Biofuels and Agricultural Sustainability

Cellulosic Biofuels
and Ecosystem Services

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GLBRC
Great Lakes Bioenergy Research Center

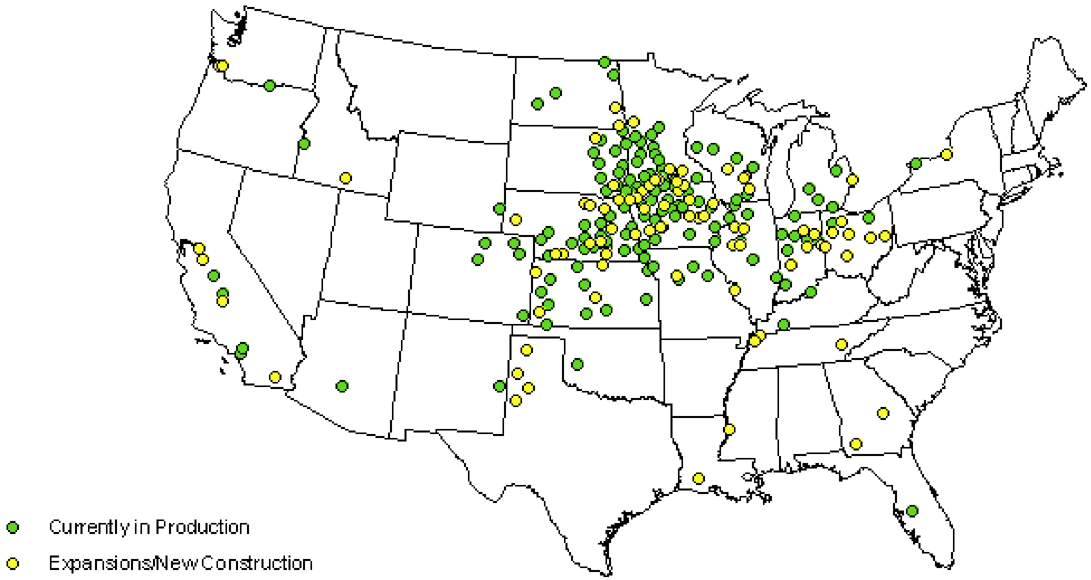
Legislated Biofuel Goals

- U.S. Energy Policy Act of 2007
  22% of transportation fuel mix in 2022
  - 36 billion gallons ethanol
    - 15 billion gallons of grain-based ethanol
    - 16-21 billion gallons of cellulosic ethanol
- European Union
  - 20% renewable energy by 2020
  - 10% of transport fuels by 2020

Corn Grain Ethanol - Current Status

	Existing Plants	Capacity bgal yr	New Plants	Production bgal yr	Capacity bgal yr
2006	109	5.3	65	4.8	9.1
2007	135	7.3	76	6.4	13.5
2008				9.1_{est}	
2022				15*	

*** US Energy Policy Act of 2007**



From K. Thelen; source: CARD, 2008 (www.card.iastate.edu/research/bio/tools/ethanol.aspx); USDA 2008; DOE 2008; RFA 2009

Legislated Biofuel Goals

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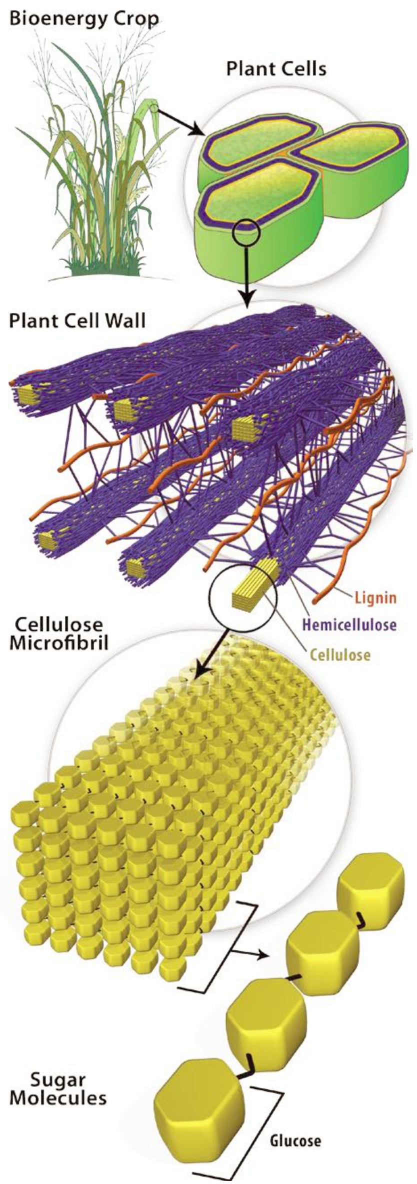
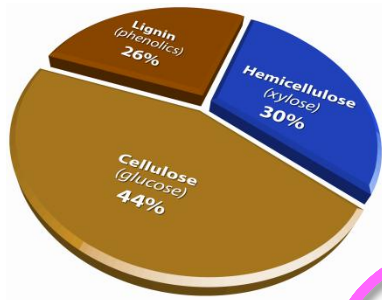
Ethanol Production from cellulose





DOE; http://genomics.energy.gov

A diversity of production systems

environmental performance?

High Diversity

Restored prairie

Early successional

Poplar trees

Native grasses

Switchgrass

Miscanthus

Corn-Soybean-Canola

Corn

Low Diversity

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  22% of transportation fuel mix in 2022
  - 36 billion gallons ethanol
    - 15 billion gallons of grain-based ethanol
    - 21 billion gallons of cellulosic ethanol
- 2008 Farm Bill
  - $1.01 / gallon subsidy for cellulosic ethanol
  - $45 / ton of cellulosic feedstock

How much cellulosic biomass is needed?

Time period	EtOH	Biomass required[1]
Today (2007)	0 bgal	0
Tomorrow (2022)[2]	21 bgal	266 MMT
Future (2050)[3]	80 bgal	1,013 MMT

[1] 0.3 L ethanol / kg biomass
[2] Energy Policy Act of 2007
[3] USEPA, NRDC 2050 scenarios

Compare to

- 110 x 10^6 MT corn stover of 196 x 10^6 MT available[4]
- 106 x10^6 MT industrial wood waste[5]

Leaving

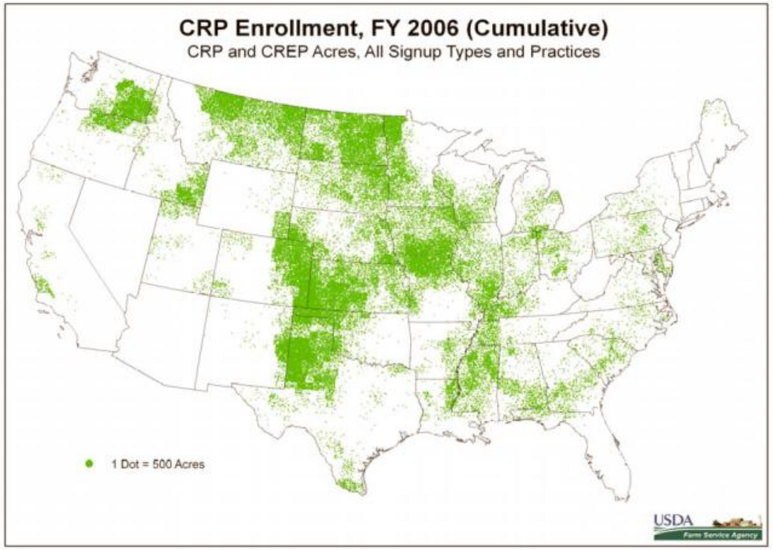
- ~800 MMT to be grown

[4] Graham et al. 2007 Agron J 99:1-11
[5] Perlack et al. 2005 Technical *feasibility of a billion-ton annual supply*. DOE.

How much land?

