Lifecycle impacts of 1st and 2nd generation biofuels: Technical and environmental challenges

Biofuels in the Midwest: A Discussion

The Joyce Foundation

Chicago, IL

September 6, 2008

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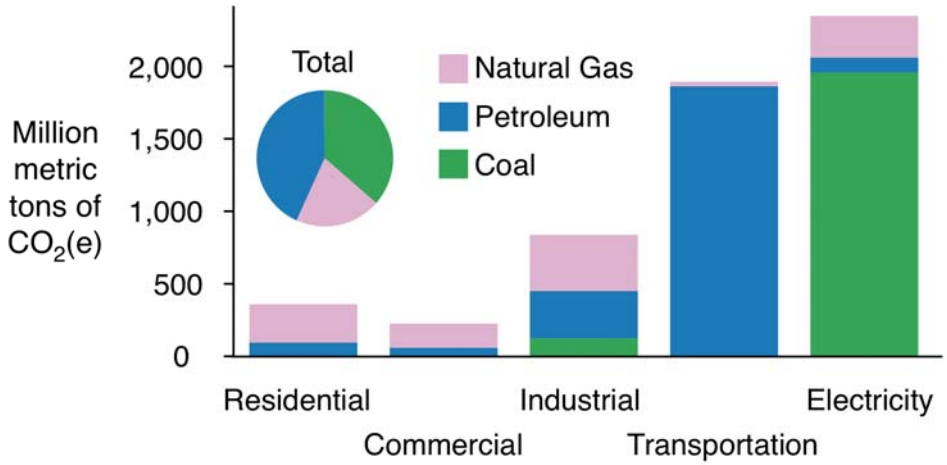
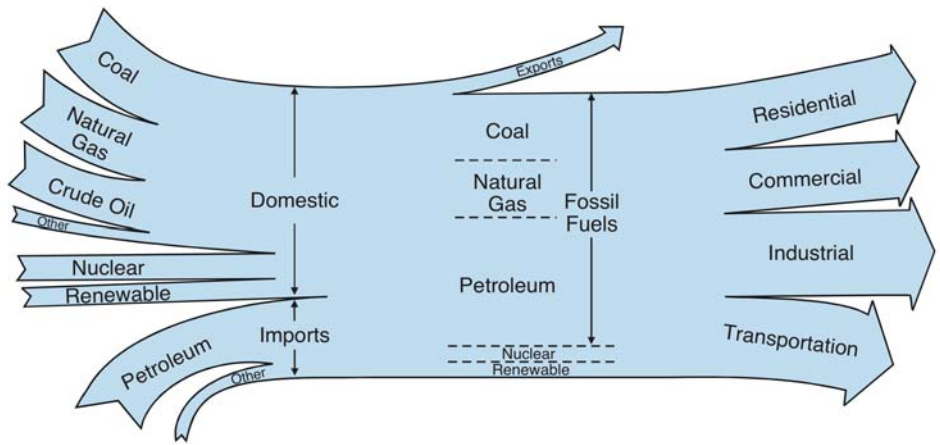
The search for petroleum alternatives

- Supply volumes
- Supply stability
- Record prices
- Greenhouse gas emissions
- Overwhelming dependence upon oil for transportation



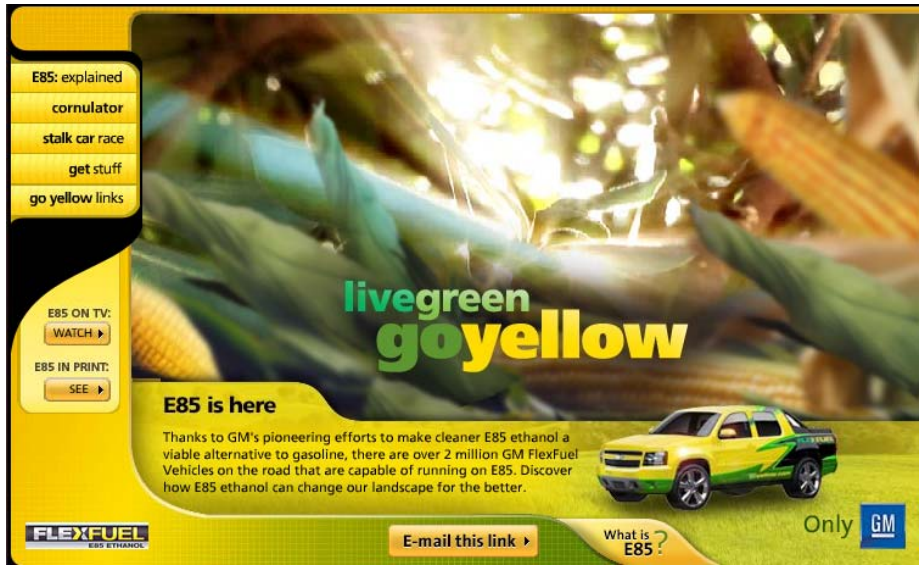


Striving for energy independence

Biodiesel Facts
Amount per Gallon

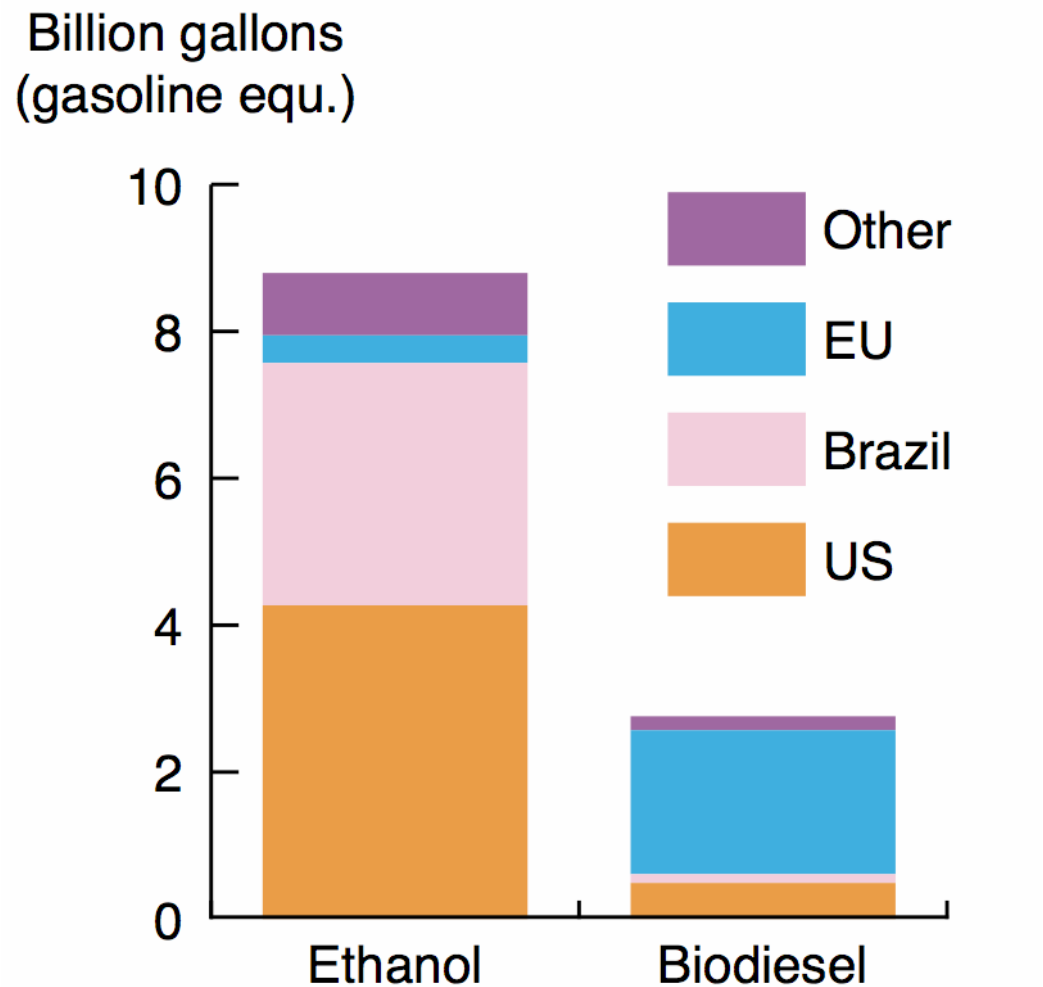
	% Driving Values
Renewable Fuel	100%
Cleaner Burning	100%
Made in America	100%
Dependence on Foreign Oil	0%

