Biomass & Climate Change

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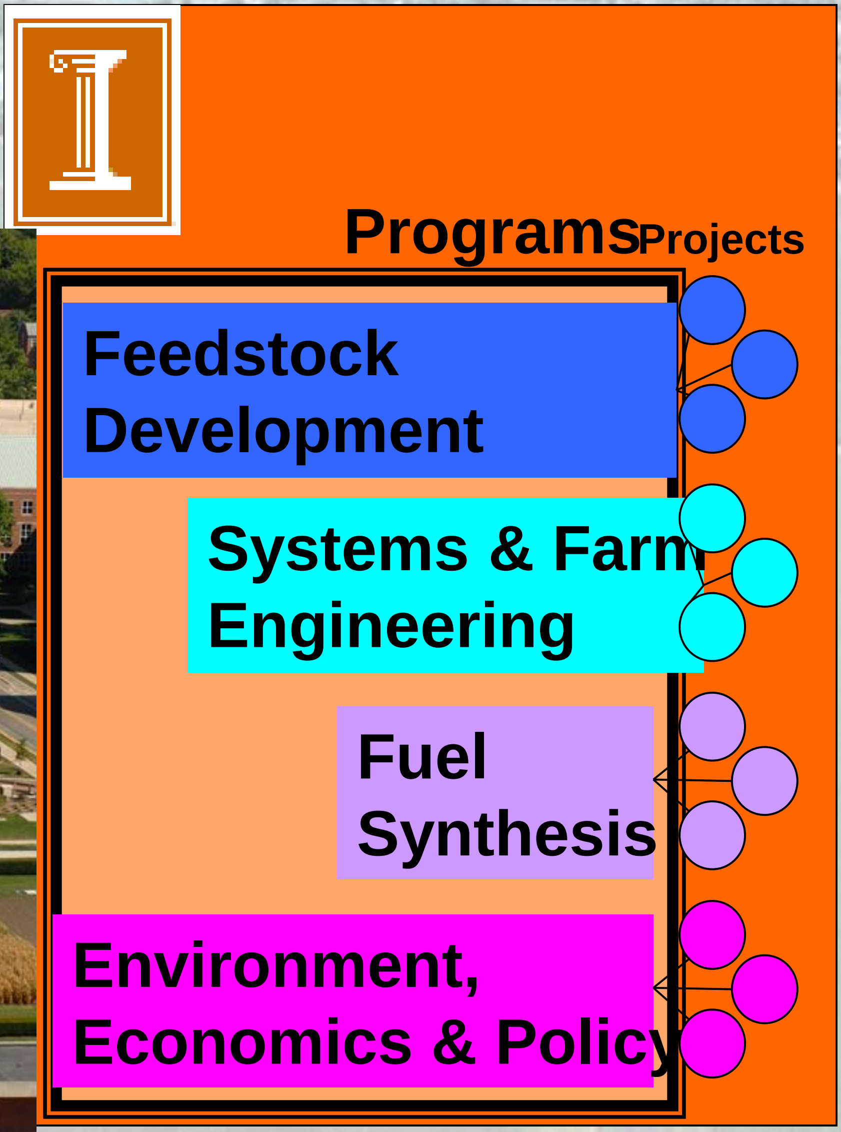
17 Aug 2011

NCSA

Energy Biosciences Institute

NSF

- Unique integration from crops to fuel and environment to law
- Does not fund PI's labs, but funds PI's to participate within the EBI (now >100 staff).
- New model for academic-business collaboration.



OUTLINE

Climate Change, Food, Feed and Biomass - Impacts

Agriculture part of the problem

Second generation and sugarcane ameliorating the problem.

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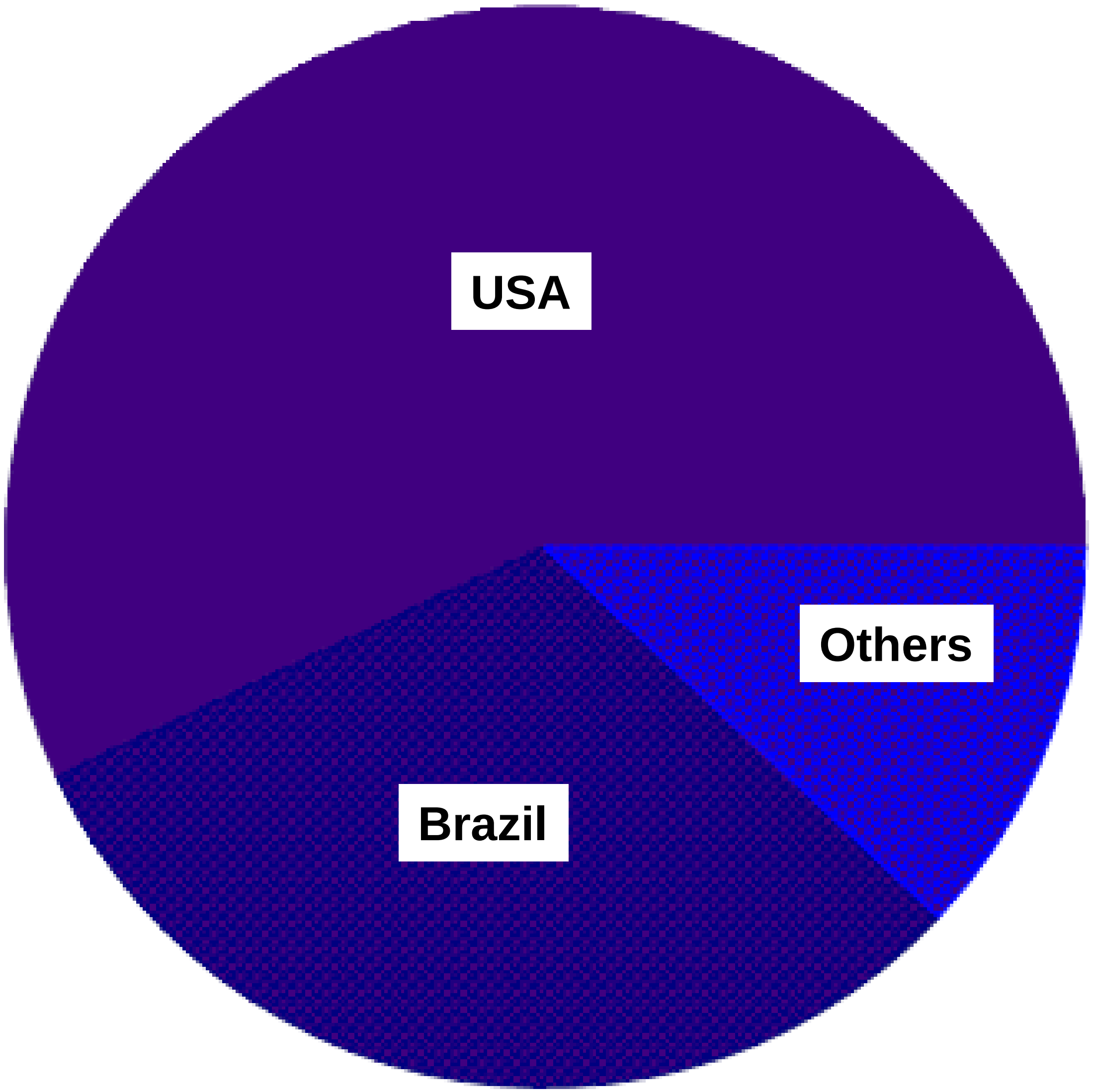
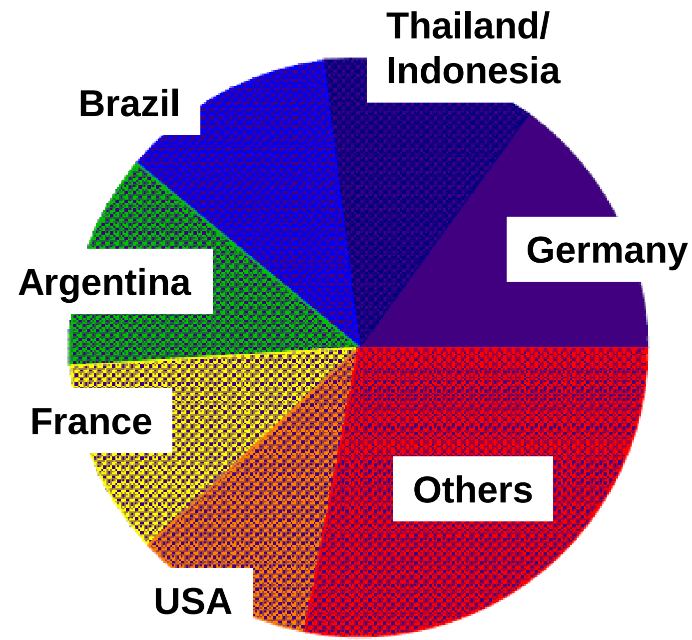
Liquid Biofuels Production in 2010

Ethanol 86 Billion liters



Biodiesel 19 Billion liters

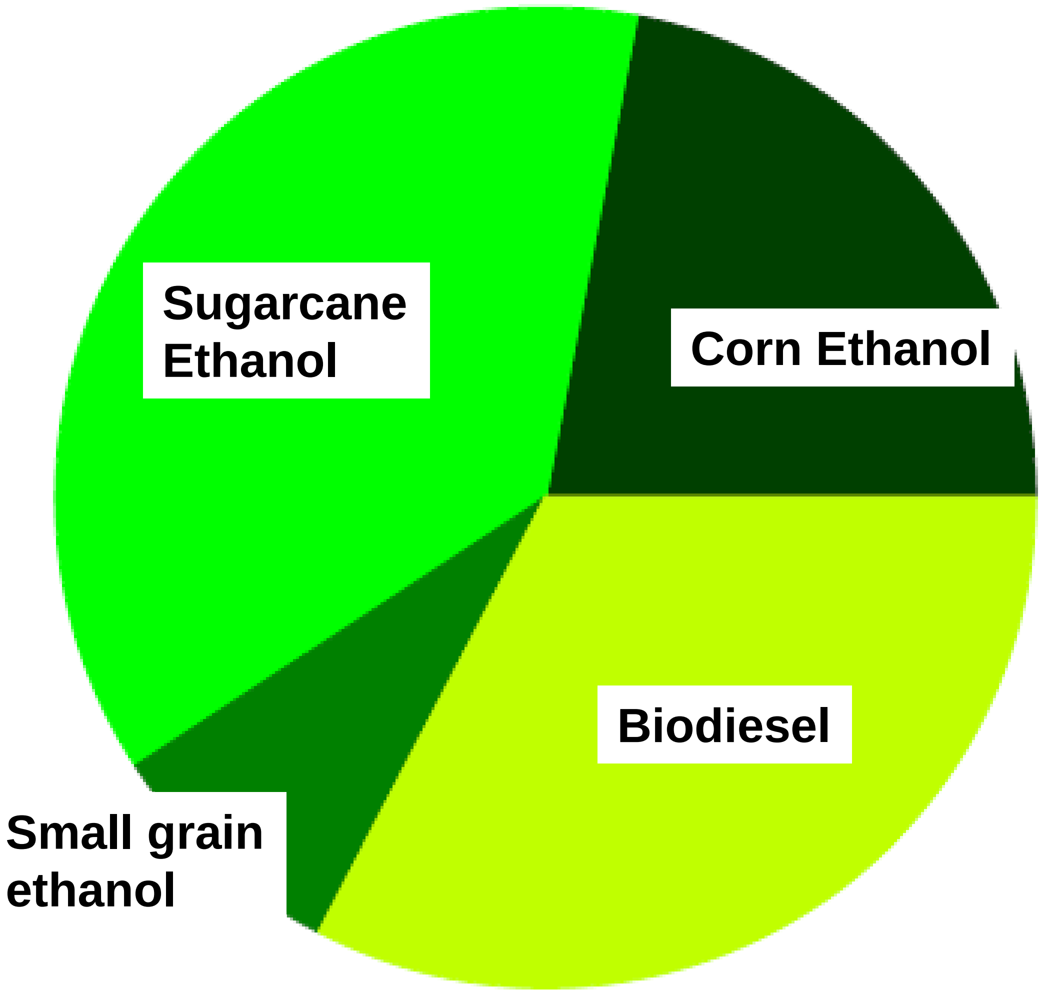


Advanced/Cellulosic ?

REN21 (2011) Renewables 2011 Global Status Report. REN21 Secretariat, Paris.

Fossil Fuel C emissions avoided 2010

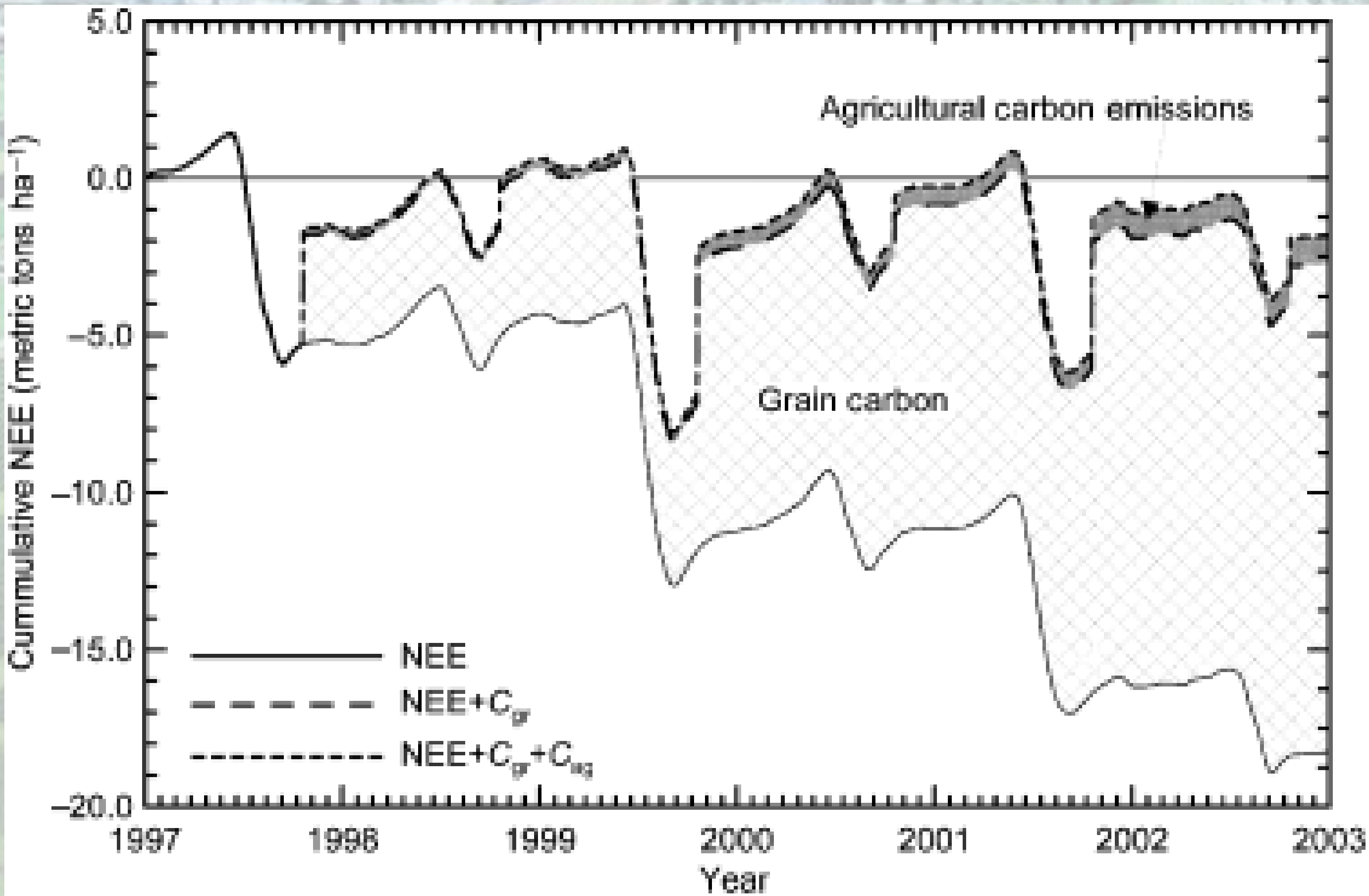
41 Mt (C)



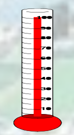
Calculated from:
REN21 (2011)
Assuming Gain over FF of

SC EtOH	88%
Corn EtOH	28%
SG EtOH	50%
Biodiesel	88%

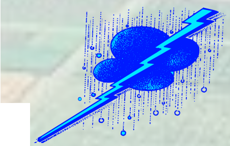
Eddy–covariance measurement of net C exchange to the atmosphere over no-till maize-soybean. Bernacchi et al. (2005) Global Change Biology 11: 1867. (2t C accumulated over 5 years)



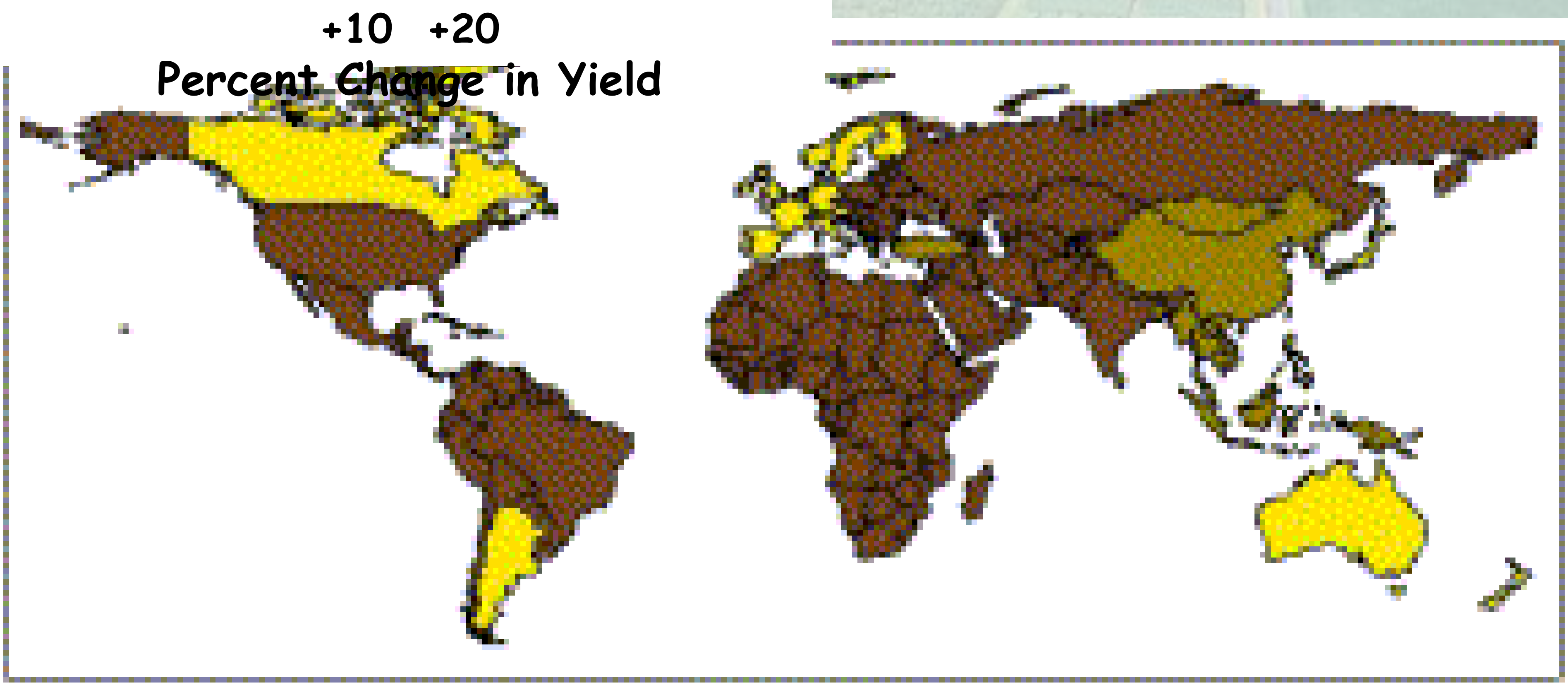
Predicted effect of climate change 2050 on crop yield (Parry et al. 2004). Without CO_2



Temperature



Precipitation

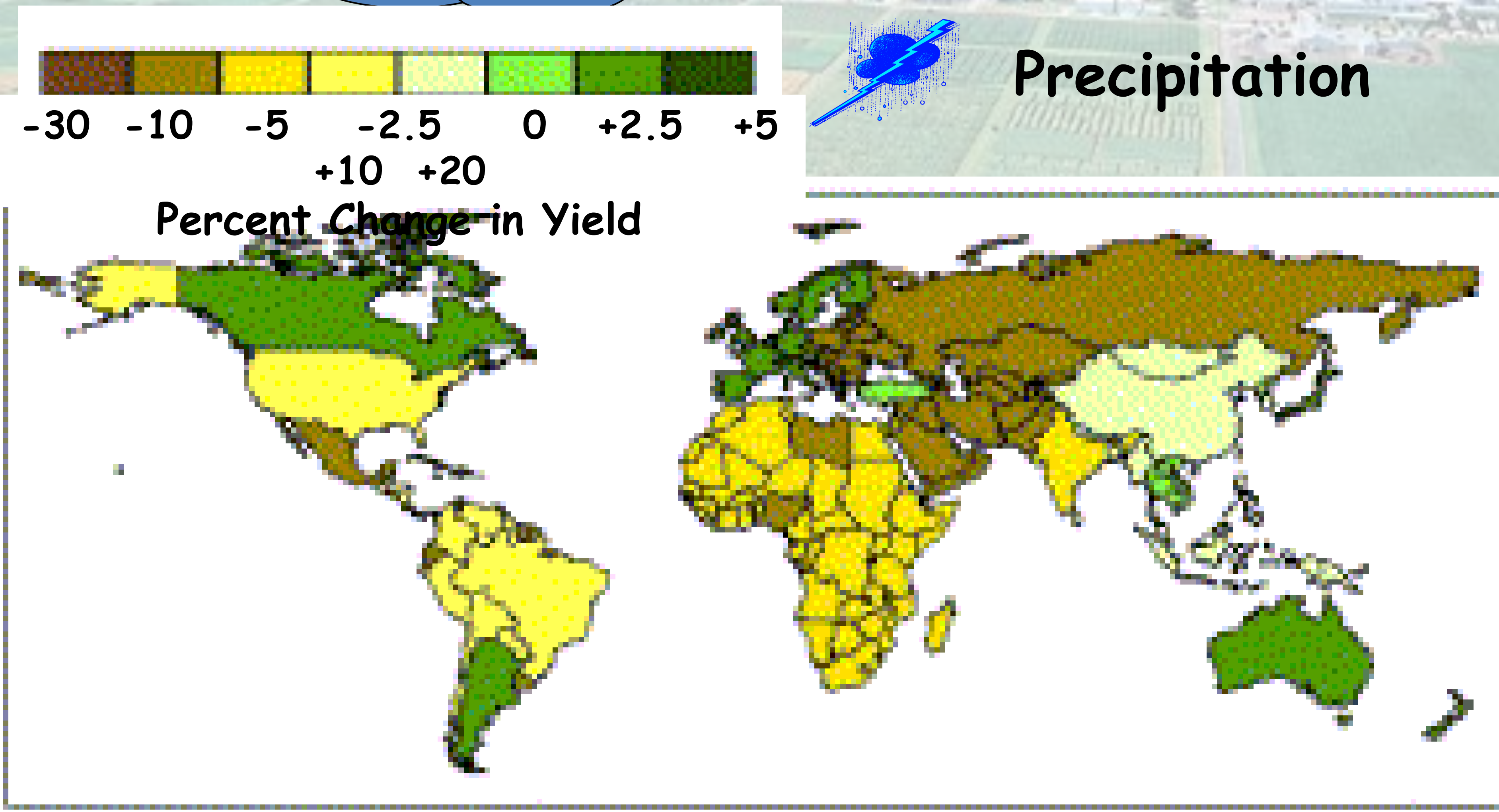


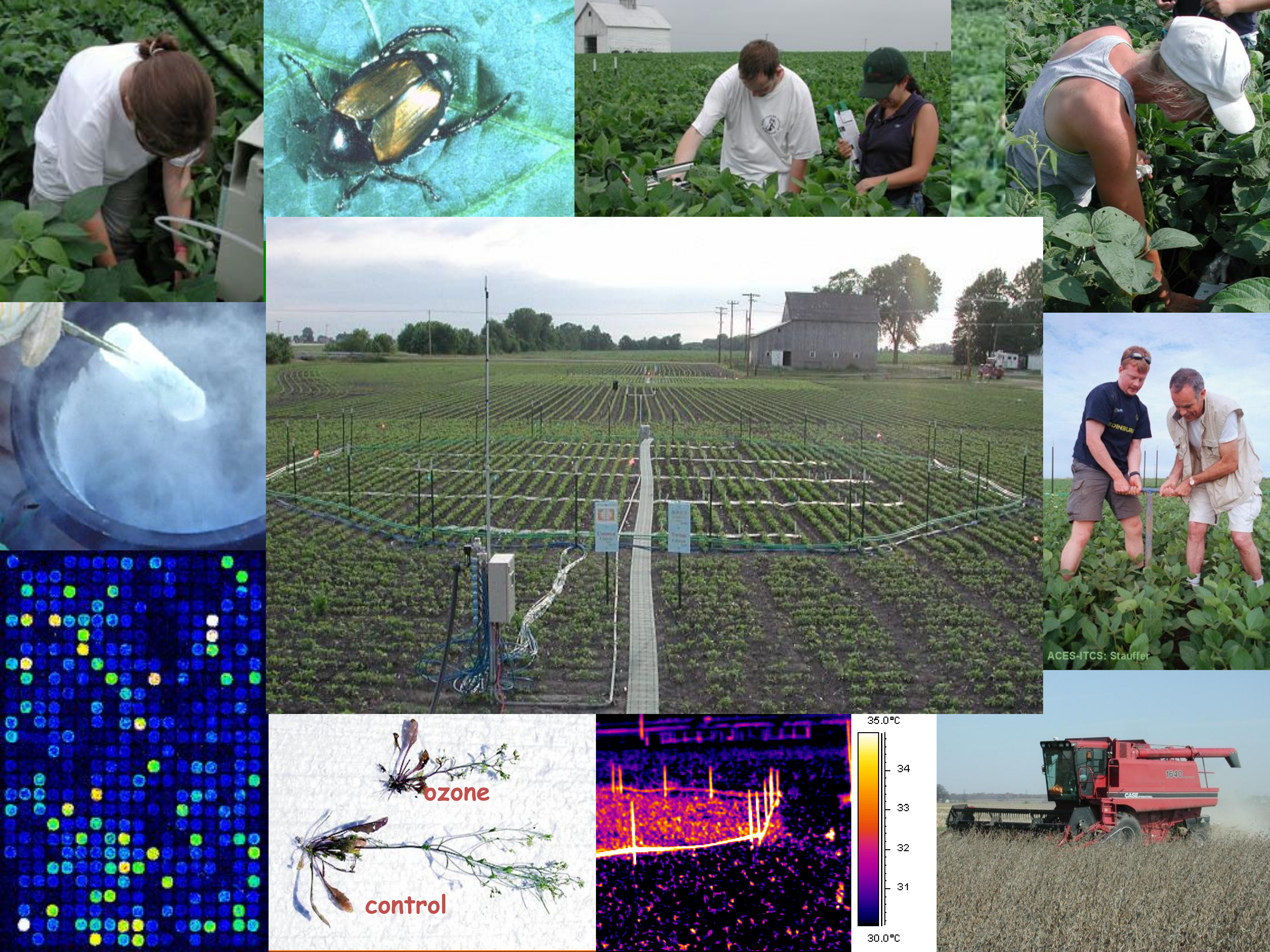
Predicted effect of climate change 2050 on crop yield (Parry et al. 2004)

