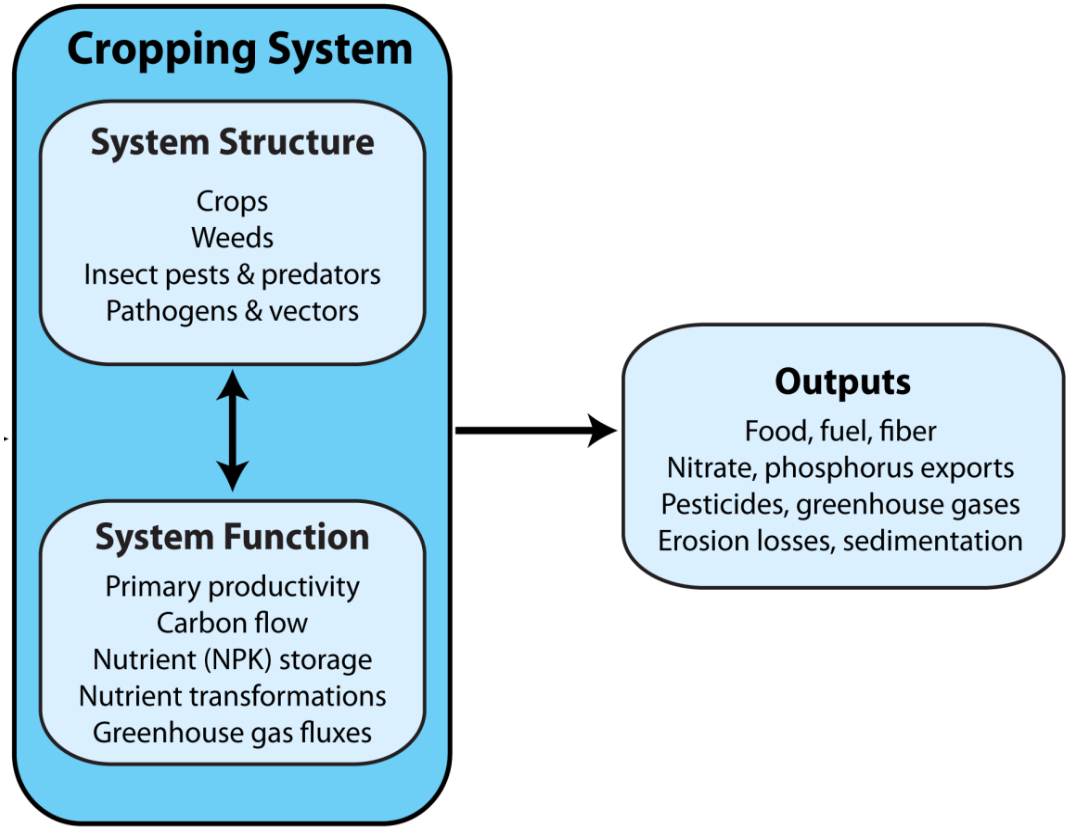
How we conceptualize the row-crop ecosystem



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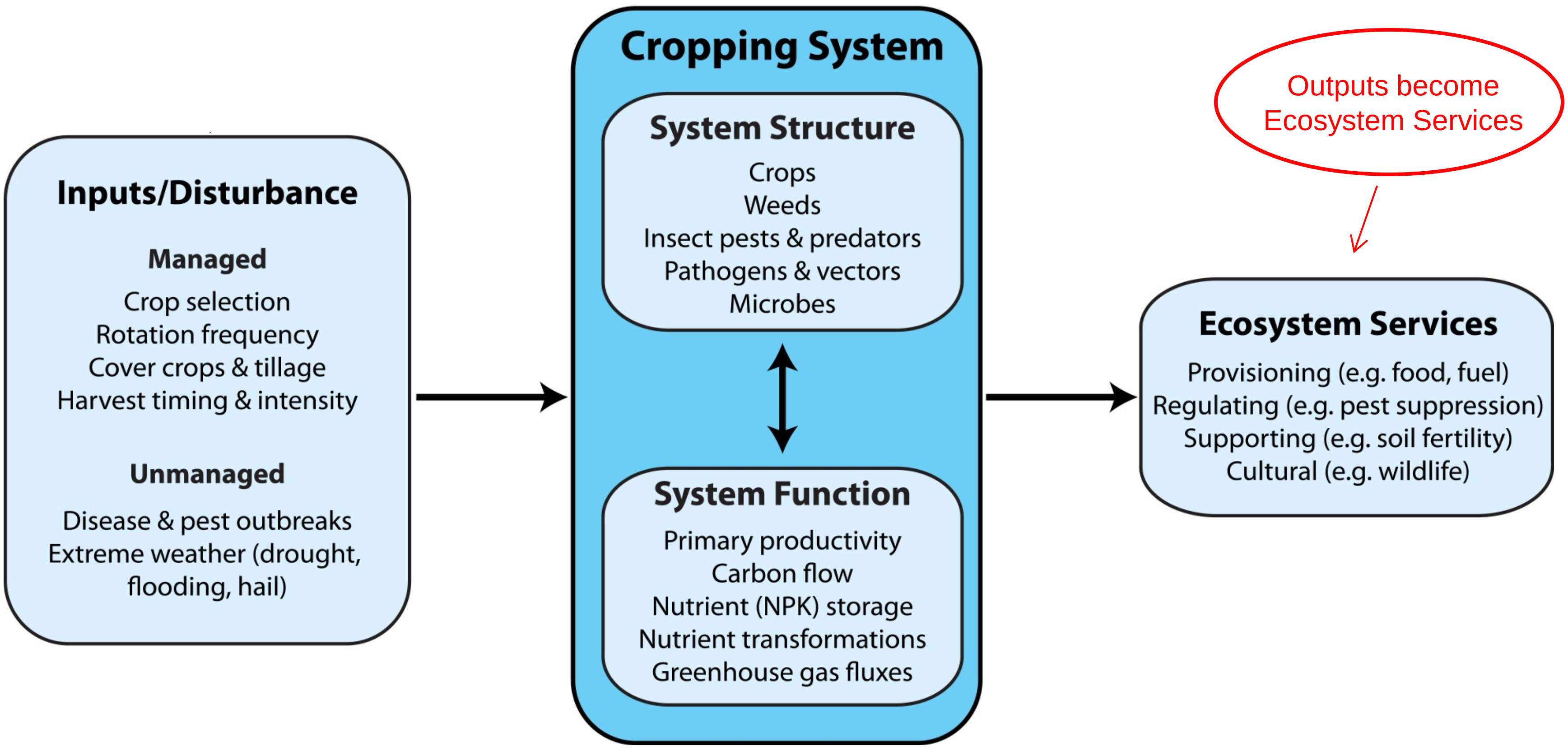
How we conceptualize the row-crop ecosystem