- Land Requirements for 800 x 10^6 MT biomass
  - Switchgrass today[1] at 8 (6-9) MT/ha = 100 x 10^6 ha

- Compare to
  - 180 x 10^6 ha cropland
  - 240 x 10^6 ha range, grasslands
  - 15 x 10^6 ha CRP



[1] Schmer et al. 2008 *PNAS* 105:464-468

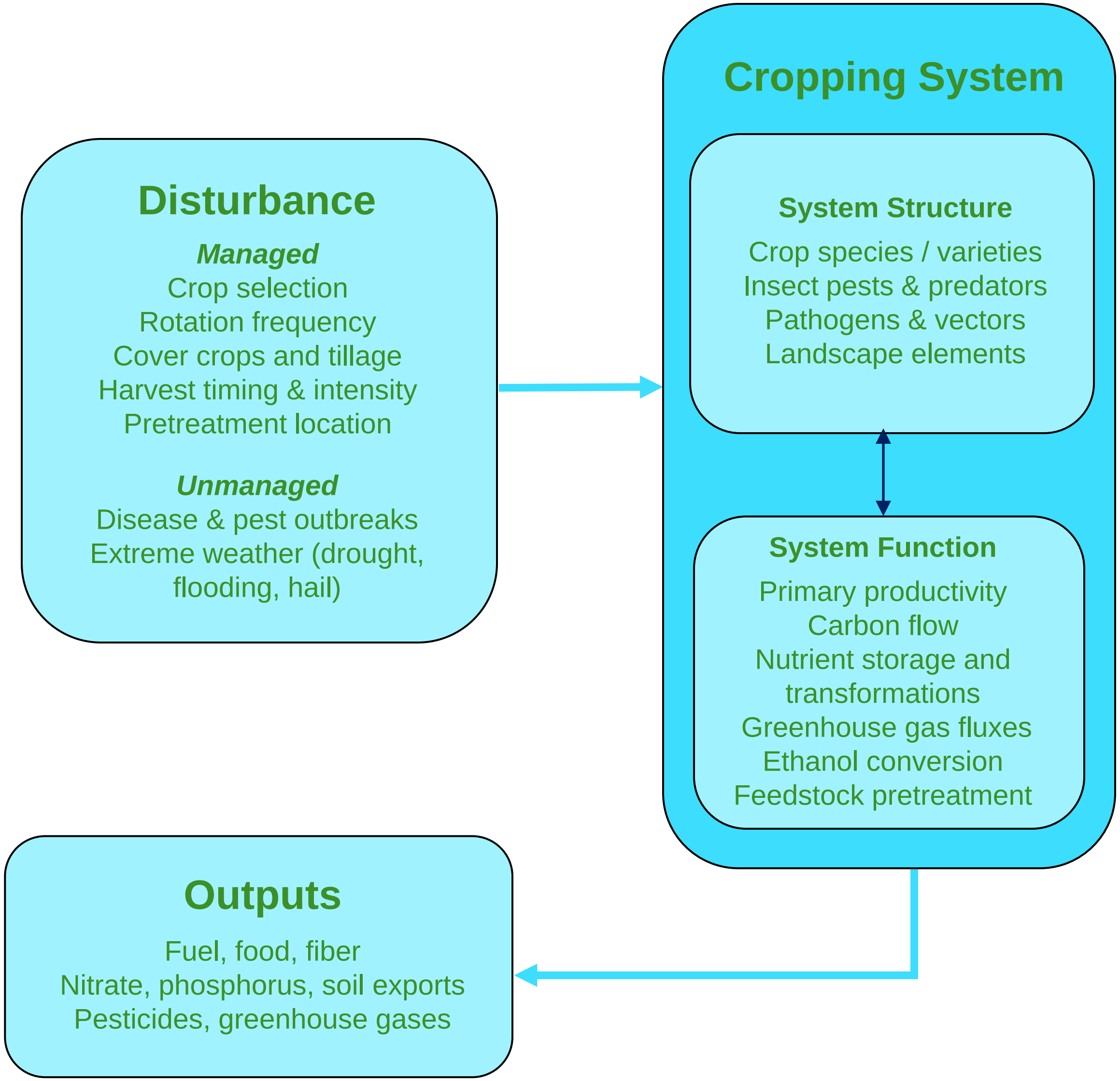
Elements of Biofuel Sustainability

- Economic
  - ✓Profitable

- Environmental
  - ✓Carbon negative (climate stabilizing)
  - ✓Nutrient, water conservative
  - ✓Biodiversity benefits

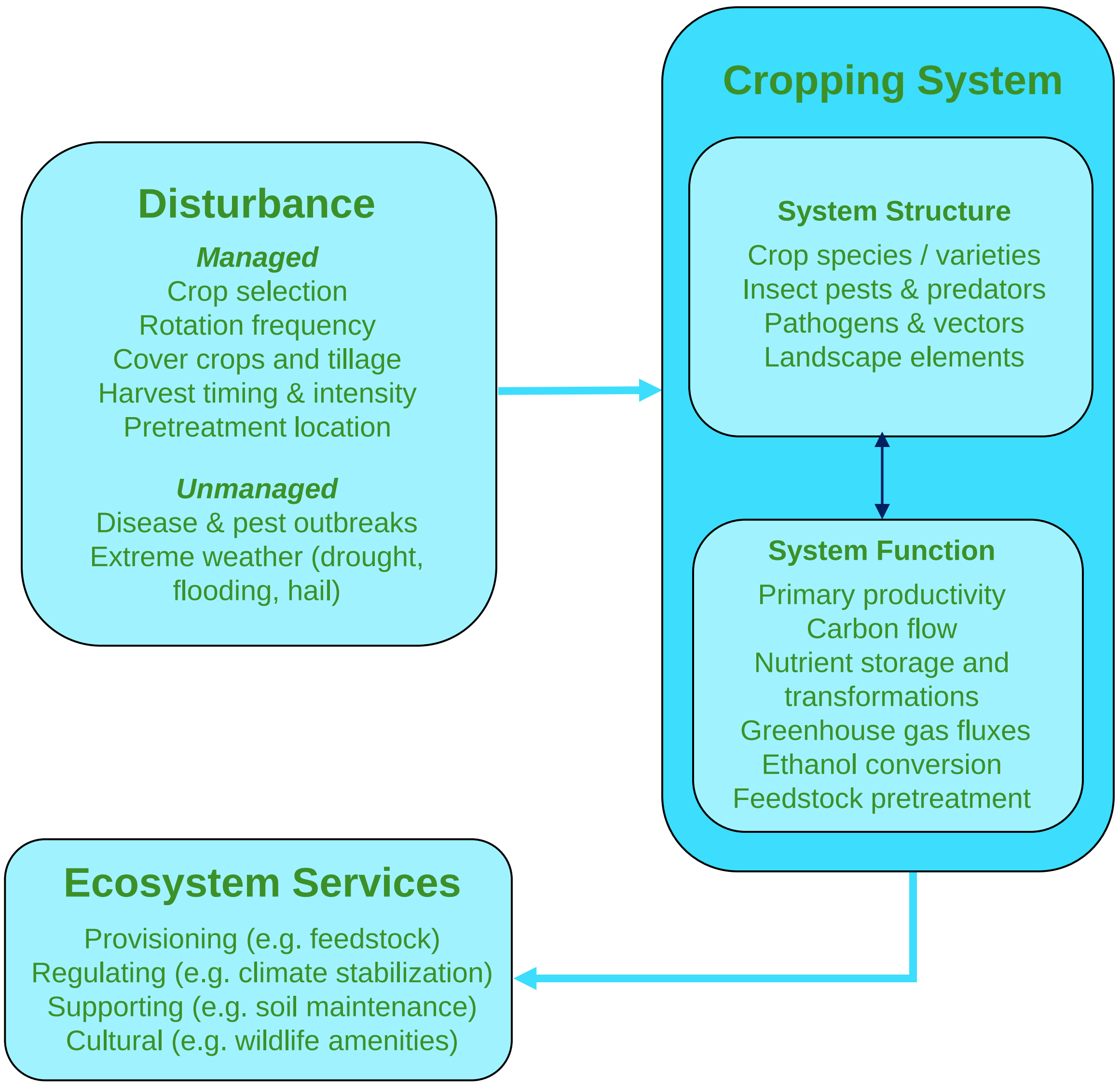
- Social
  - ✓Food, energy security
  - ✓Rural community health

