Terrestrial Sequestration & Mitigation

Fourth Annual Conference on Carbon Capture and Sequestration
Arlington, Virginia

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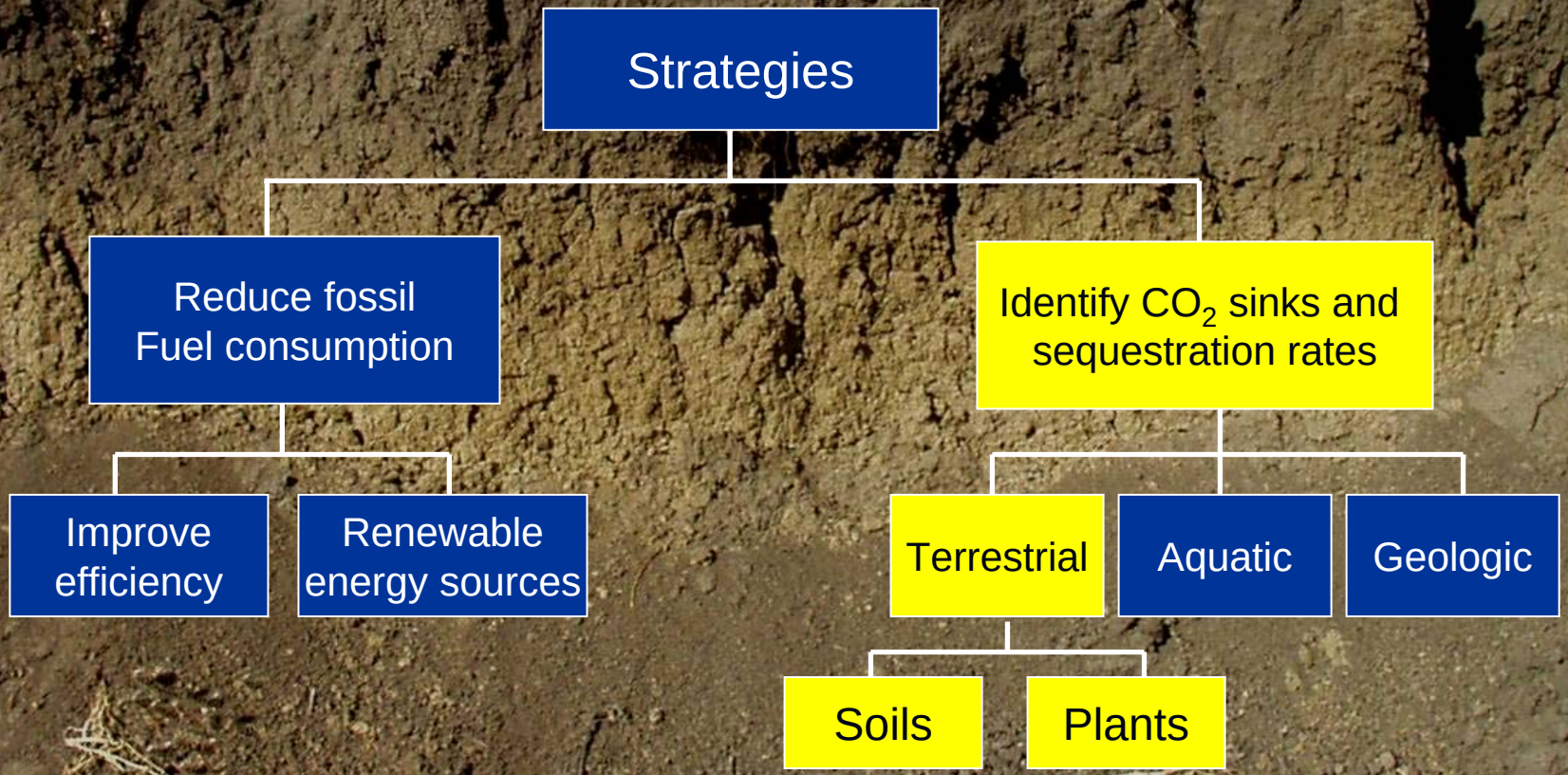
Main Strategies to Stabilize Atmospheric CO_2



Source C.W. Rice

Potential CO_2 Stabilization Options

	Rapidly Deployable	Not Rapidly Deployable
Minor Contributors <0.2 PgC/y	• Biomass co-fire electric generation • Cogeneration (small scale) • Hydropower • Natural Gas Combined cycle • Niche options (geothermal, small scale solar)	• Integrated photovoltaics • Forest management (fire suppression) • Ocean fertilization
Major Contributors >0.2 PgC/y	• Carbon sequestration in agricultural soils • Improved appliance efficiency • Improved buildings • Improved vehicle efficiency • Non-CO_2 gas abatement from industry • Non-CO_2 gas abatement from agriculture • Reforestation • Stratospheric sulfates	• Biomass to hydrogen • Biomass to fuel • Cessation of deforestation • Energy-efficient urban and transportation systems • Fossil-fuel C separation with geologic or ocean storage • High efficiency coal technology • Large-scale solar • Next generation nuclear fission • Wind with H_2 storage • Speculative technologies (space solar, nuclear fusion, etc.)

Caldeira, Morgan, Baldocchi, Brewer, Chen, Nabuurs, Nakicenovic, & Robertson. 2004. A portfolio of carbon management options, p. 103-130. *In* C. B. Field and M. R. Raupach, eds. The Global Carbon Cycle. Island Press, Washington, DC.

Potential CO_2 Stabilization Options

Rapidly Deployable

Major Contrib-utors >0.2 PgC/y

- Carbon sequestration in agricultural soils
- Improved appliance efficiency
- Improved buildings
- Improved vehicle efficiency
- Non-CO_2 gas abatement from industry
- Non-CO_2 gas abatement from agriculture
- Reforestation
- Stratospheric sulfates

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Contemporary Global CO_2 Budget

Source/Sink (Pg C / y)	1990's
<u>Sources</u>	*Pg C / y*
Emissions from fossil fuels	6.3
Emissions from deforestation	1.6
Total Sources	7.9
<u>Sinks</u>	
Atmospheric increase	3.3
Oceanic uptake	2.3
Terrestrial Uptake	2.3
Total Sinks	7.9

Source IPCC (2002)