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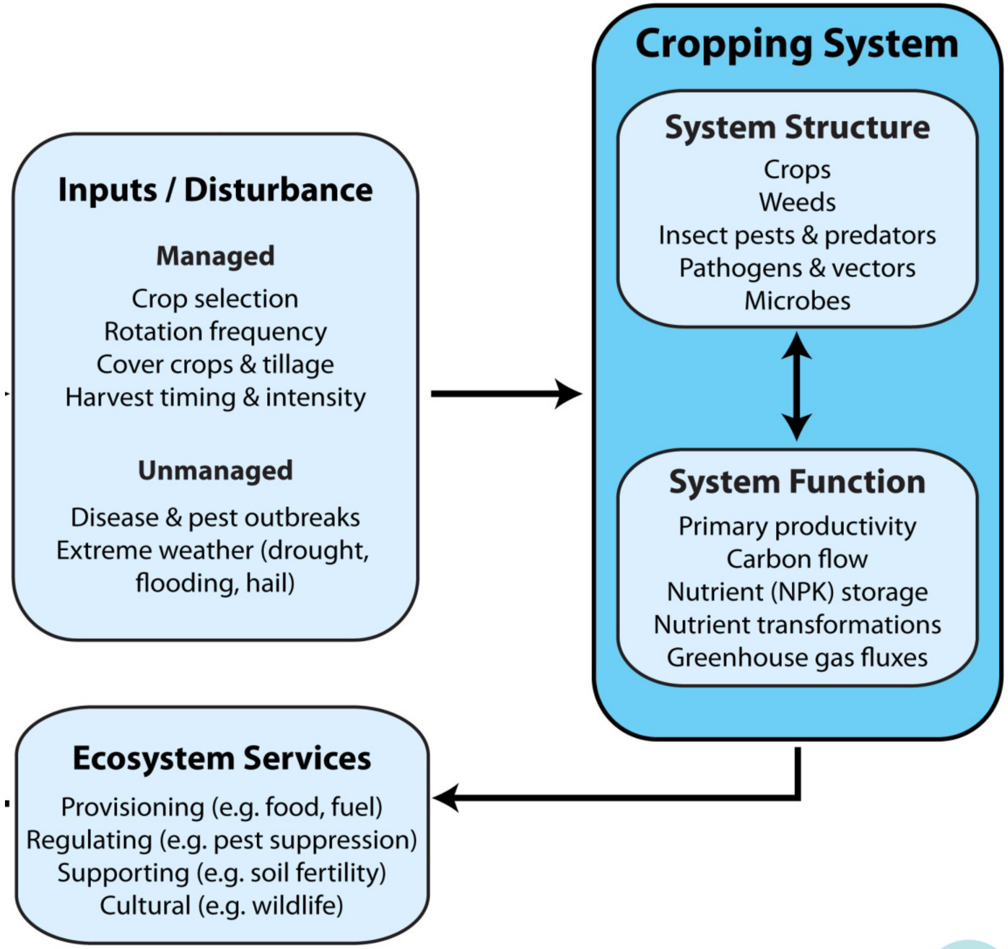

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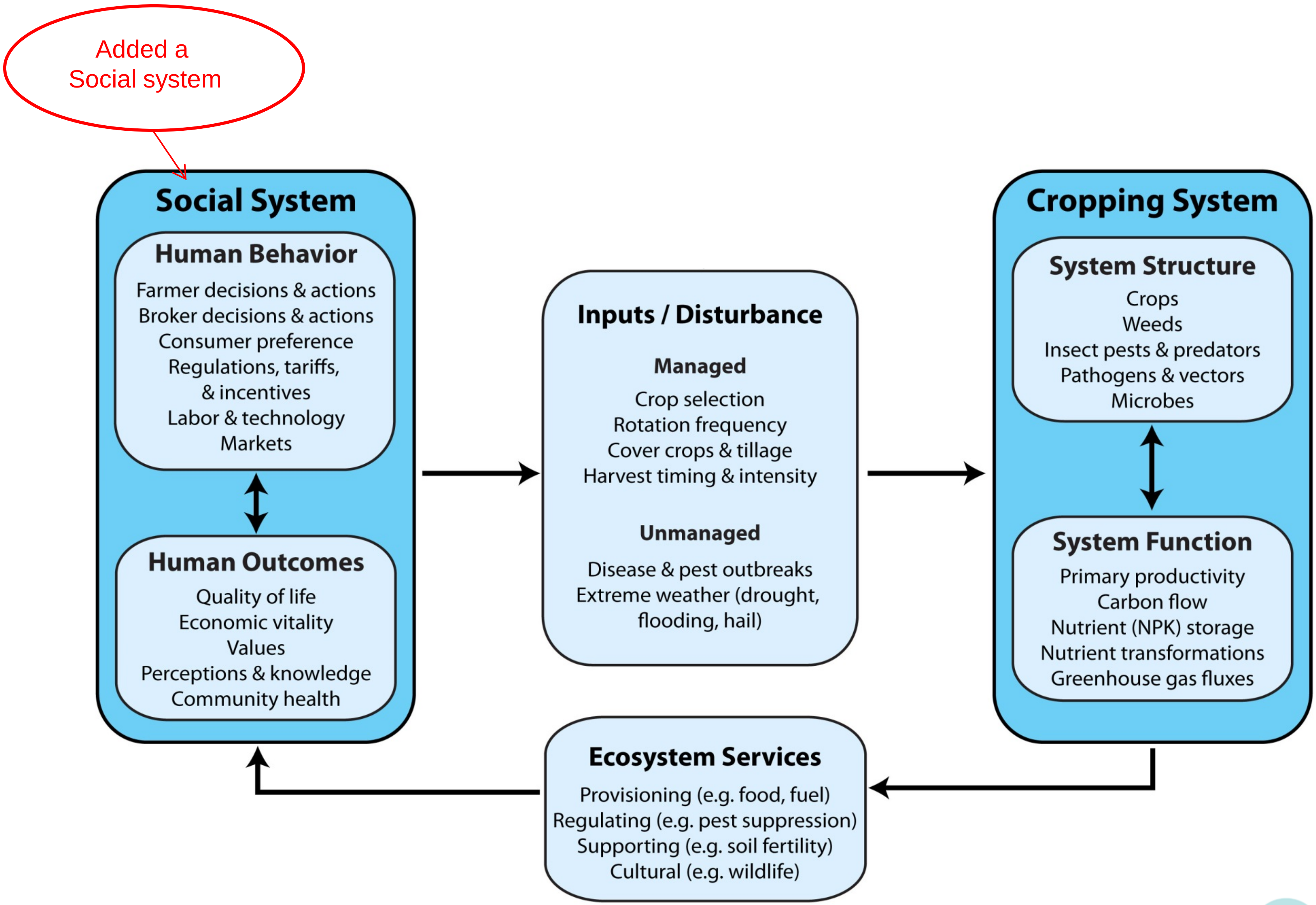
How we conceptualize the row-crop ecosystem