Biofuels as a green alternative

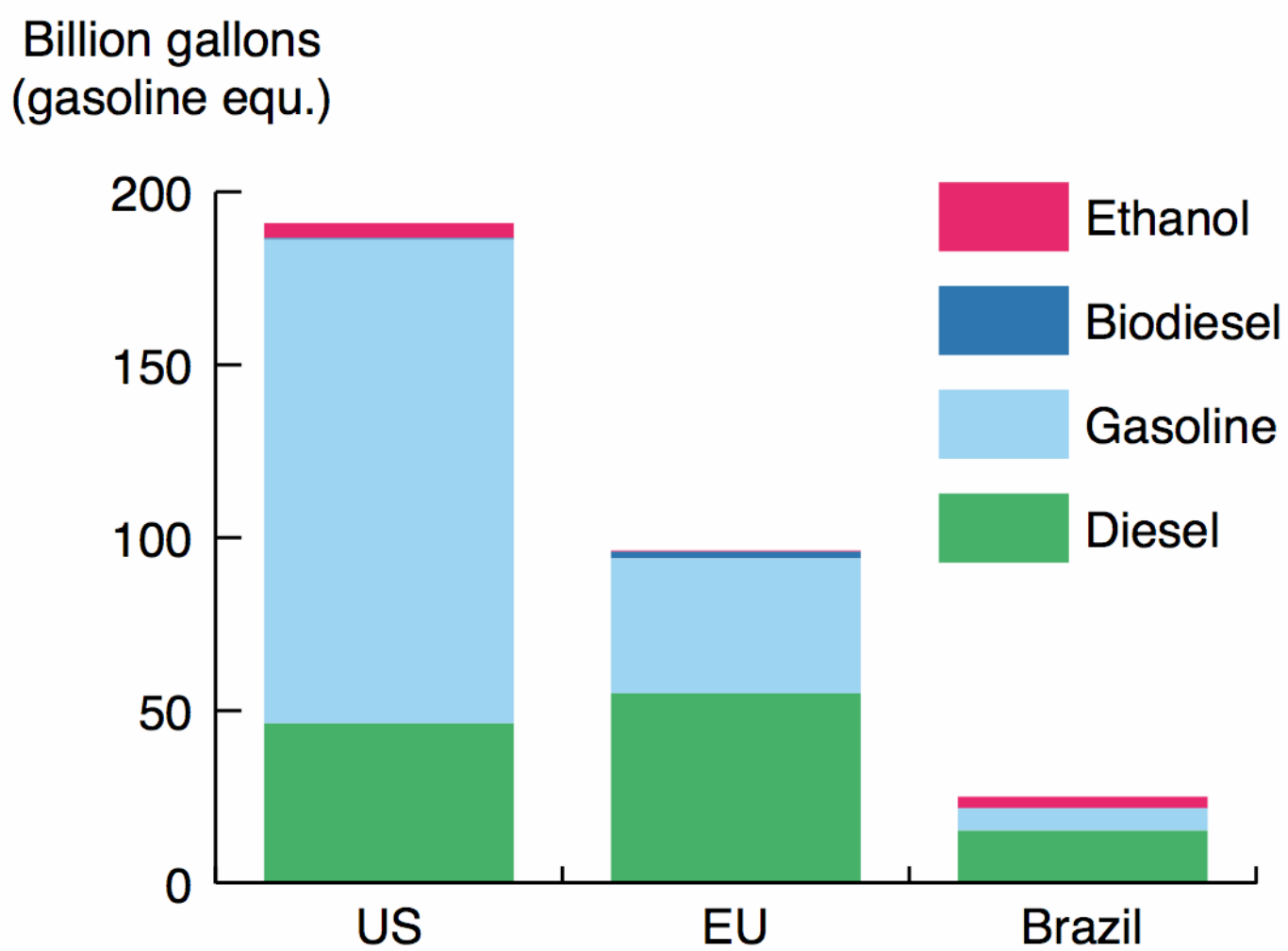


Growing concerns over biofuels

World biofuel production in 2007



Three largest biofuel producers in 2007



Land use for biofuel production 2007

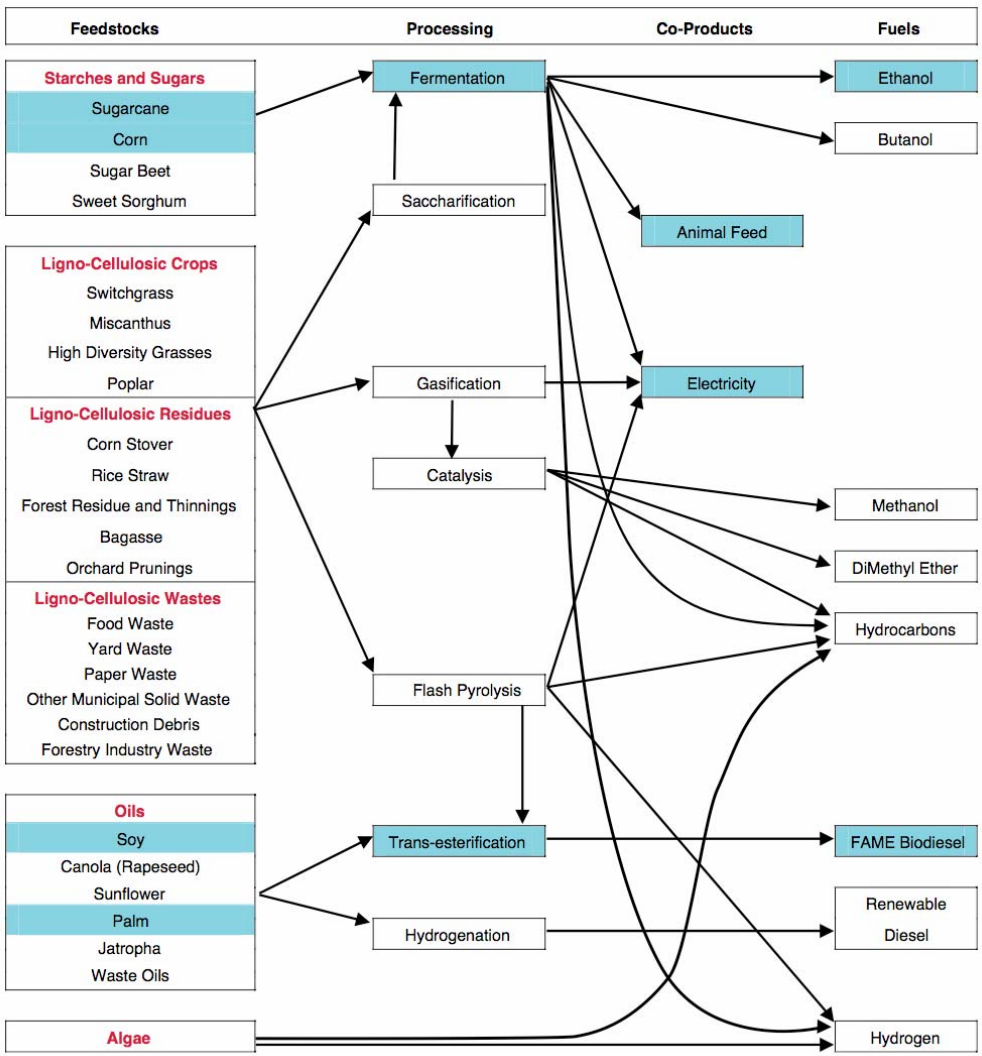
Biodiesel

Country	Million Gal	Million L	L Per Tonne	Million Tonnes	kg Per ha Harvested	Harvest %	Tonnes Per ha Planted	Million ha	% Allocated to Biofuel	Allocated Land
EU Rapeseed	1,550	5,866	360	16.3	3,061	97%	3.0	5.5	67	3.7
EU Soy	225	853	183	4.7	2,569	98%	2.5	1.8	39	0.7
Malaysia Palm	449	1,700	223	7.6	18,419	90%	16.6	0.5	87	0.4
US Soy	400	1,513	183	8.3	2,745	98%	2.7	3.1	39	1.2
US Rapeseed	44	168	360	0.5	1,640	97%	1.6	0.3	67	0.2
Brazil Soy	108	409	183	2.2	2,428	98%	2.4	0.9	39	0.4
Indonesia Palm	101	382	223	1.7	15,035	90%	13.5	0.1	87	0.1
Argentina Soy	73	276	183	1.5	2,603	98%	2.6	0.6	39	0.2
Total	2,950	11,167						**12.8**		**6.9**