Pg C = 10^{15} g C = GT C = 1000 MMT C

Forest Carbon Sequestration Strategies

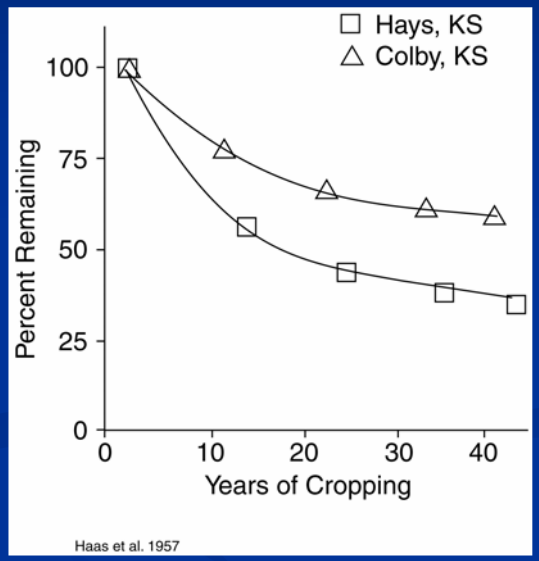
	Magnitude (Pg C y^{-1})
1. Improve Forest Management ▪ prolong rotations ▪ better fire control ▪ fertilization	.17
2. Expand Forested Areas ▪ afforestation ▪ reforestation	.2
3. Reduce Deforestation Rate ▪ currently 1.6 Pg C y^{-1}	.1 - .2
Total	.5 - .6 Pg C y^{-1}

Source: Lal 1999, Smith 2004, Caldeira et al. 2004

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} , to 54 Pg C max

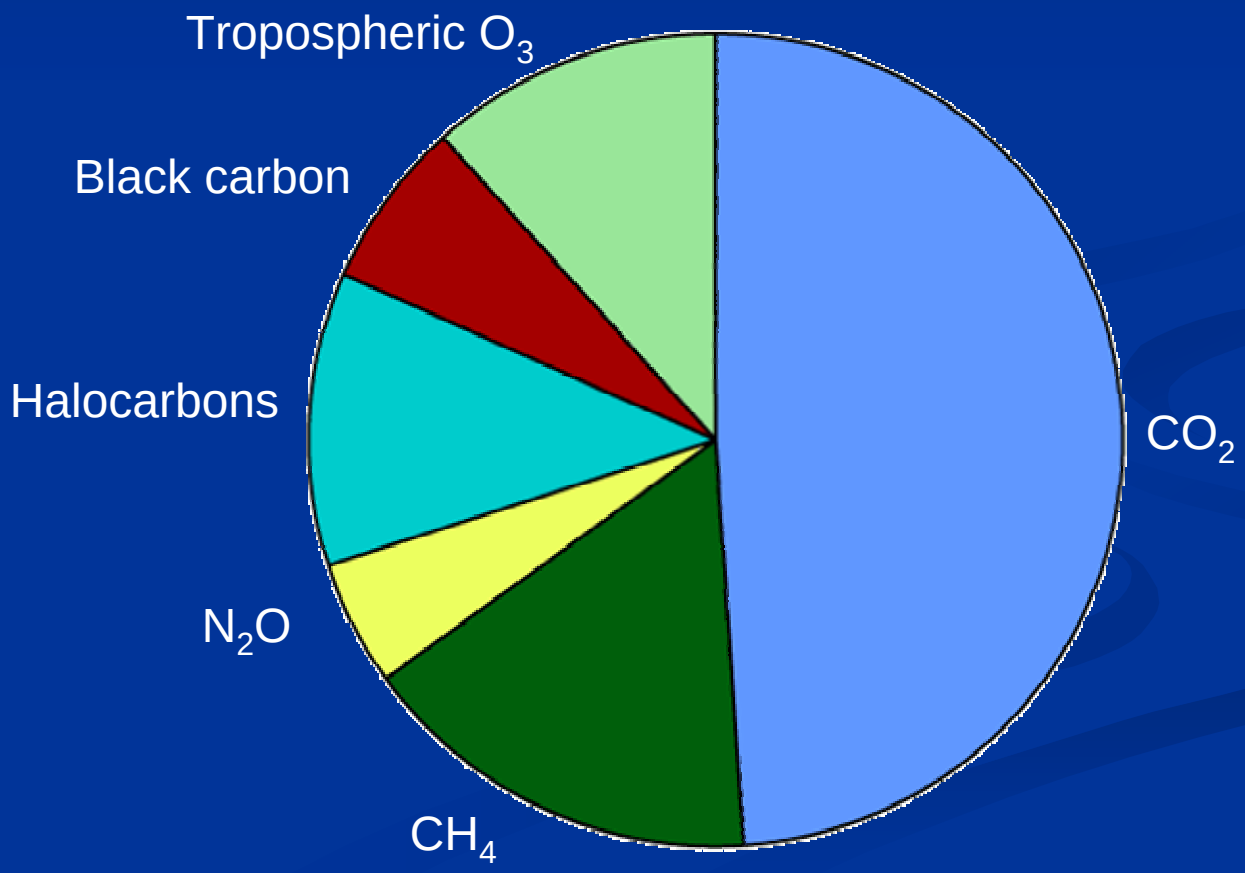
Source: Lal 1999, Smith 2004

How to Restore Soil Carbon?

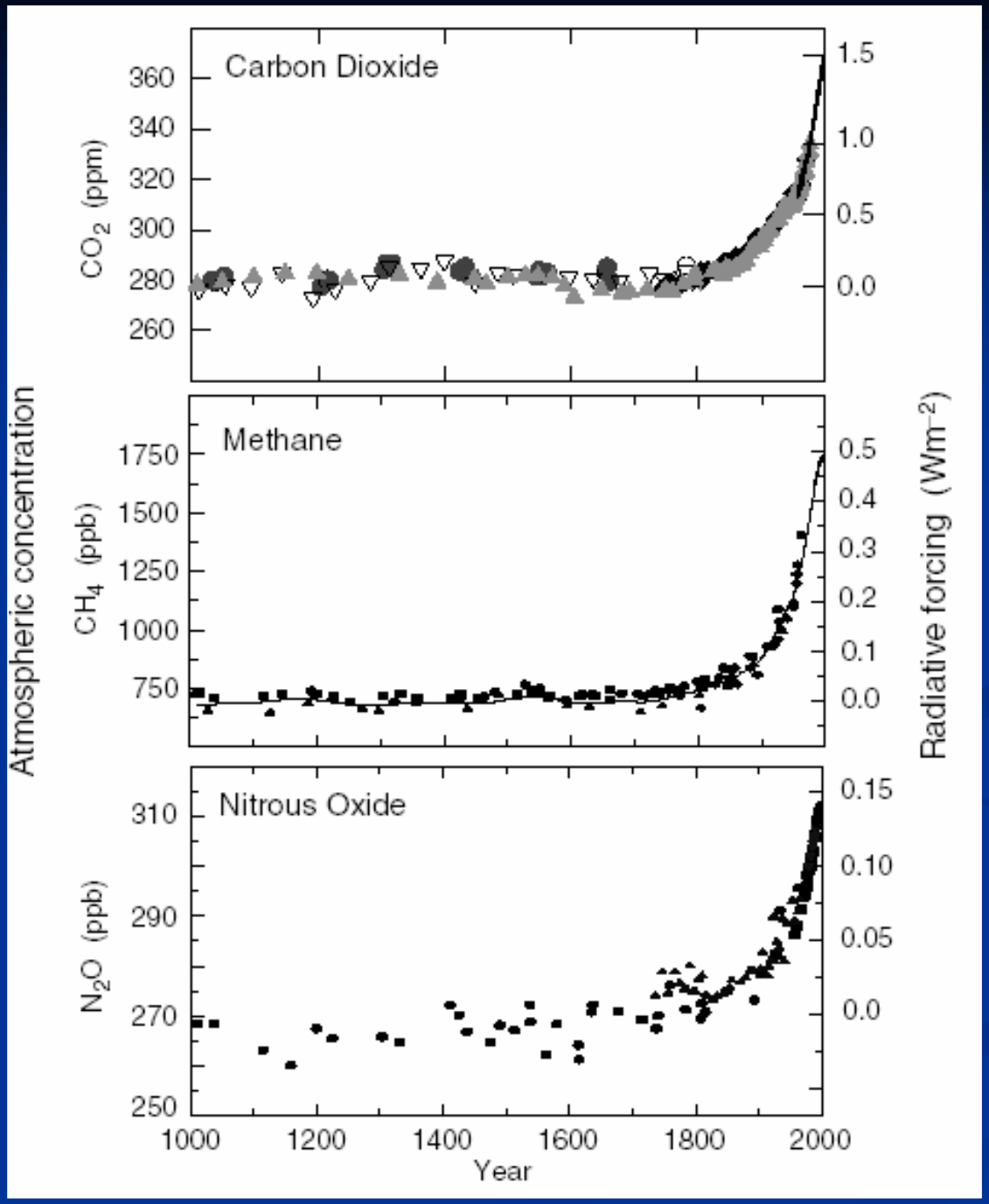
1. Increase C inputs to soil
   - Cover crops
   - Rotations
   - Residue quantity