Source: Robertson & Hamilton, 2015; after Collins et al. 2011

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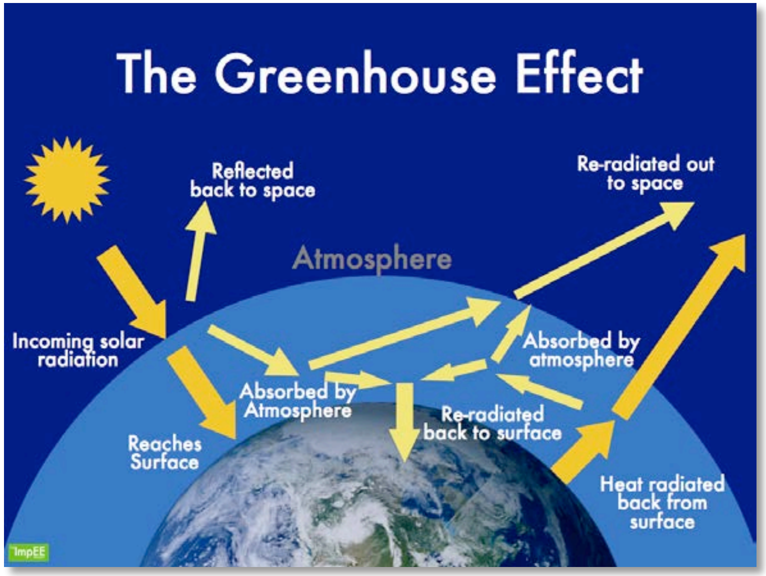
Illustrate with a greenhouse gas story

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



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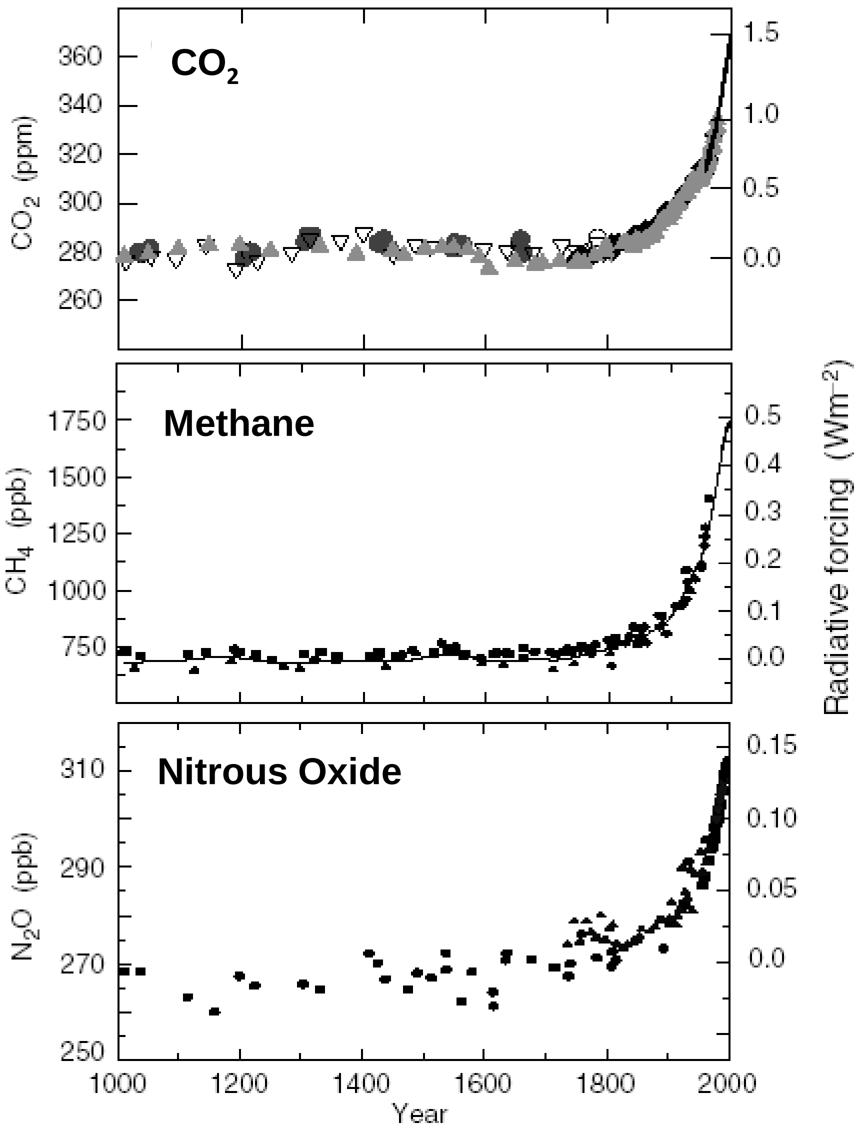
All 3 of the major biogenic greenhouse gases are affected by agriculture (10-14% of total global GHG load)

Atmospheric Concentrations from 1000 C.E.



CO_2 GWP = 1

GWP = Global Warming Potential

CH_4 GWP = 23

N_2O GWP = 296

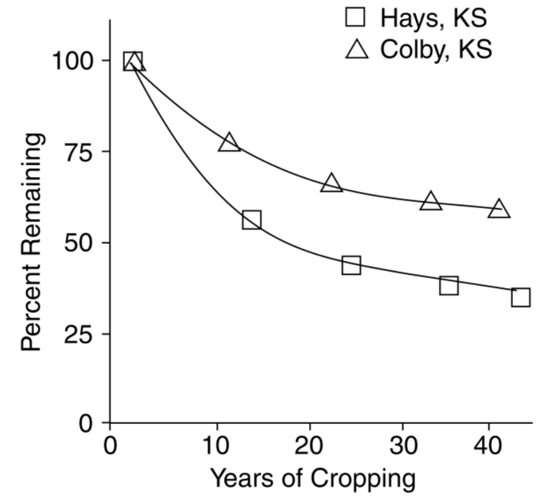
Source: IPCC (2001, 2007)

Field crops influence global fluxes of all three gases

- CO_2
  - Soil carbon change
  - Fuel use
  - Nitrogen fertilizer
  - Lime (carbonate) inputs
  - Pesticides, seeds, other inputs
- N_2O
  - Soil microbes
- CH_4
  - Microbial consumption

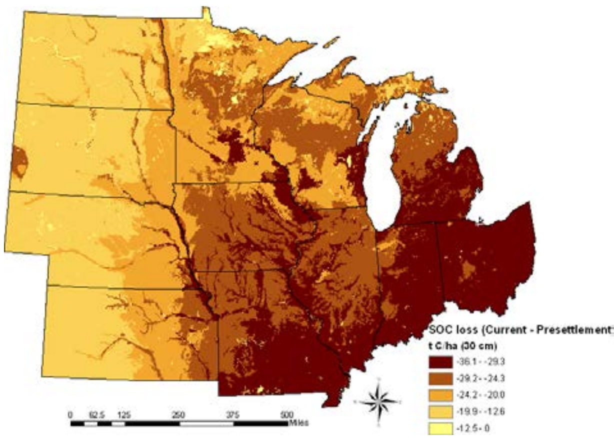
Historical Soil Carbon Loss from Cropping Systems