Ethanol

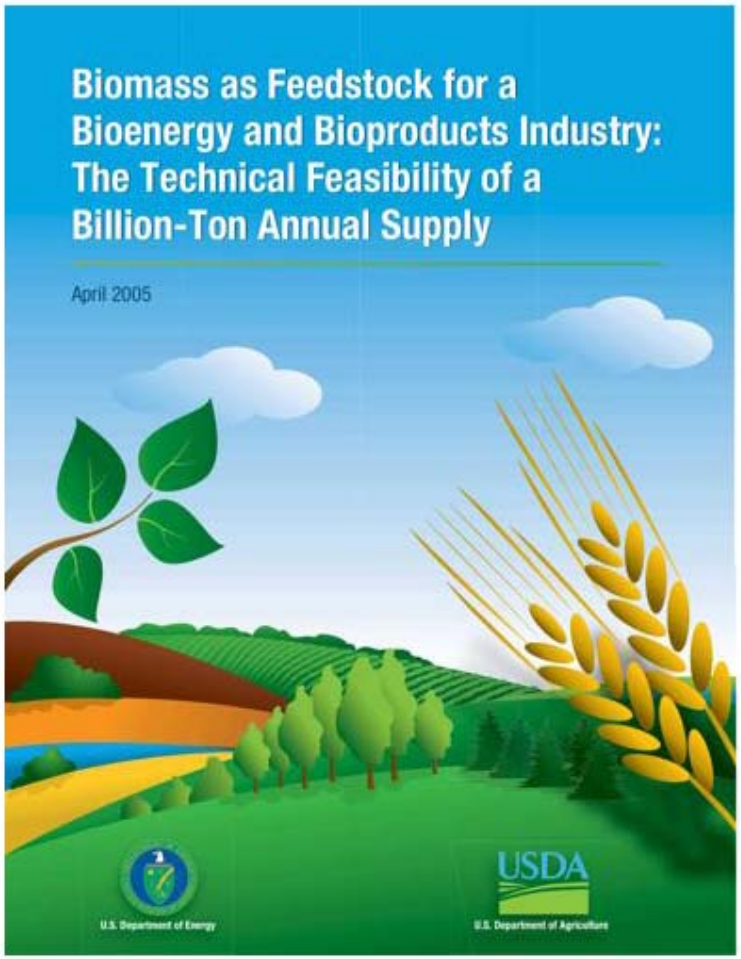
Country	Million Gal	Million L	L Per Tonne	Million Tonnes	kg Per ha Harvested	Harvest %	Tonnes Per ha Planted	Million ha	% Allocated to Biofuel	Allocated Land
US Corn	6,499	24,600	410	60.0	9,410	91.0%	8.6	7.0	83	5.8
Brazil Sugarcane	5,019	19,000	81	234.6	73,577	83.3%	61.3	3.8	100	3.8
EU Wheat	266	1,008	389	2.6	5,104	85.3%	4.4	0.6	83	0.5
EU Corn	95	361	410	0.9	6,517	91.0%	5.9	0.1	83	0.1
EU Barley	209	792	389	2.0	4,174	87.1%	3.6	0.6	83	0.5
China Corn	486	1,840	410	4.5	5,147	91.0%	4.7	1.0	83	0.8
Canada Corn	146	552	410	1.3	8,293	91.0%	7.5	0.2	83	0.1
Canada Wheat	65	248	389	0.6	2,547	85.3%	2.2	0.3	83	0.2
Thailand Sugarcane	40	150	81	1.9	55,619	83.3%	46.3	0.0	100	0.0
Thailand Cassava	40	150	180	0.8	21,091	90.0%	19.0	0.0	83	0.0
Columbia Sugarcane	75	284	81	3.5	92,255	83.3%	76.9	0.0	100	0.0
India Sugarcane	53	200	81	2.5	63,663	83.3%	53.1	0.0	100	0.0
Rest World Mix	109	412						0.1		0.1
Total	13,102	49,595						**13.9**		**12.2**

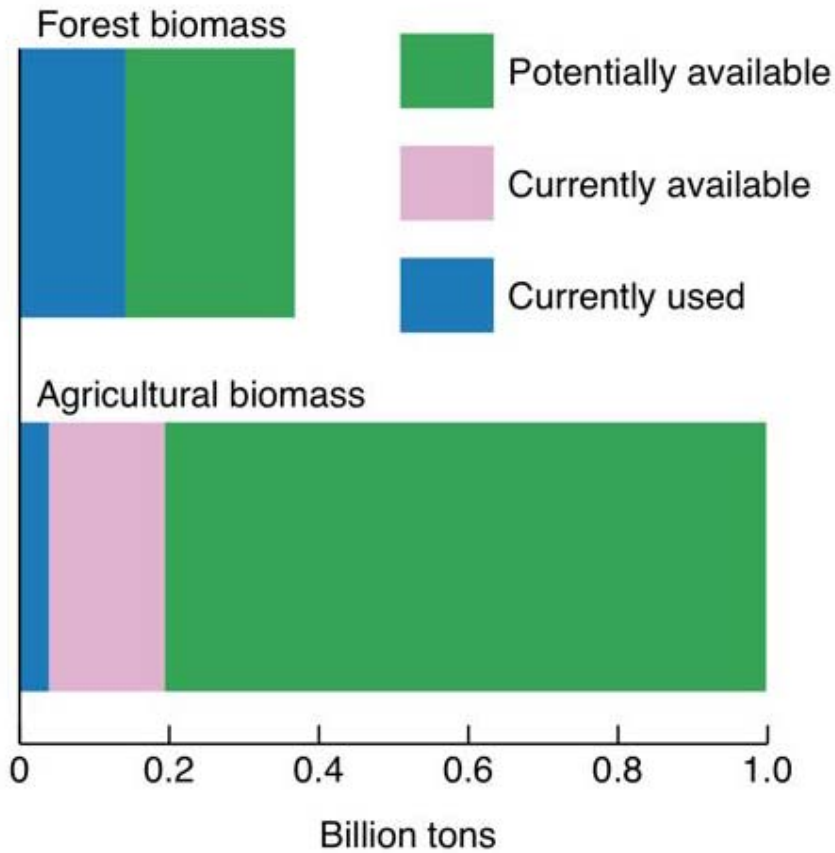
New biofuels from new feedstocks



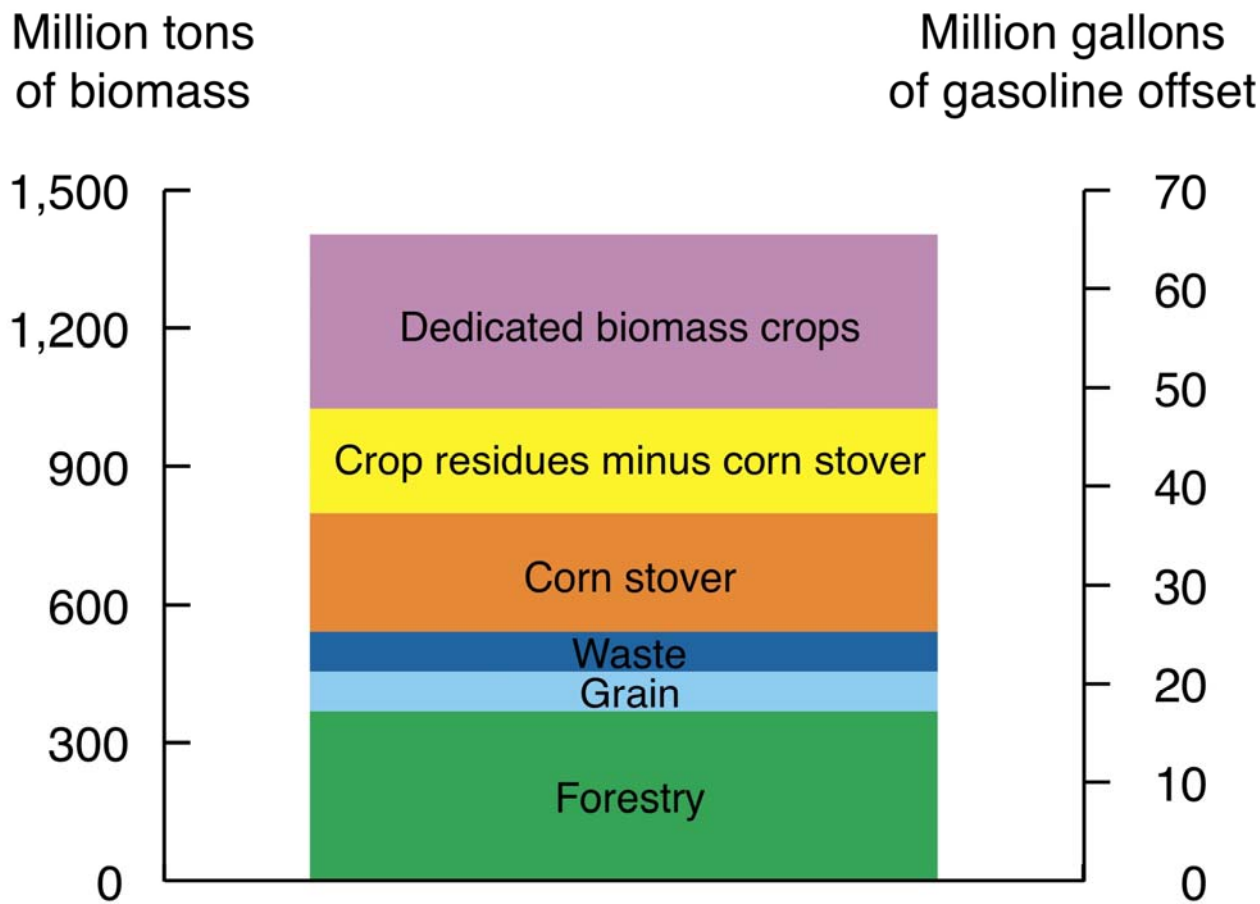
From Farrell and Gopal (2008)