2. Decrease C loss from soil (slow decomposition)
   - Tillage reduction
   - Residue quality

Global Sources of Atmospheric Radiative Forcing 1750 - 1998



Source IPCC 2001



Atmospheric concentrations of the biogenic greenhouse gases (CO_2, methane, and nitrous oxide) from 1000 A.D.

From IPCC (2001)

How to compare a Tg of CH_4 to a Tg of N_2O to a Tg of CO_2?

Global Warming Potential (GWP)

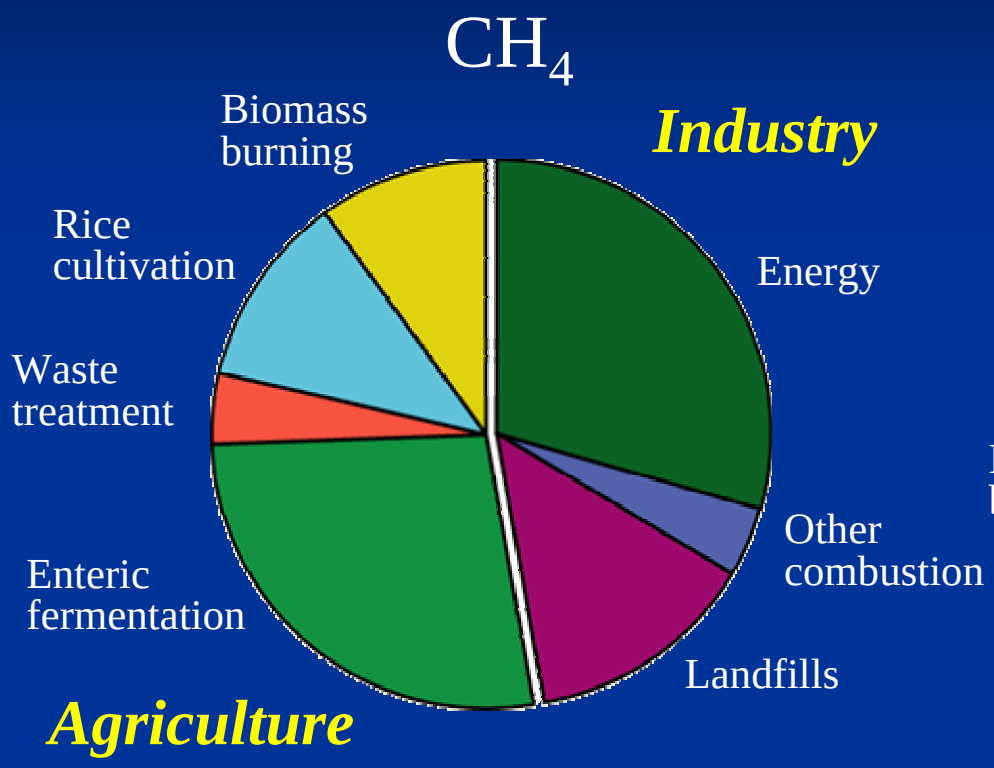
- A measure of the potential for a gas to contribute to the radiative forcing of the atmosphere
  - CO_2
  - CH_4
  - N_2O
  - Halocarbons
  - Ozone precursors (NO_x)
- Measured in CO_2 - equivalents

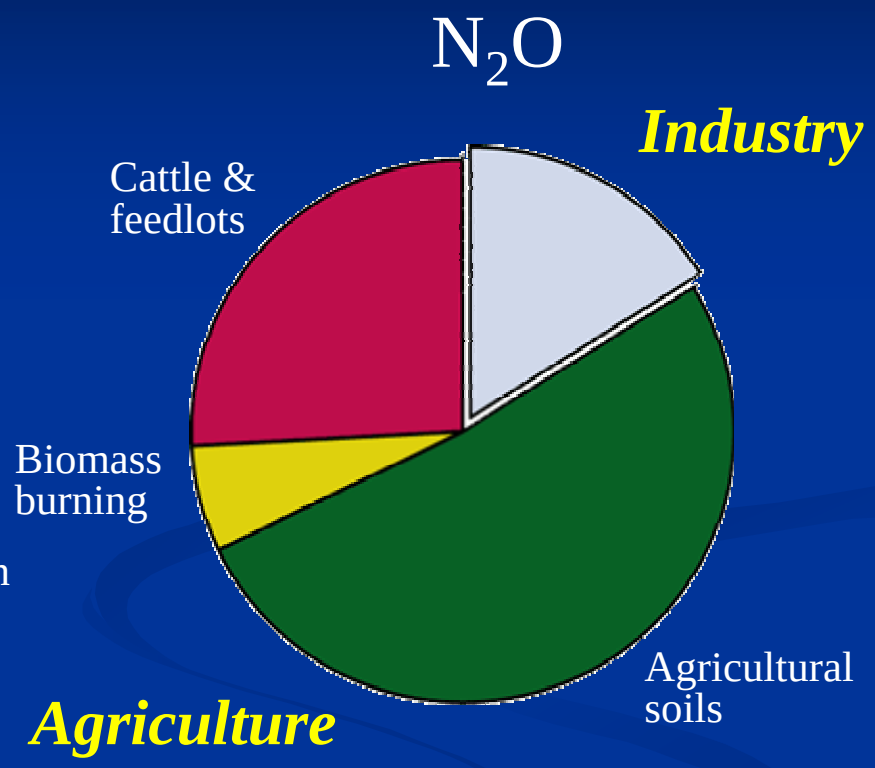
Global Warming Potential (GWP)
Biogenic Gases