- 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%)



Haas et al. 1957

- potential for recovering 0.3 – 0.5 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

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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)

Ecosystem Type	**Management Intensity**
Annual Grain Crops (Corn - Soybean - Wheat)	
Conventional tillage	High
No-till	↓
Low-input with legume cover	
Biologically-based with legume cover	
Perennial Biomass Crops	
Alfalfa	
Hybrid poplars	
Unmanaged Communities	
Early successional old field	
Mid successional old field	
Late successional forest	Low

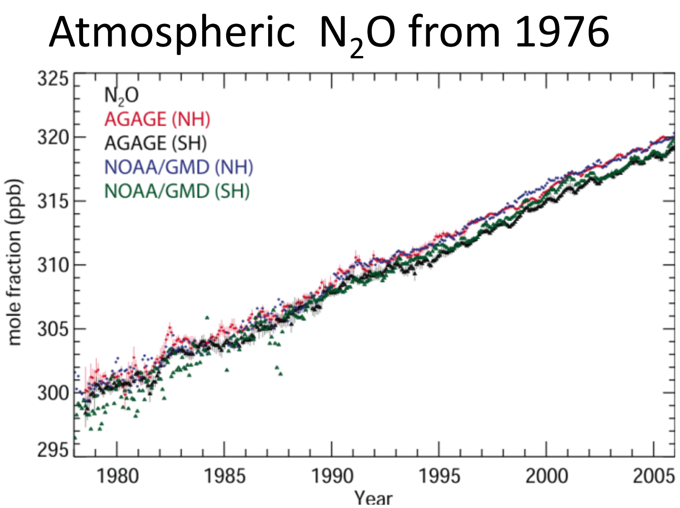
Soil carbon change in the first 10 years of KBS cropping

KBS System	Carbon		
	%C	kg/m²	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) Communities (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%

Source: Robertson et al.. 2000

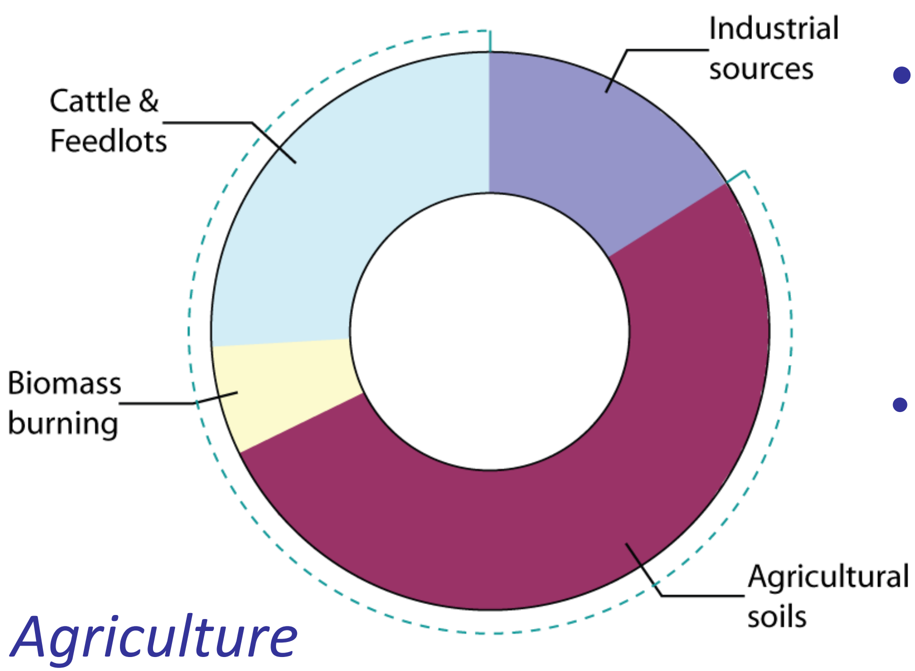
Nitrous oxide emission



The contemporary N_2O increase is largely due to agricultural intensification

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

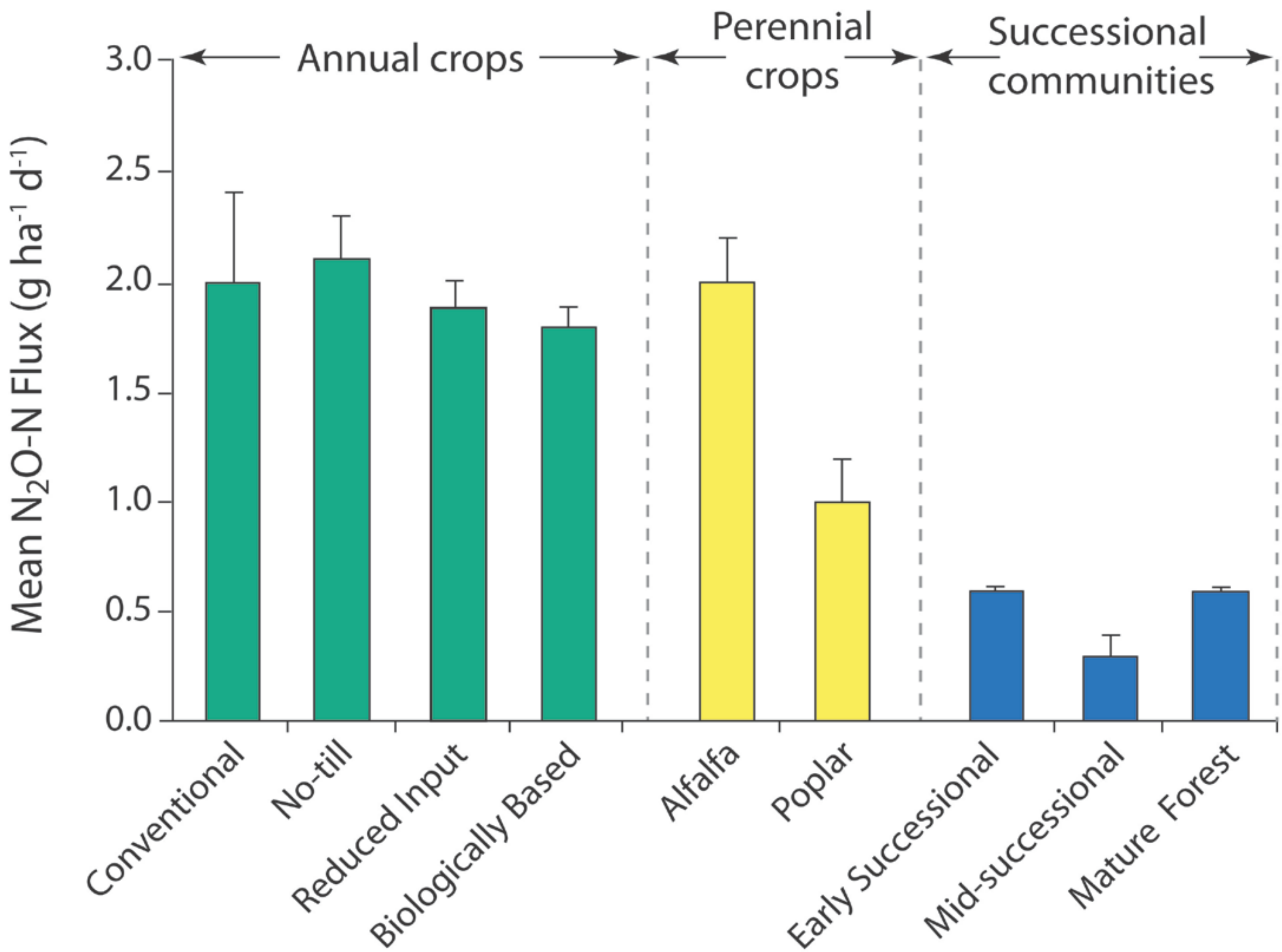
(compare to fossil fuel CO_2 loading = 4.1 Pg C per year)