Potential US biomass supply

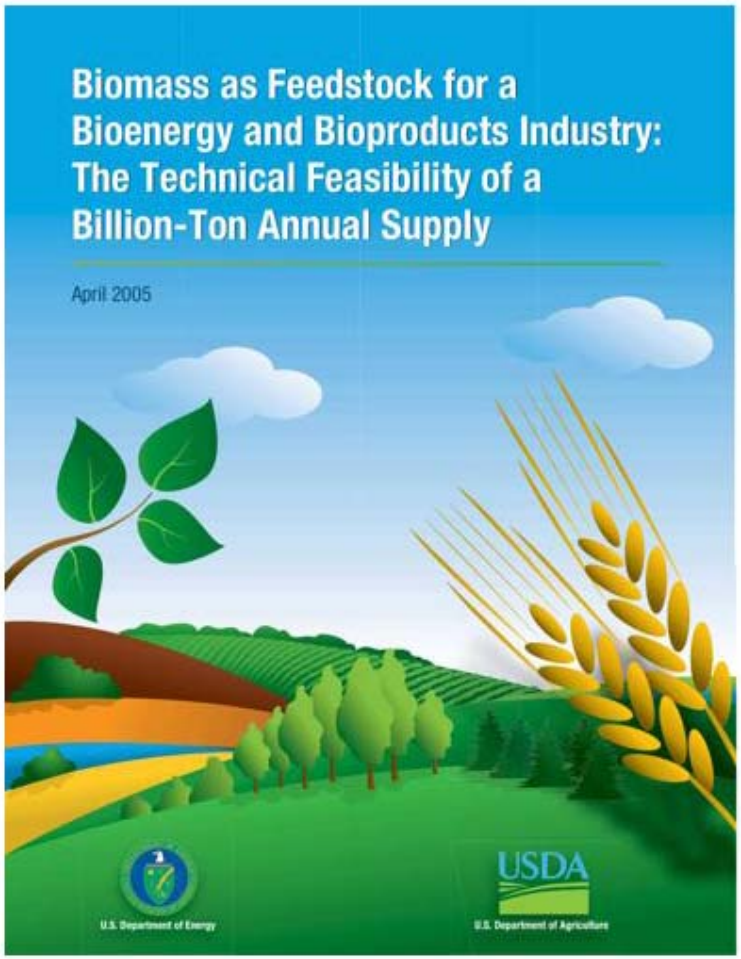




A closer look at US biomass crop potential

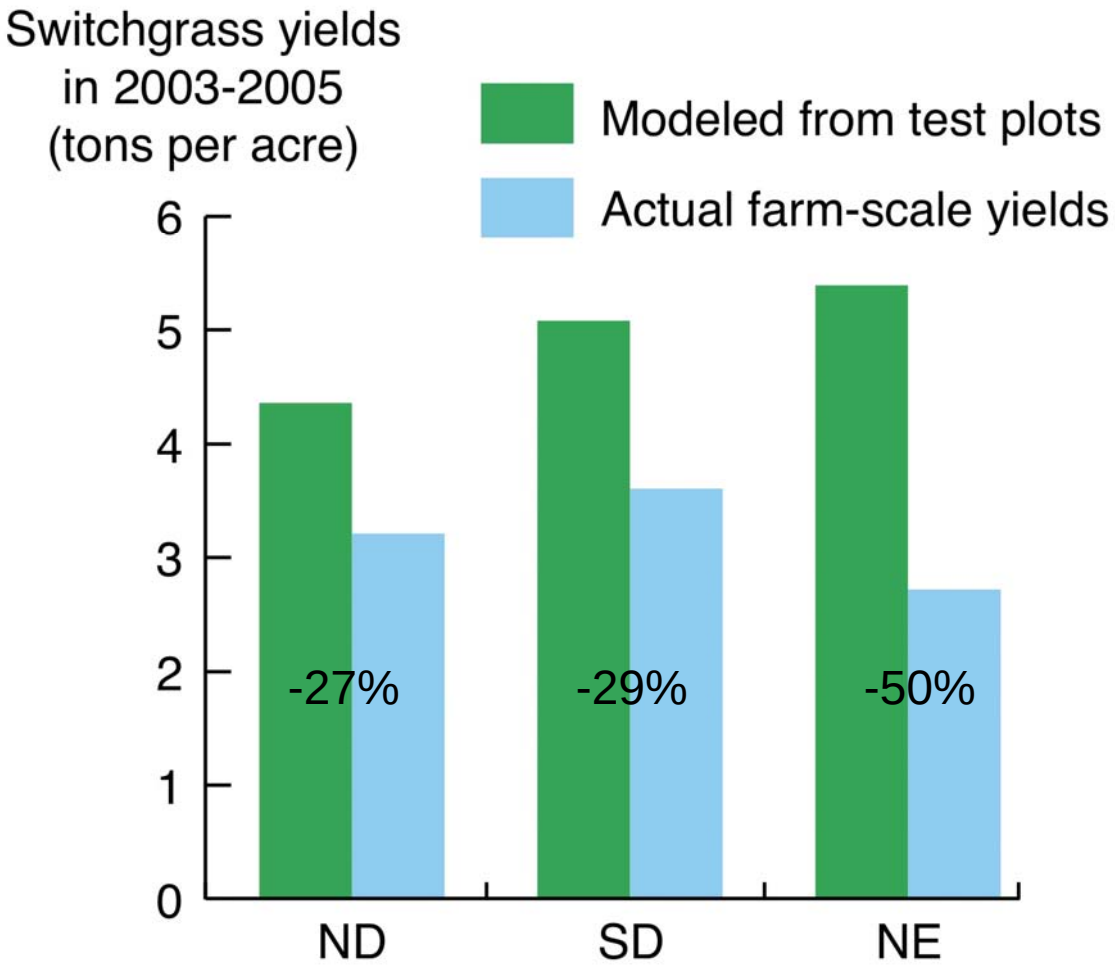


High yield increase scenario



- Land conversion (millions of acres)
  - Wheat (5)
  - Soybeans (8)
  - Pasture (25)
  - Non-alfalfa hay (5)
  - Summer fallow (5)
  - Conservation Reserve Program (10)
- Estimated yield (8 tons / acre)

Modeled and actual yield data



Average test plot yields for Nebraska 2003-2005: 6.4 tons per acre

Schmer et al. (2006) and (2008), Graham and Walsh (1999)

Ideal biomass production characteristics

- Biomass feedstock producible on land with low agricultural value
- Biomass feedstock producible with low inputs (fuel, fertilizers, herbicides, and pesticides)
- Carbon sequestration at least equal to fossil CO_2 emitted when producing biofuels

What to grow on degraded land?