	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 2001

Anthropic Sources of Methane and Nitrous Oxide Globally





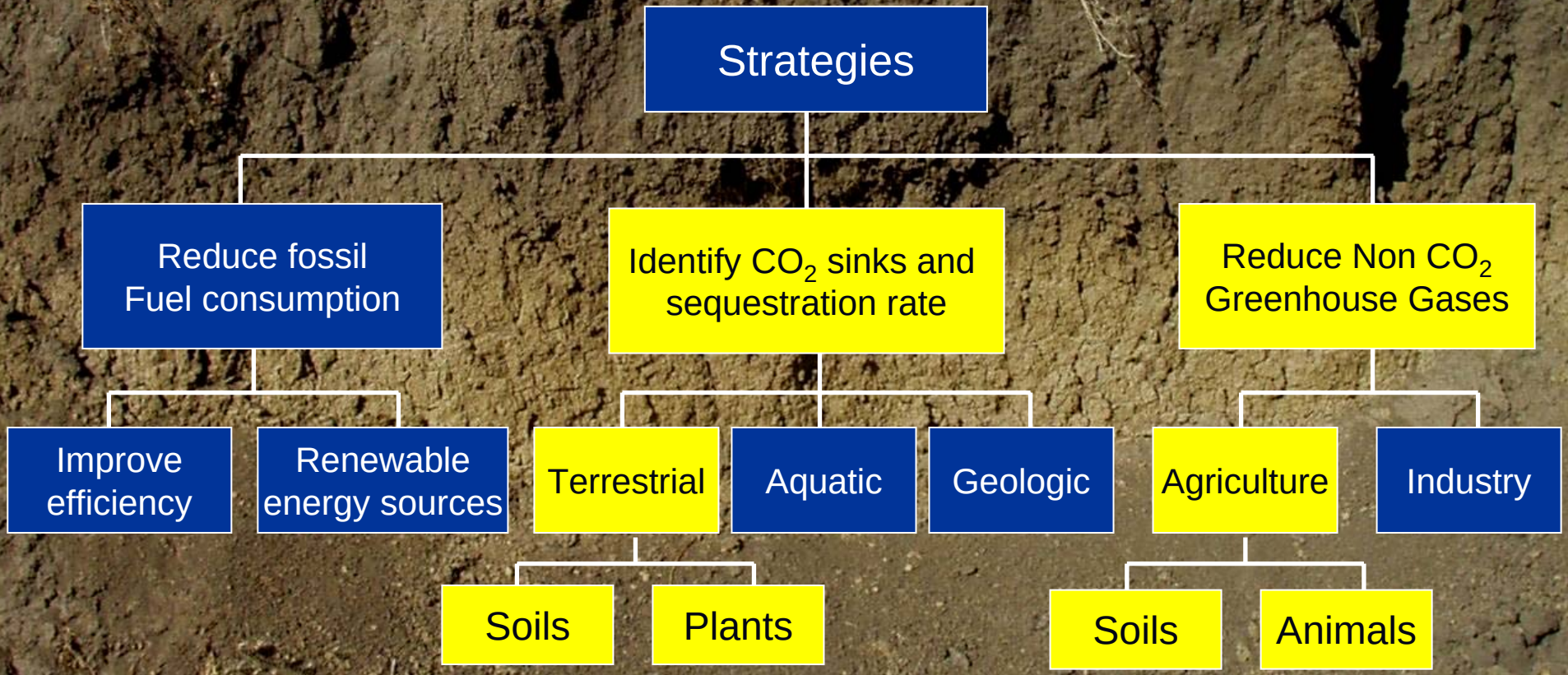
Total Impact	2.0 Pg C_{equiv}	1.2 Pg C_{equiv}

(compare to fossil fuel CO_2 loading = 3.3 Pg C per year)

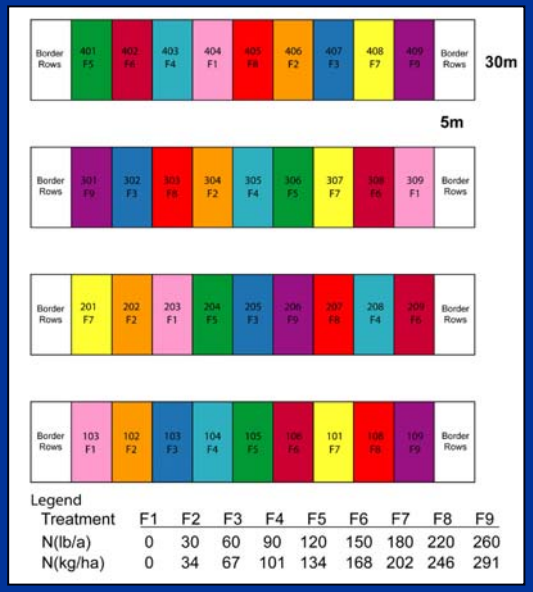
(compare to soil C sequestration of 0.3-0.5 Pg C per year)