- 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)



Source: Robertson et al. 2000 Science; Gelfand and Robertson 2014

Global Warming Impact of Field Crop Activities

	Soil-C	N-Fert	Fuel	Other Inputs	N_2O	CH_4	Net
				g CO_2-equiv / m^2/ y			
Annual Crops							
Conventional	0	33	13	19	37	-1	101

NB

a. Soil C is at equilibrium (no annual change)

b. N_2O is single largest source of GWP

c. Net impact >100 g CO_2-equiv / m^2/ y

Source: Gelfand et al. 2013 Nature; Gelfand and Robertson 2015

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Global Warming Impact of Field Crop Activities

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				g CO_2-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_2O) similar

c. Net impact is negative - mitigation

Source: Gelfand et al. 2013 Nature; Gelfand and Robertson 2015

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Global Warming Impact of Field Crop Activities

	Soil-C	N-Fert	Fuel	Other Inputs	N_2O	CH_4	Net
				g CO_2-equiv / m^2/ y			
Annual Crops							
Conventional	0	33	13	19	37	-1	101
No-till	-122	33	9	28	39	-1	-14
Biologically Based	-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_2O benefit

c. Net impact is very negative – net mitigation

Source: Gelfand et al. 2013 Nature; Gelfand and Robertson 2015

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Global Warming Impact of Field Crop Activities

	Soil-C	N-Fert	Fuel	Other Inputs	N_2O	CH_4	Net
				g CO_2-equiv / m^2/ y			
Annual Crops							
Conventional	0	33	13	19	37	-1	101
No-till	-122	33	9	28	39	-1	-14
Biologically Based	-183	0	20	8	32	-1	-124
Successional Communities (Unmanaged)							
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_2O fluxes low throughout (low nitrate availability)

c. Net impact high early, neutral late

Source: Gelfand et al. 2013 Nature; Gelfand and Robertson 2015

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Net Global Warming Impact of Cropped and Successional Ecosystems at KBS

Source: Gelfand et al. 2013 Nature; Gelfand and Robertson 2015

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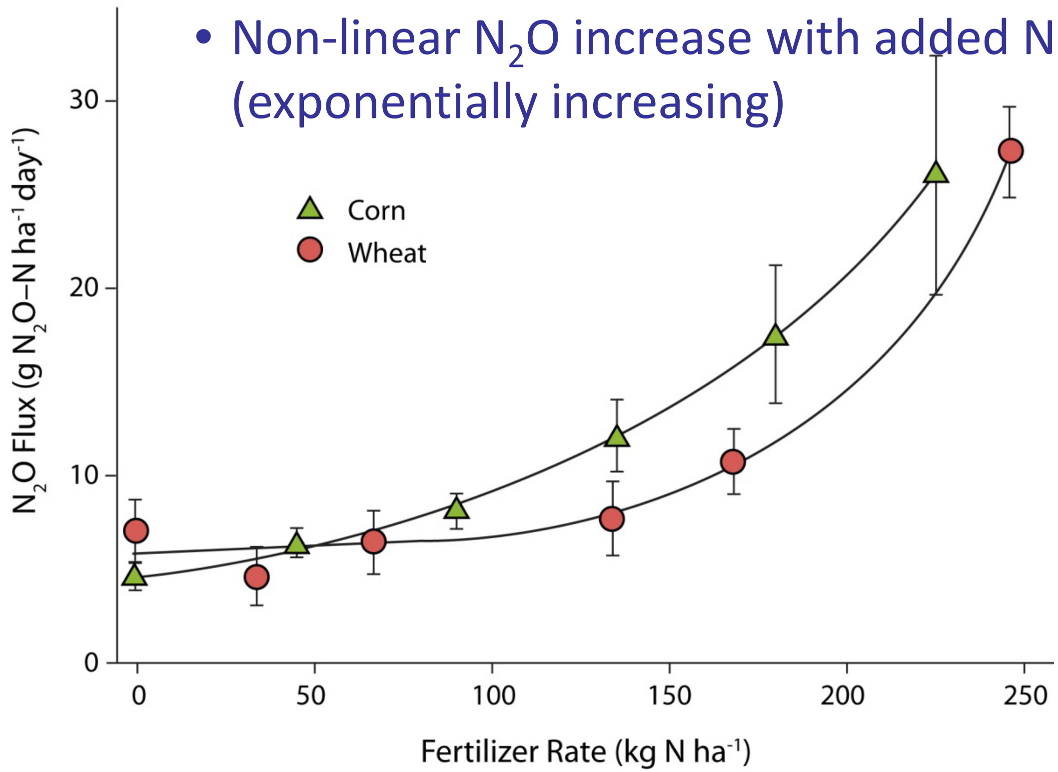
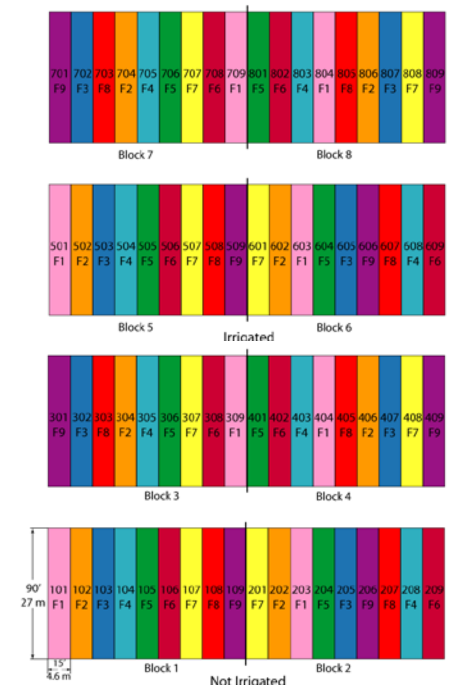
N_2O fluxes are strongly affected by nitrogen fertilizer inputs