- Native perennial plant species are well adapted to local climate, nutrient poor soils, and pests
- Native species created soils, and native species could be used to restore them

Cedar Creek Biodiversity Experiment

Cedar Creek Natural History Area in Bethel, MN

Sandy, extremely nitrogen poor agriculturally degraded soils

The least fertile soils in Minnesota

Tilman *et al*. (2006)

Experimental design

152 plots (this experiment)

10m x 10m

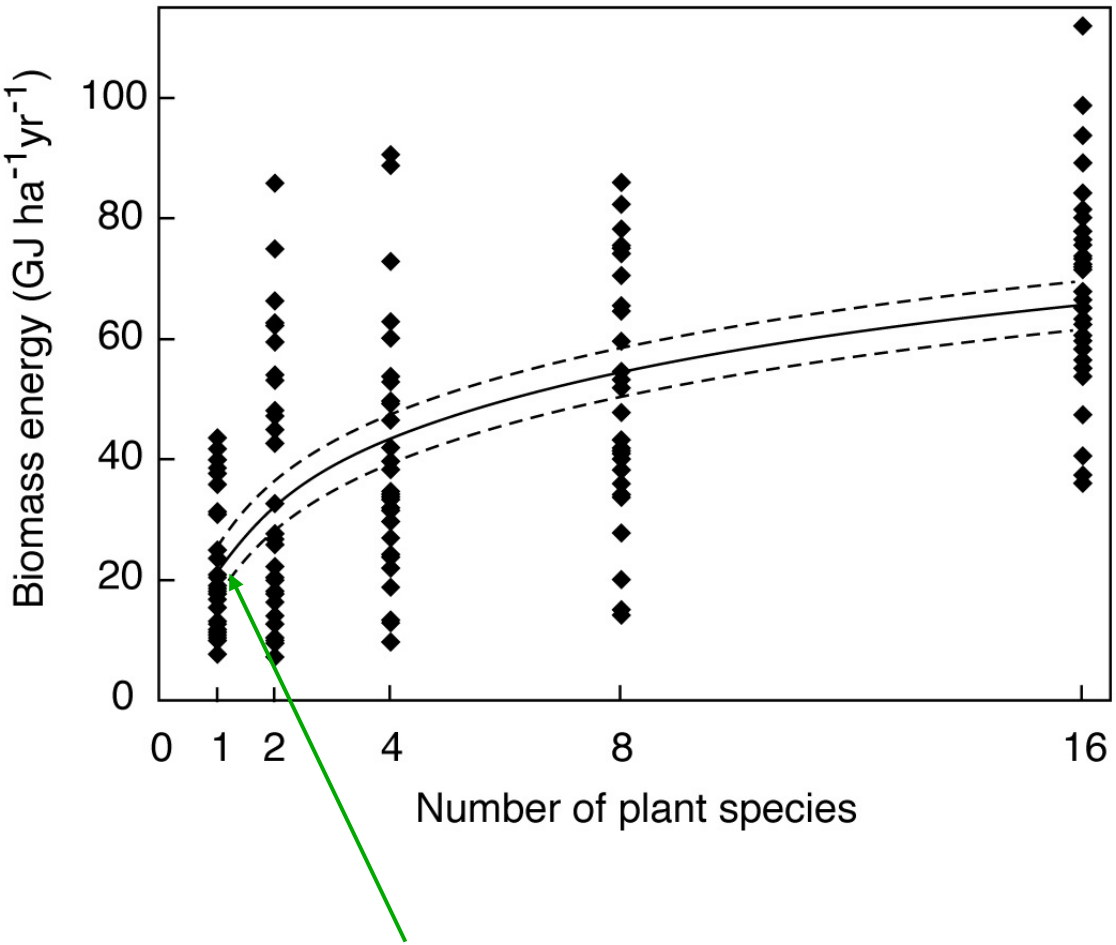
Planted to 1, 2, 4, 8, or 16 randomly chosen native perennial prairie plant species

No fertilizer and no irrigation

Species composition

Species	Functional type
Lupinis perennis	Legume
Andropogon gerardi	C_4 grass
Schizachyrium scoparium	C_4 grass
Sorghastrum nutans	C_4 grass
Solidago rigida	Forb
Amorpha canescens	Woody legume
Lespedeza capitata	Legume
Poa pratensis	C_3 grass
Petalostemum purpureum	Legume
Monarda fistulosa	Forb
Achillea millefolium	Forb
Panicum virgatum	C_4 grass
Liatris aspera	Forb
Quercus macrocarpa	Woody
Koeleria cristata	C_3 grass
Quercus elipsoidalis	Woody
Elymus canadensis	C_3 grass
Agropyron smithii	C_3 grass

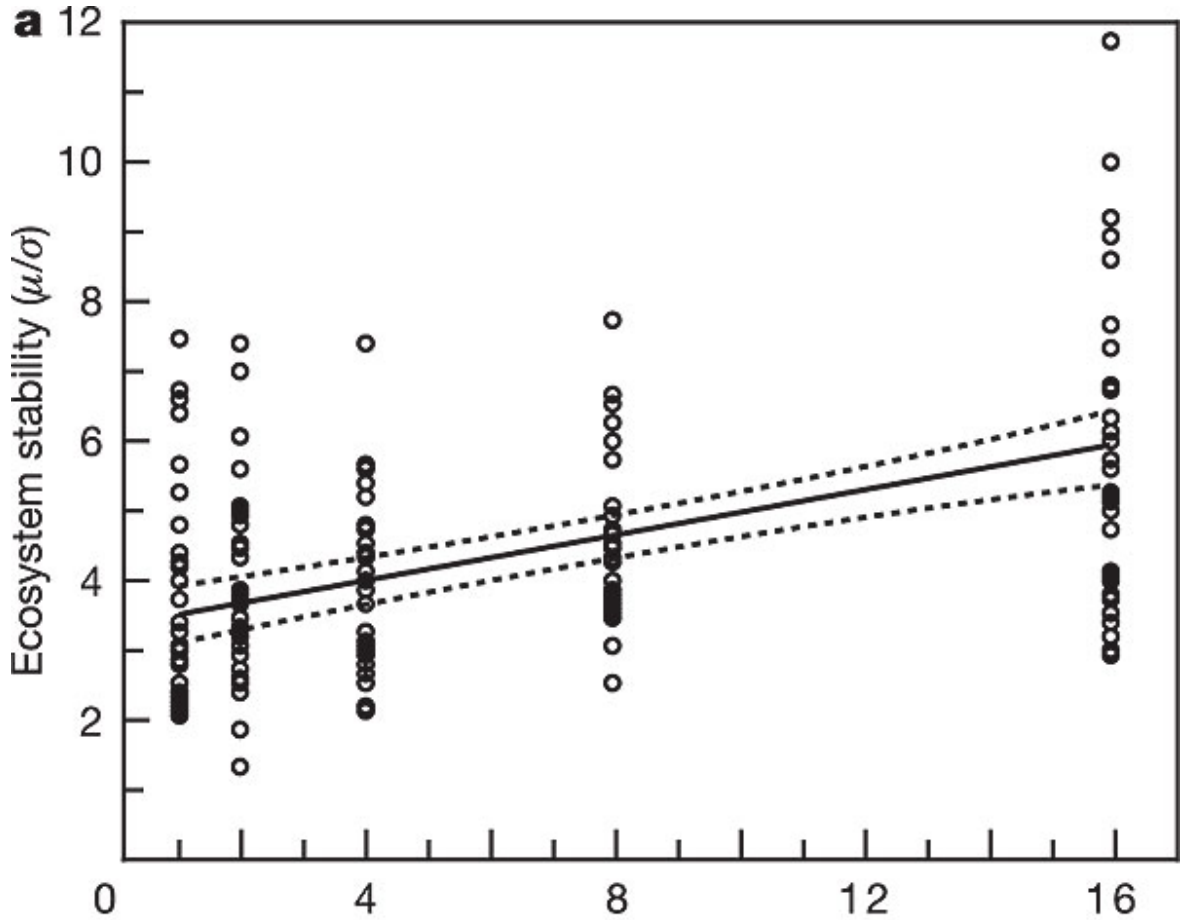
Diverse plots yielded 238% more biomass than monocultures



How general is the effect of diversity on productivity?