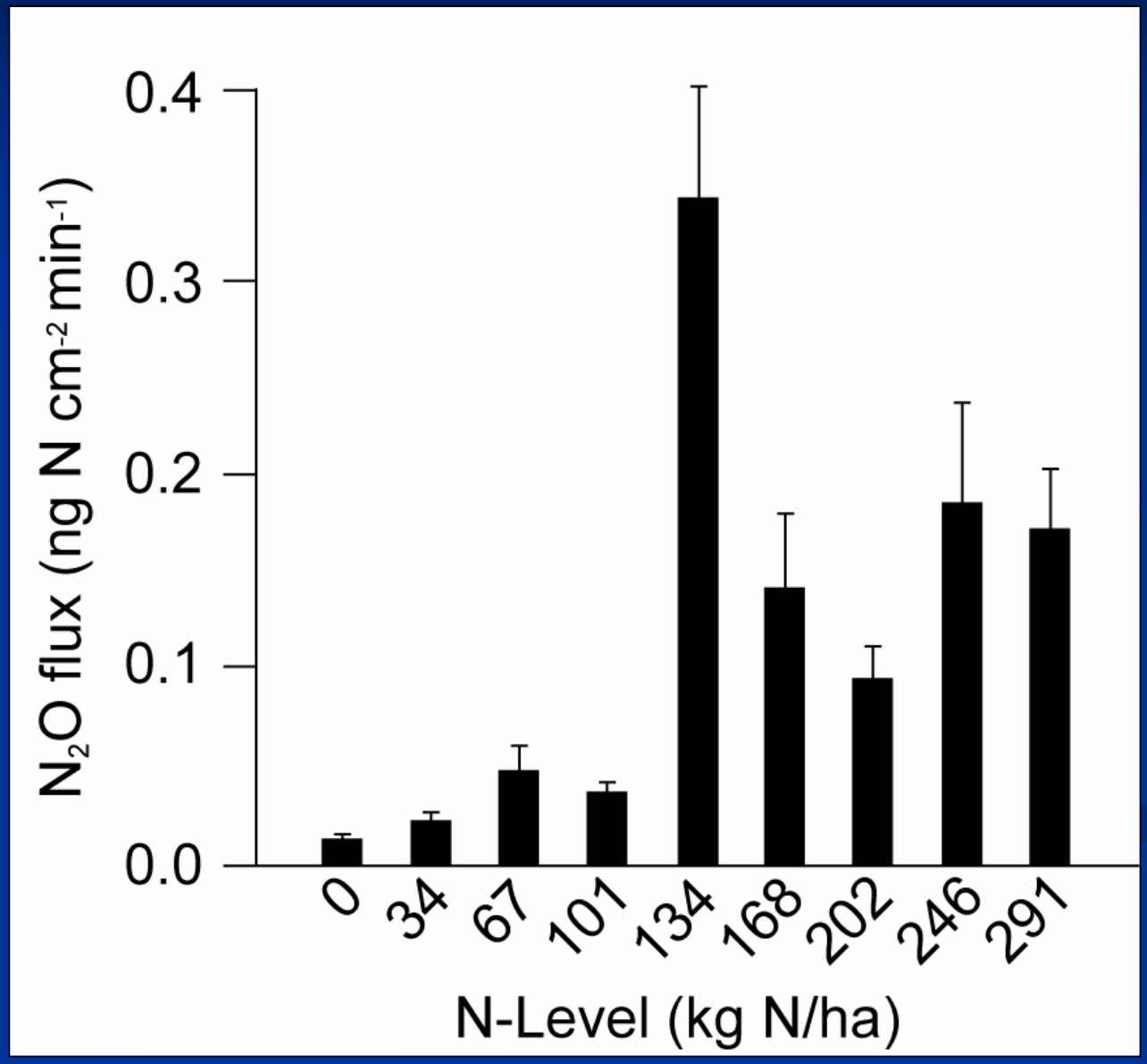
Source IPCC 2001; from Robertson 2004

Main Strategies to Stabilize Atmospheric CO_2



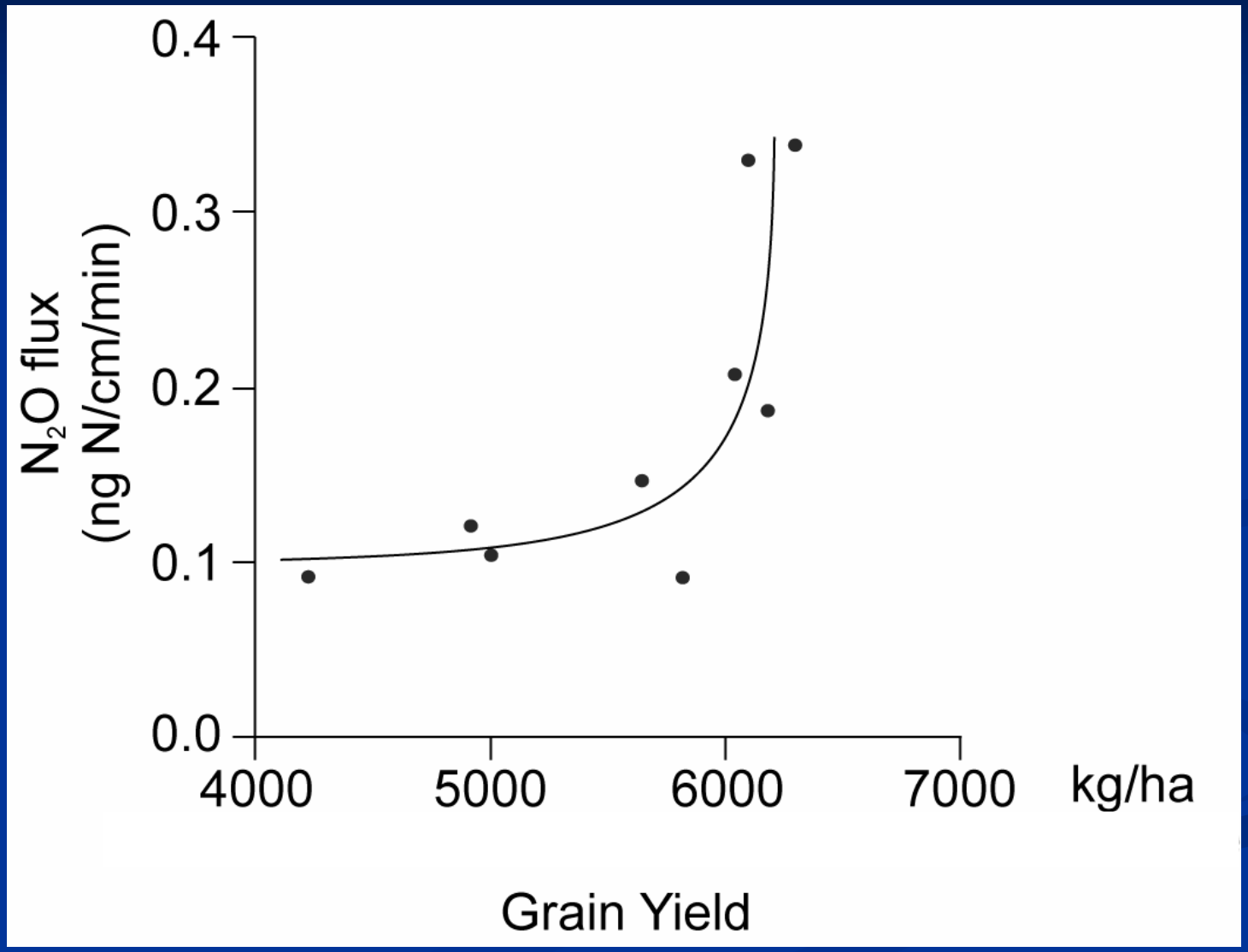
N_2O Flux x N-fertilizer Level





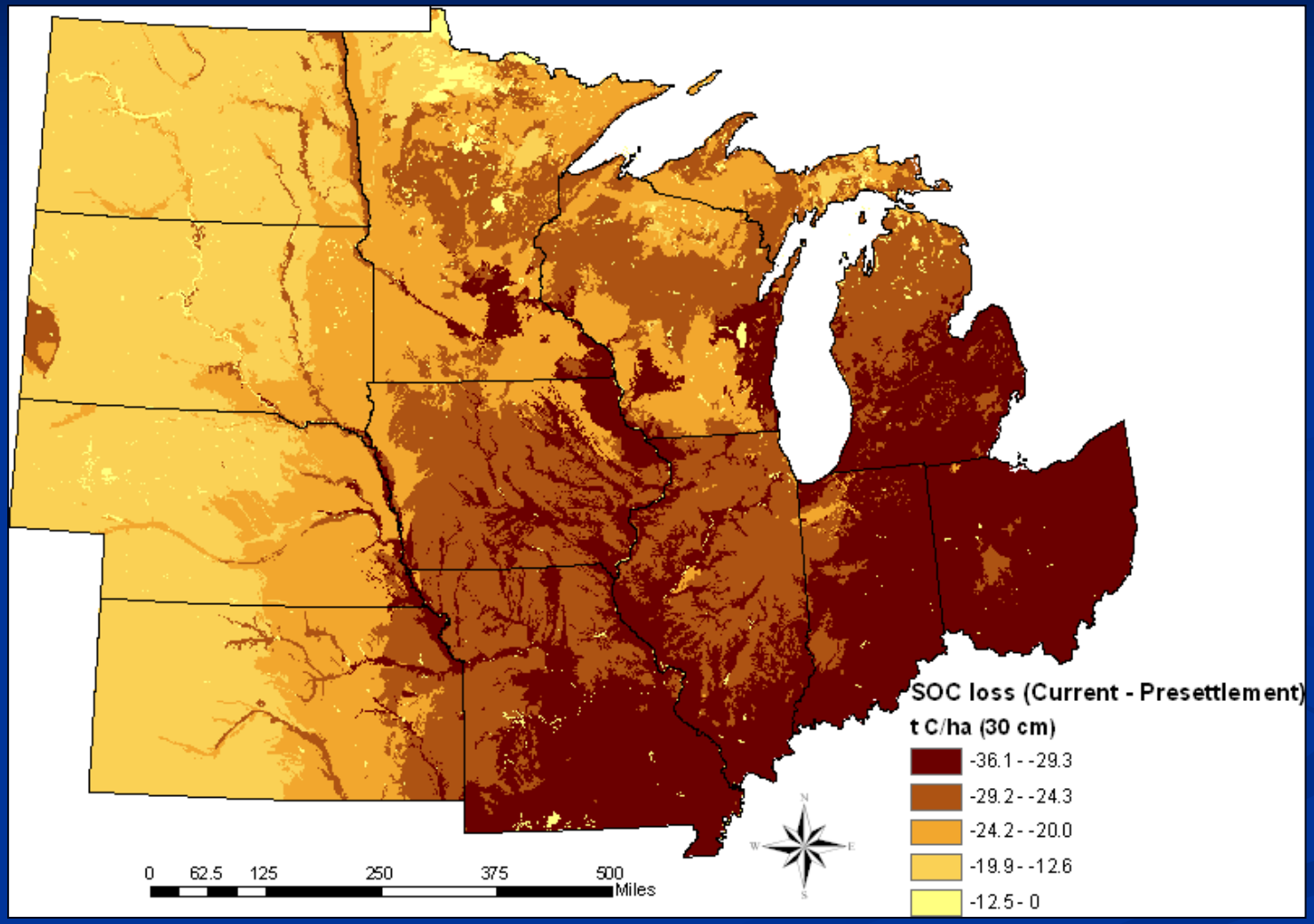