A traditional framework for understanding biofuel systems



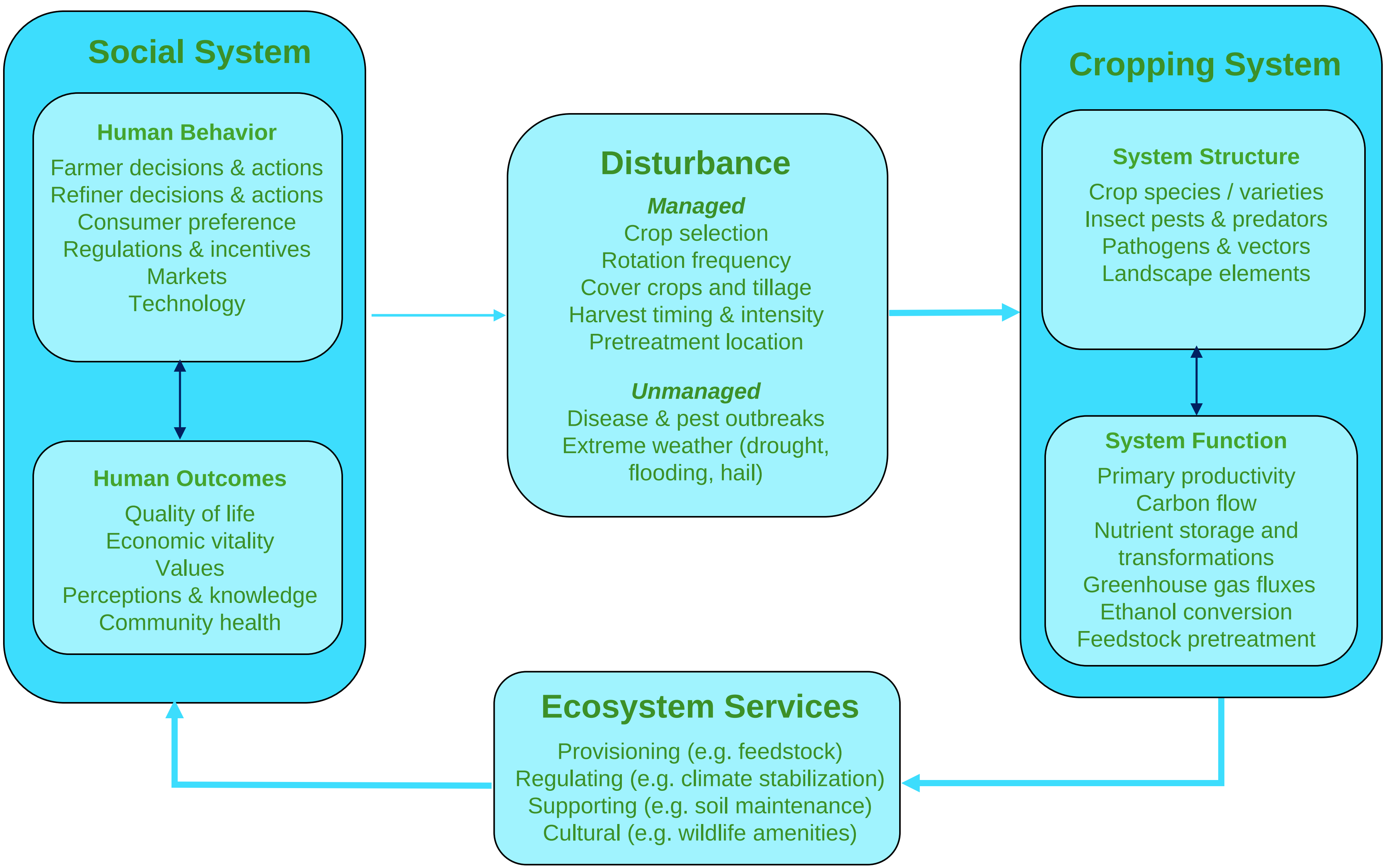
Robertson et al., in prep; After S. Collins et al. 2007

A traditional framework for understanding biofuel systems



Robertson et al., in prep; After S. Collins et al. 2007

A Socio-Ecological Framework for Biofuel Systems



Robertson et al., in prep; After S. Collins et al. 2007

Managing for multiple services is crucial for meeting societal expectation for biofuel crops

Stackable Services?

Provisioning Services

- Cellulosic feedstocks
- Food and forage production
- Surface and ground water

Regulating Services

- CO_2 Stabilization
- Pest and disease suppression
- Soil nutrient delivery

Cultural services

- Recreational opportunities
- Aesthetic attributes
- Cultural and heritage amenities

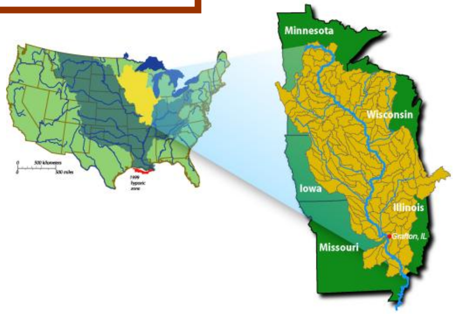
Corollary: There will be tradeoffs….

After Millennium Ecosystem Assessment 2005

Tradeoffs: Multiple environmental benefits from a uniform subsidy

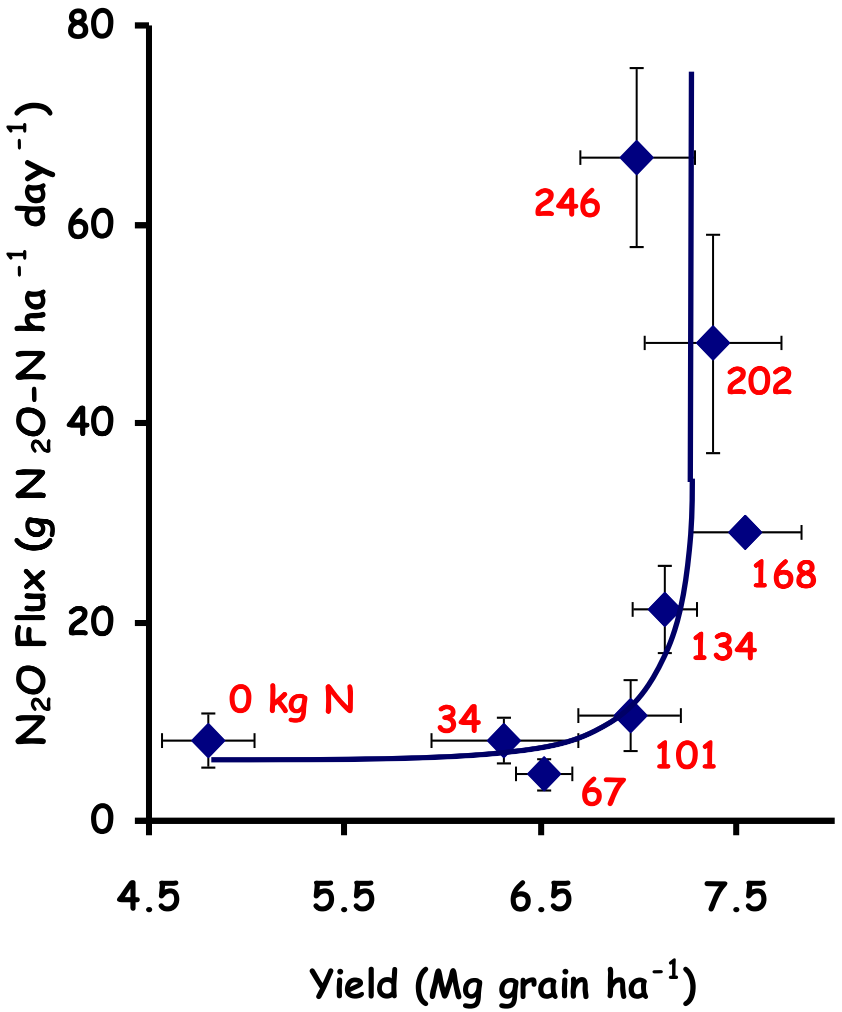
	Benefit Targeted			
Benefit gained	Carbon	Erosion	N Runoff	N Leaching
Carbon*	3.2	0.8	0.6	1.0
Erosion*	7.4	40.5	14.1	9.7
N Runoff**	2.8	5.1	11.7	2.8
N Leaching**	10.0	6.4	5.6	30.6