$CO_2\uparrow$

Temperature

Precipitation



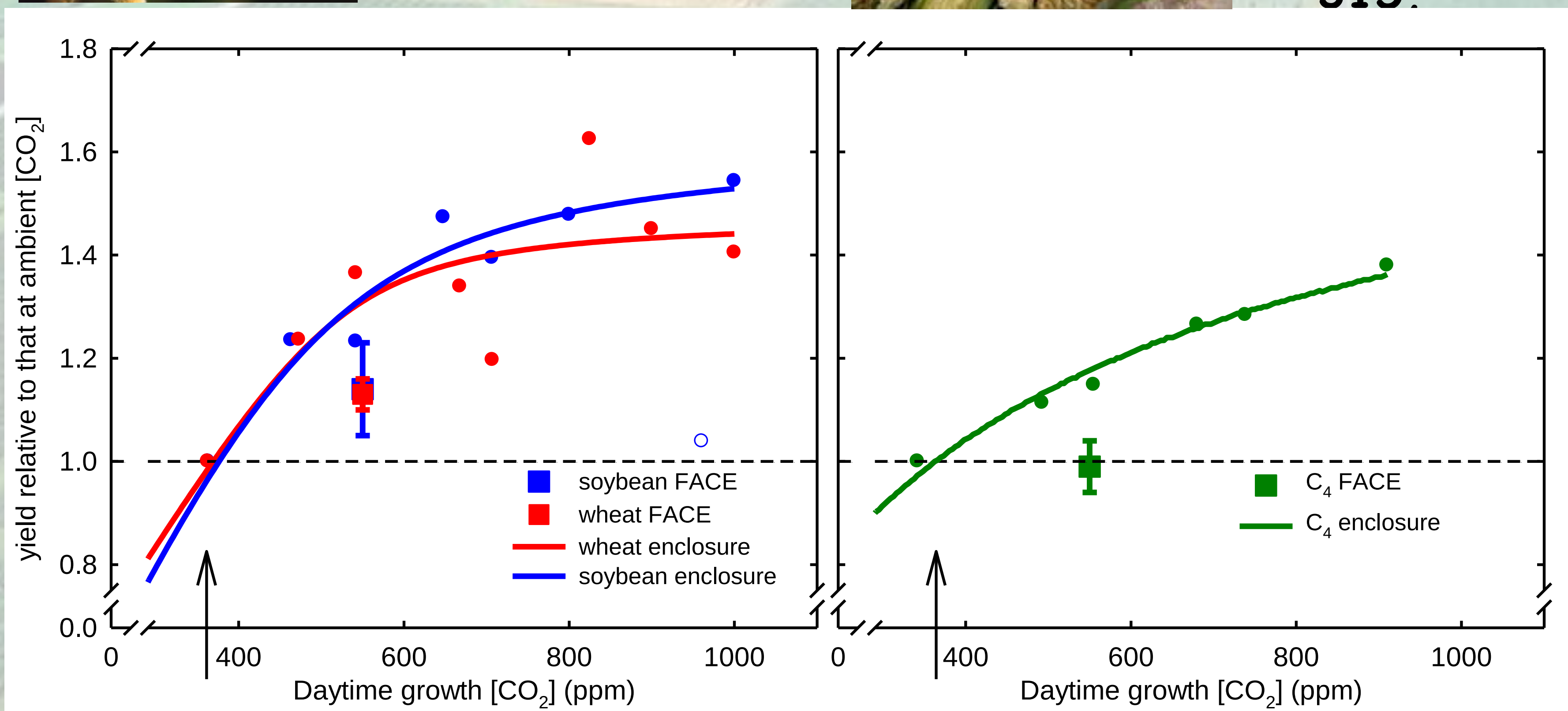

ACES-ITCS: Stauffer
ozone
control
35.0°C
34
33
32
31
30.0°C

Soybean

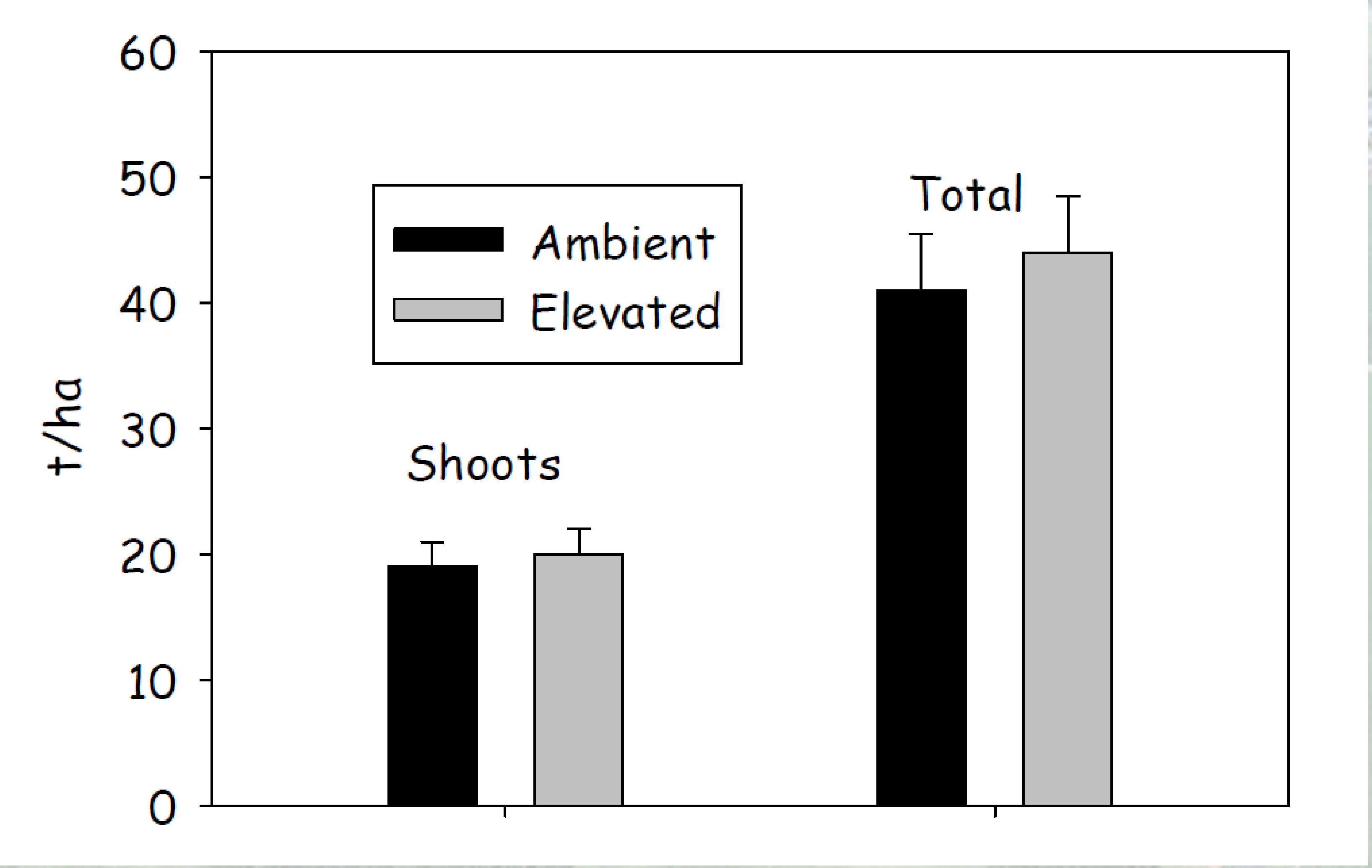
Wheat

Maize

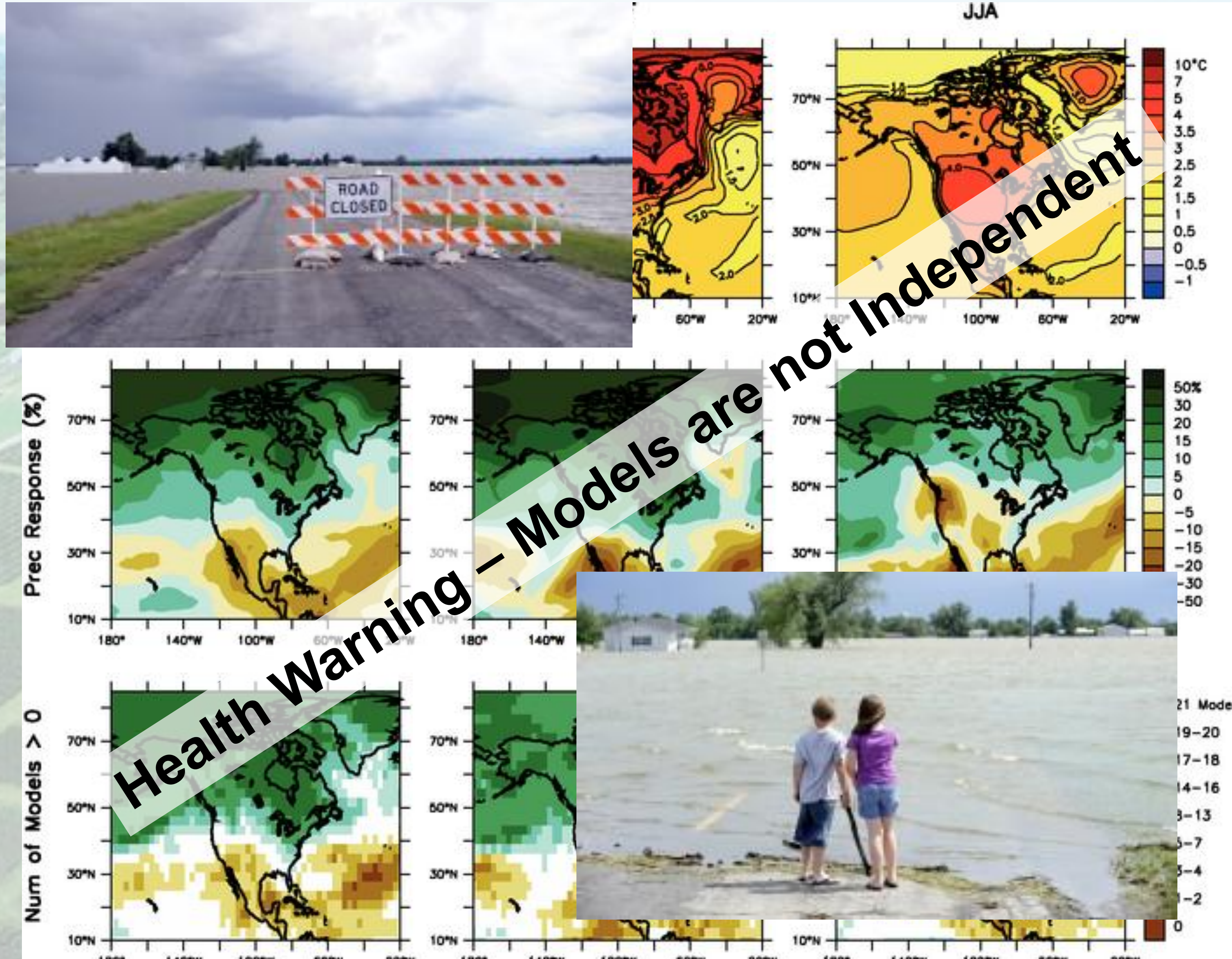
Long et al. (2006) *Science* 312, 1918-1921. & (2007) 315.



2nd Year *Miscanthus x giganteus* in 390 ppm and 600 ppm [CO_2]
Unpublished data of Souza, Arundale, Long & Buckeridge.

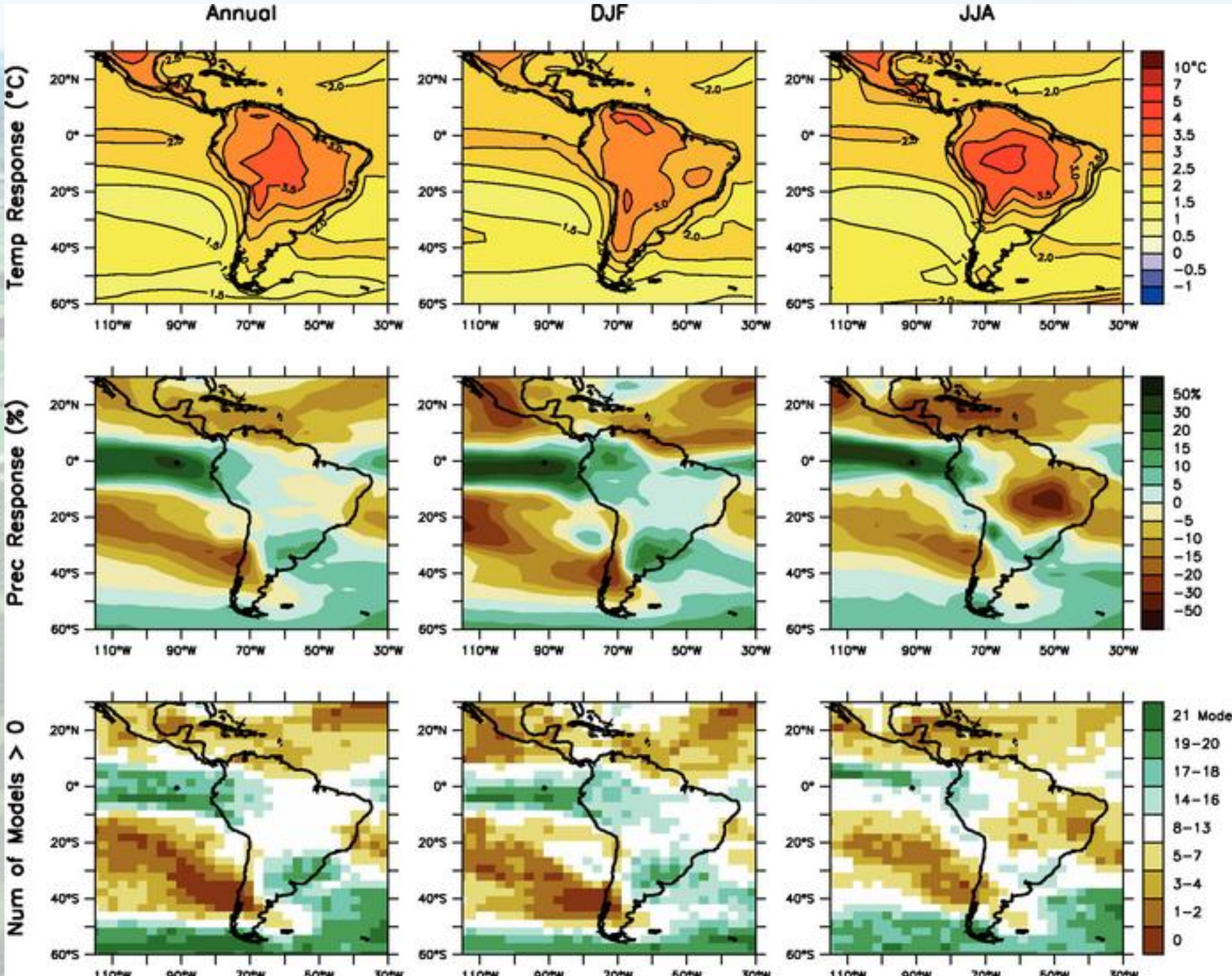


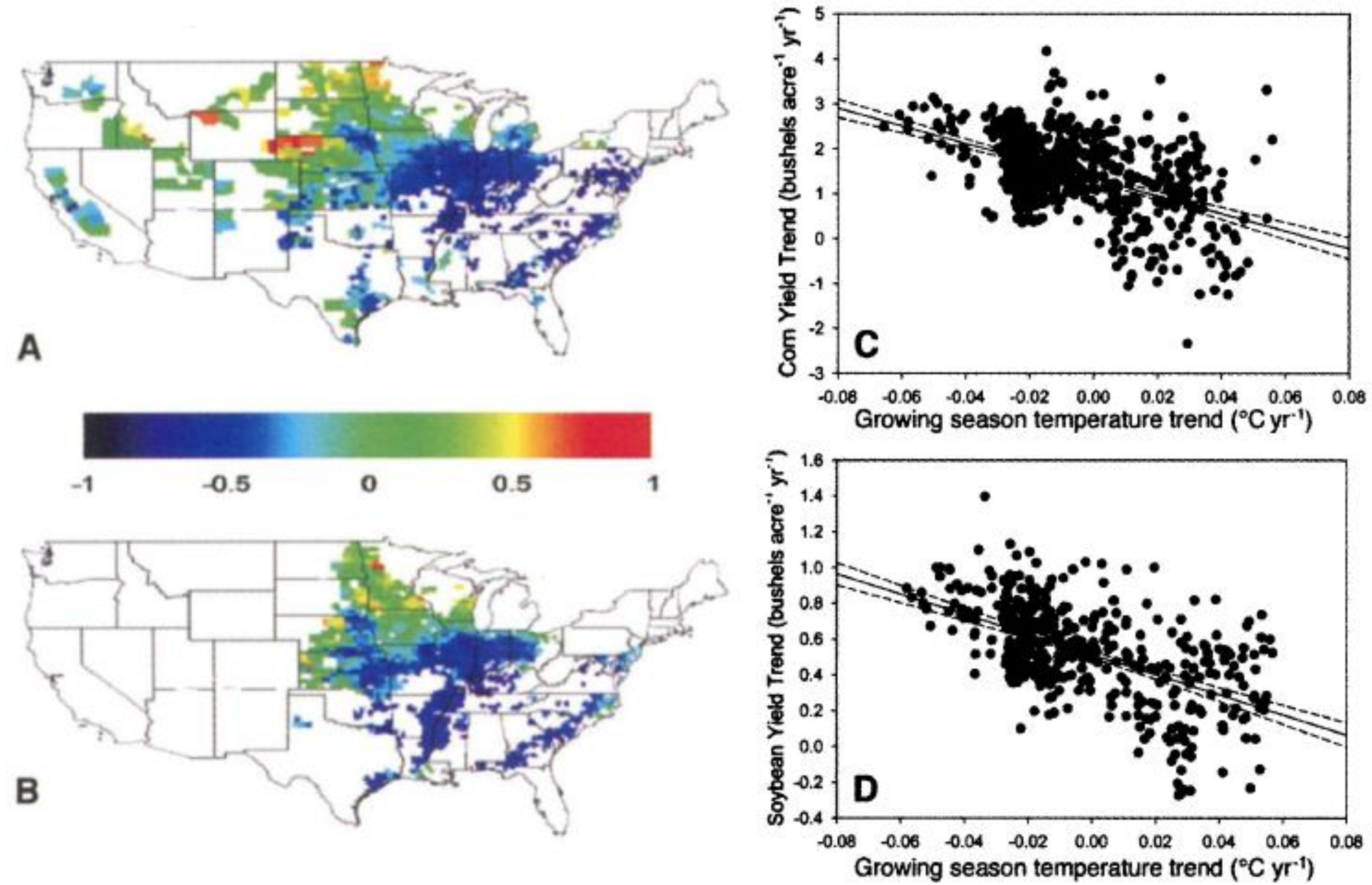
IPCC AR4 (2007)



Health Warning – Models are not Independent

IPCC AR4 (2007)





Maize (*Zea mays*) **-1.2 t ha^{-1} °C^{-1}** **2010 avg. 9.6 t ha^{-1}** **↑1.5 °C ↓19%**

Soybean (*Glycine max*) **-0.37 t ha^{-1} °C^{-1}** **2010 avg. 2.8 t ha^{-1}** **↑1.5 °C ↓20%**

Lobell & Asner Science 299: 1032; NASS (2010) USDA.GOV

Interception efficiency

Partitioning efficiency

Conversion efficiency

Total sw solar energy GJ ha^{-1}

Harvested yield t ha^{-1}

Energy content of seed GJ t^{-1}

$$W_h = S \times \varepsilon_i \times \varepsilon_c \times \eta \,/\, c$$

$$4.6 = 6200 \times 0.89 \times 0.032 \times 0.60 \,/\, 23$$

Morgan, Bollero, Nelson & Long (2005) **Global Change Biology** 11, 1856–1865

Long, Zhu, Naidu, Ort (2006) **Plant, Cell & Environment** 29: 315-330

Long, Ainsworth, Leakey, Noesberger & Ort (2006) **Science** 312 : 1918-1921

Long , Ainsworth, Leakey , Ort , Nosberger & Schimel (2007) **Science** 315, 460-461

Dermody, Long, McConnaughay, DeLucia (2008) **Global Change Biology** 14, 556–564