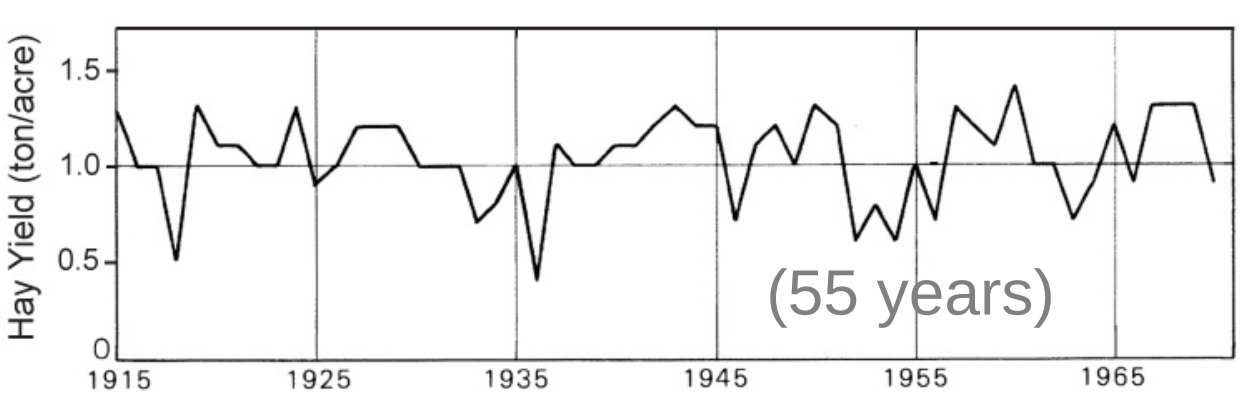
- Cardinale *et al*. (2006) showed in a meta-analysis of about 100 studies showed that, on average, highly diverse treatments have double the productivity of monocultures

Primary productivity is more stable at greater diversity (70% more stable)



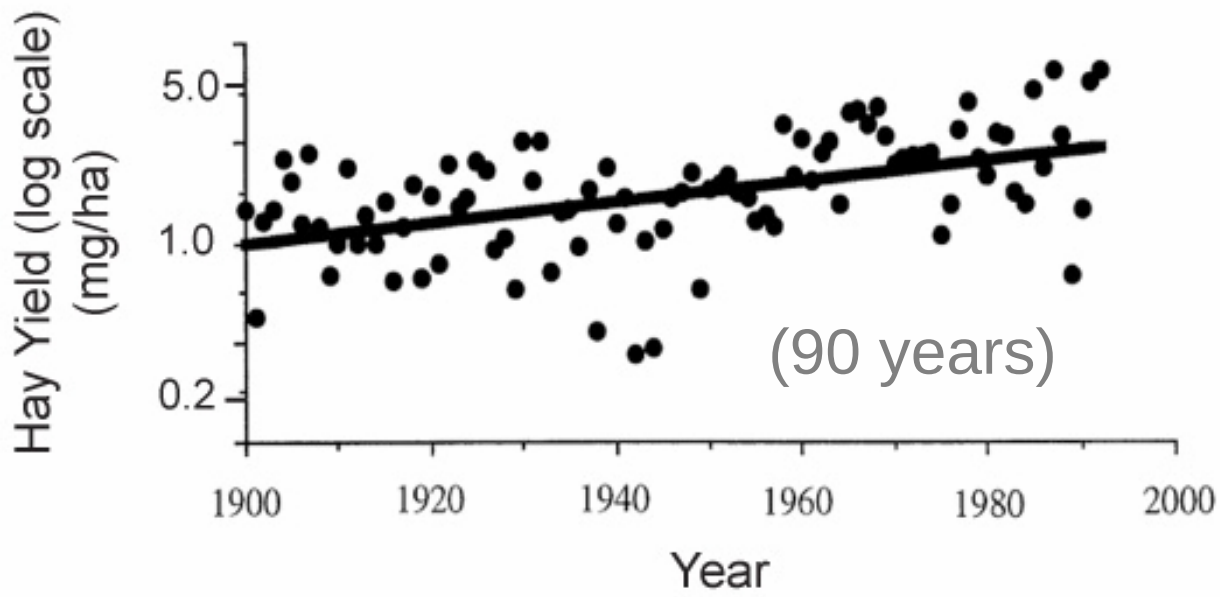
Tilman *et al*. (2006)

Kansas Prairie Hay Yields (unfertilized)



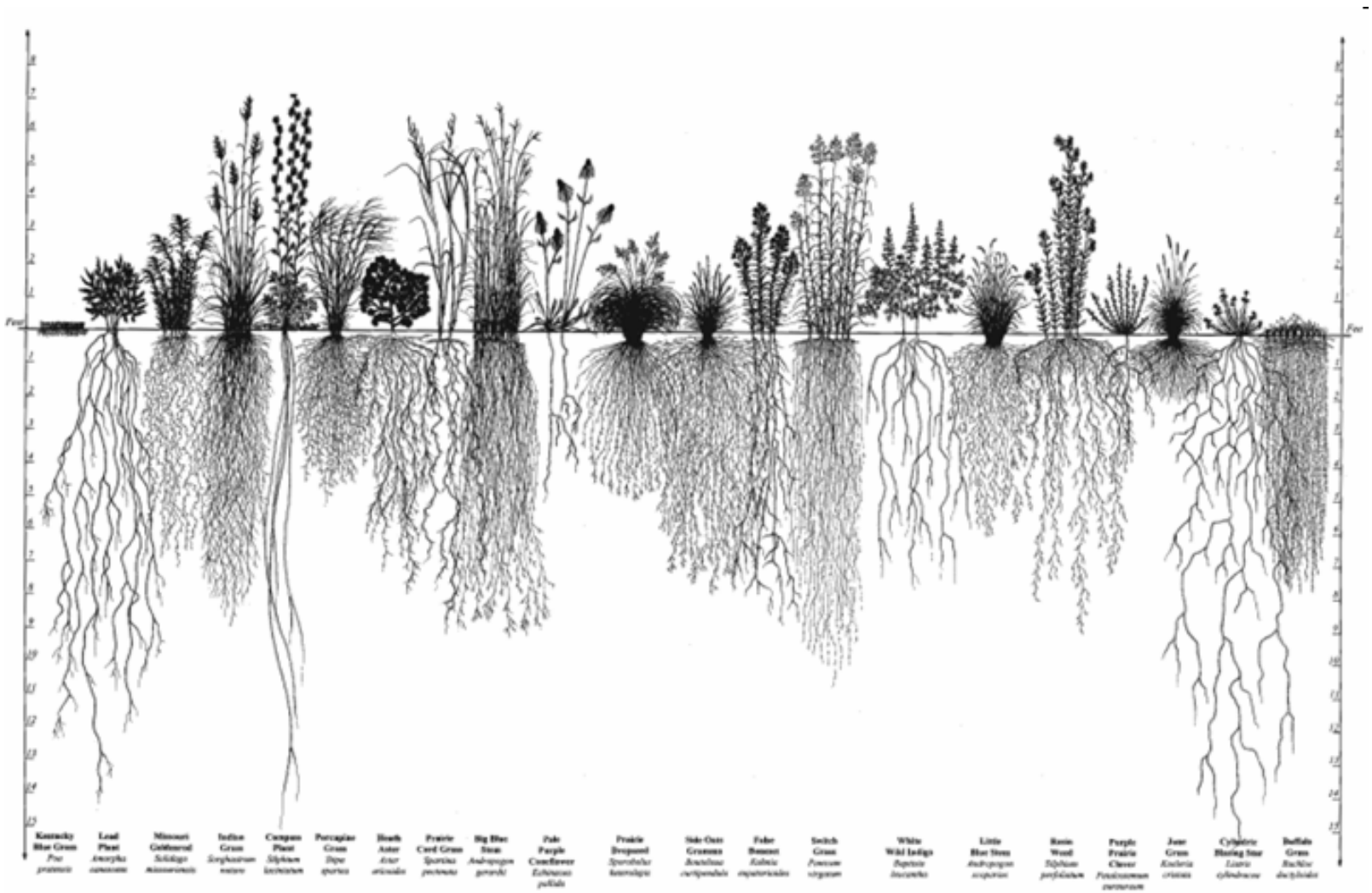
Yields Can Be Sustained with Low Inputs

British Hay Yields (unfertilized)