*Values expressed in million tons
**Values expressed in thousand tons



Source: Feng et al. 2007; *Climatic Change*

Complex Tradeoffs: N_2O flux vs. crop yield

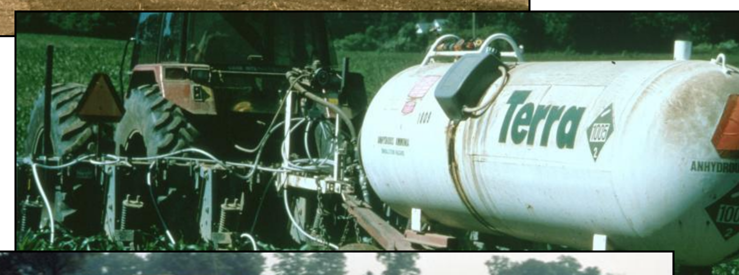


N_2O fluxes increase with crop yield but mainly at N-fertilizer rates greater than yield response

Millar et al. unpubl; McSwiney & Robertson, *Global Change Biology*, 2005.

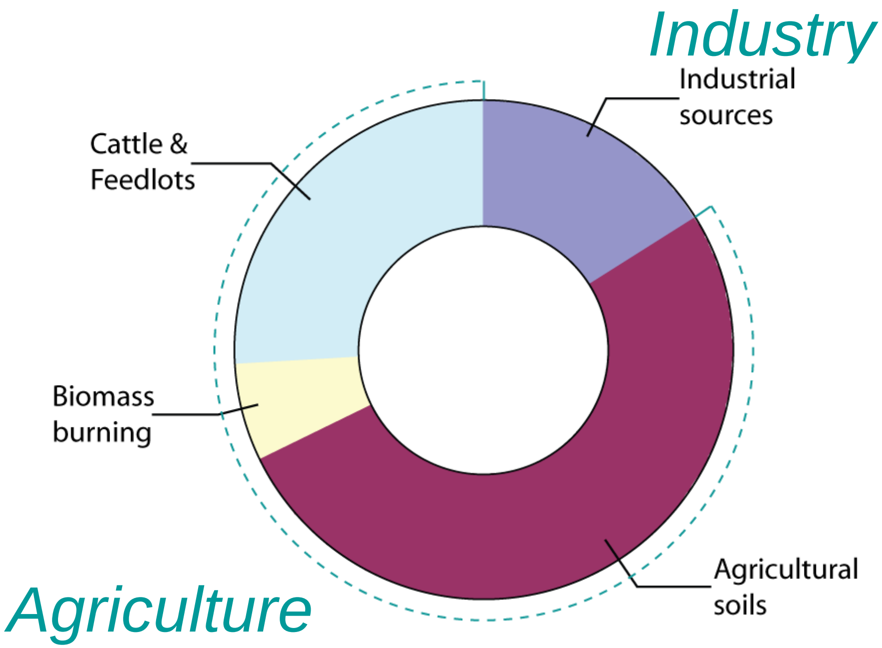
Major Potential Sources of Global Warming Impact (CO_2e) in Biofuel Cropping Systems

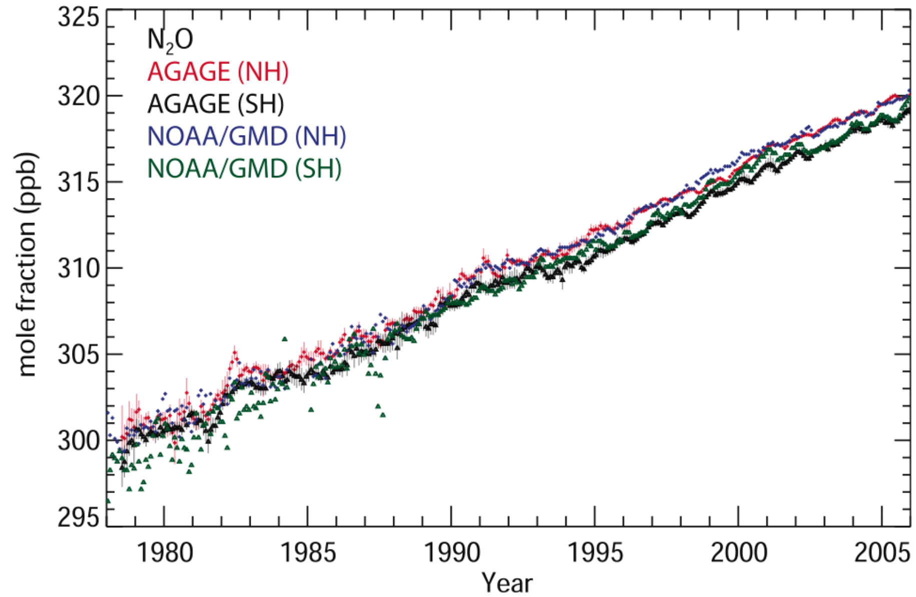
- Farm Operations
  - Fuel use
  - Fertilizer, pesticides
  - Lime ($CaCO_3$)
- Soil carbon change
- N_2O flux
- CH_4 oxidation
- Post-harvest transport
- Fuel Production (CO_2 offset)



Nitrous Oxide

Global Anthropogenic Sources





Total Annual Impact 1.2 Pg C_{equiv} (compare to fossil fuel loading = 4.1 Pg C)

Source IPCC 2001, 2007; Prinn 2004; Robertson 2004

Global Warming Potential (GWP)
Biogenic Gases

	Lifetime yr	Global Warming Potential 20 yr	100 yr	500 yr
CO_2	variable	1	1	1
CH_4	12	62	23	7
N_2O	114	275	296	156