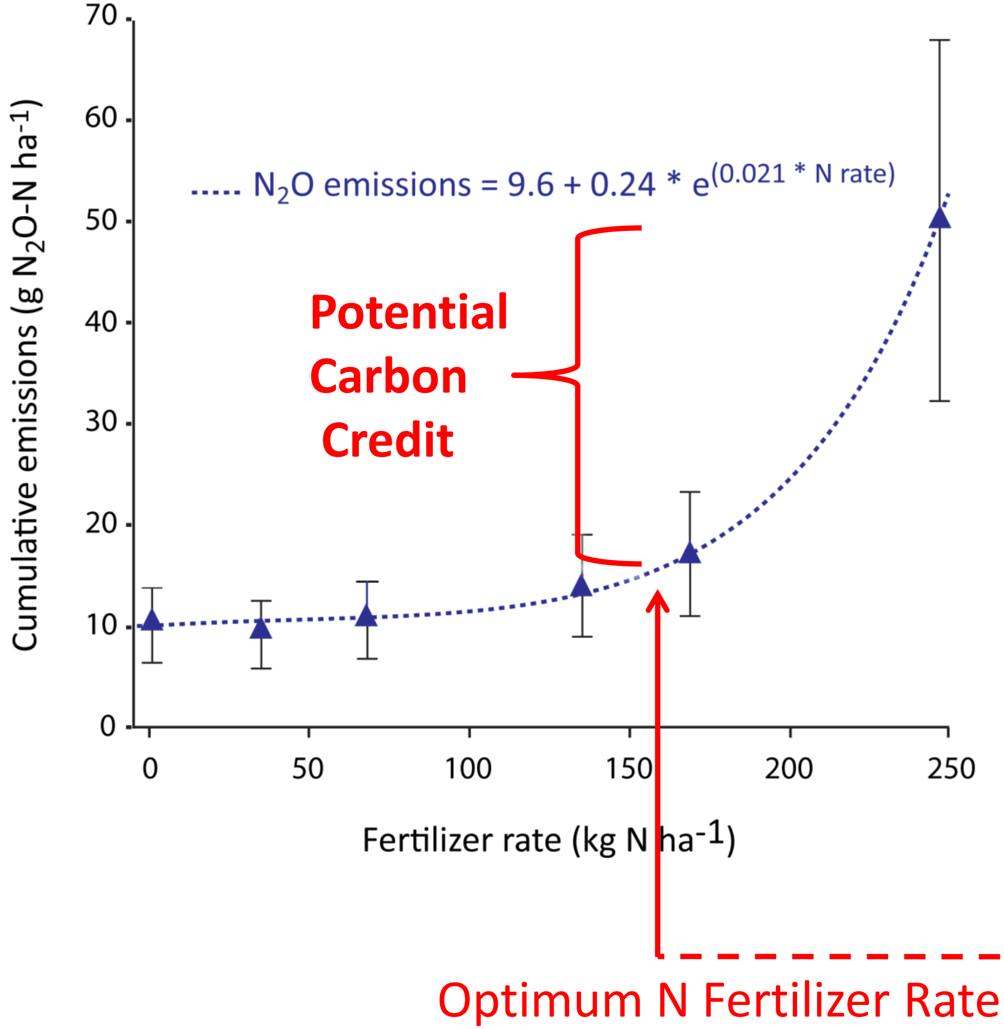
- Non-linear N_2O increase with added N (exponentially increasing)