Harvested yield t ha^{-1}

Total sw solar energy GJ ha^{-1} Growing season

Interception efficiency

Conversion efficiency

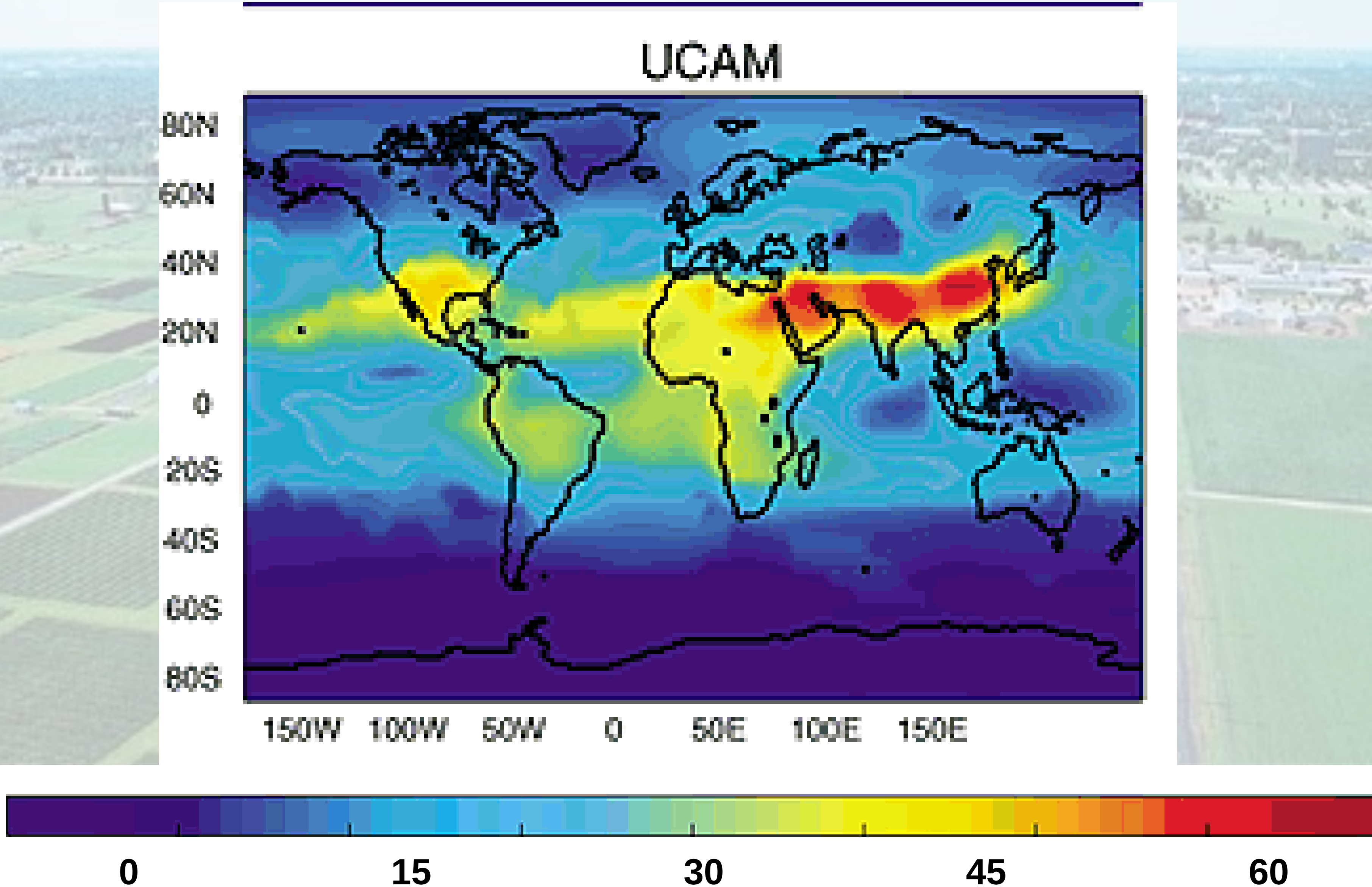
Partitioning efficiency

Energy content of seed GJ t^{-1}

$$W_h = S \times \varepsilon_i \times \varepsilon_c \times \eta / c$$

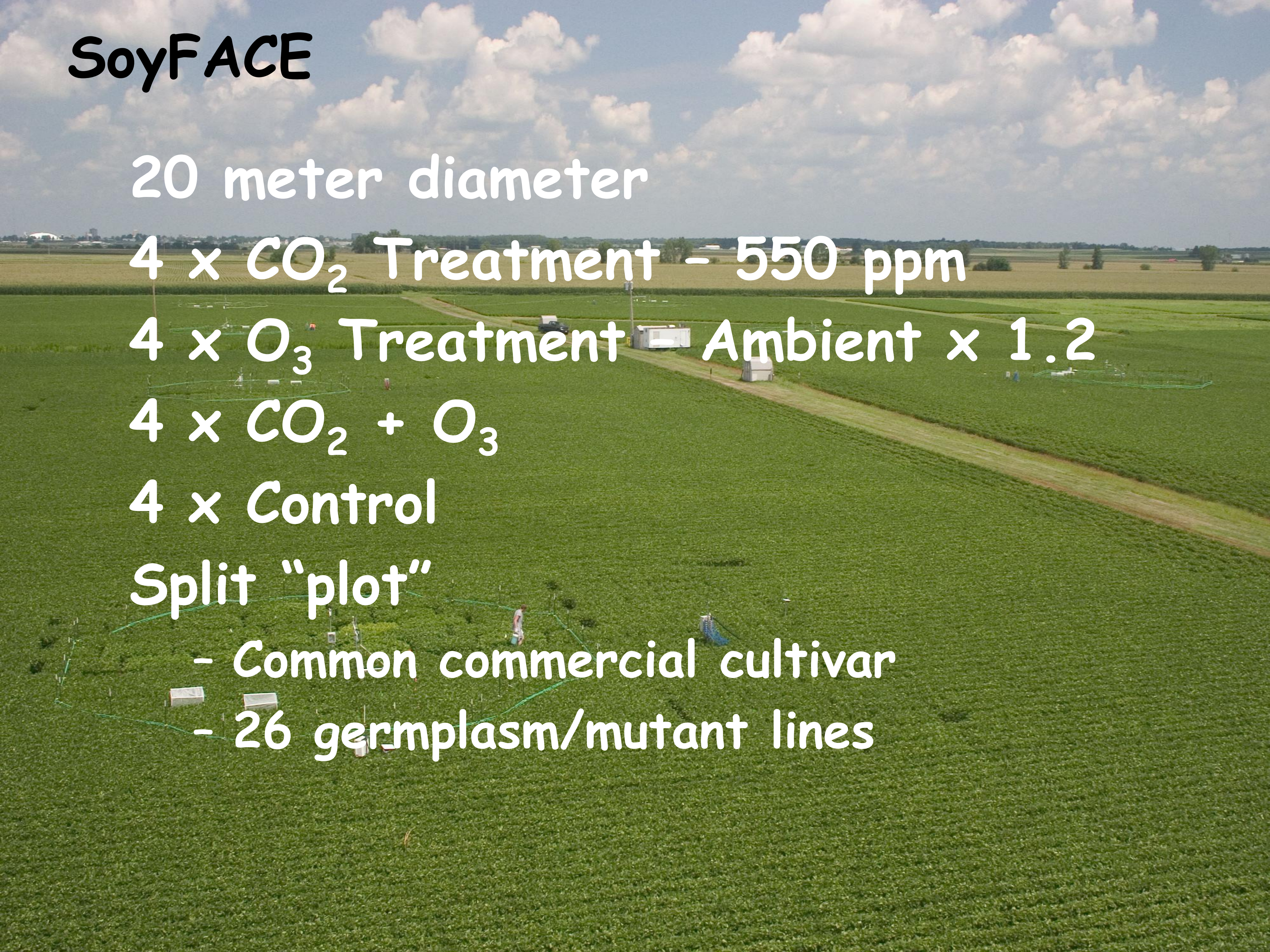
				Maturity Group
2005		4.6 =	6200 x 0.89 x 0.032 x 0.60 / 23	Group III
2050	+1.5C	3.7 =	5022 x 0.89 x 0.032 x 0.60 / 23	Group III
2050	+1.5C	5.8 =	7800 x 0.89 x 0.032 x 0.60 / 23	Group VI

Farmer adaptation converts 19% loss to 26% gain

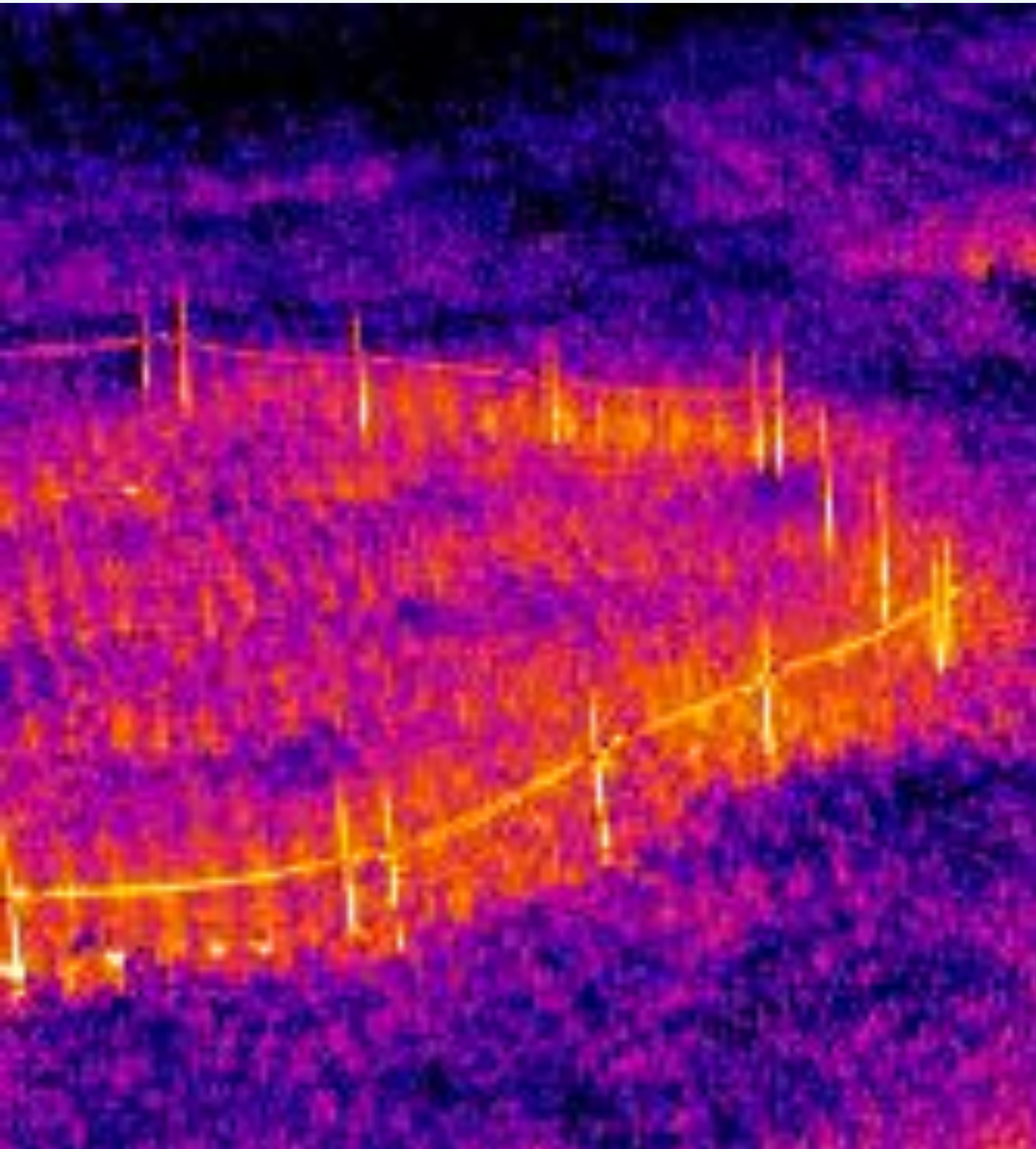


Change in July Tropospheric Ozone 2000-2100 (ppb)

SoyFACE

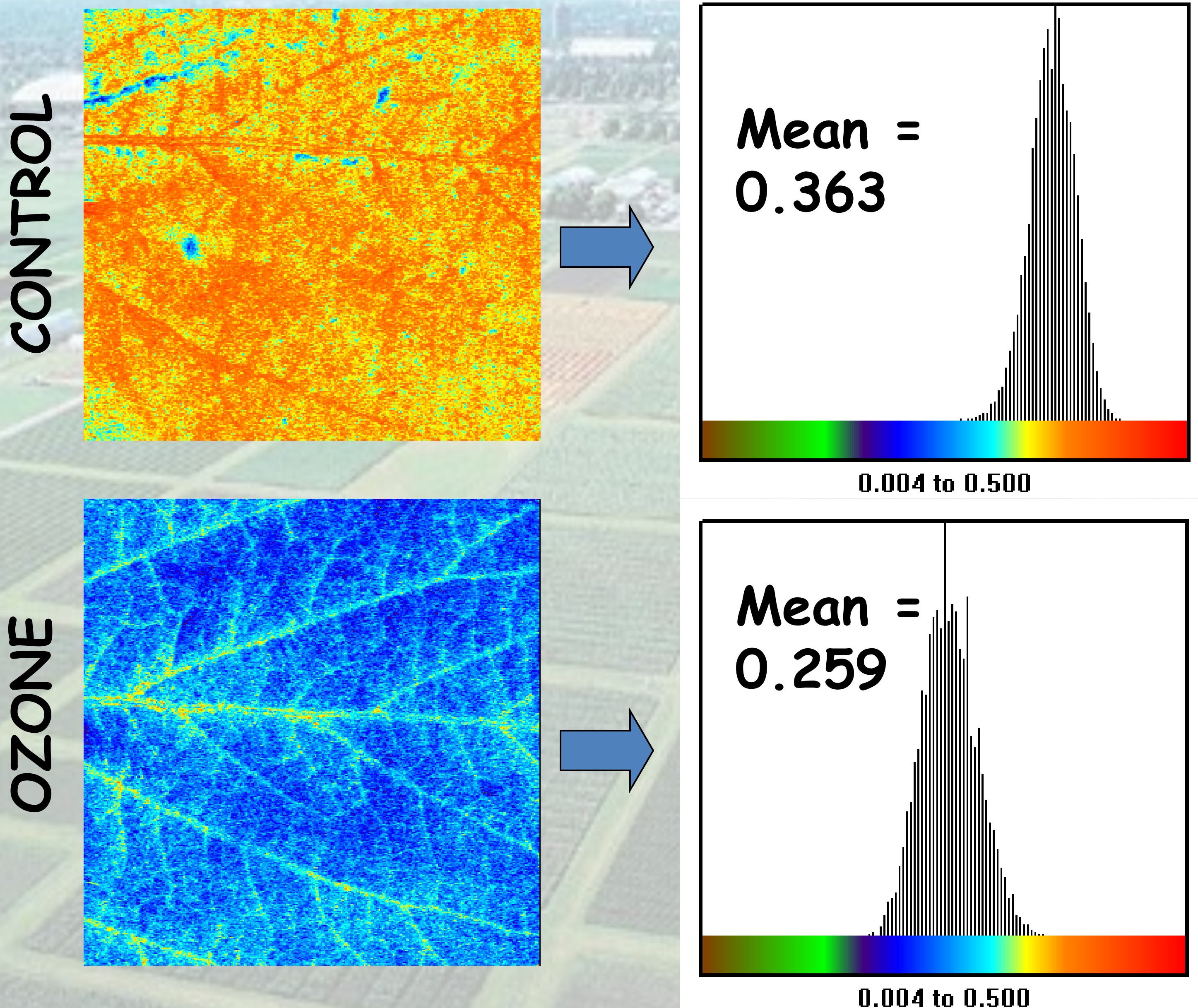


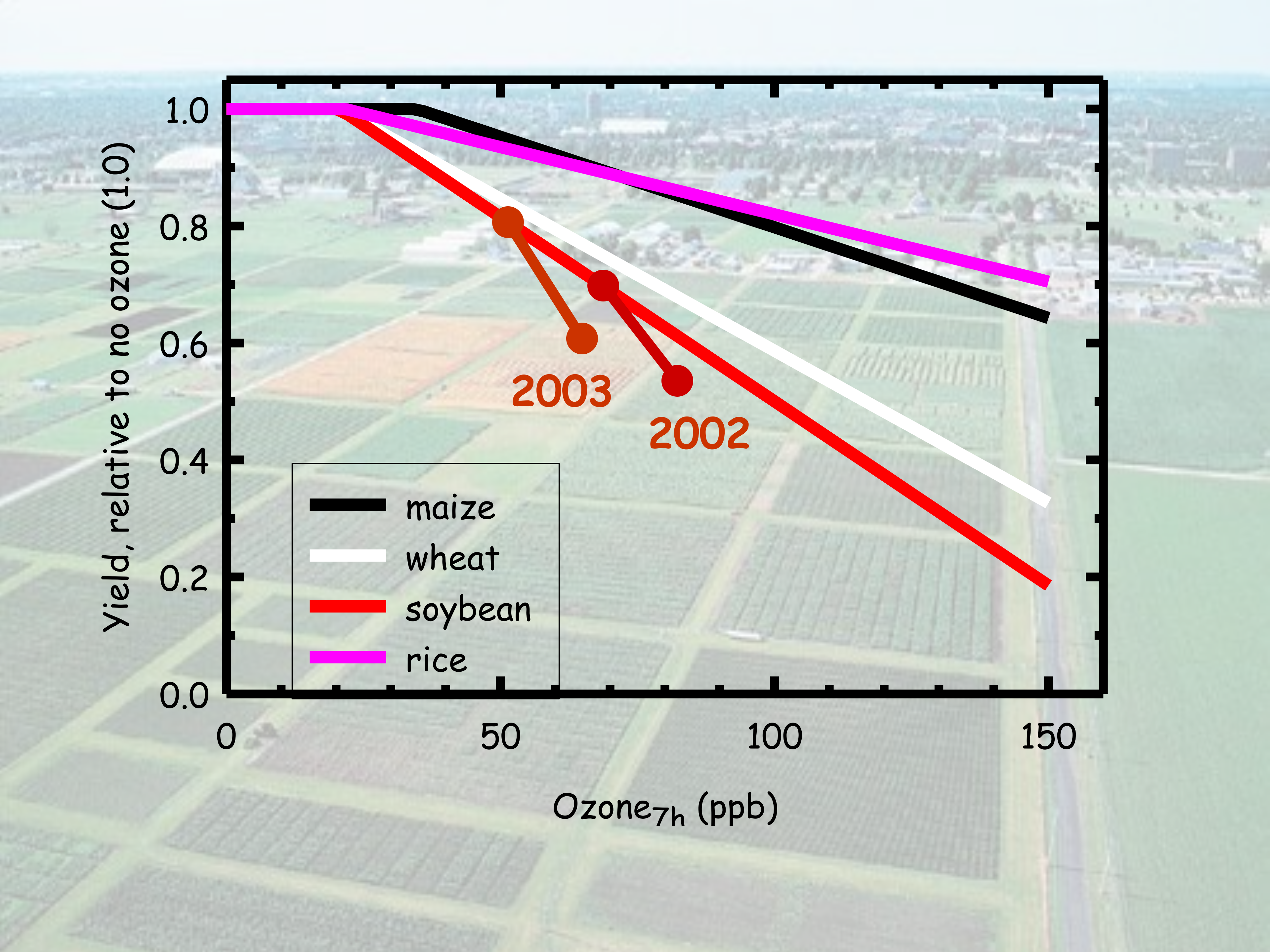
- 20 meter diameter
- 4 x CO_2 Treatment – 550 ppm
- 4 x O_3 Treatment – Ambient x 1.2
- 4 x CO_2 + O_3
- 4 x Control
- Split "plot"
  - Common commercial cultivar
  - 26 germplasm/mutant lines

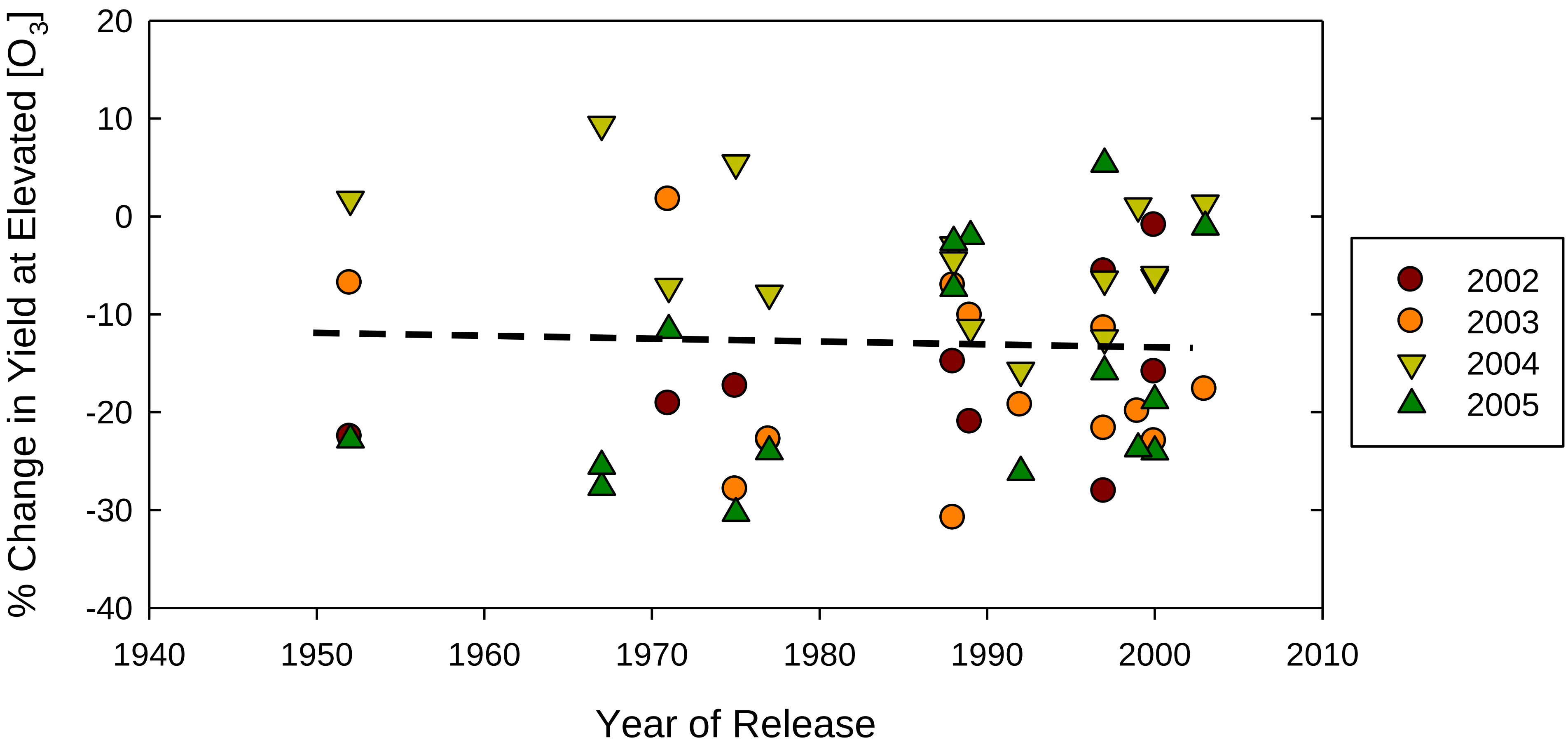


What about ozone in FACE – do findings differ?

Effect of ozone on efficiency of photosynthetic electron transport.




