PICCMAT

The role of agricultural practices in keeping or increasing soil organic matter

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ACES
Aberdeen Centre for Environmental Sustainability

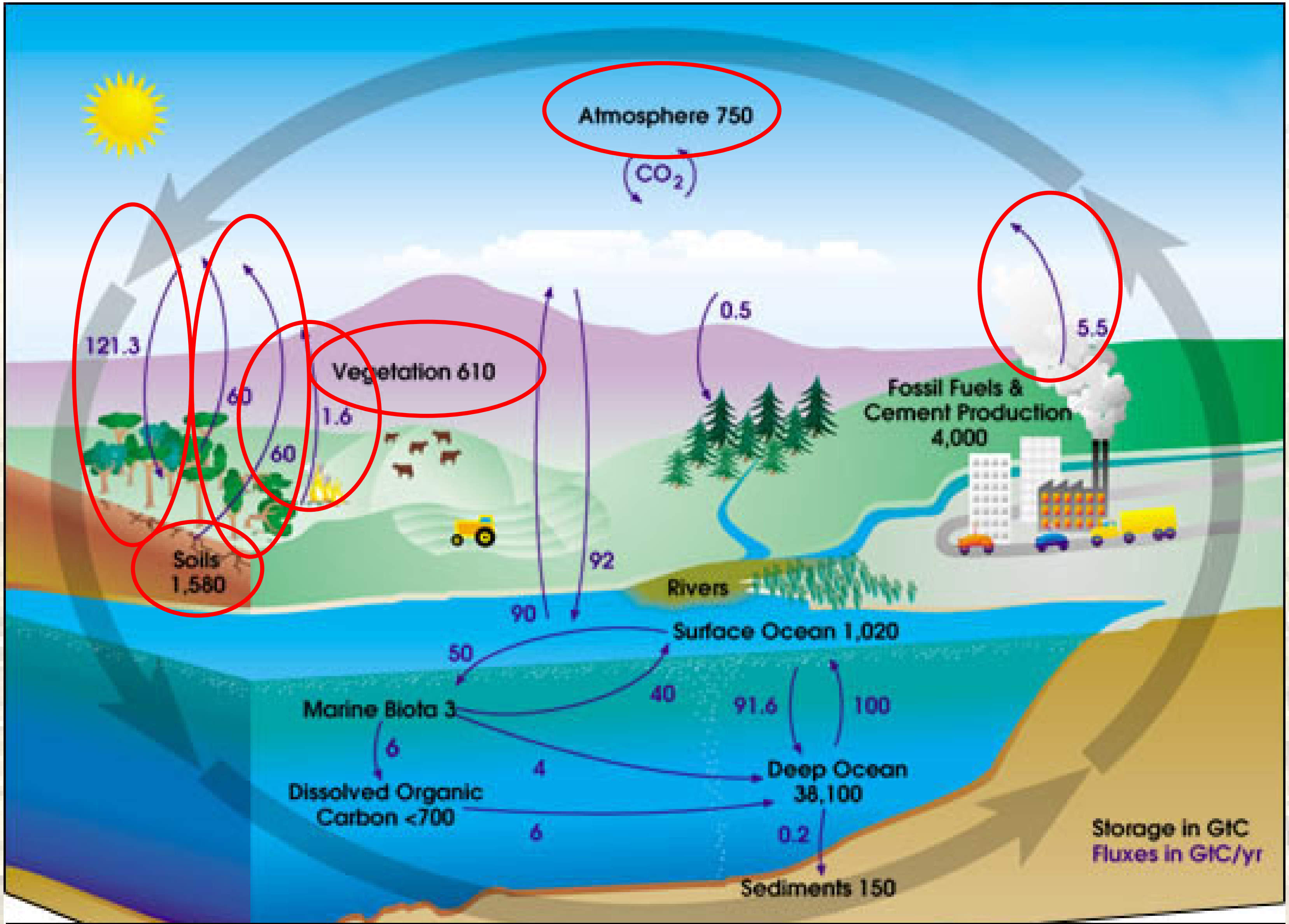
UNIVERSITY of ABERDEEN

Climate change – can soil make a difference? Brussels, Thursday 12th June 2008

Outline

- Soils in the global C cycle
- Mechanisms for soil C sequestration
- Global potential for soil C sequestration
- Response of soil C sinks to future climate change
- Conclusions