Source: IPCC 2002; 2007

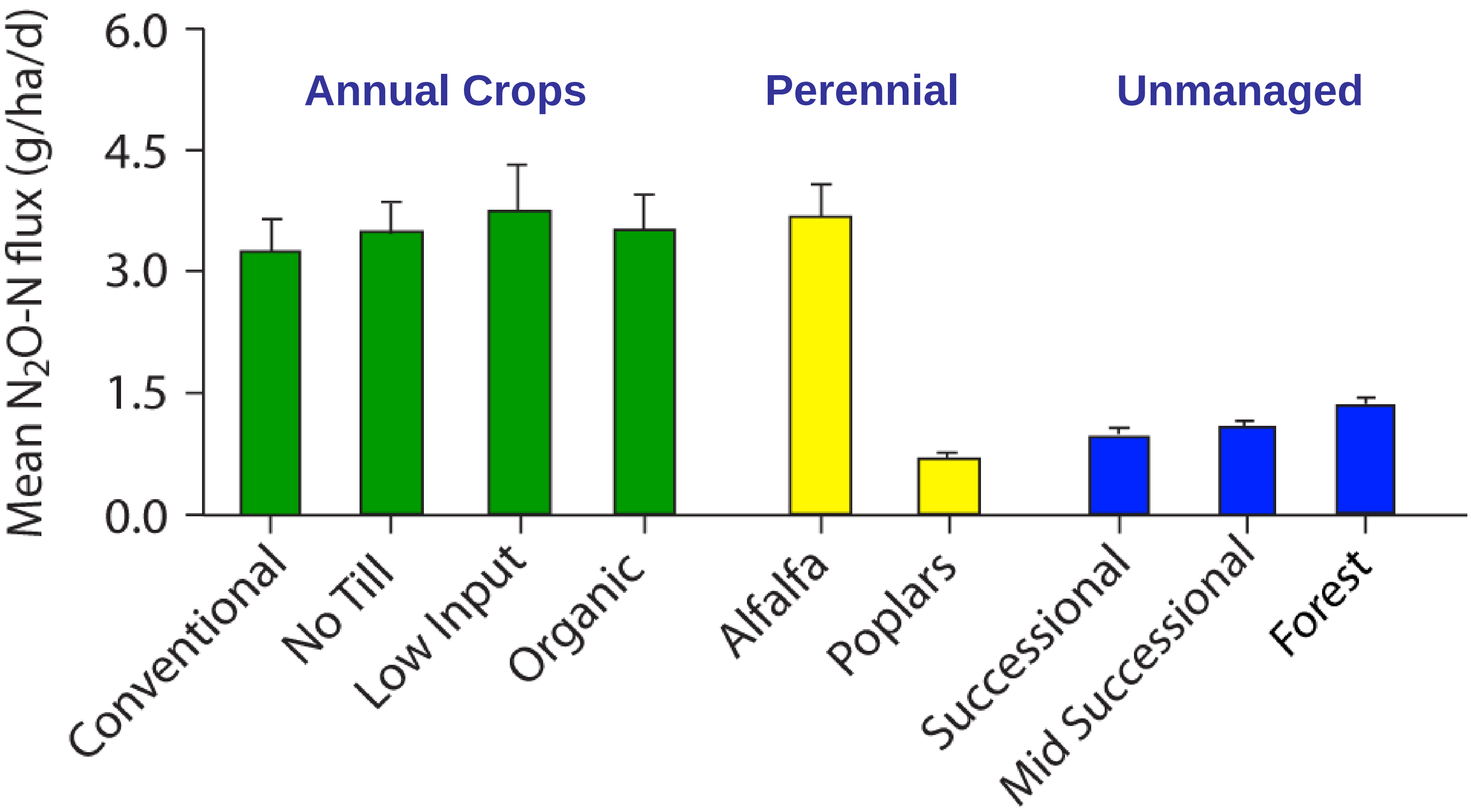
KBS Long-Term Ecological Research (LTER) Site

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





Nitrous Oxide Fluxes at KBS (1992-2007)



Robertson et al. 2000; Grandy et al. 2006 *JEQ; and Parr et al. in prep.*

GWP Impact for Field Crop Activities

	Farming	N_2O	CH_4	Soil C Δ	Fuel Offset (farm gate)	Trans-port	Net
Conventional grain/stover	46	56	-1.5	0	-641	13	-527

N_2O is largest source of CO_2e

Soil carbon is at equilibrium (no annual change)

Includes 50% of corn stover

All values = g CO_2 m^{-2} y^{-1} for 1992-2007

GWP Impact for Field Crop Activities

	Farming	N_2O	CH_4	Soil C Δ	Fuel Offset (farm gate)	Trans-port	Net
Conventional grain/stover	46	56	-1.5	0	-641	13	-527
No-till grain/stover	45	60	-1.8	-66	-606	12	-557

No change in N_2O

Soil carbon gain; offsets N_2O

Greater overall mitigation

All values = g CO_2 m^{-2} y^{-1} for 1992-2007

GWP Impact for Field Crop Activities

	Farming	N_2O	CH_4	Soil C Δ	Fuel Offset (farm gate)	Trans-port	Net
Conventional grain/stover	46	56	-1.5	0	-641	13	-527
No-till grain/stover	45	60	-1.8	-66	-606	12	-557
Alfalfa	31	56	-2.2	-186	-539	11	-618

Lower farming cost (no fertilizer)

Greater soil C gain

All values = g CO_2 m^{-2} y^{-1} for 1992-2007

GWP Impact for Field Crop Activities

	Farming	N_2O	CH_4	Soil C Δ	Fuel Offset (farm gate)	Trans-port	Net
Conventional grain/stover	46	56	-1.5	0	-641	13	-527
No-till grain/stover	45	60	-1.8	-66	-606	12	-557
Alfalfa	31	56	-2.2	-186	-539	11	-618
Early succession	3	22	-2.2	-339	-300	6	-610

Little farming cost (harvest only)