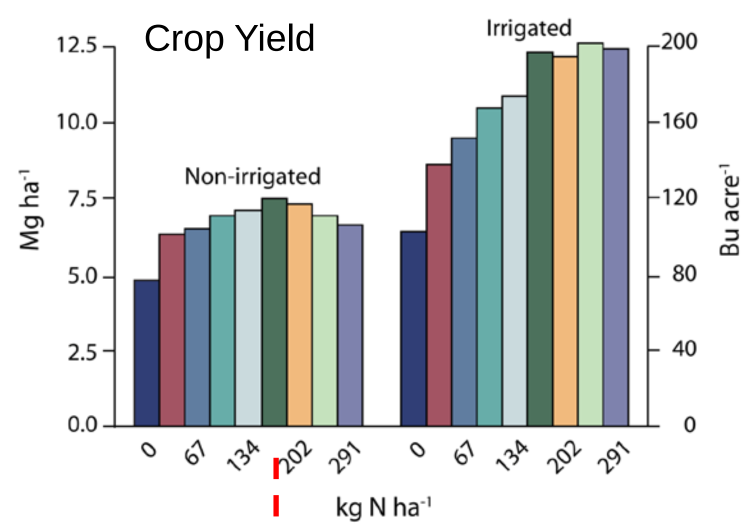


Millar and Robertson 2015

Combined, this translates to a significant potential carbon credit

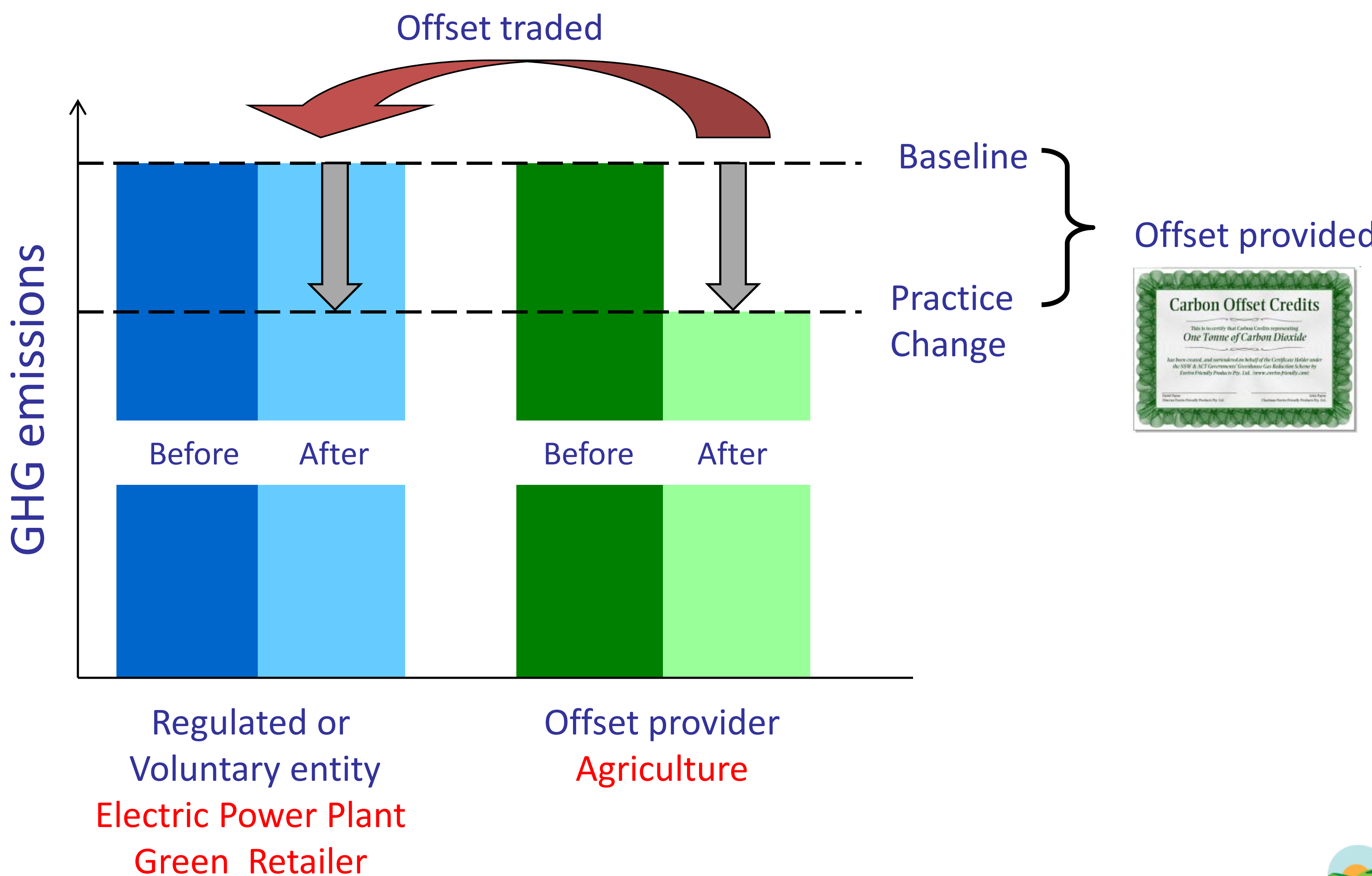


- Emissions factors vary with N-rate – especially above crop optimum

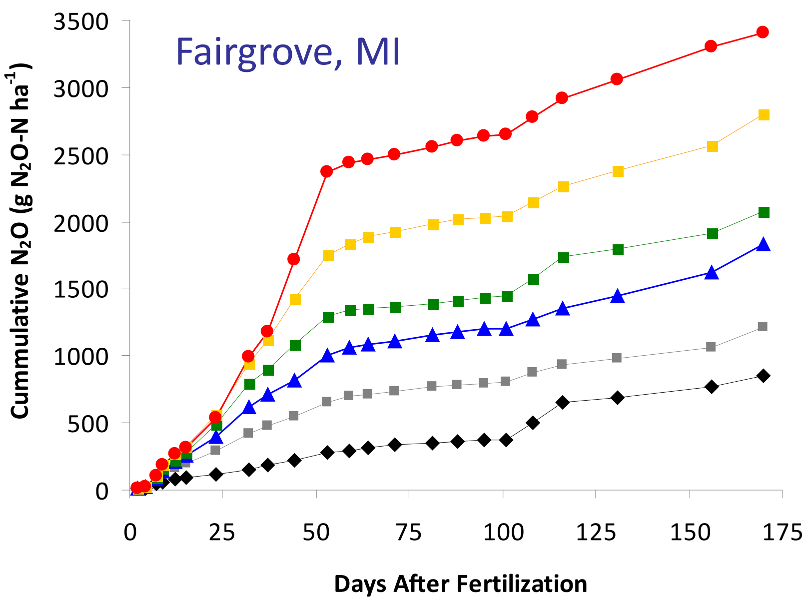


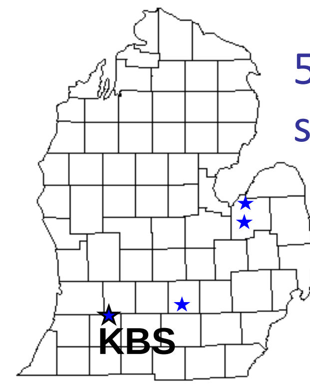
Millar et al., in review

Carbon Trading and Offsets

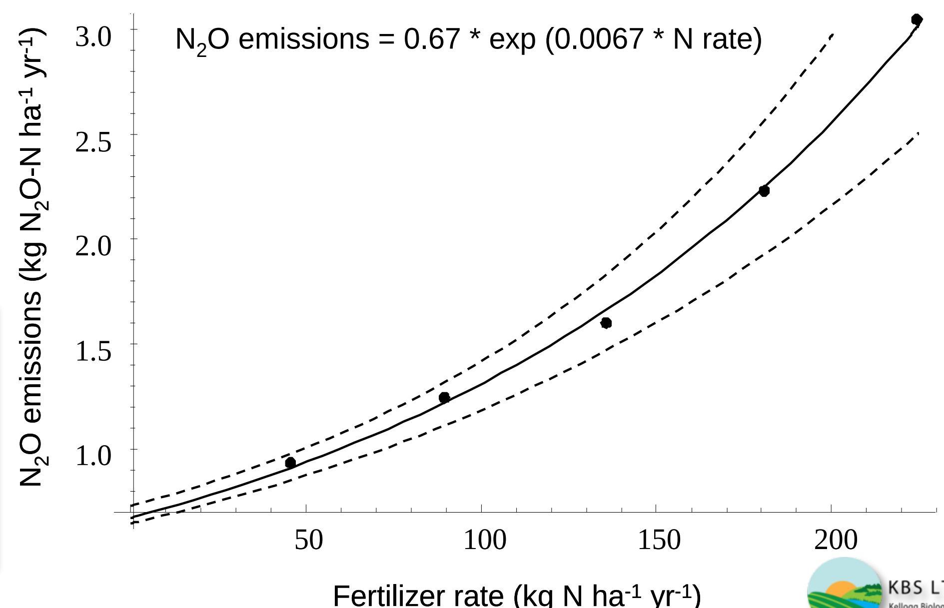


Cross-state test of non-linear N_2O response to N-fertilizer





5 commercial corn-soybean farms



Hoben et al., 2011, Global Change Biology

MSU-EPRI Nitrous Oxide Reduction Protocol

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CLIMATE ACTION RESERVE

Pays farmers for applying nitrogen fertilizer more precisely