1.0
0.8
0.6
0.4
0.2
0.0
Yield, relative to no ozone (1.0)
0
50
100
150
Ozone$_{7h}$ (ppb)
2003
2002
maize
wheat
soybean
rice


% Change in Yield at Elevated [O3]
20
10
0
-10
-20
-30
-40
1940
1950
1960
1970
1980
1990
2000
2010
Year of Release
2002
2003
2004
2005

Yield losses

ΔYield (t/ha) = $0.027 - 0.0038\Delta T(°C^{-1}) + 0.216\Delta PPT(mm^{-1})$

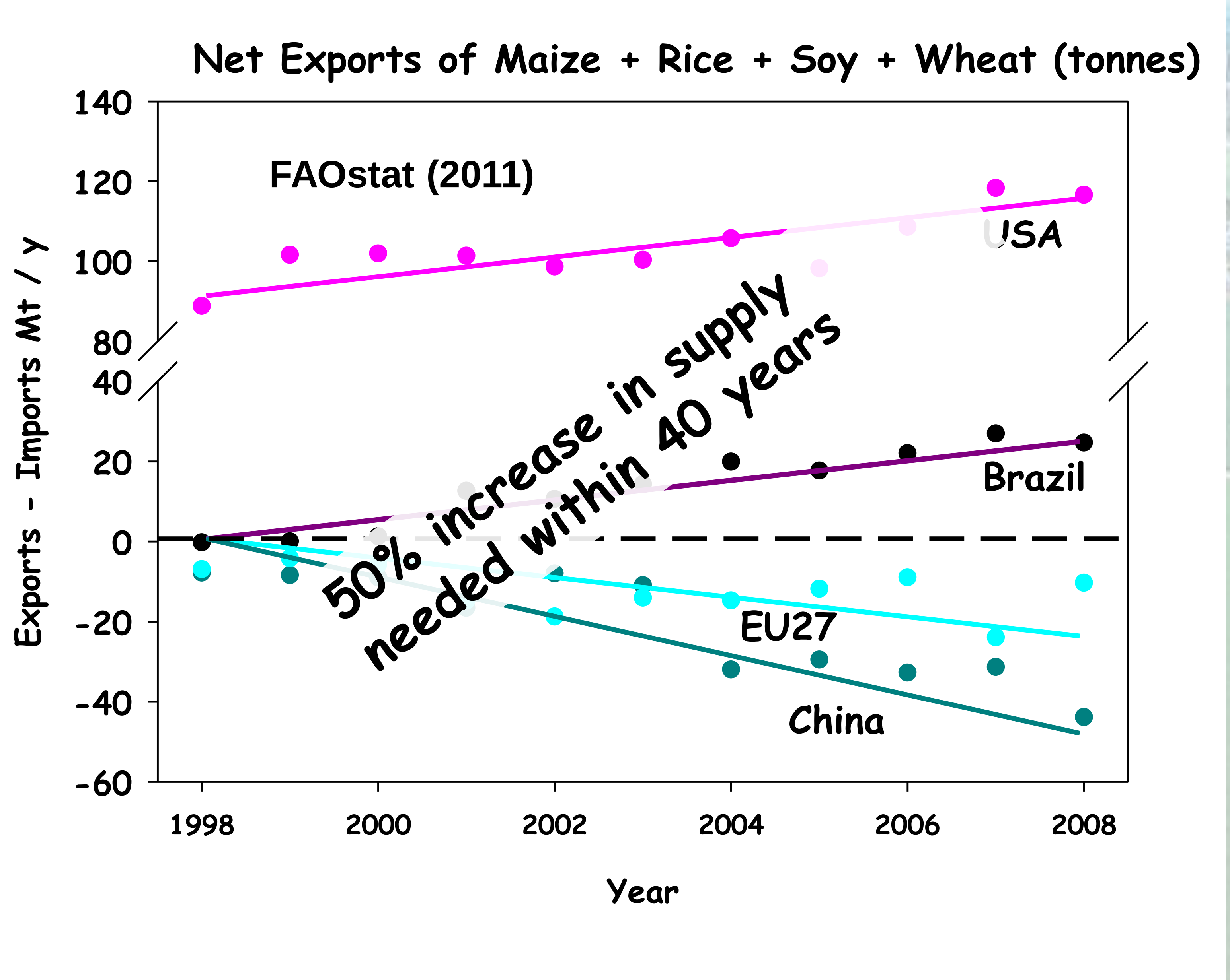
ΔYield (t/ha) = $0.027 - 0.0038\Delta T(°C^{-1}) + 0.180\Delta PPT(mm^{-1}) - 0.012\ \Delta O_3(ppb^{-1})$

i.e. 50ppb would lower yield by 0.6 t/ha

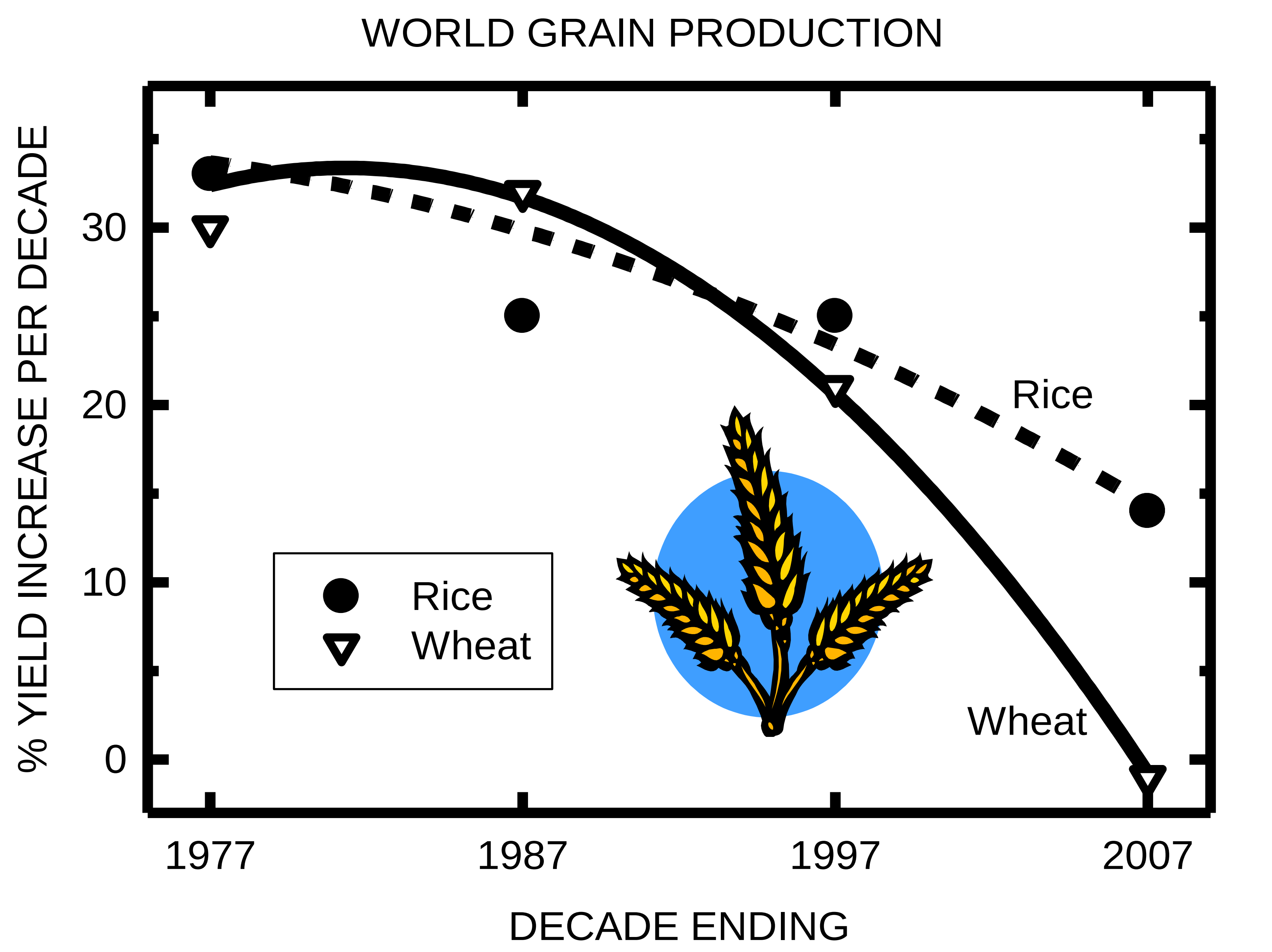
ΔYield (t/ha) = $0.144 - 0.0105\Delta T(°C^{-1}) + 0.783\Delta PPT(mm^{-1})$

ΔYield (t/ha) = $0.145 - 0.0088\Delta T(°C^{-1}) + 0.649\Delta PPT(mm^{-1}) - 0.048\ \Delta O_3(ppb^{-1})$

i.e. 50ppb would lower yield by 2.4 t/ha



Net Exports of Maize + Rice + Soy + Wheat (tonnes)
FAOstat (2011)
140
120
100
80
40
20
0
-20
-40
-60
Exports - Imports Mt / y
USA
Brazil
EU27
China
50% increase in supply
needed within 40 years
1998
2000
2002
2004
2006
2008
Year



Long & Ort (2010) Current Opinions in Plant Sciences **13**, 1-8.

Harvested yield t ha^{-1}

Total solar energy GJ ha^{-1}

Interception efficiency

Conversion efficiency

Partitioning efficiency

Energy content of seed GJ t^{-1}

$$W_h = S \times \varepsilon_i \times \varepsilon_c \times \eta \; / \; c$$

						[CO2]
4.6 =	6200 x	0.89 x	0.032 x	0.60 /	23	*380 ppm*
5.3 =	6200 x	0.89 x	0.038 x	0.58 /	23	*550 ppm*
***			***	***		

Morgan, Bollero, Nelson & Long (2005) **Global Change Biology** 11, 1856–1865

Long, Zhu, Naidu, Ort (2006) **Plant, Cell & Environment** 29: 315-330

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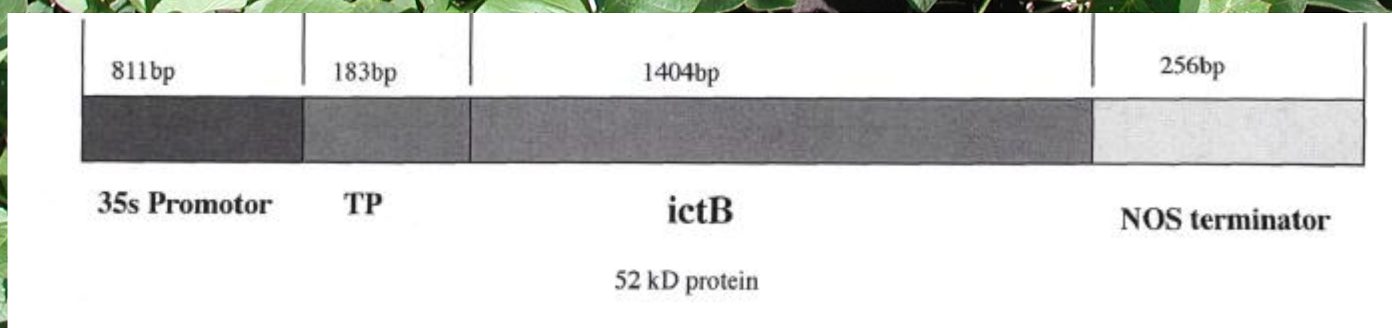
Dermody, Long, McConnaughay, DeLucia (2008) **Global Change Biology** 14, 556–564

Zhu, Long & Ort (2010) **Annu. Rev. Plant Biol. 61,** 235-261.

ictB vs. wt Soybean

unpublised data: Will Hay, Tom Clemente, Steve Long

	wt	ictB	p
A_{sat}	18.5	24.7	<0.05
Mesophyll Conductance (mmol mol^{-1})	0.244	0.304	<0.05
Seed(g)/plant	18.5	22.3	<0.05
Biomass (g/plant)	70.4	80.3	<0.05



ALTERATION	% Increase in ε_c relative to current value.	Speculated time horizon (years)
Improved canopy architecture and chlorophyll distribution	40% (0-60%)	0-10
C4 photosynthesis in C3 crops	33% (10-60%)	15-30
Increased rate of recovery from photoprotection.	15% (6-40%)	5-10
Introduction of higher kcat foreign sRubisco	22% (17-30%)	5-10
Altered allocation of resources within the photosynthetic apparatus	40% (0-60%)	0-10
Introducion of cyanobacterial CO_2 concentrating mechanisms	20% (10-30%)	0-10

Zhu et al. (2010) Annu. Rev. Plant Biol. 61:235–61

Conclusion to section

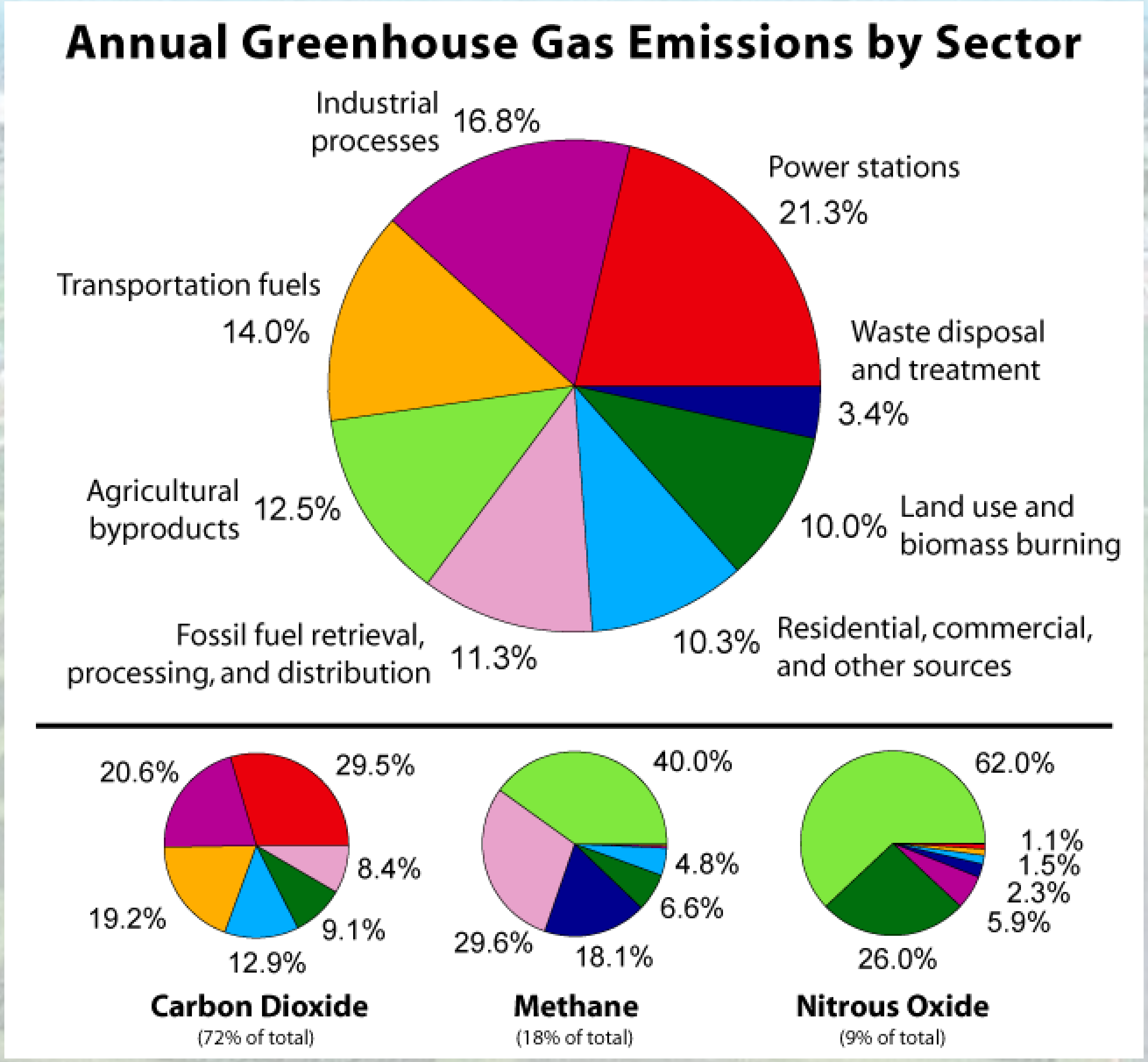
- Future capacity to simultaneously provide adequate primary foodstuffs and first generation biofuels – very uncertain.
- Depends on degree of adaptation and acceptance of biotechnology.
- Solution – feedstocks from non-arable land.

OUTLINE

Climate Change, Food, Feed and Biomass - Impacts

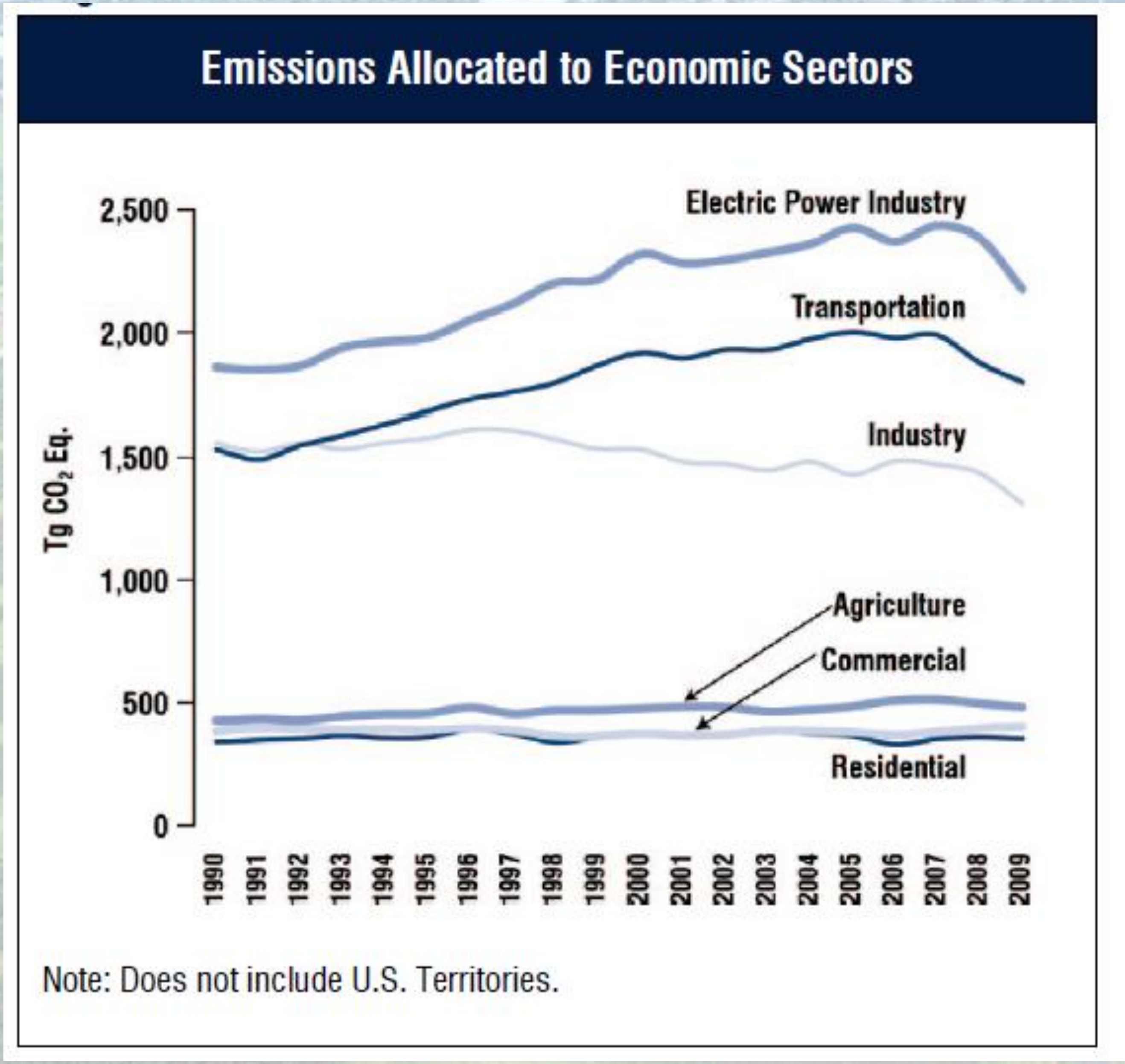
Agriculture part of the problem

Second generation and sugarcane ameliorating the problem.



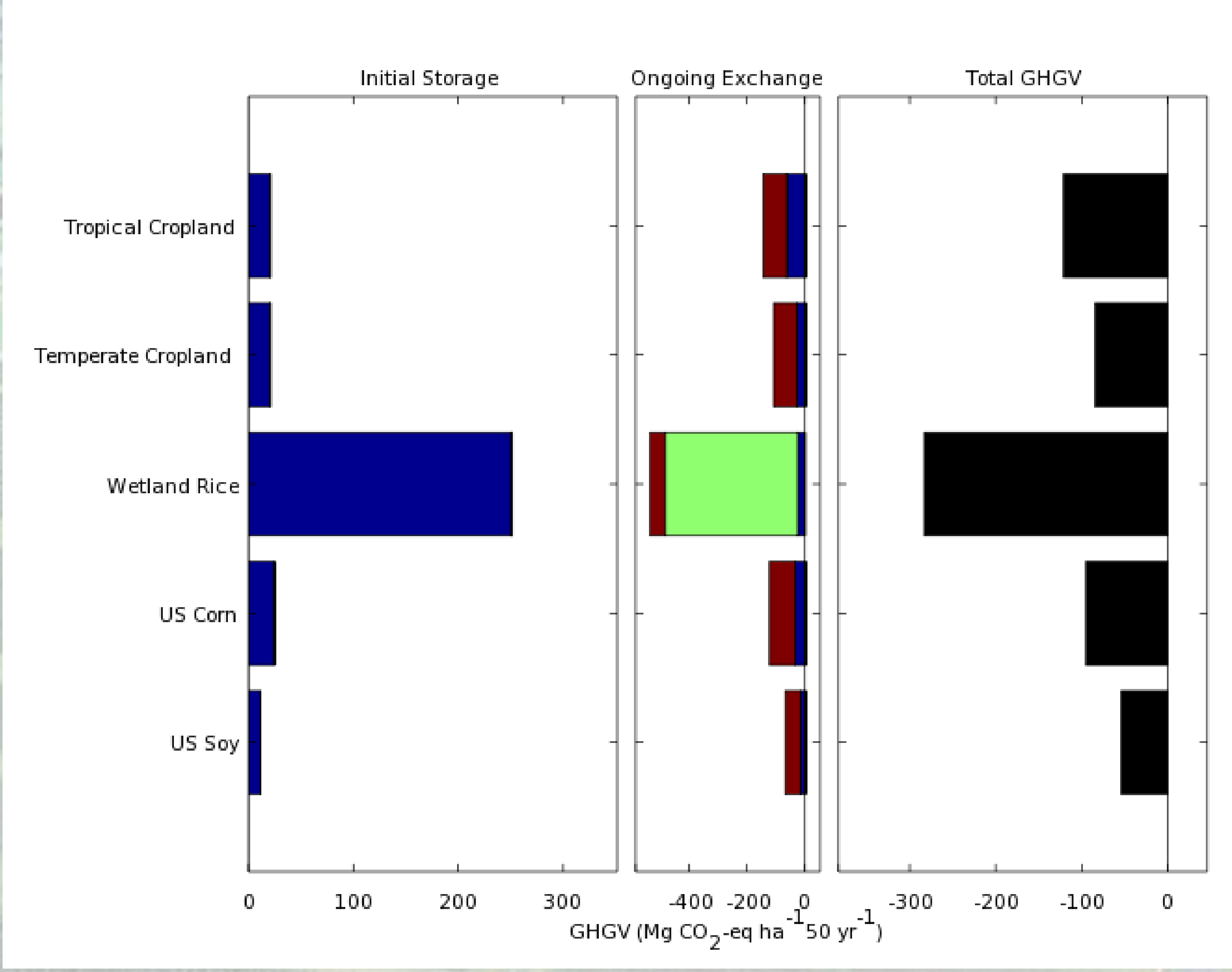
From: IPCC (2007) Climate Change – Physical Basis, Report of WG1.

USA GHG Emissions by Sector. EPA (2011)



Greenhouse Gas Value of an Ecosystem net t CO_2 equivalent per hectare over 50 year time span.

From Global Change Solutions llc (2011)



www.globalchangesolutionsllc.com

Conclusion to section

- Gaining the extra production needed for basic foodstuffs alone plus increased diversion to animal production, could double agricultural GHG emissions.
- There are opportunities to adapt, without yield loss.

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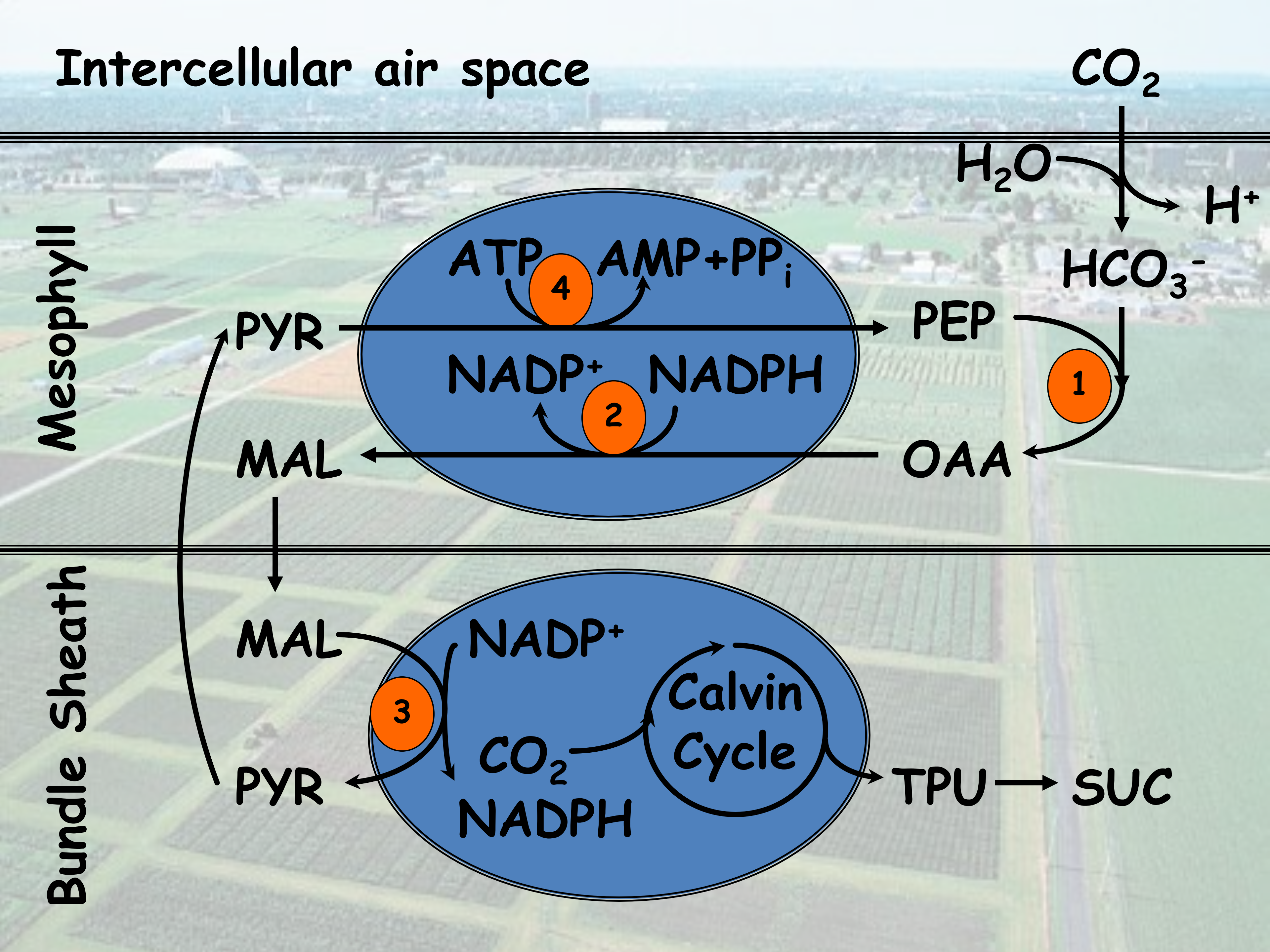
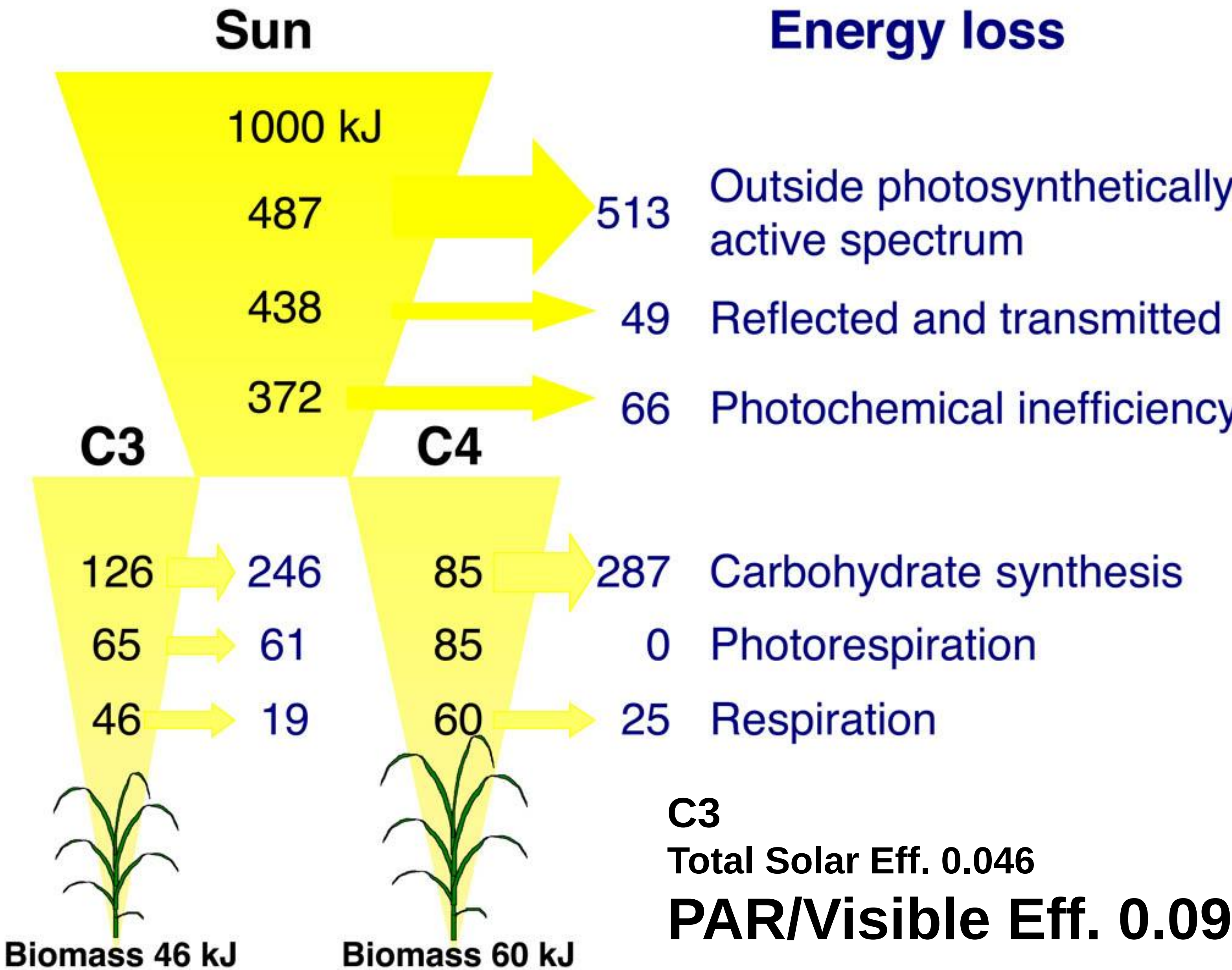