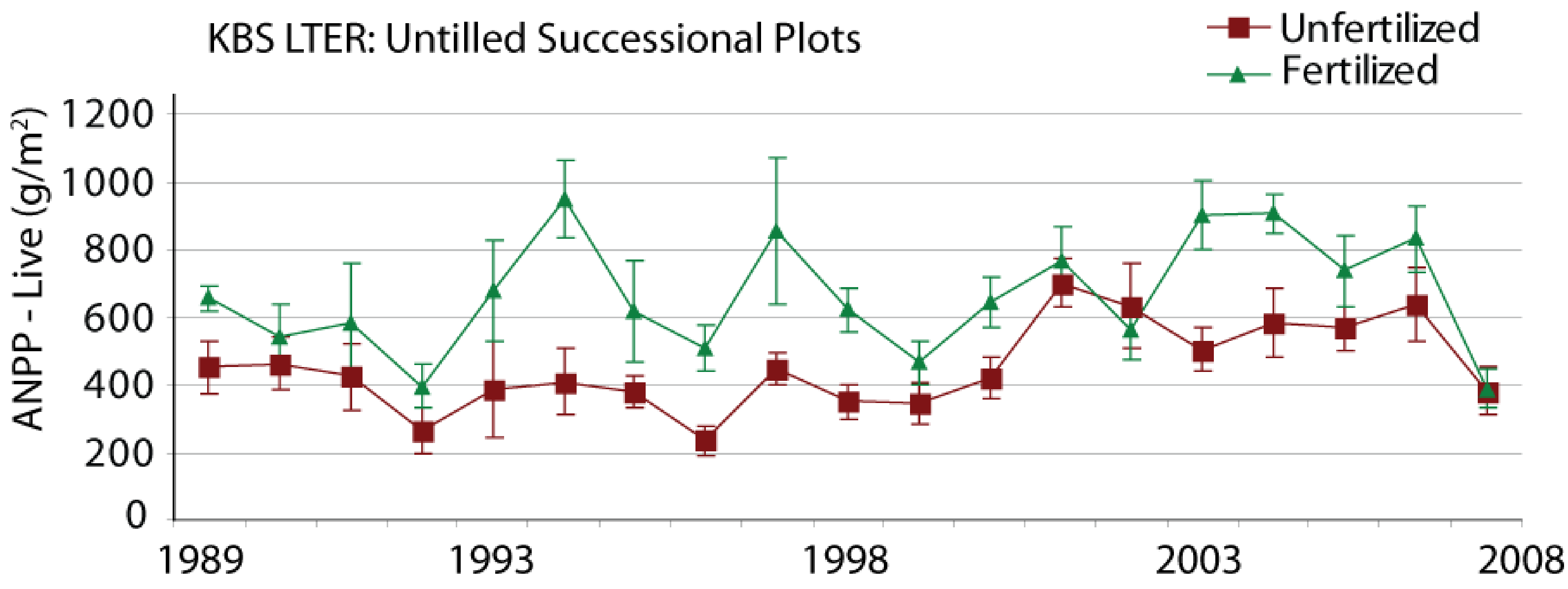
Large N_2O drop

Large SOC gain

Less biomass

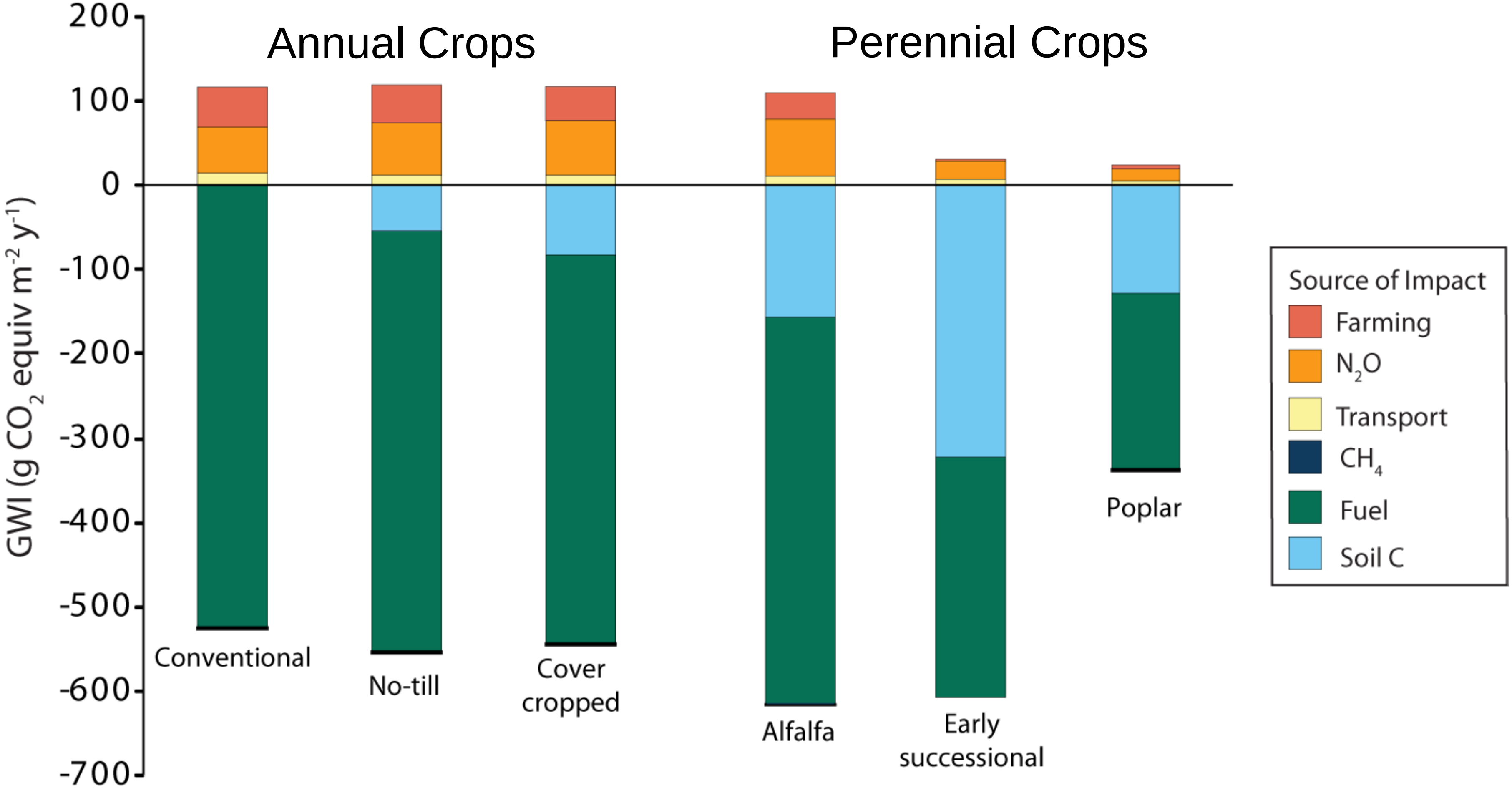
Same net

Fertilized successional yields are similar to on-farm switchgrass yields



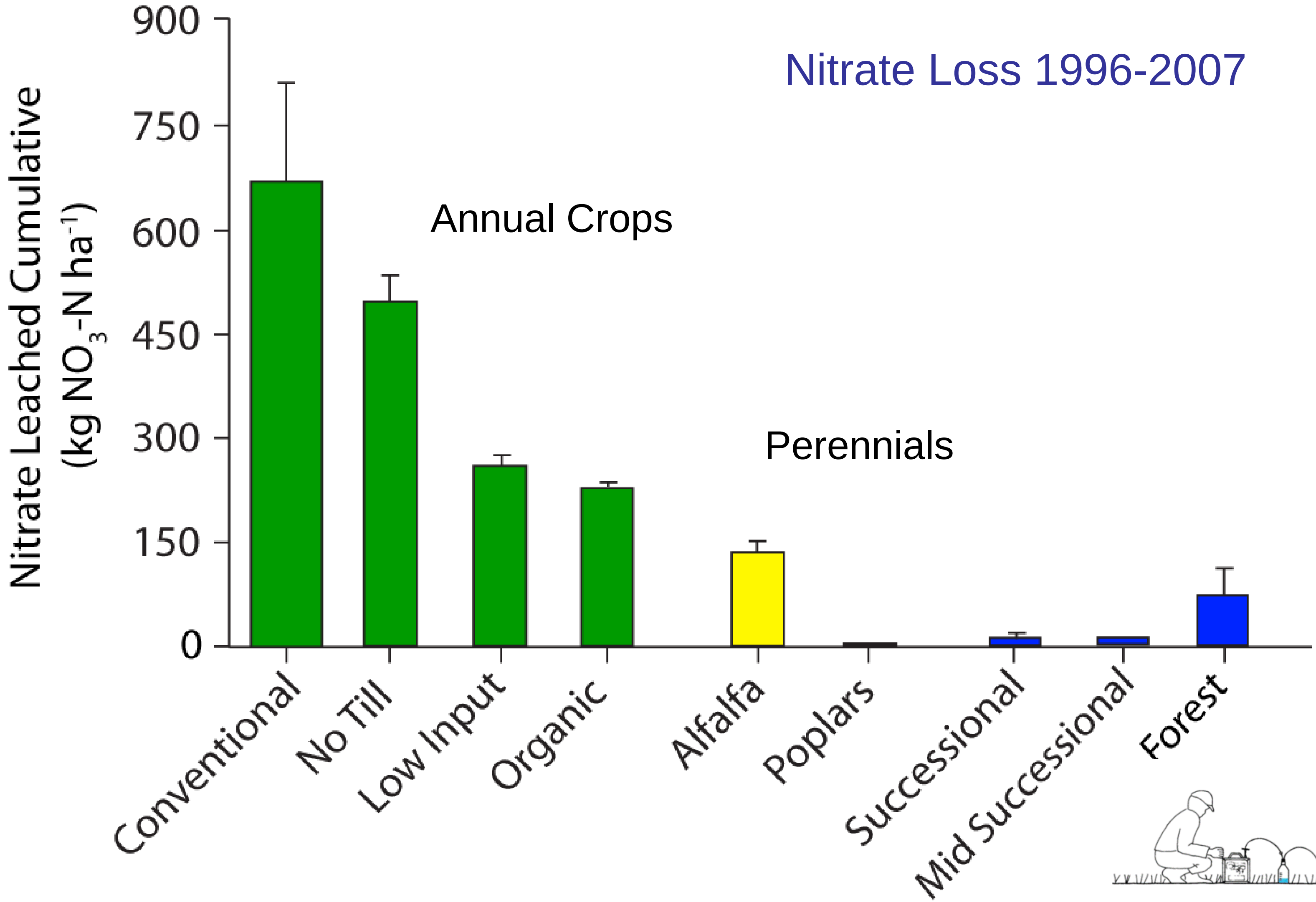
K.L. Gross et al., in prep.