Source McSwiney et al.

N_2O - Yield Threshold



McSwiney and Robertson, submitted

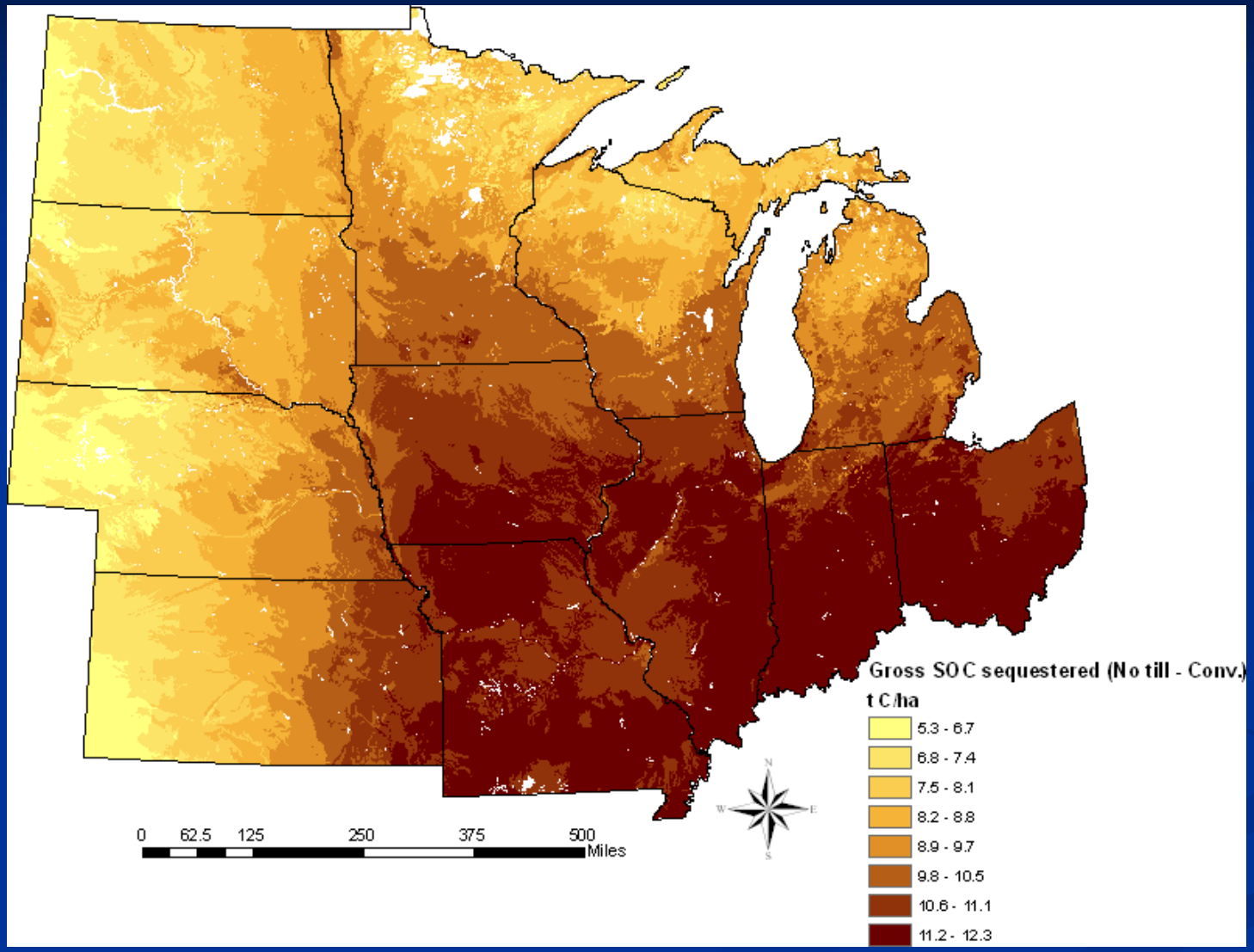
Soil Carbon Loss 1850-1990 in North Central Region



1.9 Gt C
(to 30 cm)

Source: Grace et al. 2005 *Ecosystems*, in press.