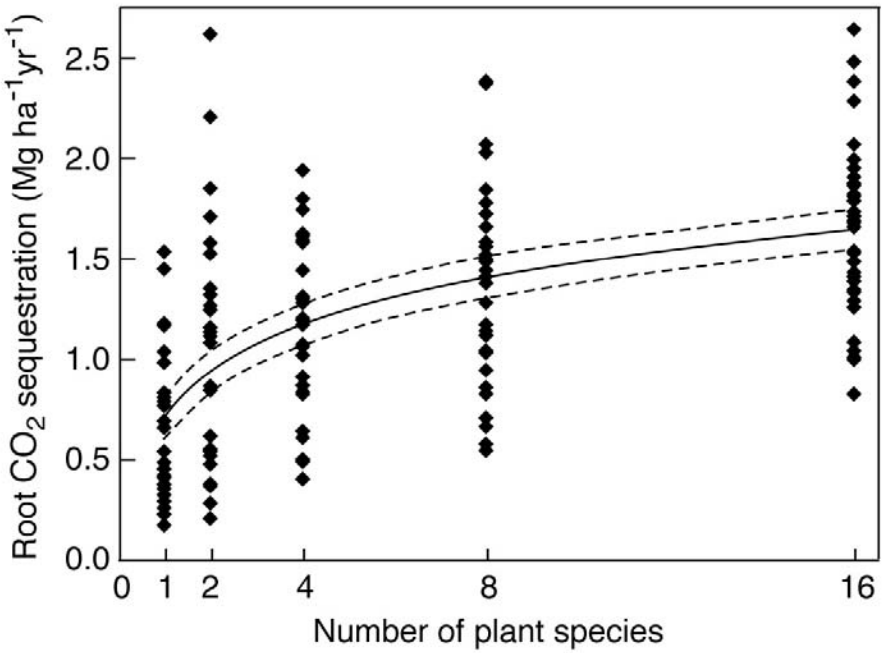


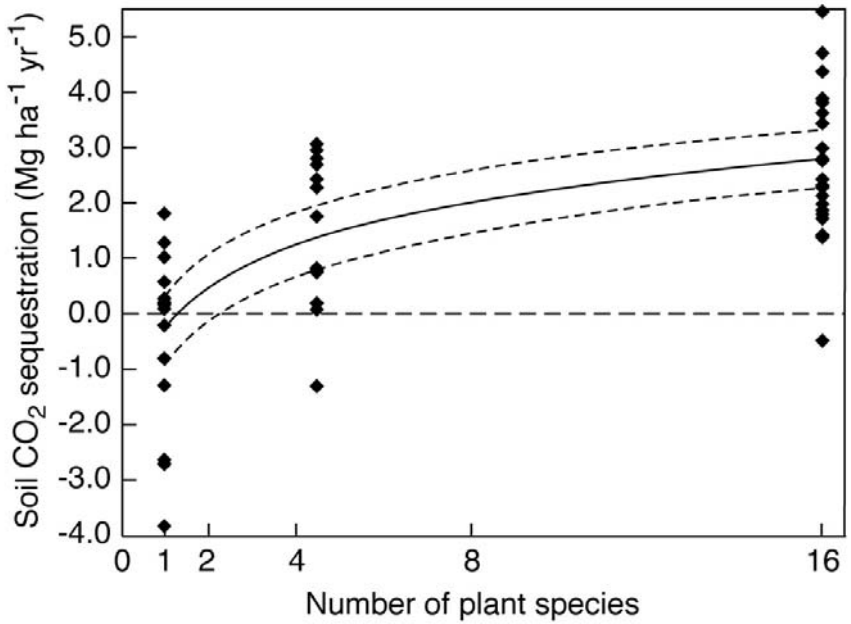
Even after 140 years of hay removal, yields were increasing in unfertilized plots because of legumes

2/3 of the prairie is below ground

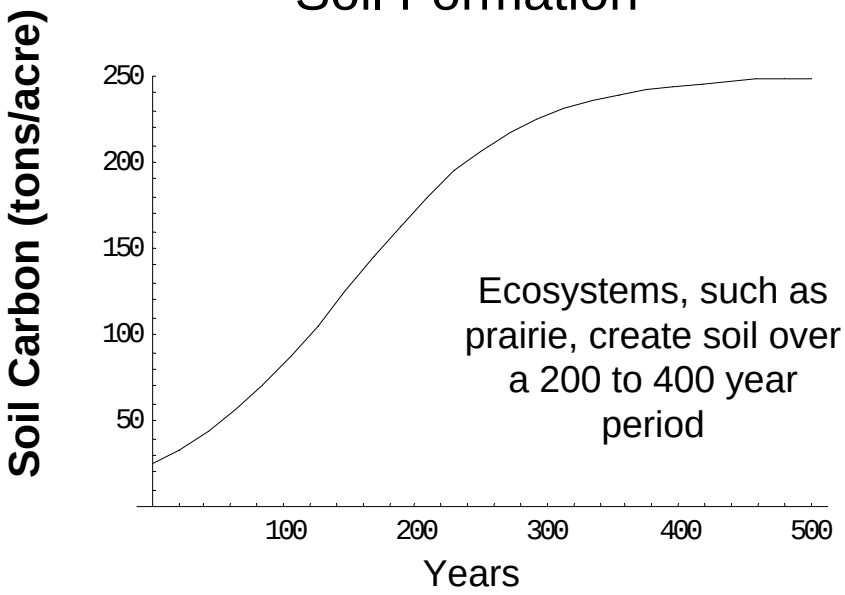


Diverse plots store more carbon

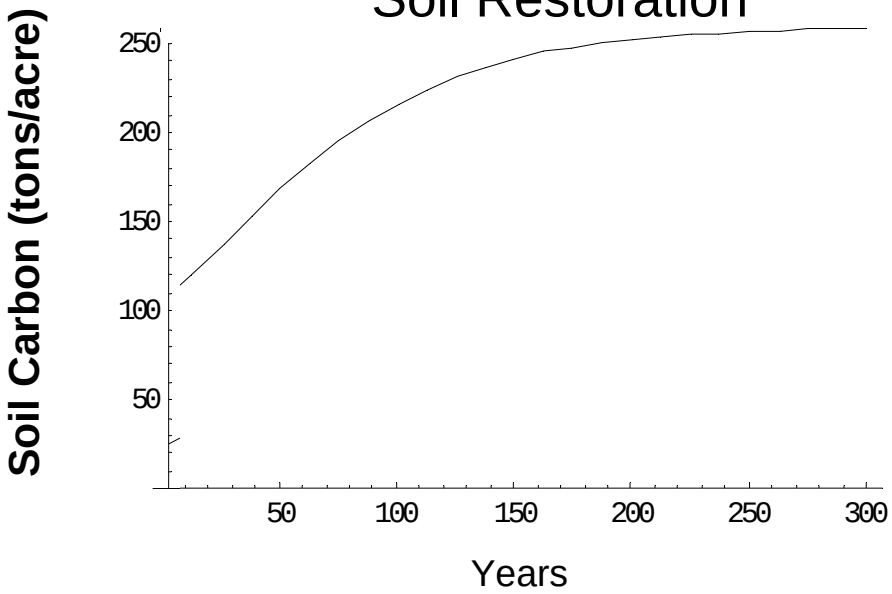




Soil Formation



Soil Restoration



Soil formation is a 200 to 400 year process during which organic carbon accumulates

↓

Farming leads to loss of ~40% of soil carbon in about 50 years. After that, soil carbon tends to be fairly stable.

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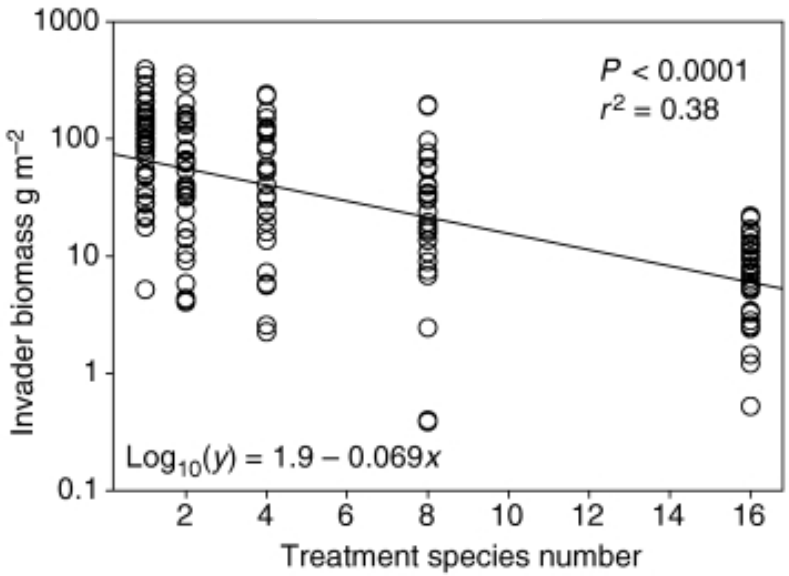
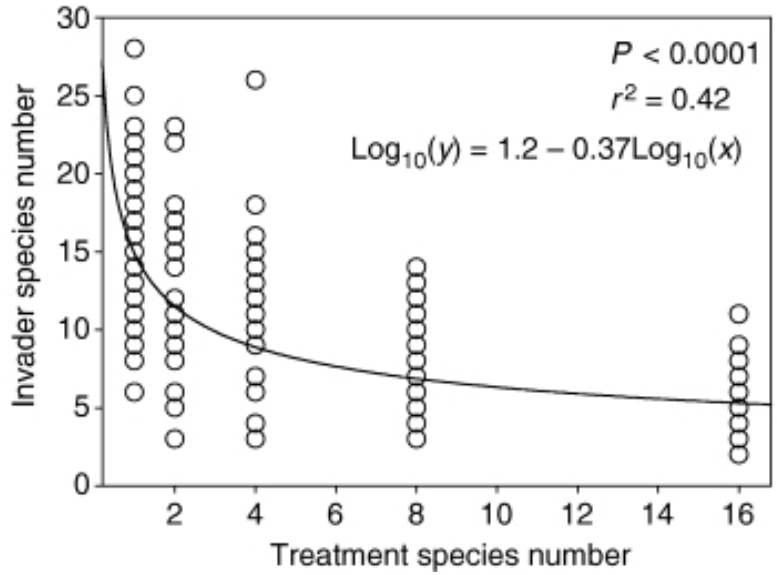
Ecosystem restoration, such as by planting with a diverse mixture of native plant species, can restore soil carbon and fertility