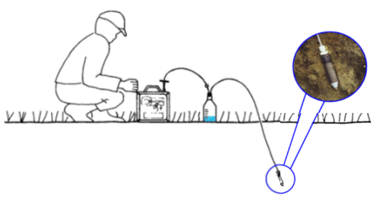
Global Warming Impact – KBS Field Crops



Missing: Indirect Land Use Costs

Other services: Nitrate Conservation

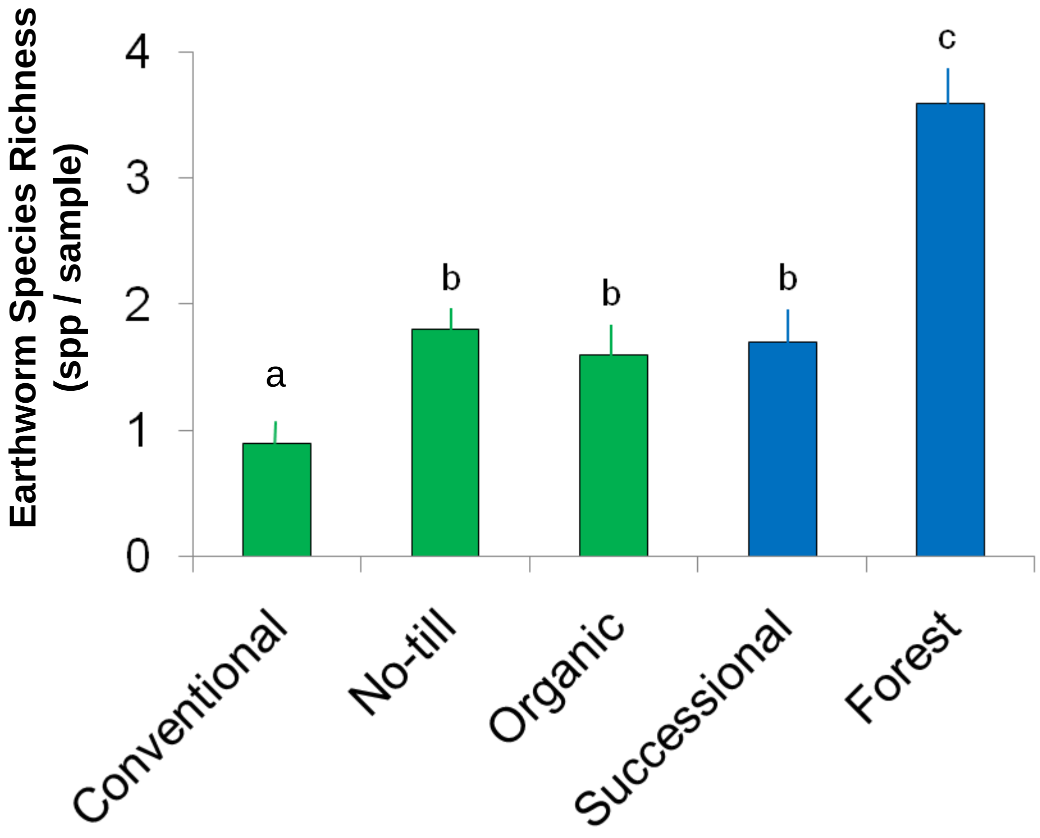




Source: Syswerda, et al. in prep.

Other services: Biodiversity

Darwin, C. 1881. The formation of vegetable mould, through the action of worms, with observations on their habits.

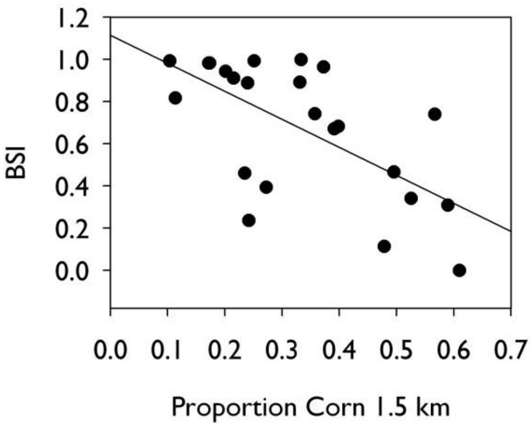


Smith et al. 2008 *Soil & Tillage Research* 100:83–88.

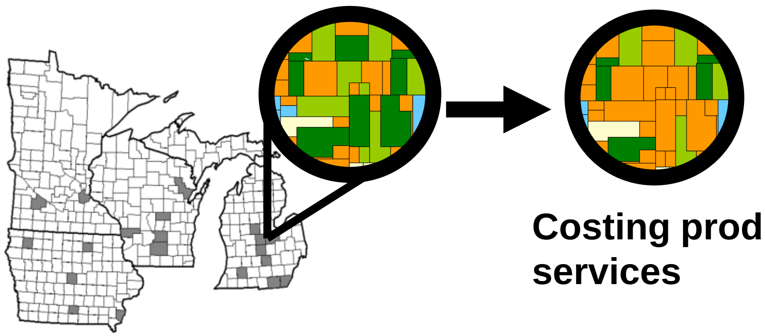
Other services: Biodiversity

Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes

Predators save soybean farmers \$13-79 acre^{-1} yr^{-1} in reduced pesticide applications and yield loss



Increased corn in the landscape reduces key predators and biocontrol services in soybean



Costing producers \$58 – 671 M yr^{-1} in forgone biocontrol services

(based on actual 2006-07 increase in corn in MI, MN, IA, WI)

Landis et al. 2008 PNAS 105:20552.

Conclusions: What do we know?

1. Land requirements are substantial (ca. 75-100 M ha US)
2. Outcomes that provide multiple benefits (ecosystem services) are possible
3. Best outcomes will depend on
   - Choice of crops (e.g. annual vs. perennial)
   - Management practices (residue return, fertilization rate, harvest intensity and timing, irrigation…)
   - Location – prior crop history
4. We know what's needed
   - Comprehensive science understanding at systems level, using a framework that includes human interactions
   - Willingness to incentivize environmental performance

Bird species with legal protection in Michigan

that were observed to breed in 2008 biofuel stands (n=30)

Northern harrier
(special concern)

Dickcissel
(threatened)

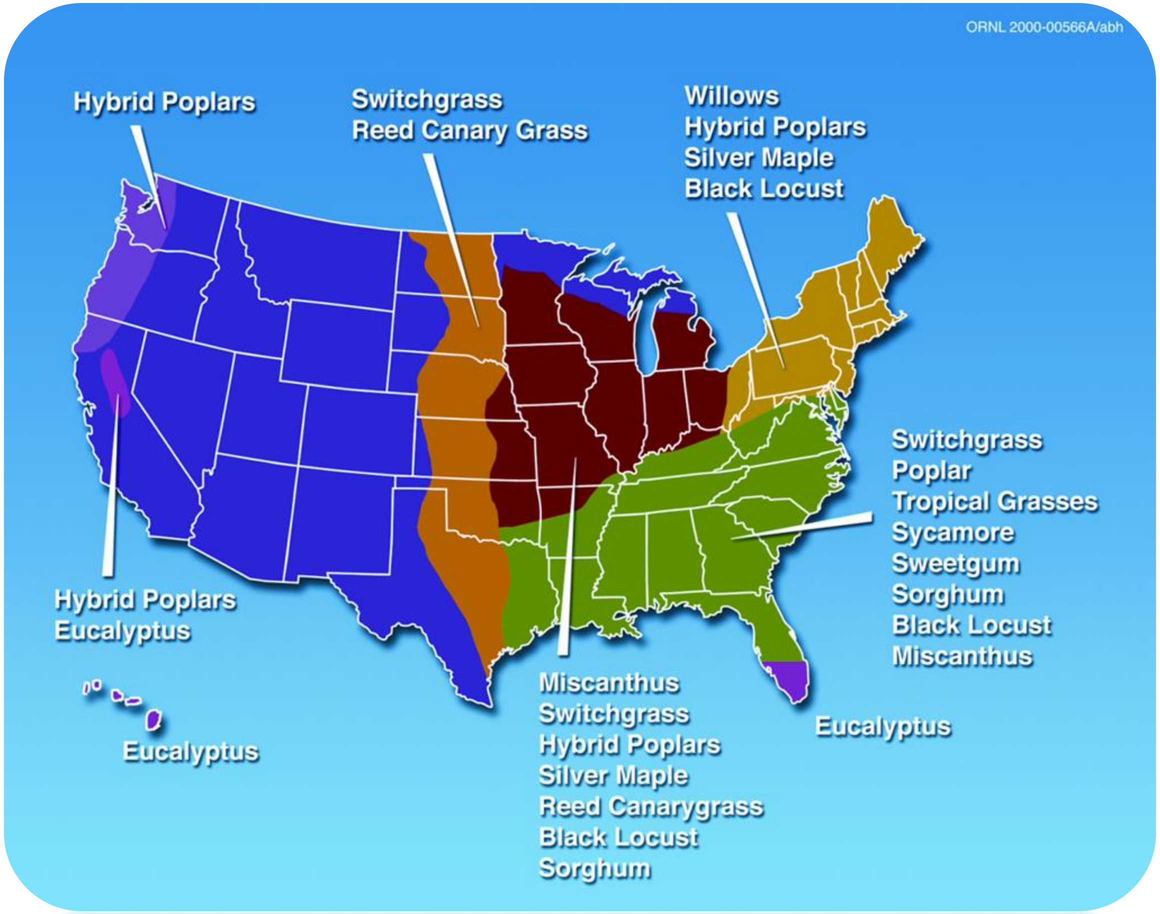
Henslow's sparrow
(threatened)