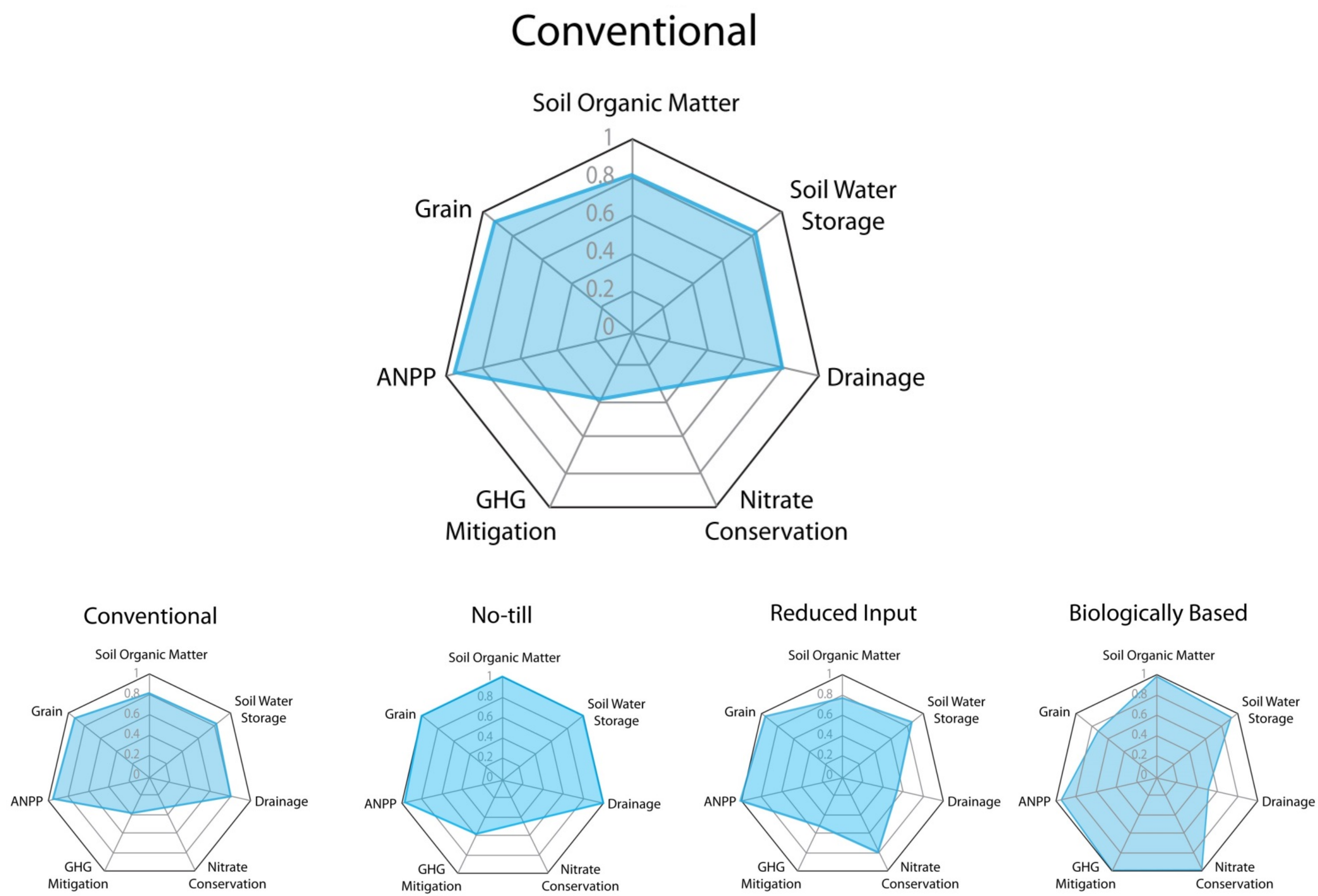
- Reduces agricultural greenhouse gases
- Reduces reactive nitrogen in environment (including nitrate)
- Incentivizes conservation using current and new technology

Current Status

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

Source: Millar et al., 2012, 2013

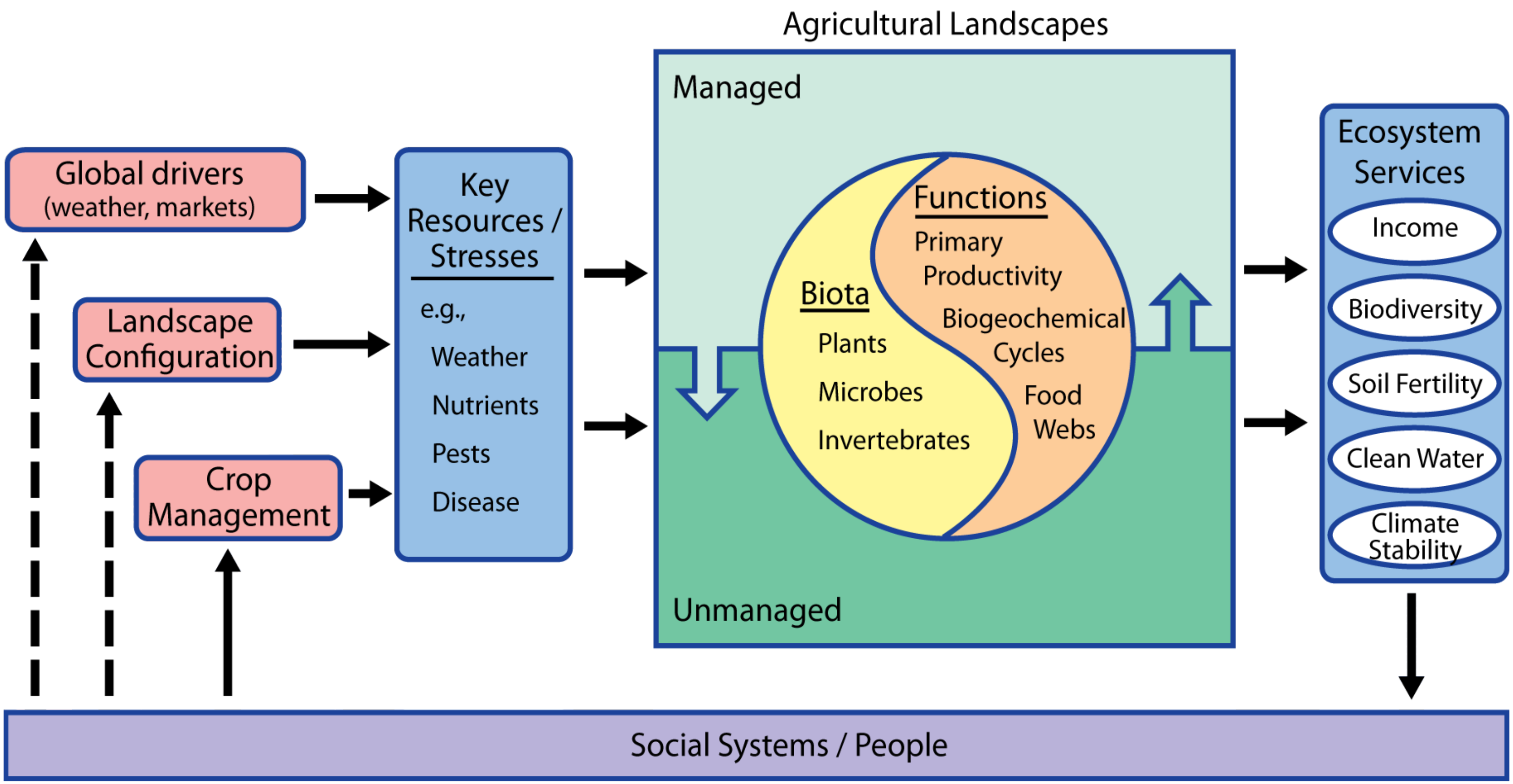
Integrating Ecosystem Services to Optimize Systems



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

Where we're headed

A provisional conceptual model for the KBS LTER future



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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

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