Intercellular air space
CO2
H2O
H+
HCO3-
Mesophyll
ATP
4
AMP+PPi
PYR
PEP
NADP+
NADPH
2
1
MAL
OAA
Bundle Sheath
MAL
NADP+
3
Calvin
Cycle
CO2
PYR
NADPH
TPU
SUC



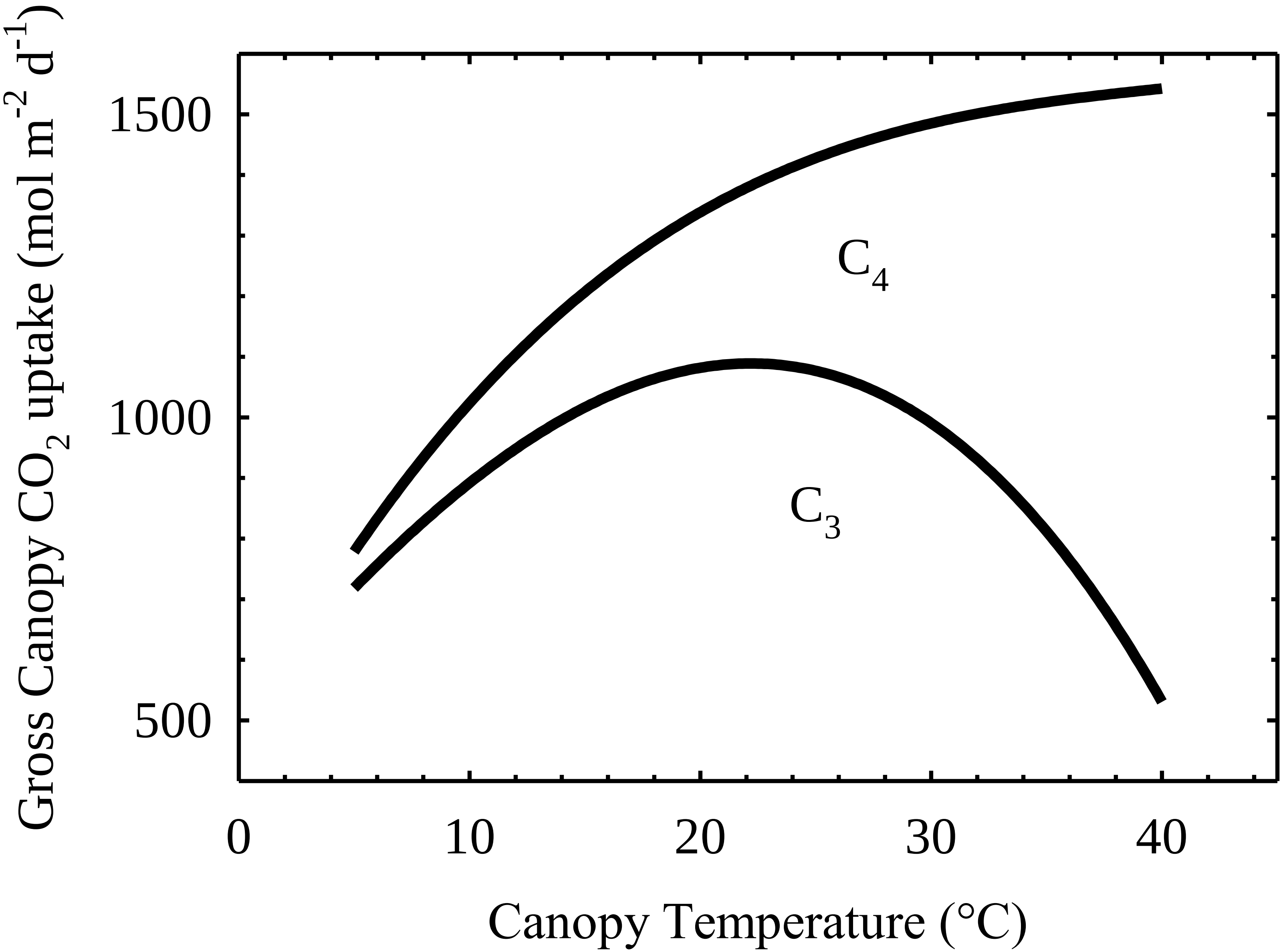
C3

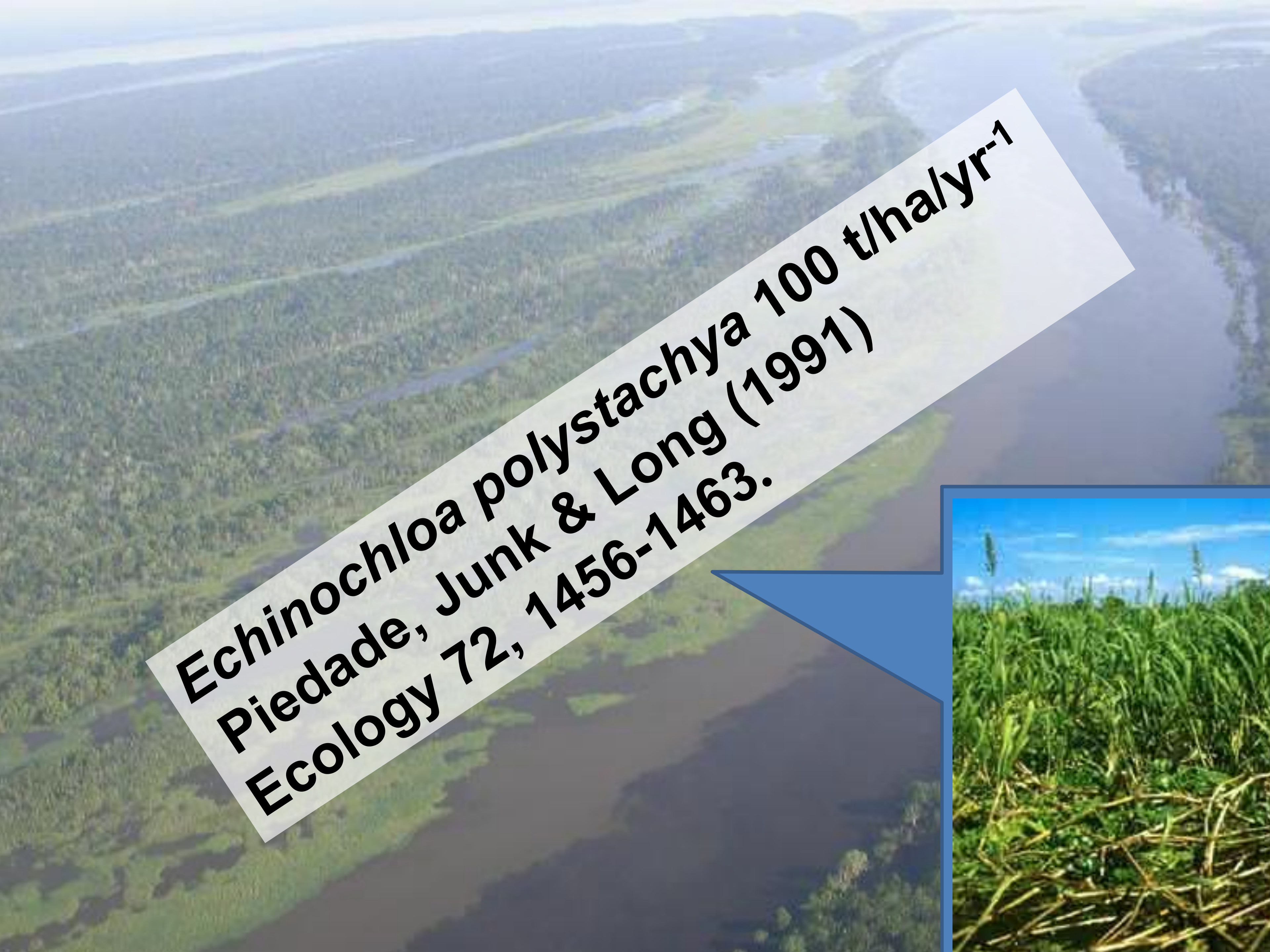
Total Solar Eff. 0.046

PAR/Visible Eff. 0.094

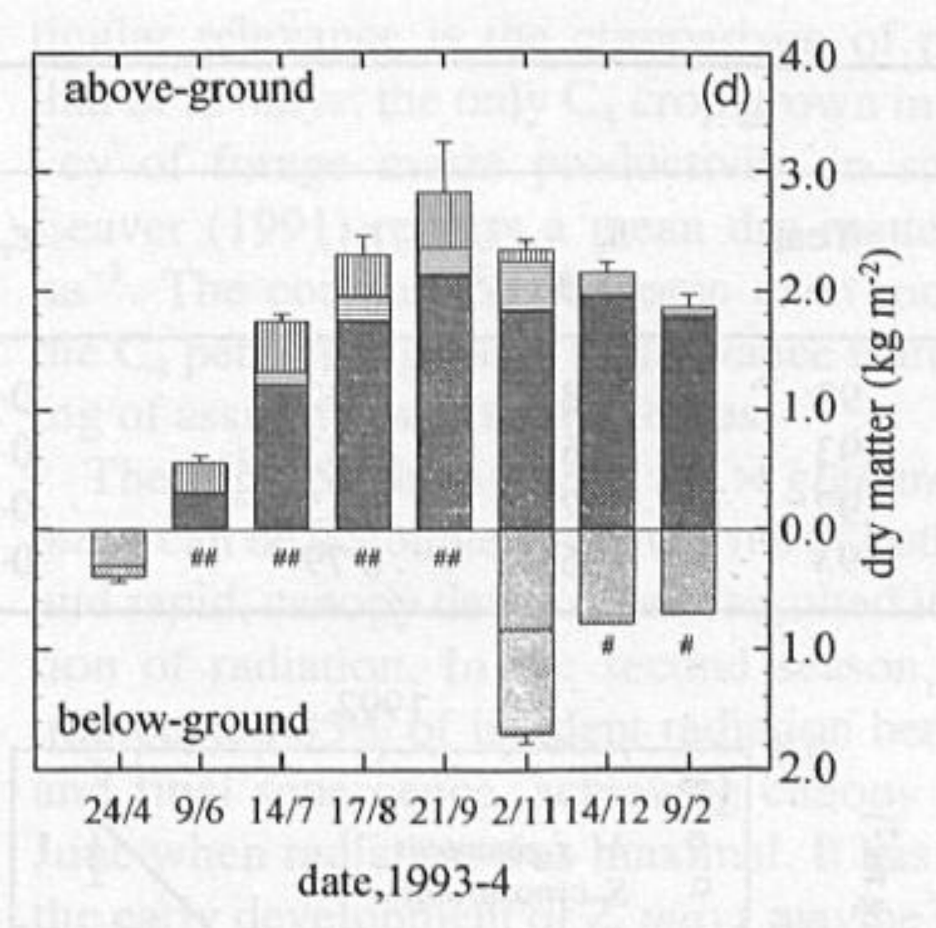
Zhu, Long and Ort (2008) Current Opinion in Biotechnology

Long (1998) In: The Biology of C_4 Photosynthesis (Sage, R.F. & Monson, R.K., eds.) Pp. 215-249.





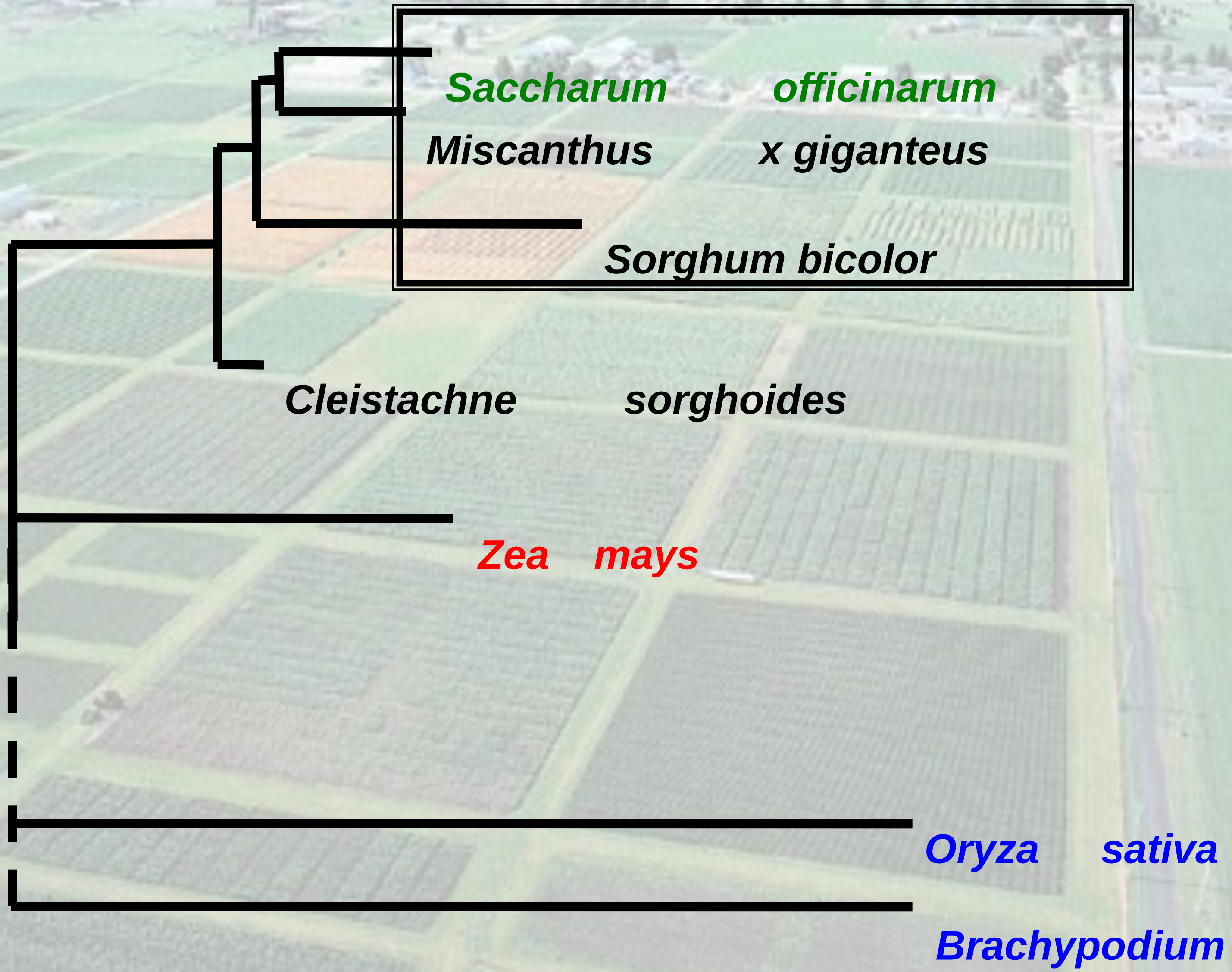
Echinochloa polystachya 100 t/ha/yr^{-1}
Piedade, Junk & Long (1991)
Ecology 72, 1456-1463.



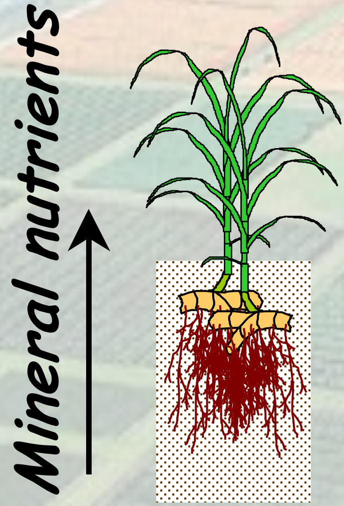
***Miscanthus x giganteus* in**
S. England. 52 °N

Beale & Long (1995)
Plant, Cell & Env. 18: 641-

Relationships



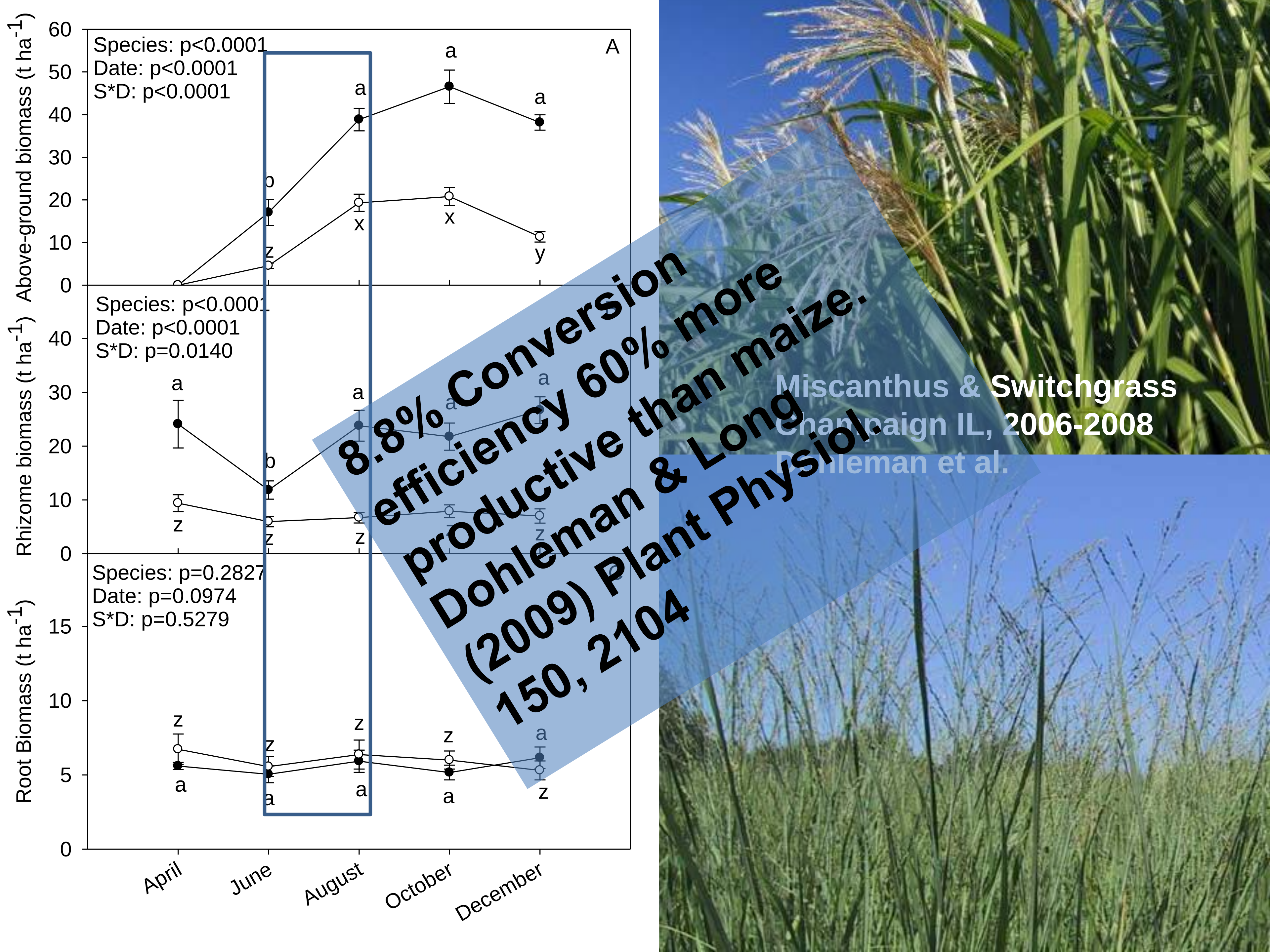
Nutrient Use Efficiency - Theory

SPRING/ SUMMER	FALL	WINTER
		
Translocation from rhizomes to growing shoot	Translocation to rhizome as shoot senesces	Lignocellulose dry shoots harvested, nutrients stay in rhizomes

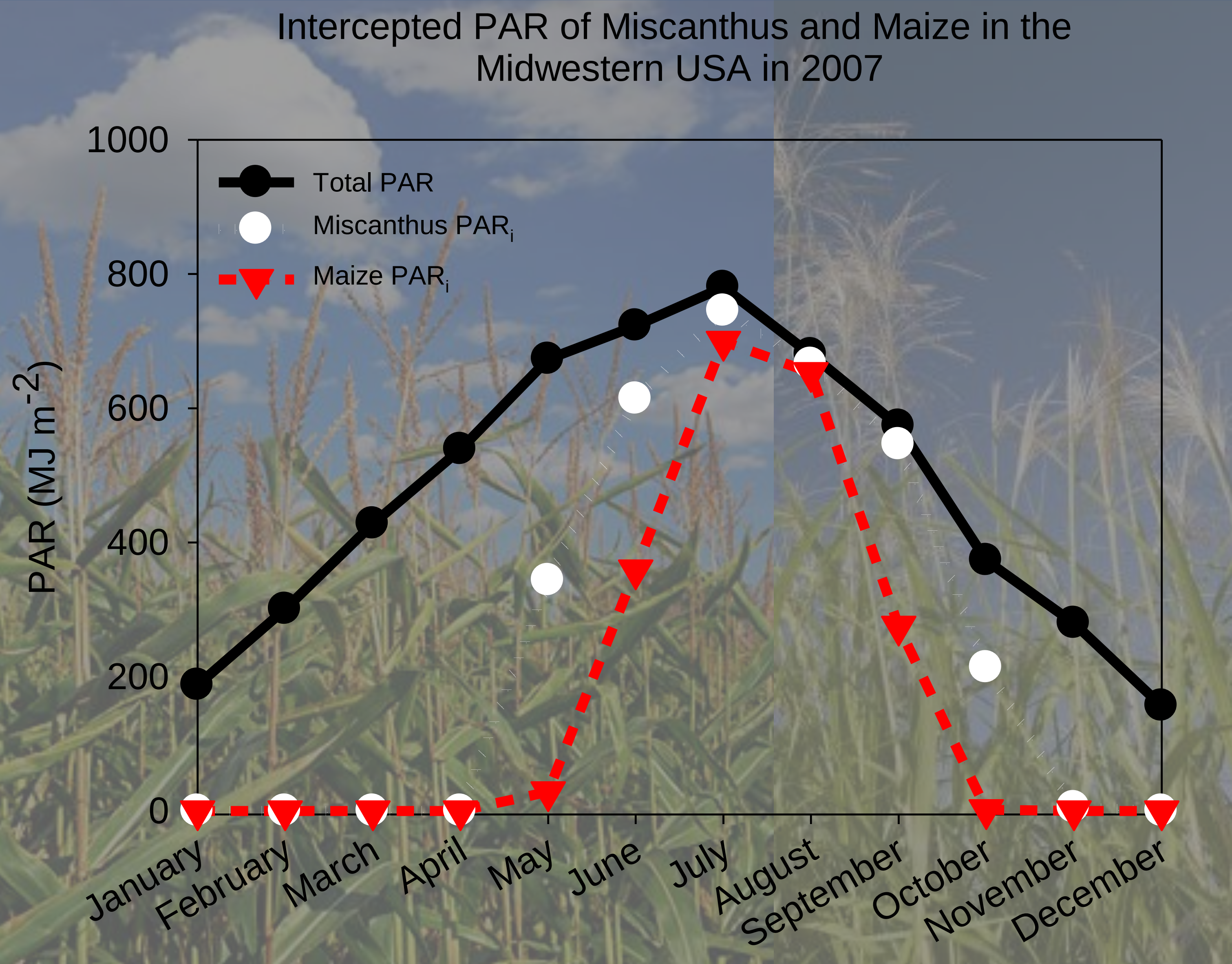
Miscanthus can be productive on marginal land

The *Miscanthus x giganteus* in Cashel Co. Tipperary, Ireland photographed in September 1996 with 72HP tractor for scale.