Soils in the global C cycle

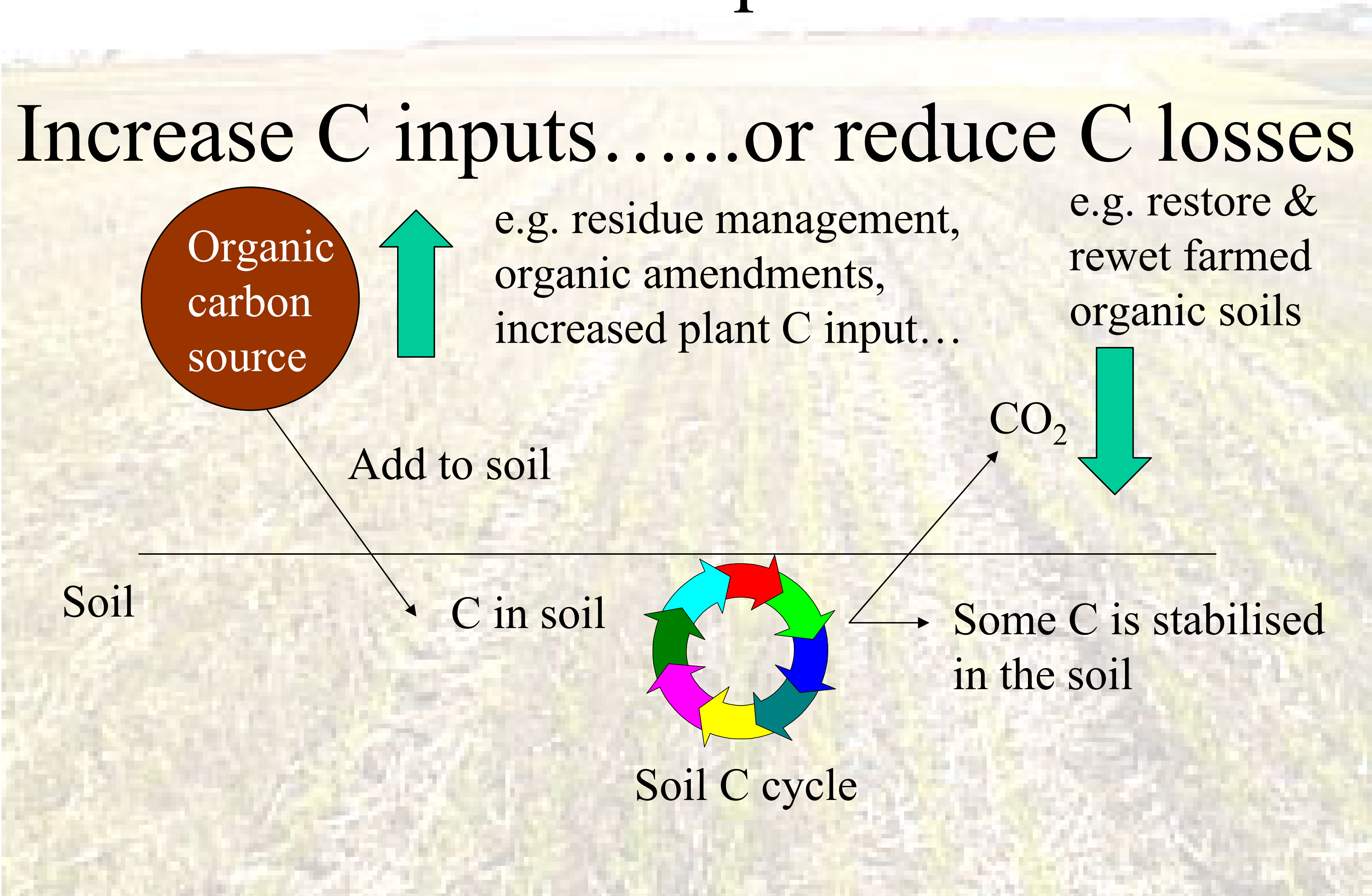


The Carbon Cycle

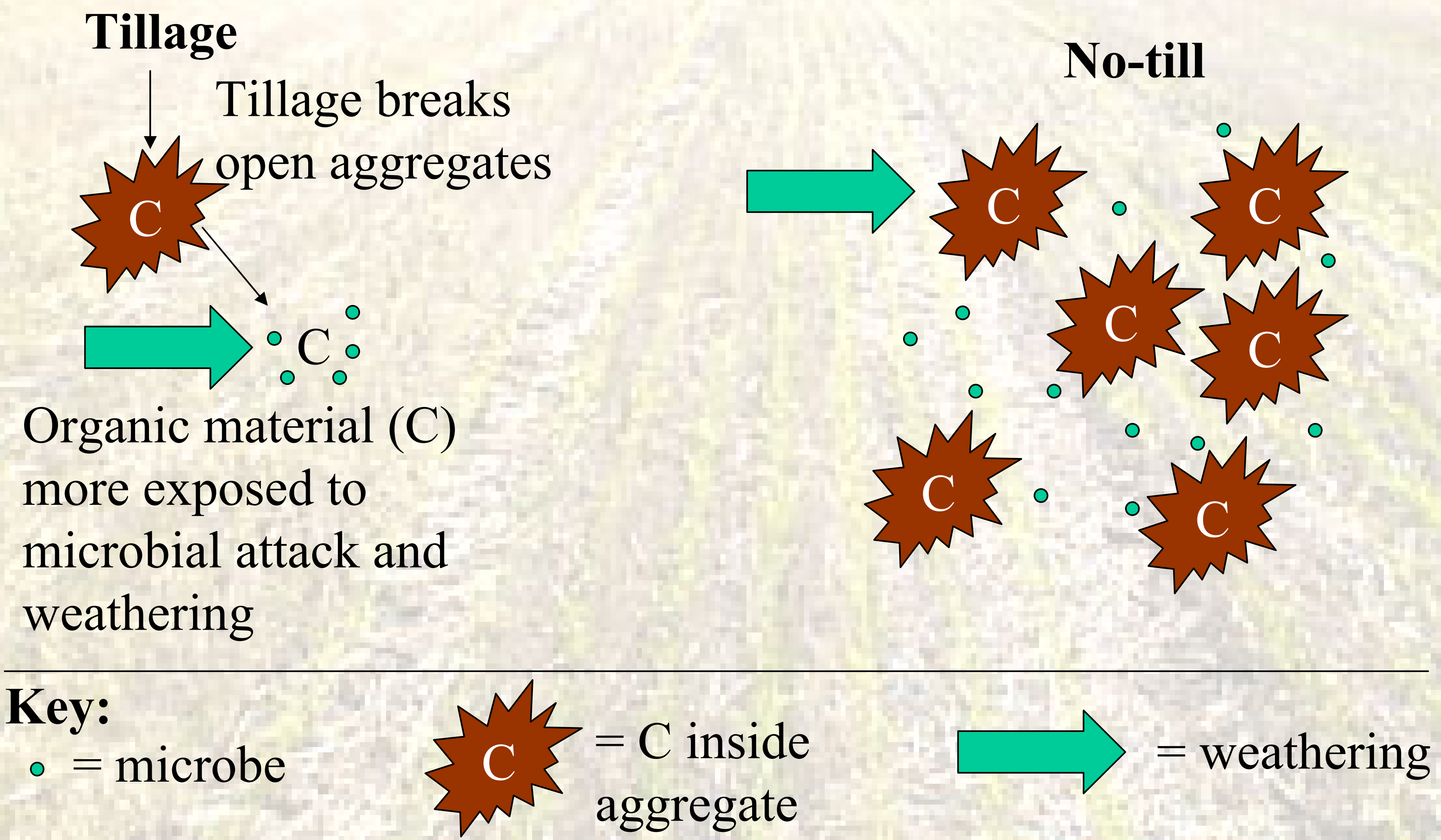
http://www.global-greenhouse-warming.com/global-carbon-cycle.html

Mechanisms for soil C sequestration

How does soil C sequestration work?



How does soil C sequestration work? – reduced disturbance



Mechanisms for soil C sequestration in agriculture

Activity	Practice	Specific management change	Increase C inputs	Decrease C losses	Reduce disturbance
Cropland management	Agronomy	Increased productivity	X		
		Rotations	X		
		Catch crops	X		
		Less fallow	X		
		More legumes	X		
		Deintensification			X
		Improved cultivars	X		
	Nutrient management	Fertilizer placement	X		
		Fertilizer timing	X		
	Tillage / residue management	Reduced tillage			X
		Zero tillage			X
		Reduced residue removal	X		X
		Reduced residue burning	X		X
	Upland water management	Irrigation	X		
		Drainage	X		
	Set-aside and land use change	Set aside	X		X
		Wetlands	X	X	
	Agroforestry	Tree crops inc. Shelterbelts etc.	X		X
Grazing land management	Livestock grazing intensity	Livestock grazing intensity		X	
	Fertilization	Fertilization	X		
	Fire management	Fire management		X	
	Species introduction	Species introduction	X		
	More legumes	More legumes	X		
	Increased productivity	Increased productivity	X		
Organic soils	Restoration	Rewetting / abandonment		X	X
Degraded lands	Restoration	Restoration	X	X	X