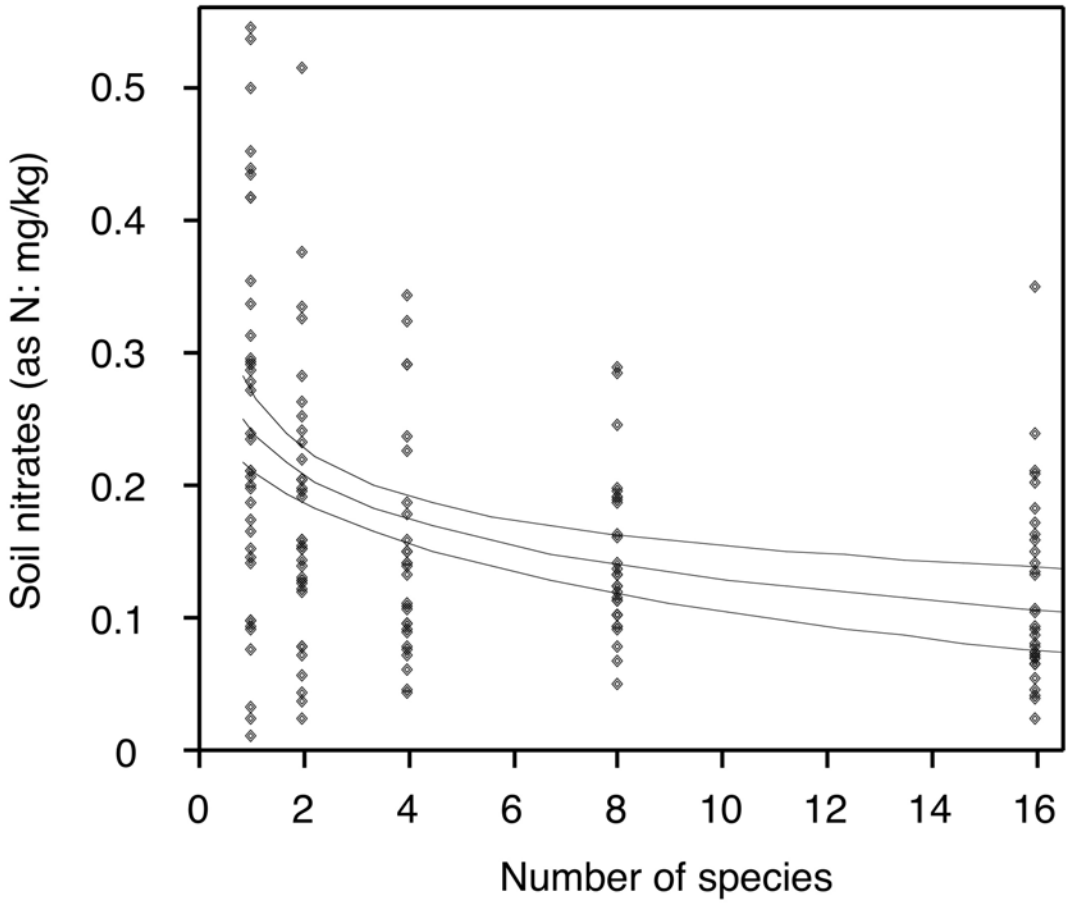
Diverse polycultures better resist invasion



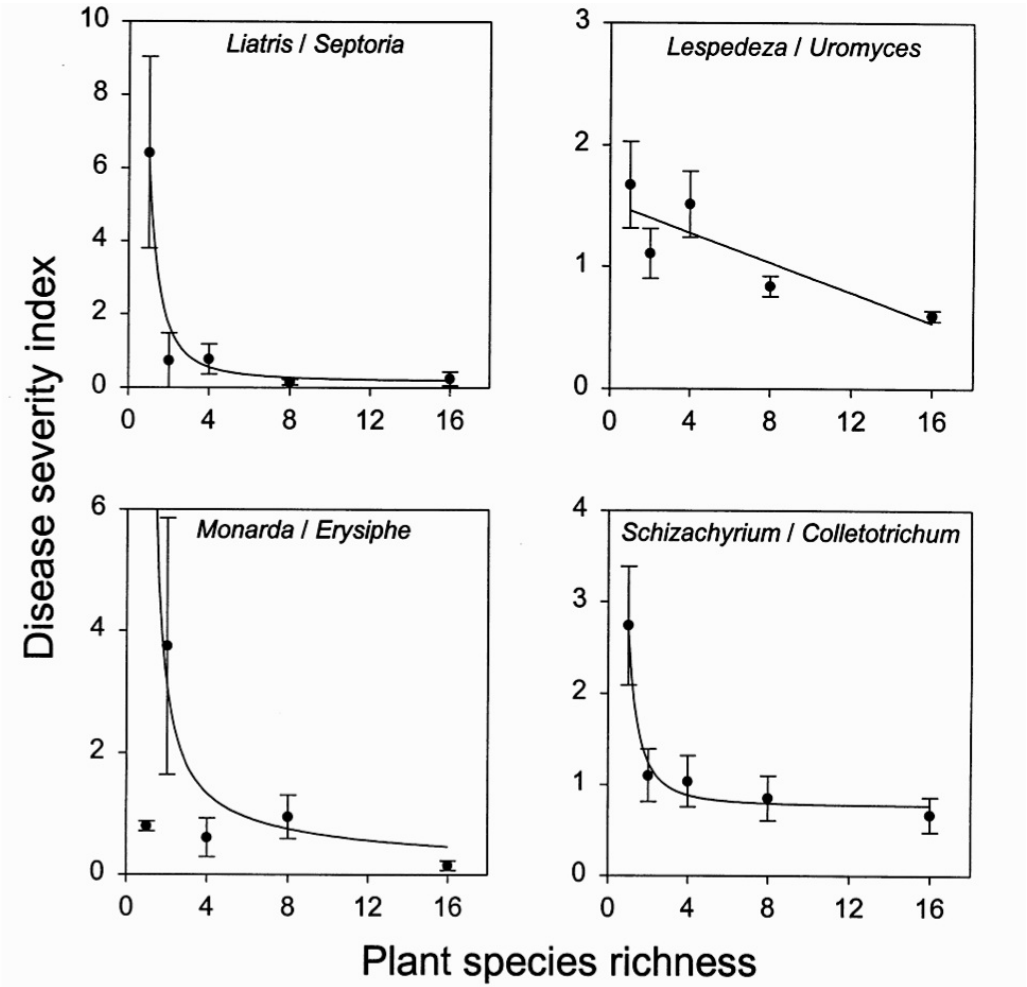


Fargione and Tilman (2005)

Higher diversity leads to greater use of soil nitrate and less leaching



Plant disease incidents decrease with higher diversity



Knops *et al*. (1999)

Bird use of potential biofuel crops in Southern Wisconsin

Habitat	# pairs / 40 ha	# species of greatest conservation need
Dense switchgrass (N=8)	224	5
Sparse switchgrass (N=8)	195	5
Mixed warm-season grasses (N=7)	195	8
Dry prairie (N=6)	153	7
Corn (N=16)	60	2

Sample *et al*. (In preparation).

Benefits of low-input high-diversity

- Producible on degraded agricultural lands, sparing both native ecosystems and prime cropland
- Highly sustainable and stable fuel supply
- As much or more net energy gain per acre than current food-based biofuels
- Restoration of wildlife habitat
- Land in LIHD agriculture can supply of a host of ecosystem services (*e.g.*, soil C and N enrichment, agrichemical runoff mitigation, pollinator habitat)

Hill (2007)

Thank you

Other slides not needed