RANDOMIZED PLOT TRIALS


8.8% Conversion
efficiency 60% more
productive than maize.
Dohleman & Long
(2009) Plant Physiol.
150, 2104
Miscanthus & Switchgrass
Champaign IL, 2006-2008
Dohleman et al.
Above-ground biomass (t ha-1)
Species: p<0.0001
Date: p<0.0001
S*D: p<0.0001
A
Rhizome biomass (t ha-1)
Species: p<0.0001
Date: p<0.0001
S*D: p=0.0140
Root Biomass (t ha-1)
Species: p=0.2827
Date: p=0.0974
S*D: p=0.5279
April
June
August
October
December

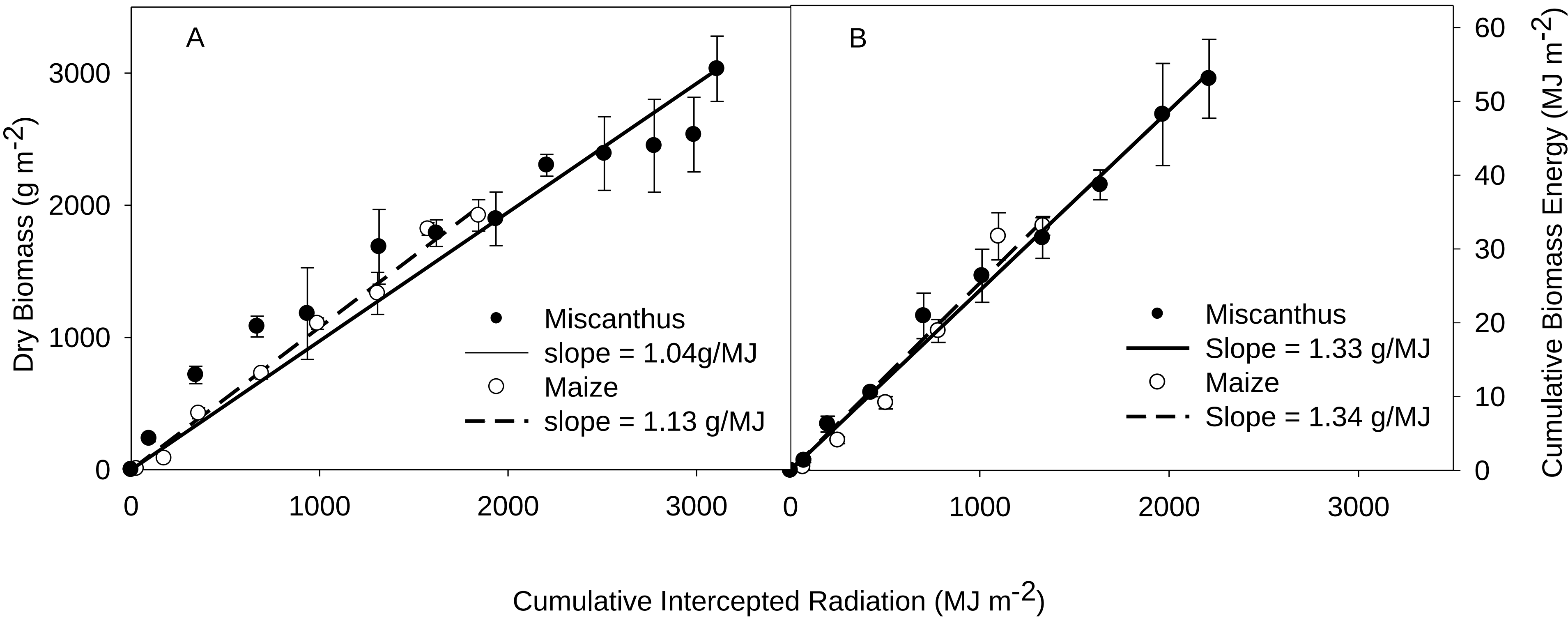
Light Capture



Dohleman & Long (2009) Plant Physiology, 150, 2104-2115

Conversion Efficiency

Dohleman & Long (2009) Plant Physiol. 150, 2104



Harvested yield t ha^{-1}

Total solar energy GJ ha^{-1}

Interception efficiency

Conversion efficiency

Partitioning efficiency

Energy content of seed GJ t^{-1}

$$W_h = S \times \varepsilon_i \times \varepsilon_c \times \eta \; / \; c$$

Mxg	**40.7 =**	**13670** x	**0.80** x	**0.075** x	**1.0 /**	**18**
Switch.	**12.0 =**	**13670** x	**0.76** x	**0.021** x	**1.0 /**	**18**
Maize	**24.0 =**	**8202** x	**0.80** x	**0.076** x	**1.0 /**	**20**

Heaton et al. (2008) Global Change Biology, 14, 2000–2014

Dohleman et al. (2009); Plant Physiology, 150: 2104–2115

JANUARY

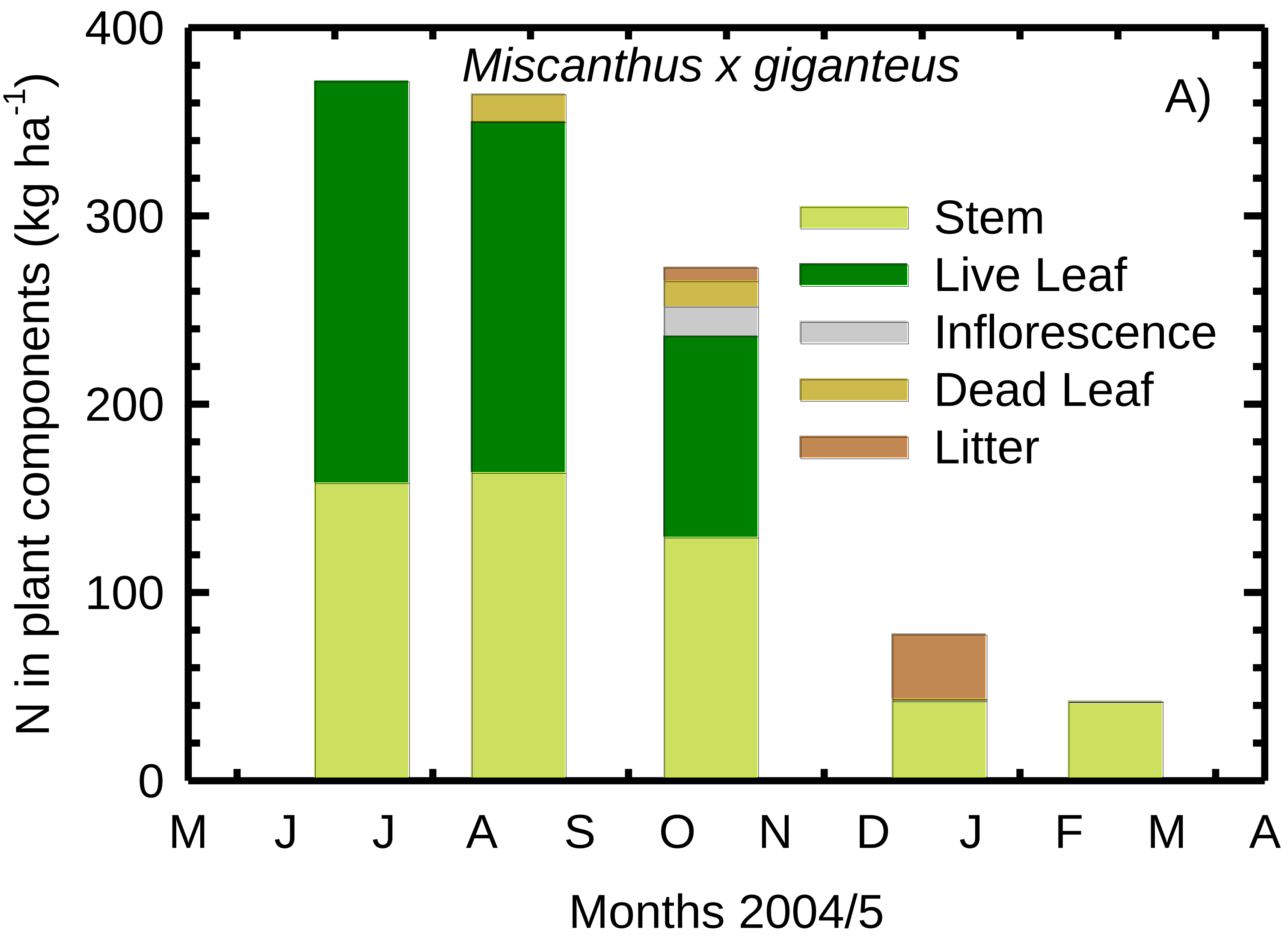
FEBRUARY HARVEST

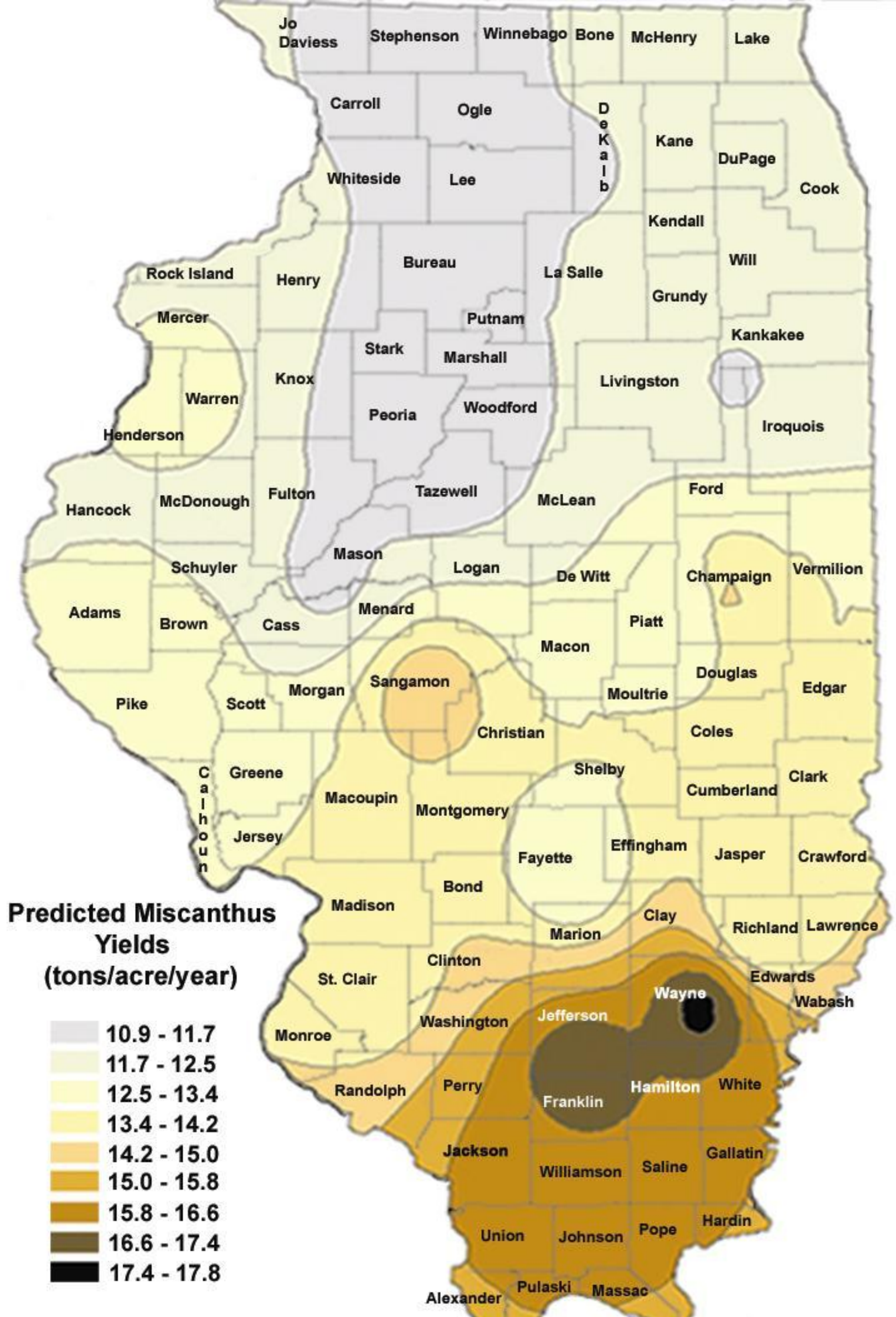
Winter cutting (followed by baling) of demonstration plot of *Miscanthus x giganteus* at the South Farms, University of Illinois, Urbana, early 2007.

MISCANTHUS – TRADITIONAL THATCHING MATERIAL IN JAPAN

Miscanthus nitrogen in the shoot

Heaton et al. (2009) GCB Bioenergy (2009) 1, 297–307





Heaton E. H., Clifton-Brown J., Voigt T.B., Jones M.B., and Long S.P.
Biomass Crops for Renewable Energy Generation: European Union Experience with Miscanthus and Projections for Illinois. 2003, In Review
Map courtesy of Paul Stampfl

Expected Miscanthus Yields in Illinois

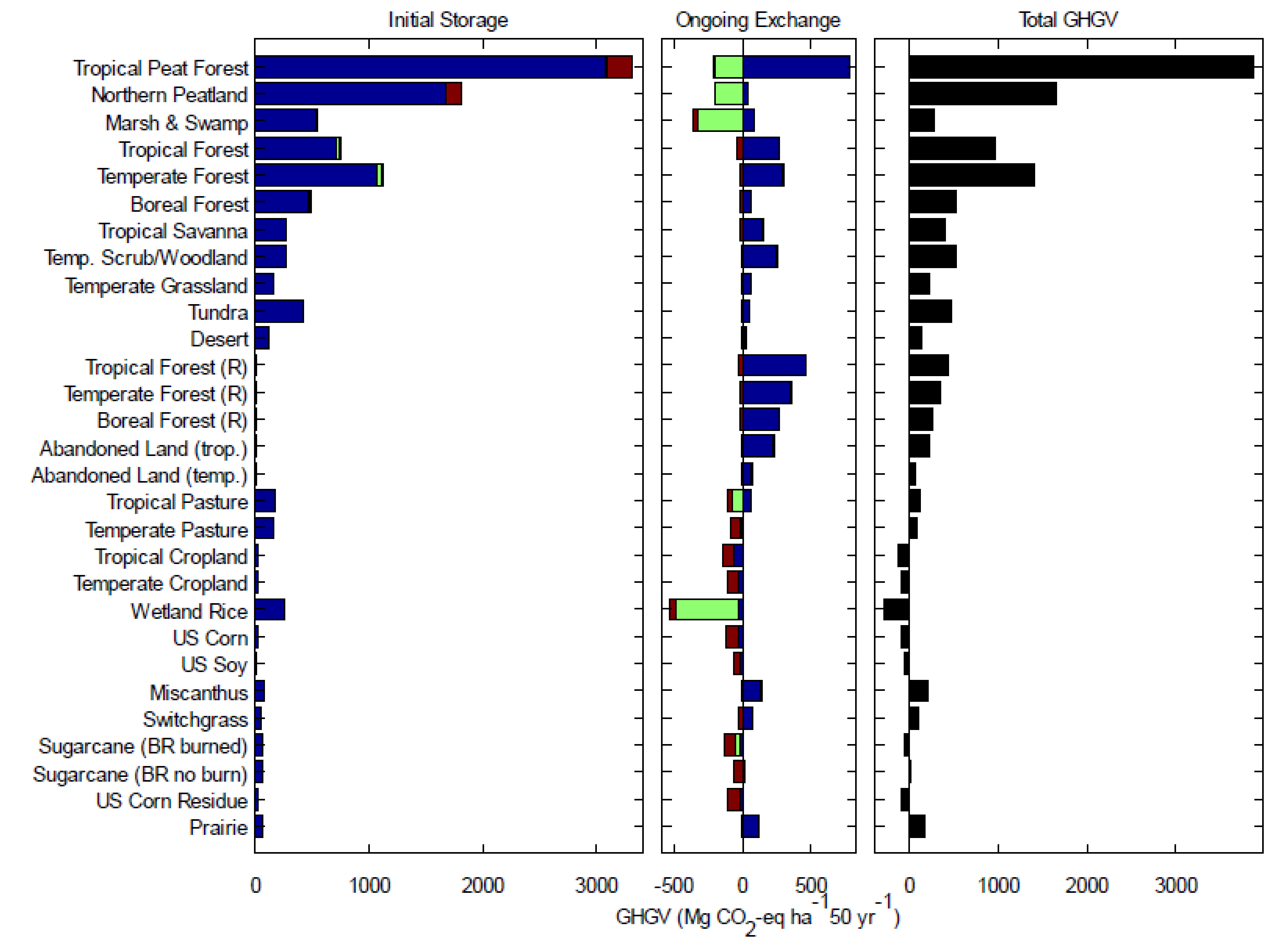
- 11 – 18 tons/acre

Predicted using :

- agro – climatic computer model (Clifton-Brown et al. 2000)

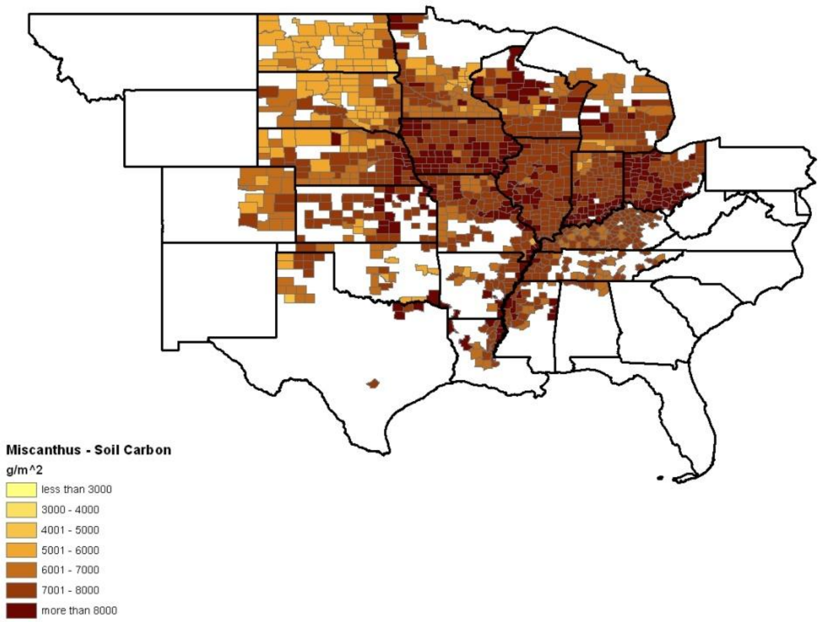
and

- IL State Water Survey climate data 1996-1999

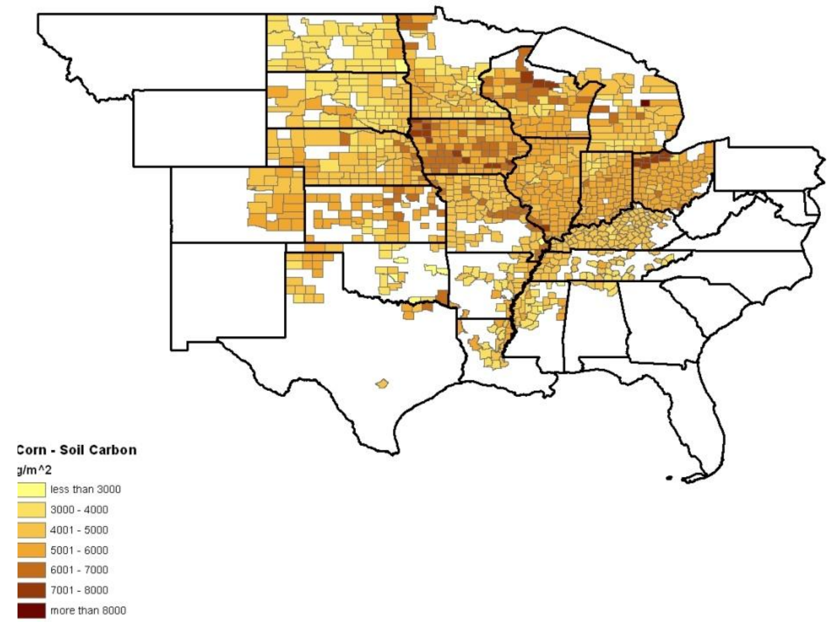


Initial Storage
Ongoing Exchange
Total GHGV
Tropical Peat Forest
Northern Peatland
Marsh & Swamp
Tropical Forest
Temperate Forest
Boreal Forest
Tropical Savanna
Temp. Scrub/Woodland
Temperate Grassland
Tundra
Desert
Tropical Forest (R)
Temperate Forest (R)
Boreal Forest (R)
Abandoned Land (trop.)
Abandoned Land (temp.)
Tropical Pasture
Temperate Pasture
Tropical Cropland
Temperate Cropland
Wetland Rice
US Corn
US Soy
Miscanthus
Switchgrass
Sugarcane (BR burned)
Sugarcane (BR no burn)
US Corn Residue
Prairie
0
1000
2000
3000
-500
0
500
0
1000
2000
3000
GHGV (Mg CO_2-eq ha^{-1} 50 yr^{-1})