Grasshopper sparrow
(special concern)

	Northern harrier (special concern)	Dickcissel (threatened)	Henslow's sparrow (threatened)	Grasshopper sparrow (special concern)
Corn	-	-	-	-
Switchgrass	-	-	-	+
Prairie	+	+	+	+

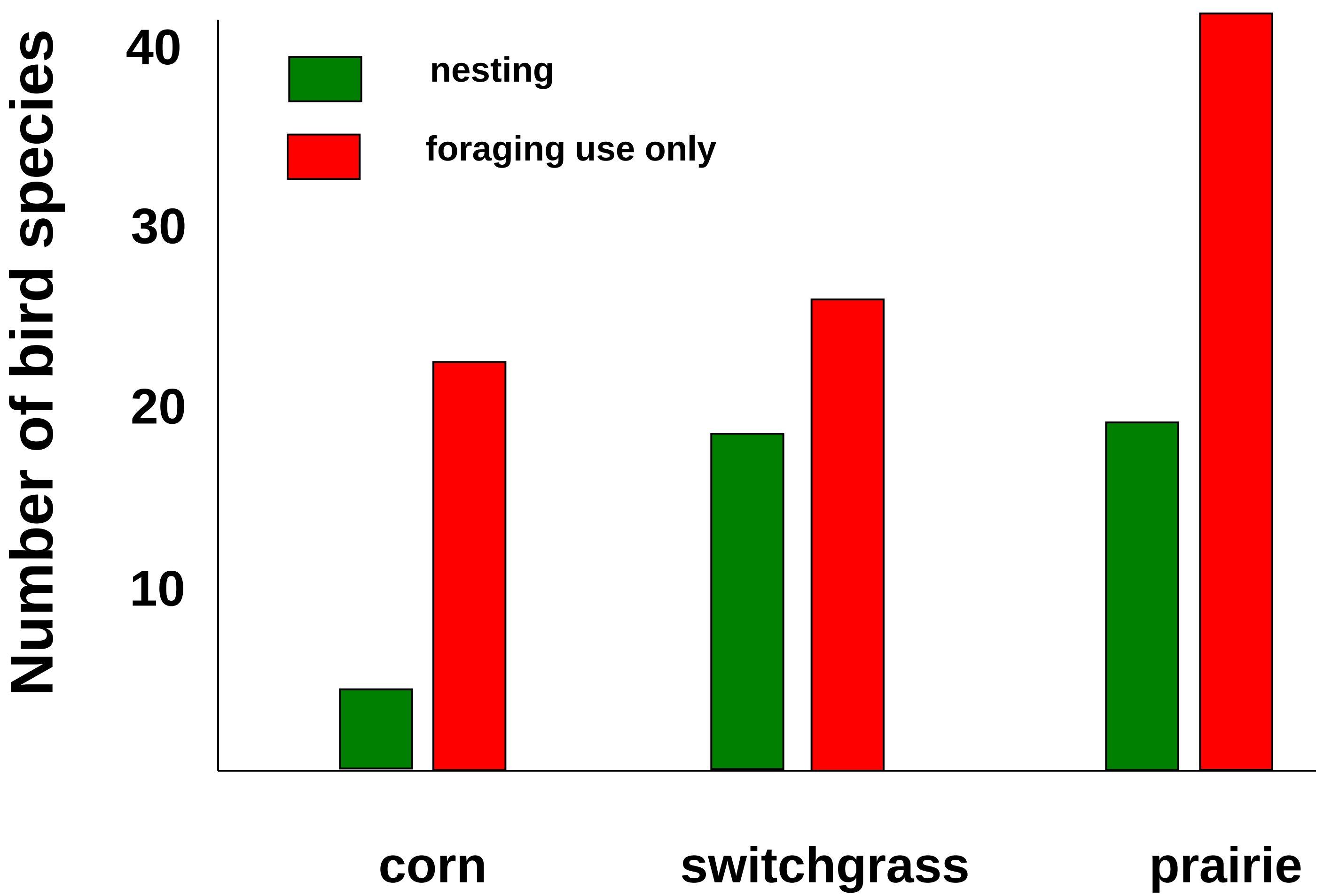
(B. Robertson, D. Schemske, D. Landis 2009, unpbubl.)

Geographic Distribution of Biomass Crops



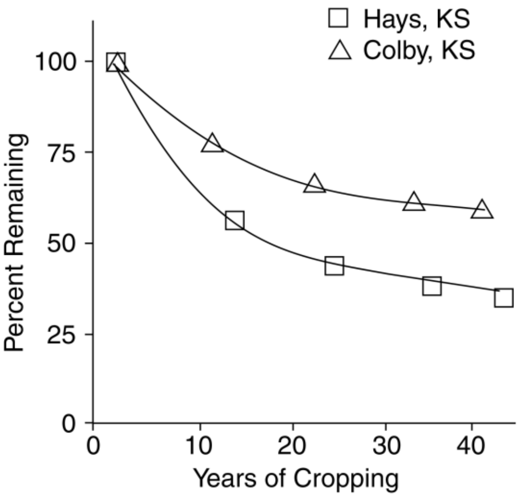
U.S. DOE. 2006. Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda, DOE/SC/EE-0095, U.S. Department of Energy Office of Science and Office of Energy Efficiency and Renewable Energy, http://genomicsgtl.energy.gov/biofuels/.

Bird diversity and biofuel production systems

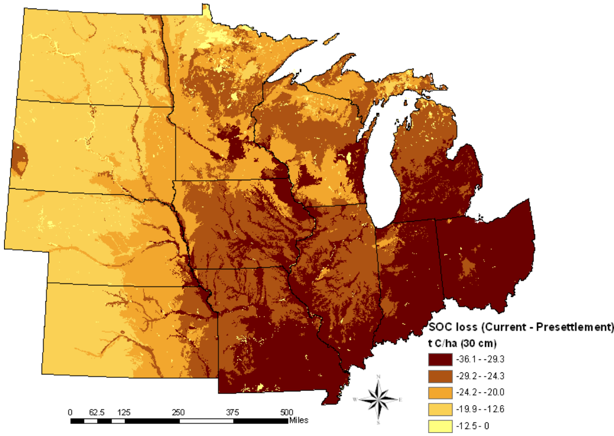


Historical Soil Carbon Loss from Cropping Systems

- 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 Pg C y^{-1}
  - Increasing C inputs (crop residues, cover crops)
  - Slowing decomposition (no-till)



Haas et al. 1957



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