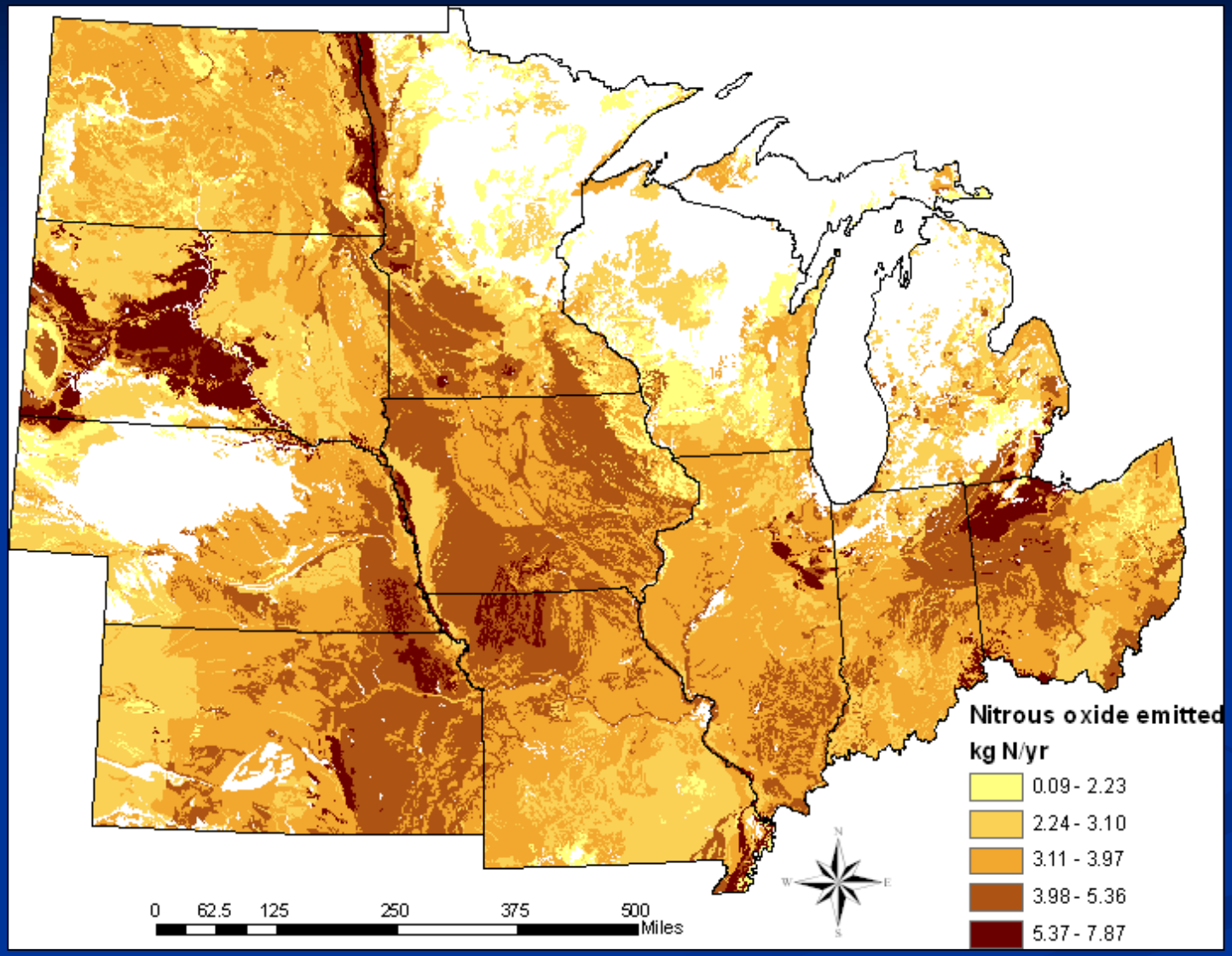
Soil C Sequestration with No-till in NCR



0.7 Gt C (to 30 cm) after 100y

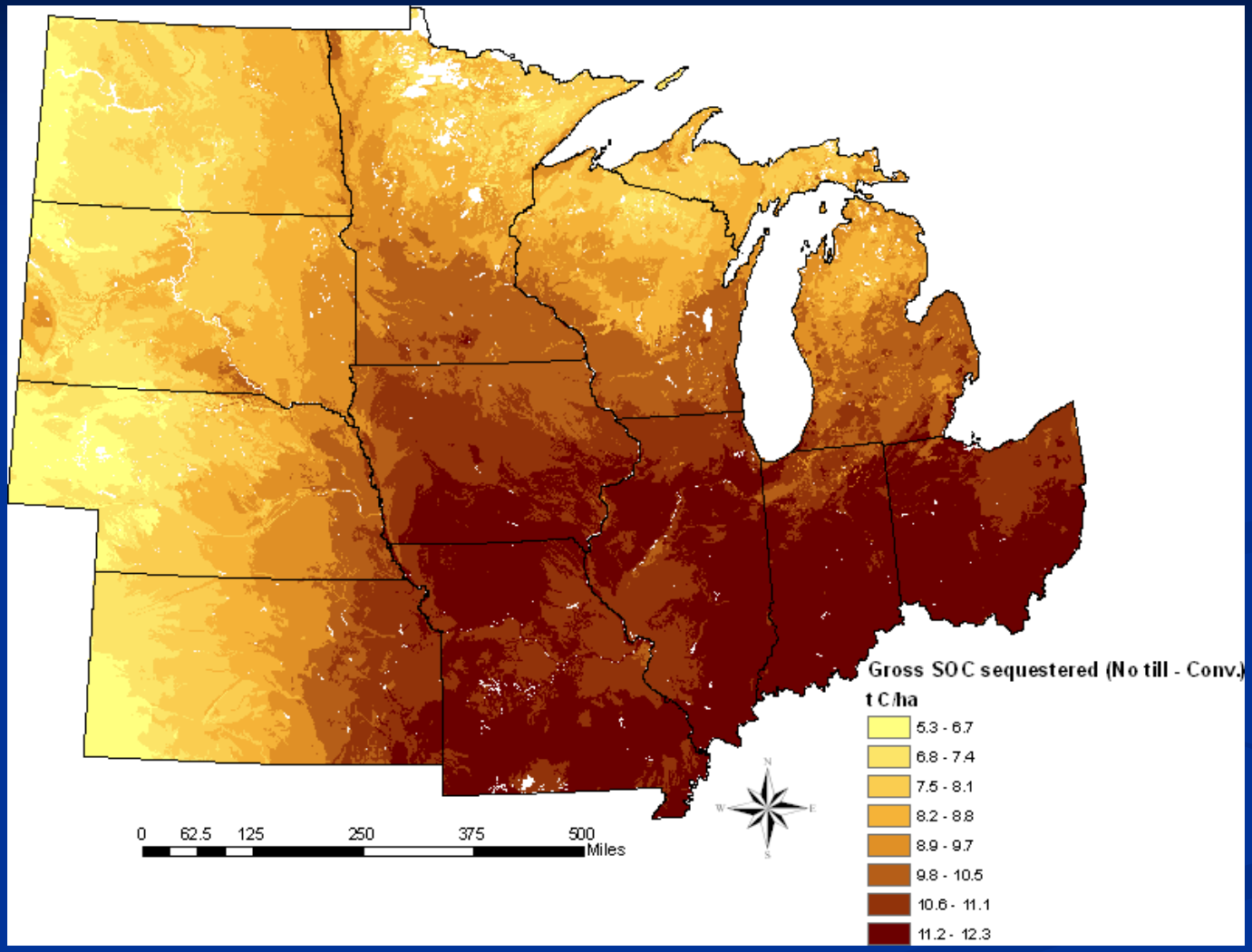
Source: Grace et al. 2005 *Ecosystems*, in press.