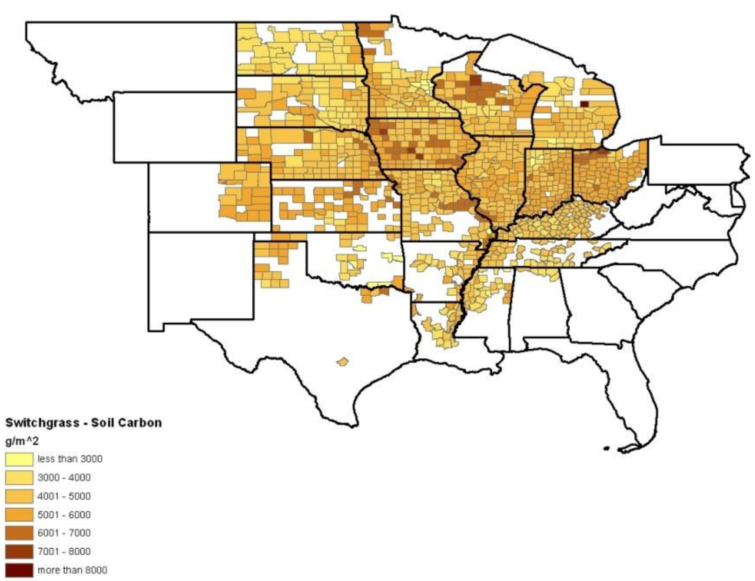
Miscanthus - Soil Carbon



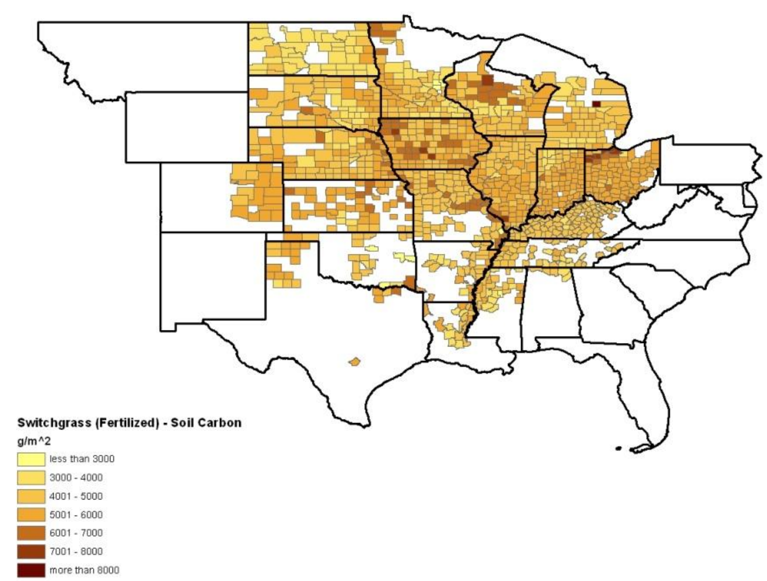
Corn - Soil Carbon



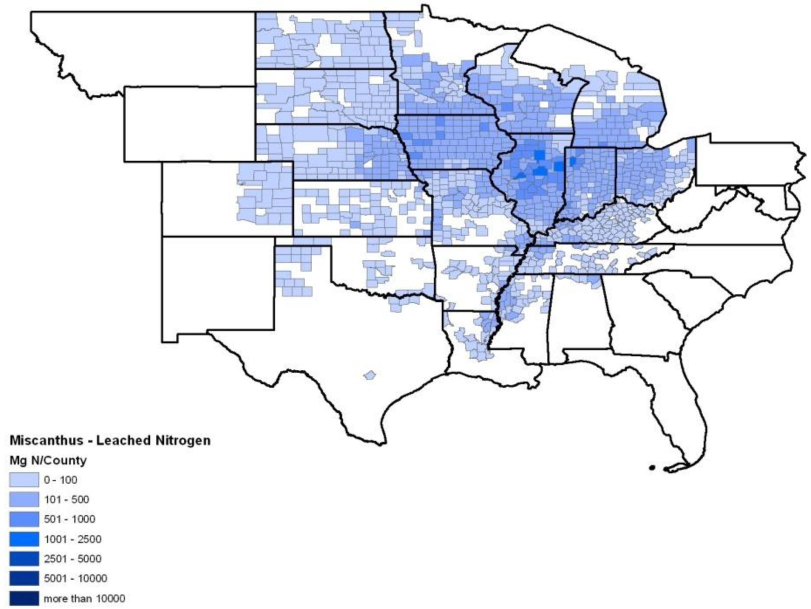
Switchgrass - Soil Carbon



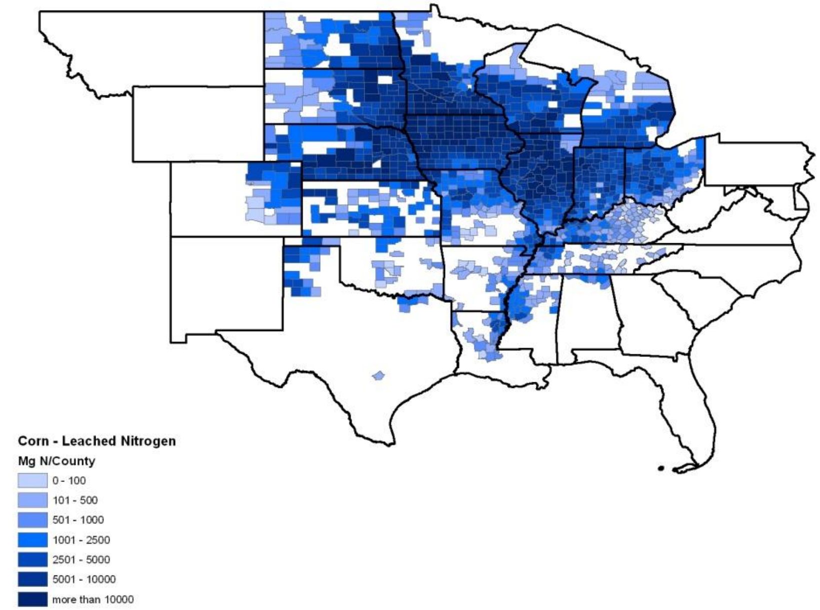
Switchgrass (Fertilized) - Soil Carbon



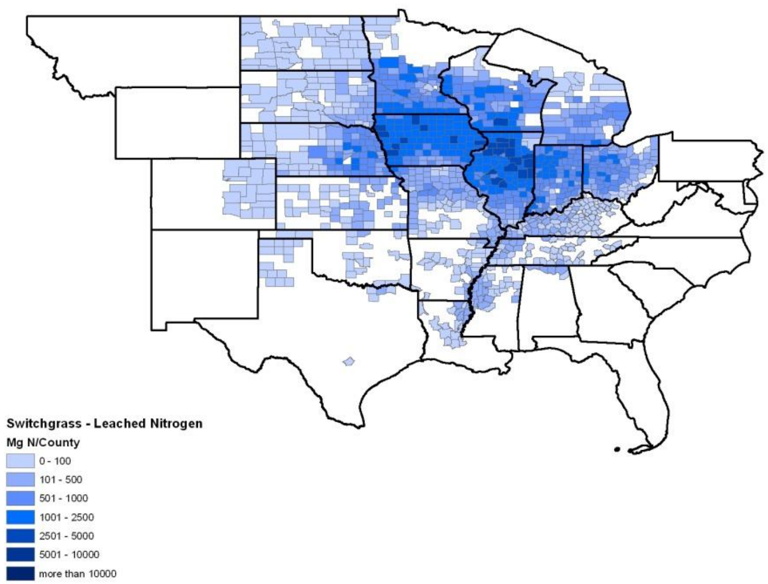
Miscanthus - Leached Nitrogen



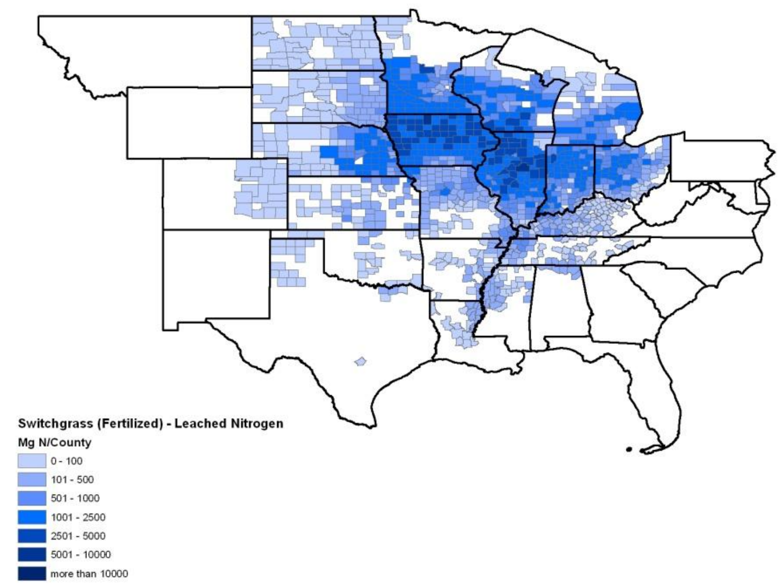
Corn - Leached Nitrogen



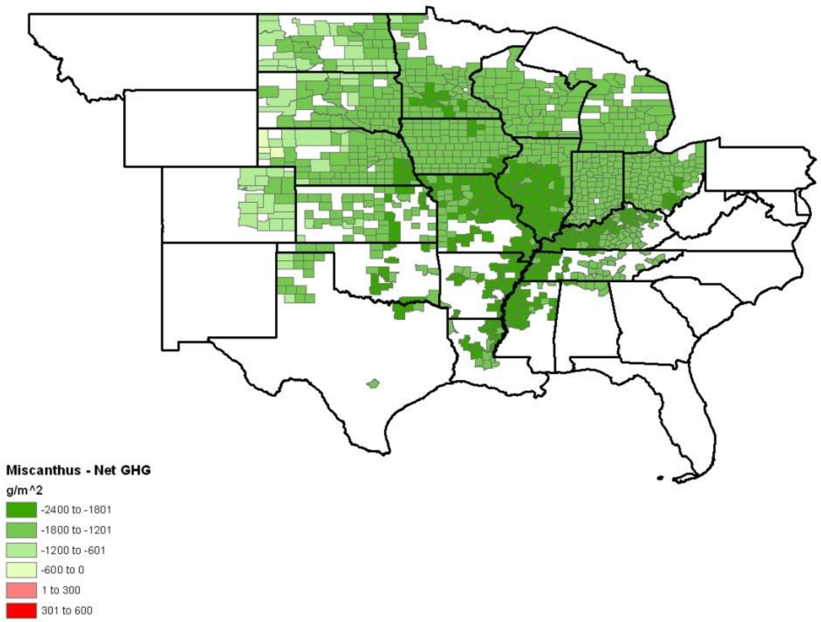
Switchgrass - Leached Nitrogen



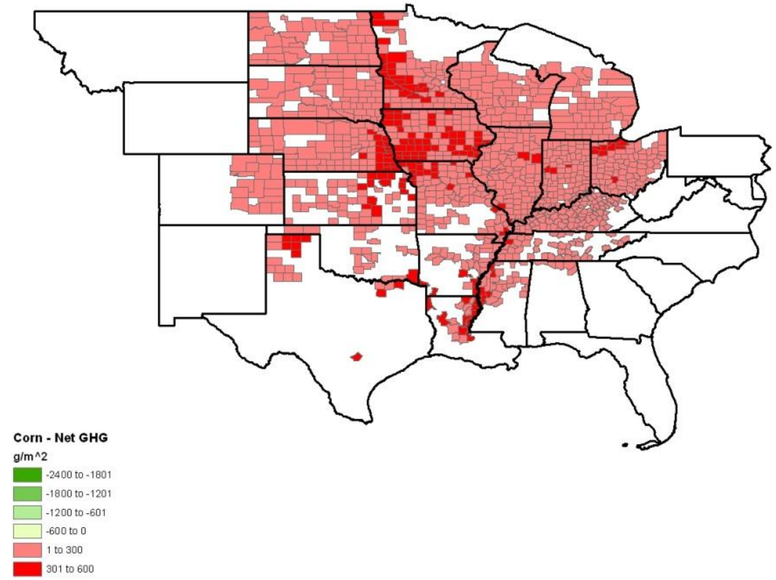
Switchgrass (Fertilized) - Leached Nitrogen



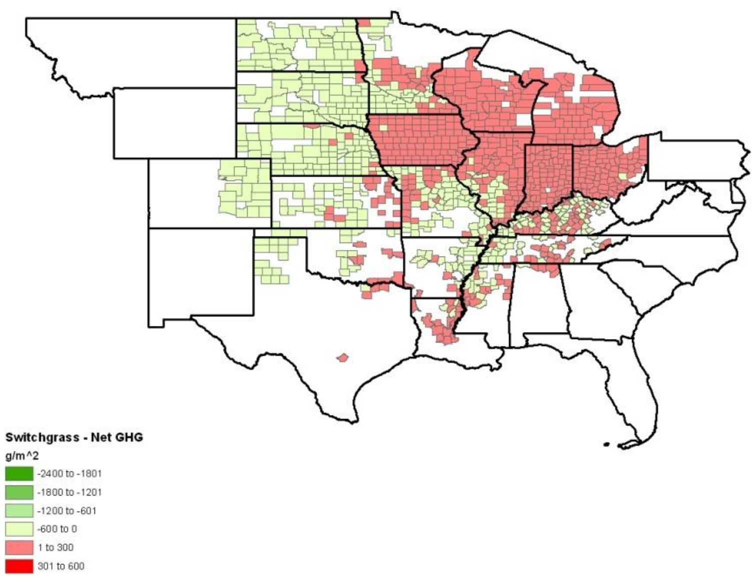
Miscanthus - Net GHG



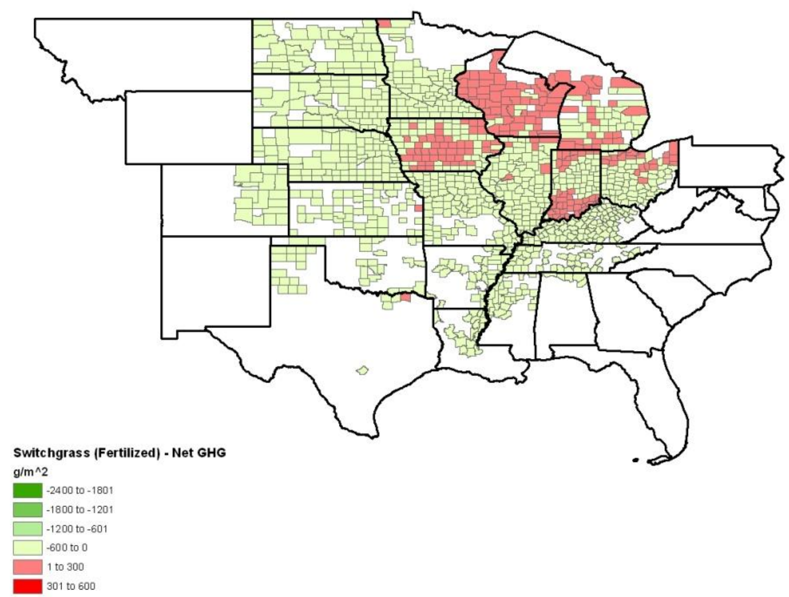
Corn - Net GHG

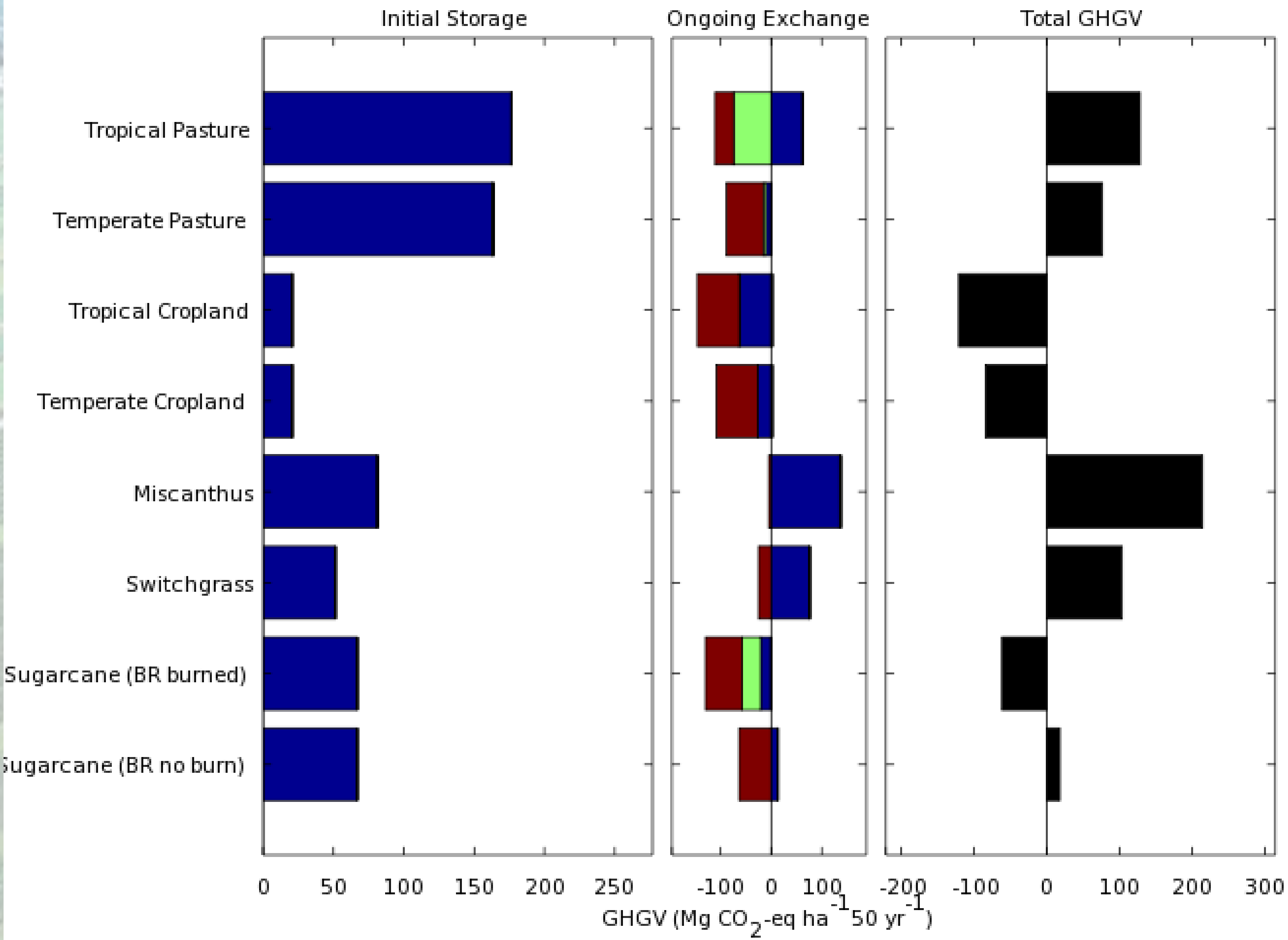


Switchgrass - Net GHG

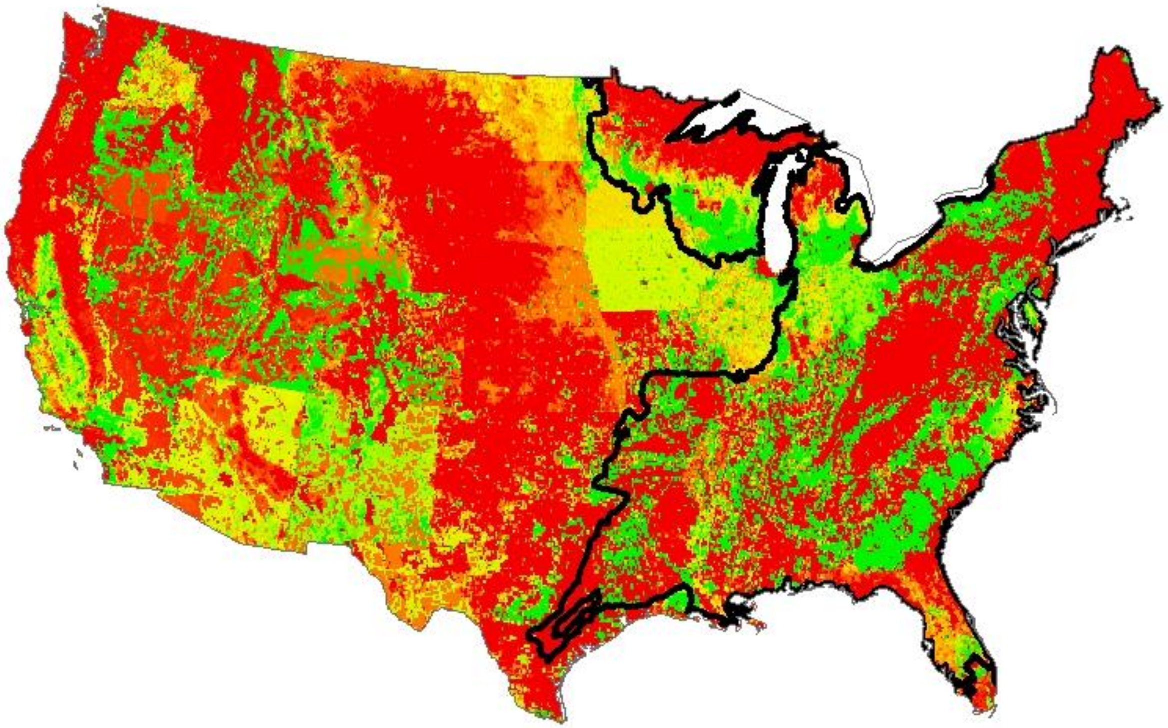


Switchgrass (Fertilized) - Net GHG

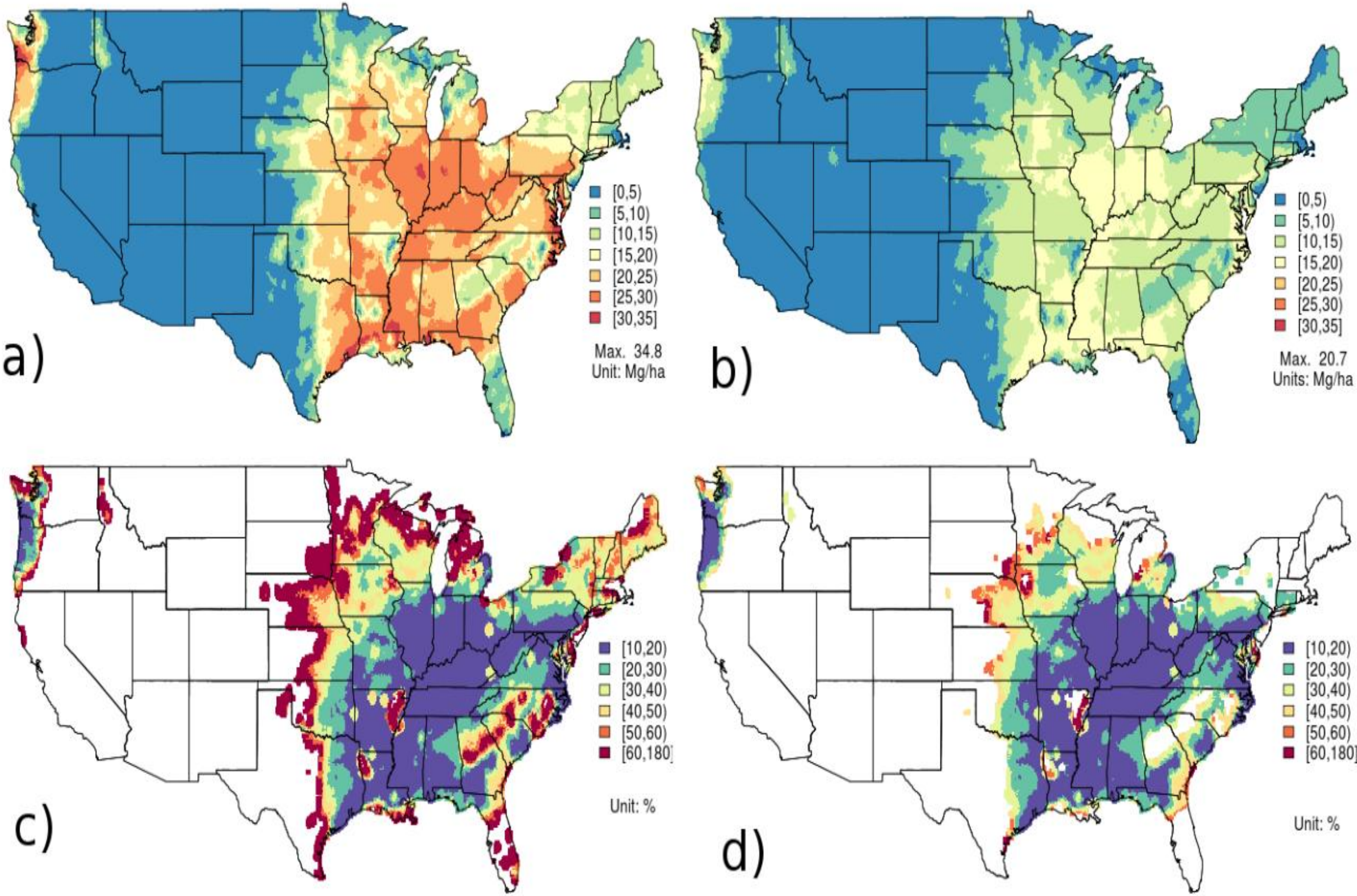



Initial Storage
Ongoing Exchange
Total GHGV
Tropical Pasture
Temperate Pasture
Tropical Cropland
Temperate Cropland
Miscanthus
Switchgrass
Sugarcane (BR burned)
Sugarcane (BR no burn)
0
50
100
150
200
250
-100
0
100
-200
-100
0
100
200
300
GHGV (Mg CO_2-eq ha^{-1} 50 yr^{-1})

Recently abandoned land (green high red low)



Miscanthus x giganteus *Panicum virgatum*



Miguez et al.

Somerville, Youngs, Davis & Long (2010) Science, 329, 790-792.