N_2O Production in NCR



Source: Grace et al. 2005, unpubl.

GWP_{100y} with NT and N_2O Mitigation



-0% N_2O:
0.9 Gt C_{eq}

-5% N_2O:
1.1 Gt C_{eq}

-10% N_2O:
1.3 Gt C_{eq}

-20% N_2O:
1.7 Gt C_{eq}

-50% N_2O:
2.8 Gt C_{eq}

Source: Grace et al. 2005, unpubl.

Recap

- Portfolio approach to CO_2 stabilization is crucial
  - 3 of 8 currently deployable strategies (<20 y) with major impact (>0.2 Pg/y) are related to agriculture and forestry (soil C, non-CO_2, reforestation)
- N_2O and CH_4 mitigation in agriculture can have impact equal to soil C sequestration and reforestation (with less long-term risk)
- GWP approach (full-cost accounting) is absolutely necessary to fully evaluate all options

Full-Cost GWP Accounting

- Considers all sources of global warming potential (GWP) in a cropping system
  - not just soil carbon balance: other sinks and sources of C
  - not just CO_2: other greenhouse gases
- Considers all sources of mitigation
  - not just soil C sequestration
  - other conservation / mitigation options

Major Potential Sources of GWP in Field Crop Ecosystems

- Soil carbon change
- Fuel use
- Nitrogen fertilizer
- Lime and other carbonate inputs
- N_2O flux (soil source)
- CH_4 flux (soil sink and source)

Full Cost Accounting: GWP of Field Crop Activities

	Soil-C	N-Fert	Lime	Fuel	N_2O	CH_4	Net
	g CO_2 -equiv / m^2 / y						
Annual Crops							
Conventional tillage	0	27	23	16	52	-4	114

Soil carbon is at equilibrium (no annual change)

N_2O is largest source of GWP

Full Cost Accounting: GWP of Field Crop Activities

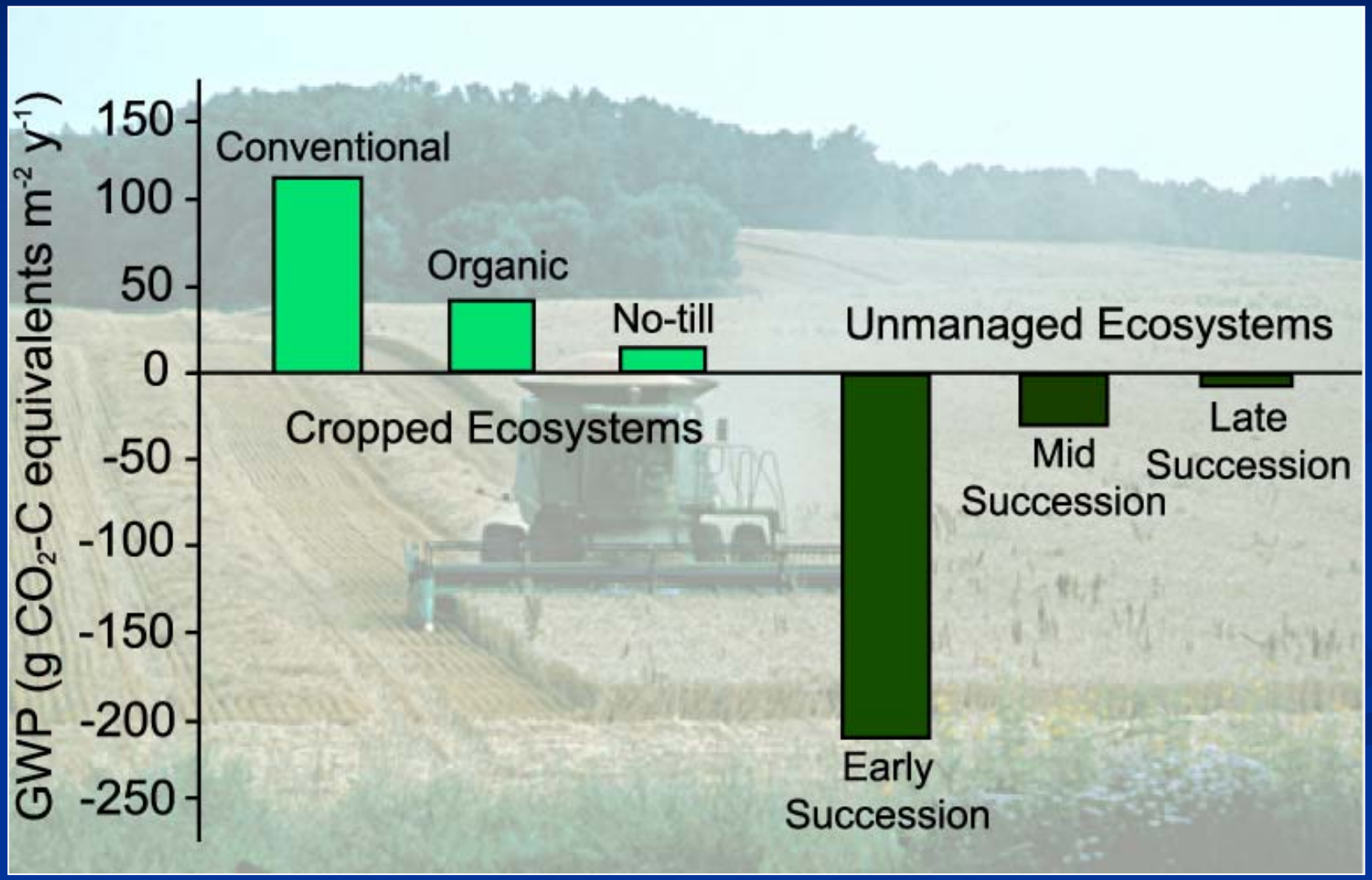
	Soil-C	N-Fert	Lime	Fuel	N_2O	CH_4	Net
	g CO_2 -equiv / m^2 / y						
Annual Crops							
Conventional tillage	0	27	23	16	52	-4	114
No-Till	-110	27	34	12	56	-5	14

No-till soil carbon gain provides substantial mitigation

Importance of N_2O does not change with no-till

Source: Robertson, Paul & Harwood. 2000. *Science* 289:1922-1925.

Net Global Warming Impact of Managed and Unmanaged Ecosystems at KBS



Source: Robertson, Paul & Harwood. 2000. *Science* 289:1922-1925.