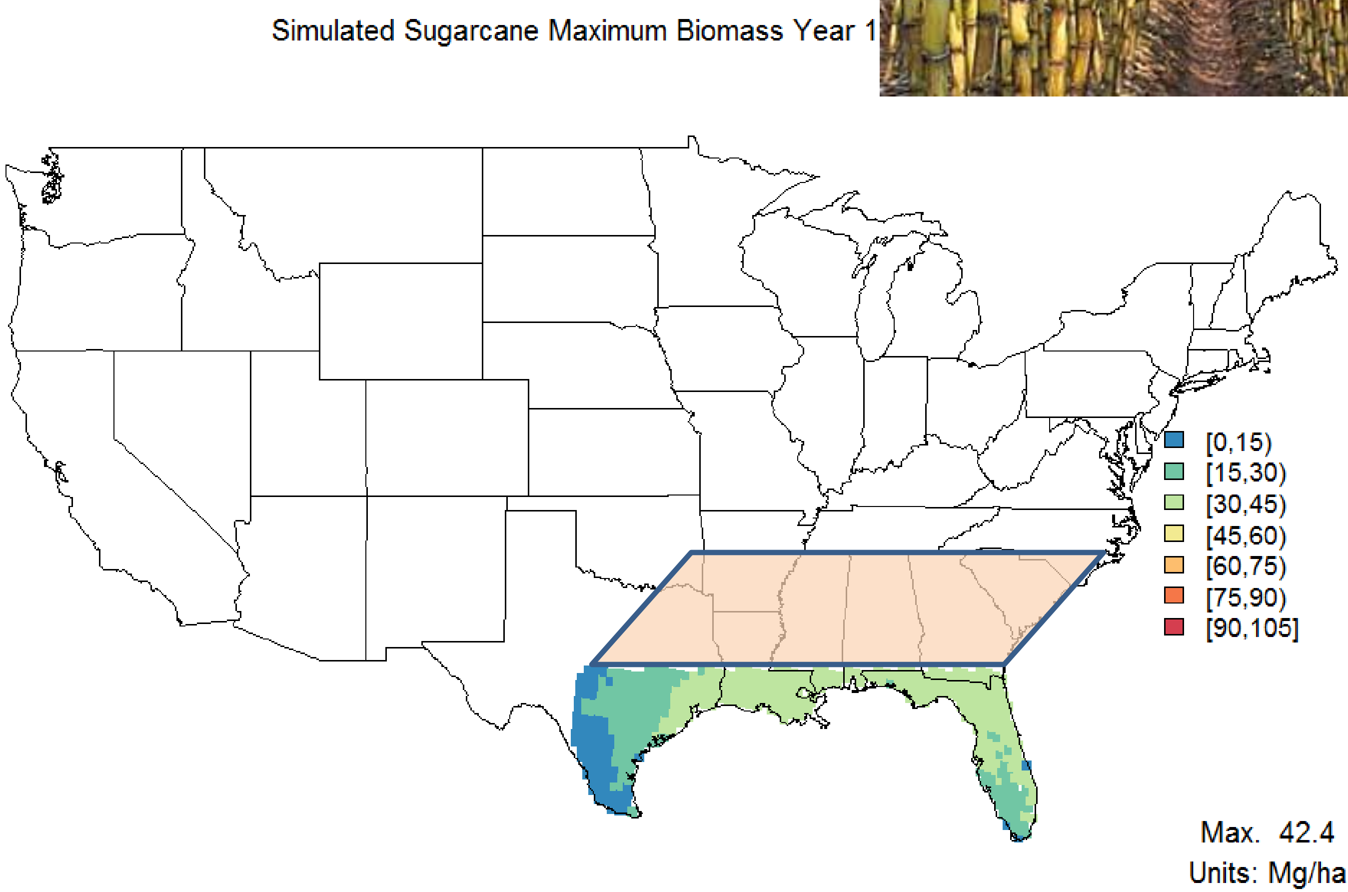
PERSPECTIVE

Feedstocks for Lignocellulosic Biofuels

Chris Somerville,[1*] Heather Youngs,[1] Caroline Taylor,[1] Sarah C. Davis,[2] Stephen P. Long[2]

In 2008, the world produced approximately 87 gigaliters of liquid biofuels, which is roughly equal to the volume of liquid fuel consumed by Germany that year. Essentially, all of this biofuel was

- **Energy Independence and Security Act (2007) mandates 132.5 Gl ethanol by 2020.**
- **Assuming 40 Mg/ha dry matter, and 341 l/Mg conversion, then the mandate could be met with 9.7 Mha + 40Mt/y CO_2 equivalents sequestered.**
- **Currently 176 Mha is in grain, oil seed and fibre production.**
- **37 Mha is in set aside (and 32 Mha rainfed crop land currently in pasture) ; 14 Mha dropped from Agriculture 1997 vs. 2007 census.**


Simulated Sugarcane Maximum Biomass Year 1
[0,15)
[15,30)
[30,45)
[45,60)
[60,75)
[75,90)
[90,105]
Max. 42.4
Units: Mg/ha

Salinated lands FAO/UNESCO

Region	Area (10^6ha)
Africa	69.5
Near and Middle East	53.1
Asia and Far East	19.5
Latin America	59.4
Australia	84.7
North America	16.0
Europe	20.7

Spartina alterniflora 22 t/ha, Georgia USA, in seawater

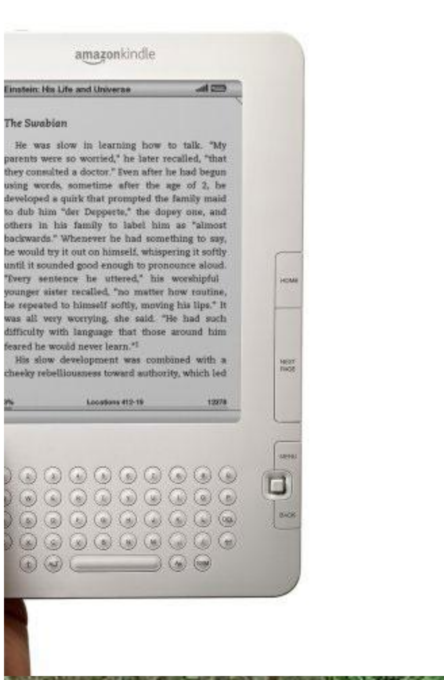
Long, Incoll & Woolhouse Nature 257, 622-624.

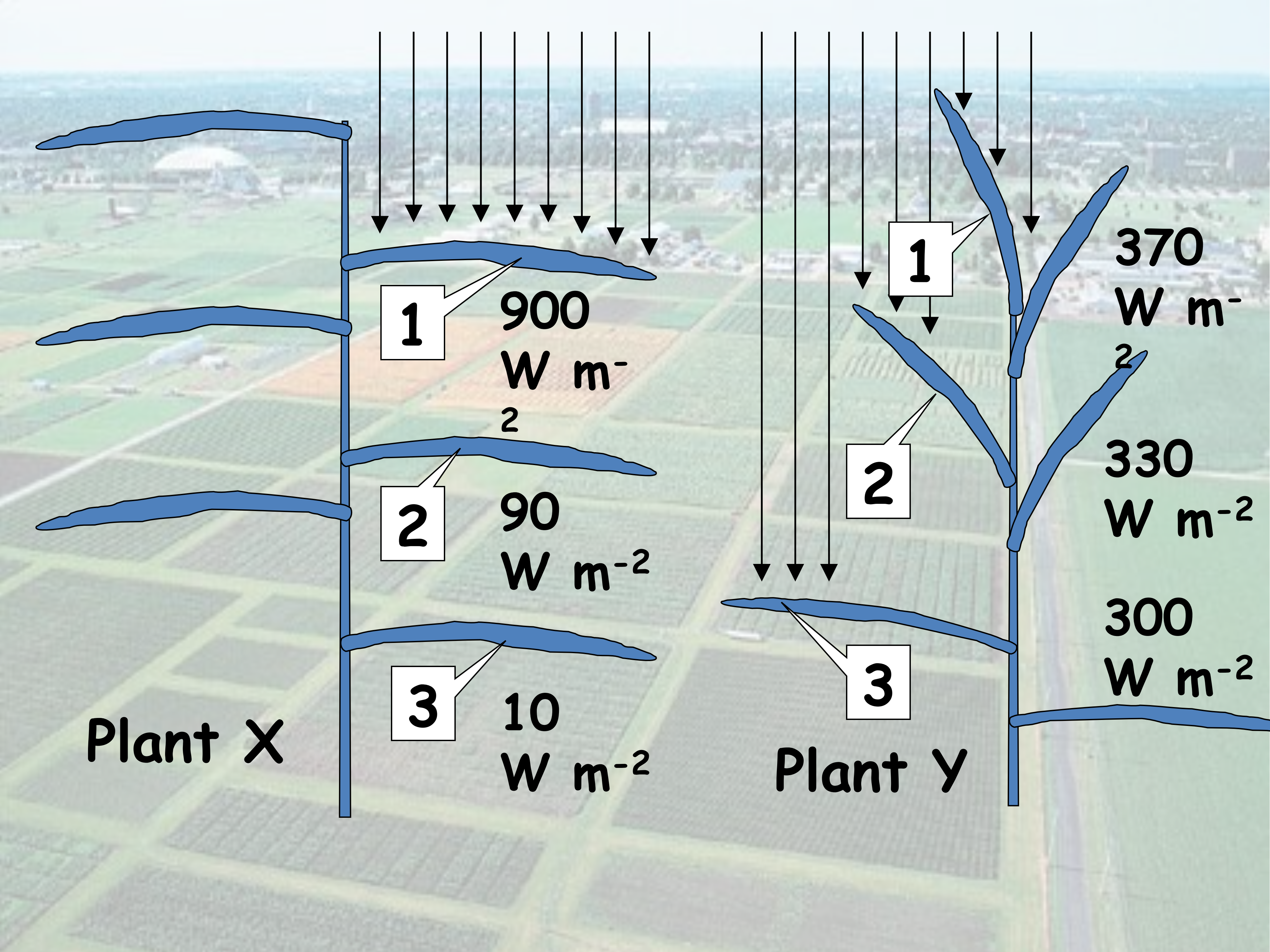
Wiegert, Chalmers & Randerson (1983) Oikos 41, 1-6

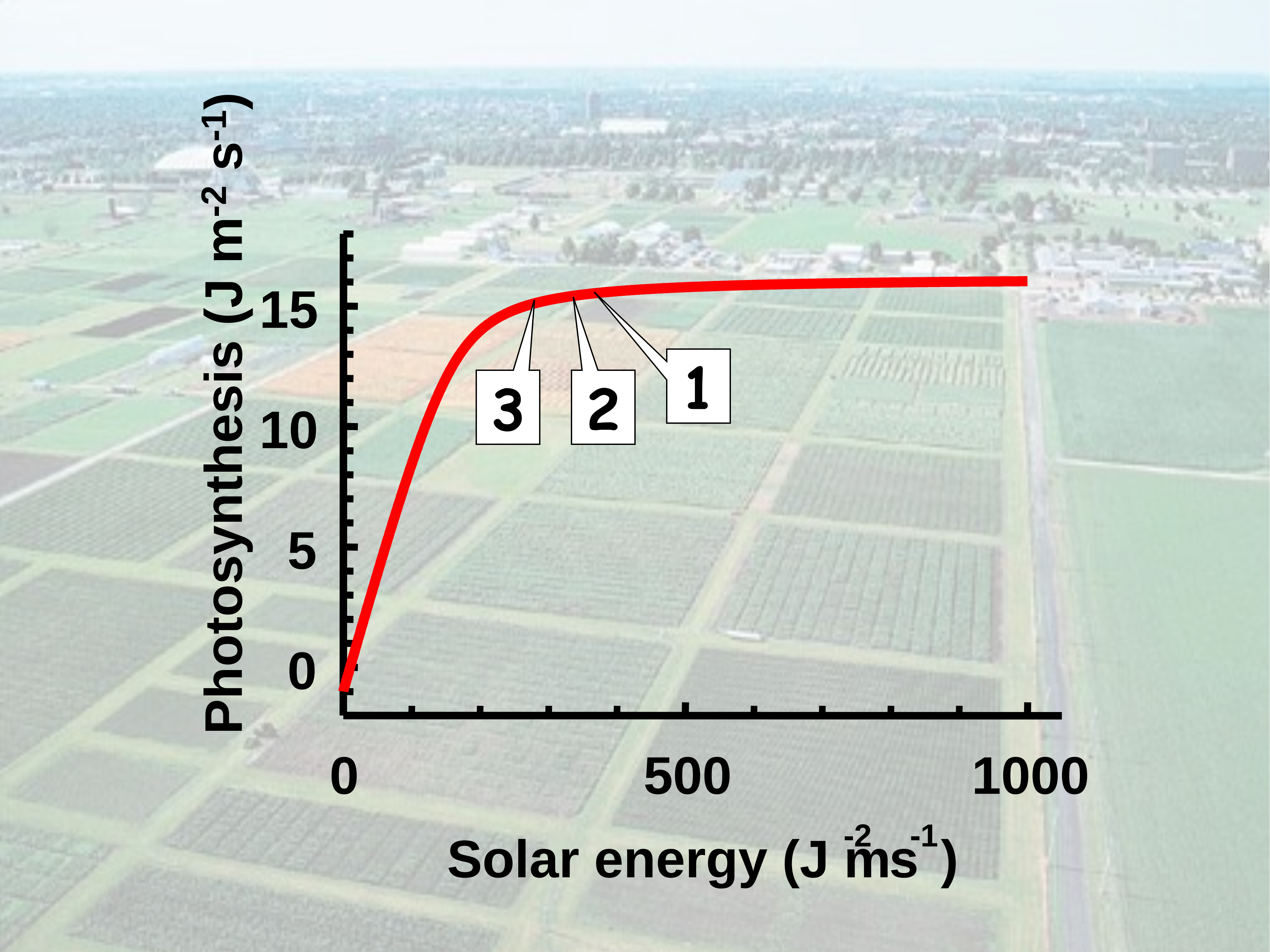
Agave mapisaga and A. saimiana 40 t/ha in semi-desert, Mexico DF.

Nobel, Garcia-Moya & Quero (1992) Plant Cell & Environment 15, 329-335.

World produced 185 Mt of pulp in 2010 (FAOstat)




1
900 W m-2
2
90 W m-2
3
10 W m-2
Plant X
1
370 W m-2
2
330 W m-2
3
300 W m-2
Plant Y

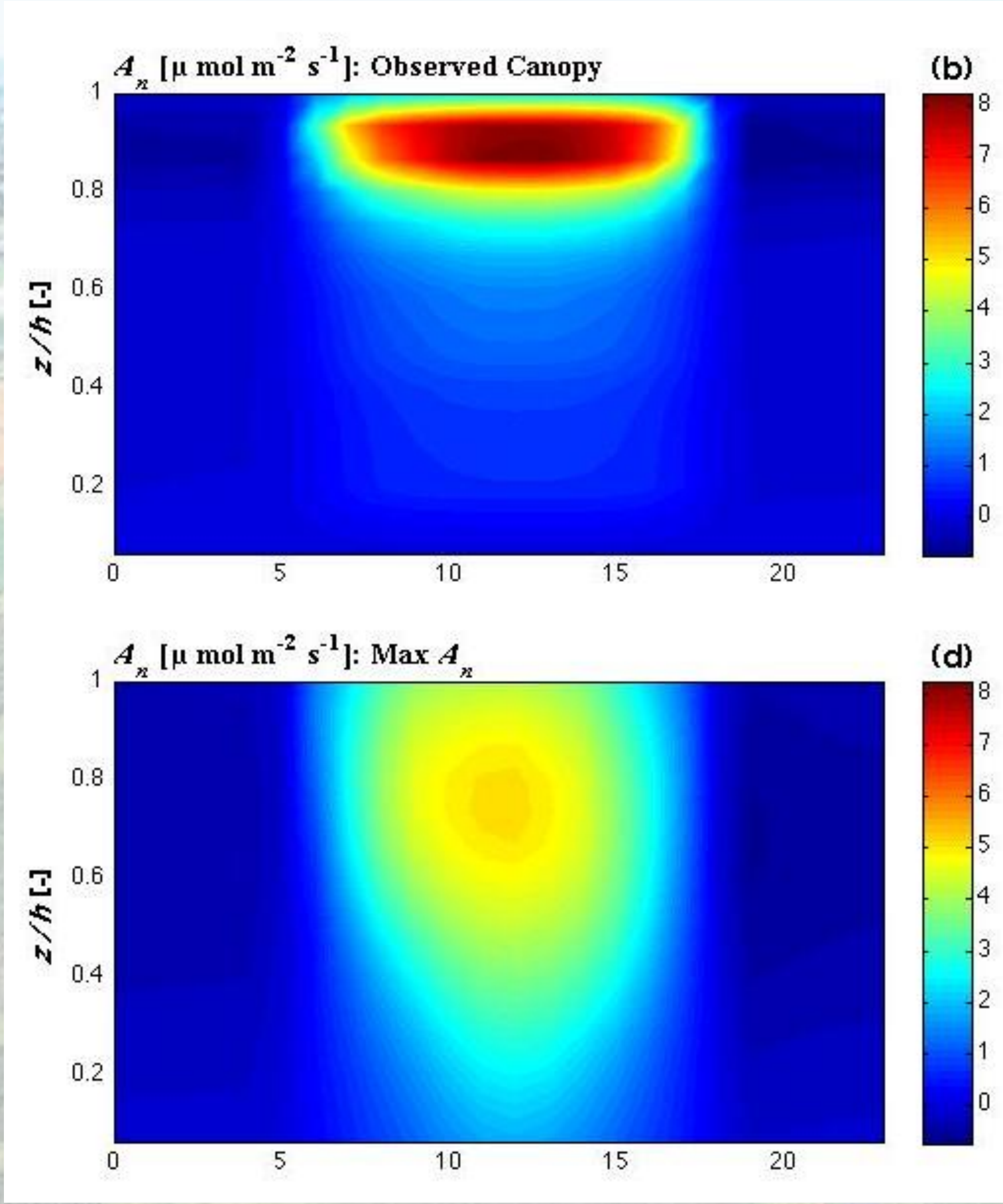


Photosynthesis (J m^{-2} s^{-1})
15
10
5
0
3
2
1
0
500
1000
Solar energy (J m^{-2} s^{-1})

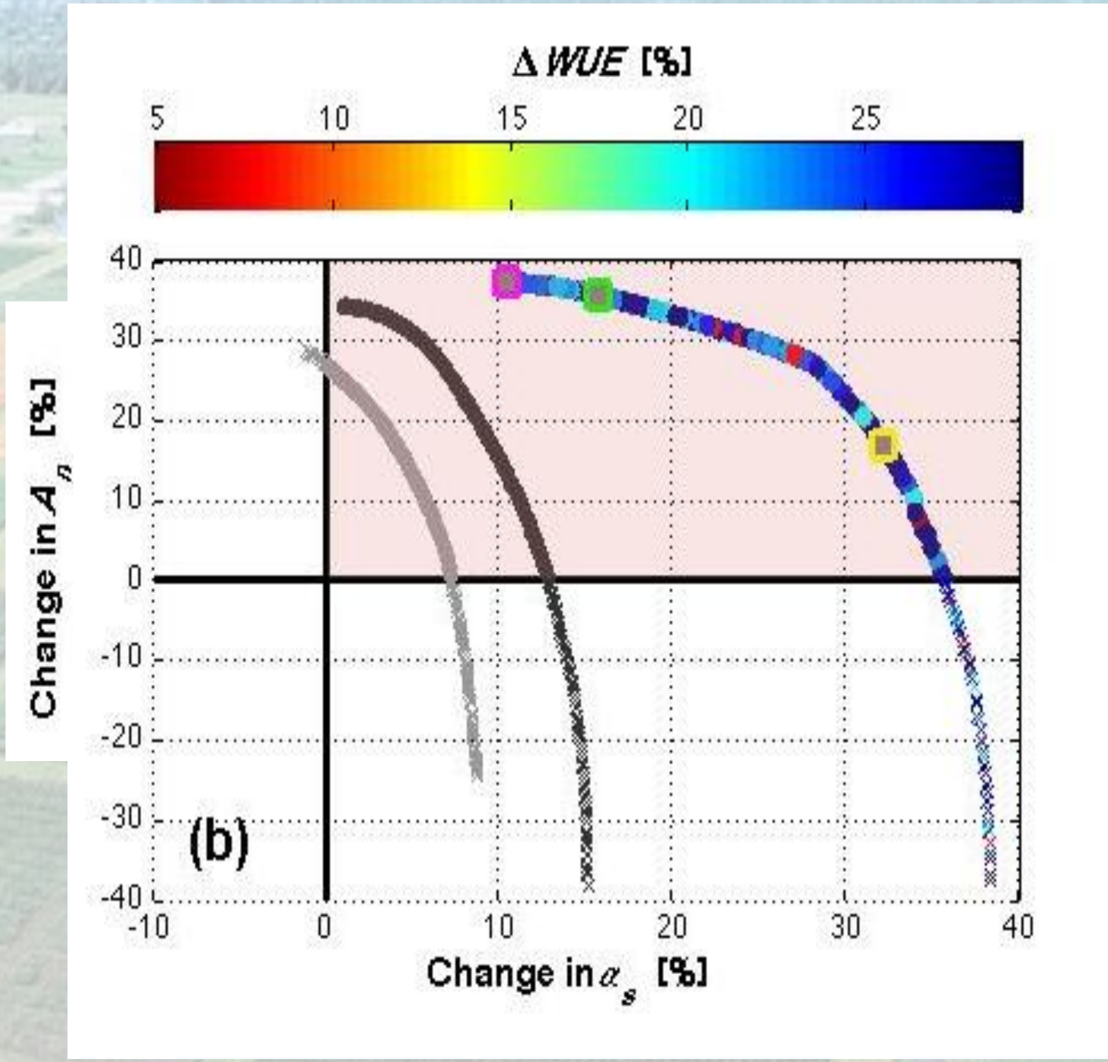
	Solar energy		Photosynthesis	
	$J\ m^{-2}\ s^{-1}$		$J\ m^{-2}\ s^{-1}$	
Plant	A	B	A	B
1	900	370	16	16
2	90	330	8	15
3	10	300	1	14
Total	1000	1000	25	45
Efficiency			*0.025*	*0.045*

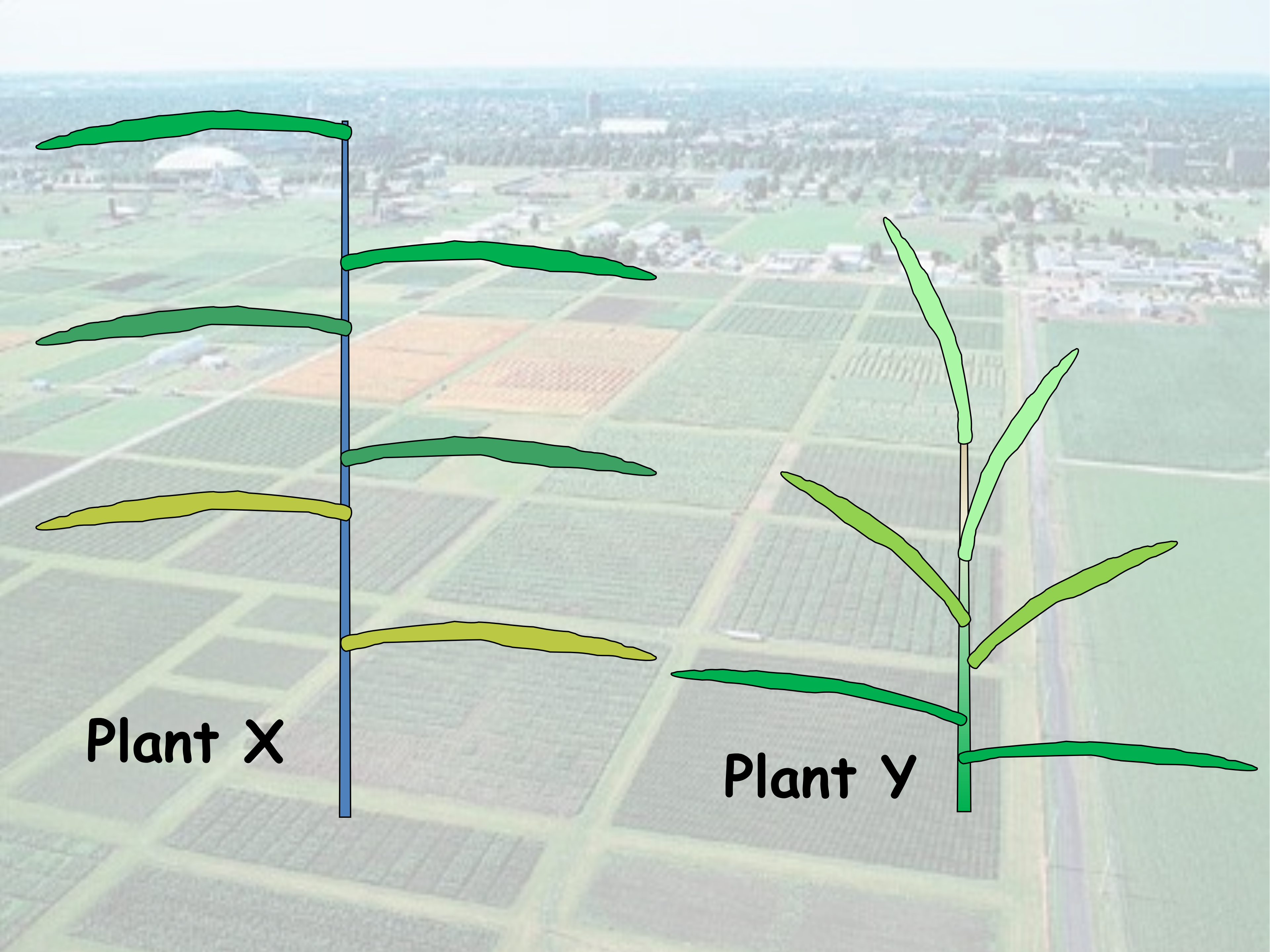
Ort & Long (2003) In: Chrispeels and & Sadava, pp. 240-269. ASPB.

Drewry et al. (in prep) numerical selection of canopy design optimiising carbon gain and ecosystem services (water use and albedo)



Drewry et al. (in prep) selection of canopy design optimizing carbon gain and ecosystem services (water use and albedo)




Plant X
Plant Y

Conclusion to section

- There are sufficient feedstocks capable of production on non-cropland to allow substantial offset of transportation liquid fossil fuels, with significant GHG benefits.
- This requires use of high productivity low input crops and careful site selection.