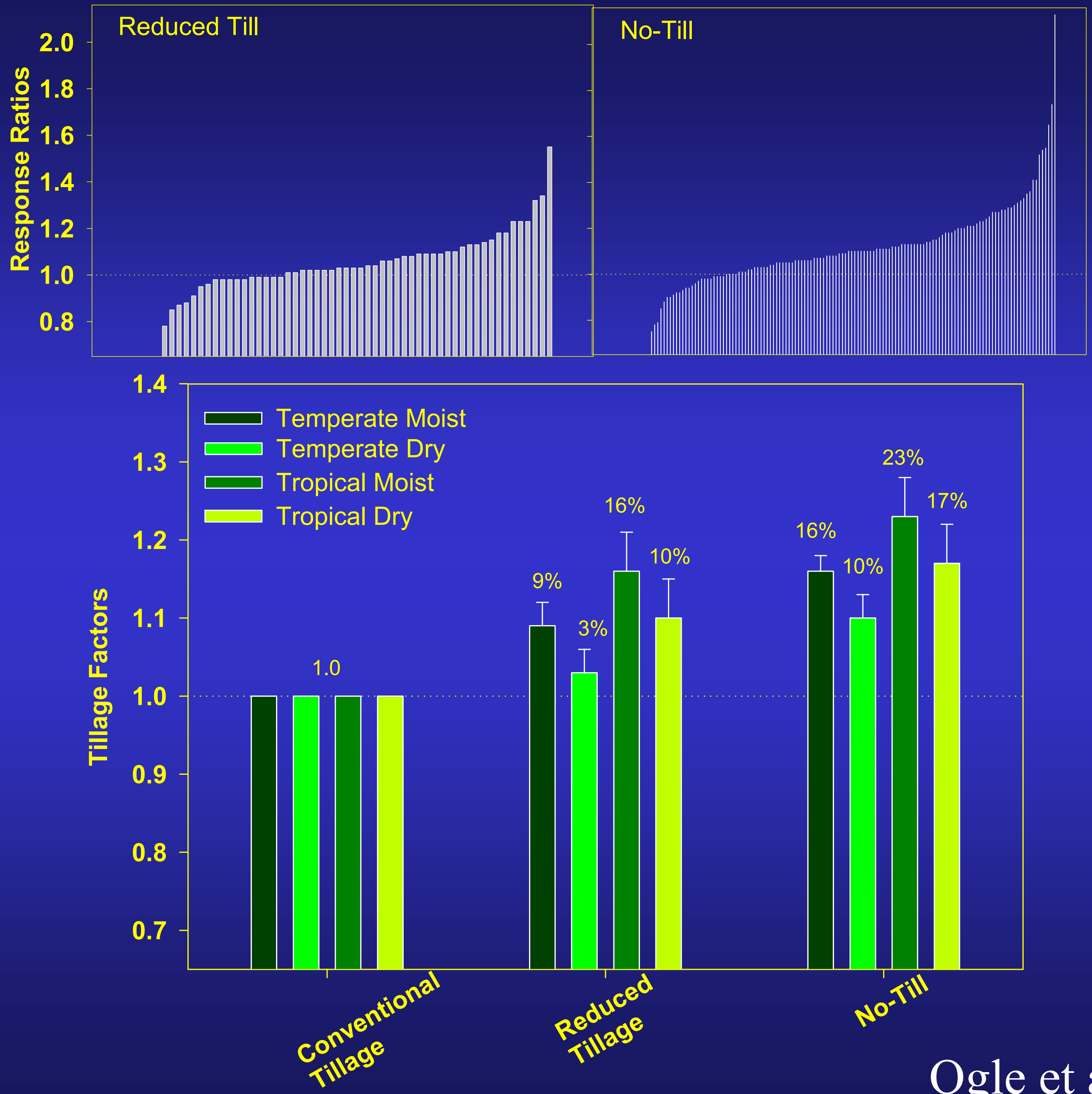
Smith et al. (2007a)


Global potential for soil C sequestration


Method

- Database of over 200 experiments to derive per-area / per-animal mitigation efficiencies for >60 agricultural mitigation options, for four climate zones
- Mean estimates and low and high 95% CI values derived from mixed effects modelling
- Applied to appropriate agricultural (crop, grass) areas in each climate zone in each region

Smith et al. (2007a)



Ogle et al. (2003)

Method

- Database of over 200 experiments to derive per-area / per-animal mitigation efficiencies for >60 agricultural mitigation options, for four climate zones
- Mean estimates and low and high 95% CI values derived from mixed effects modelling
- Applied to appropriate agricultural (crop, grass) areas in each climate zone in each region

Smith et al. (2007a, 2008)

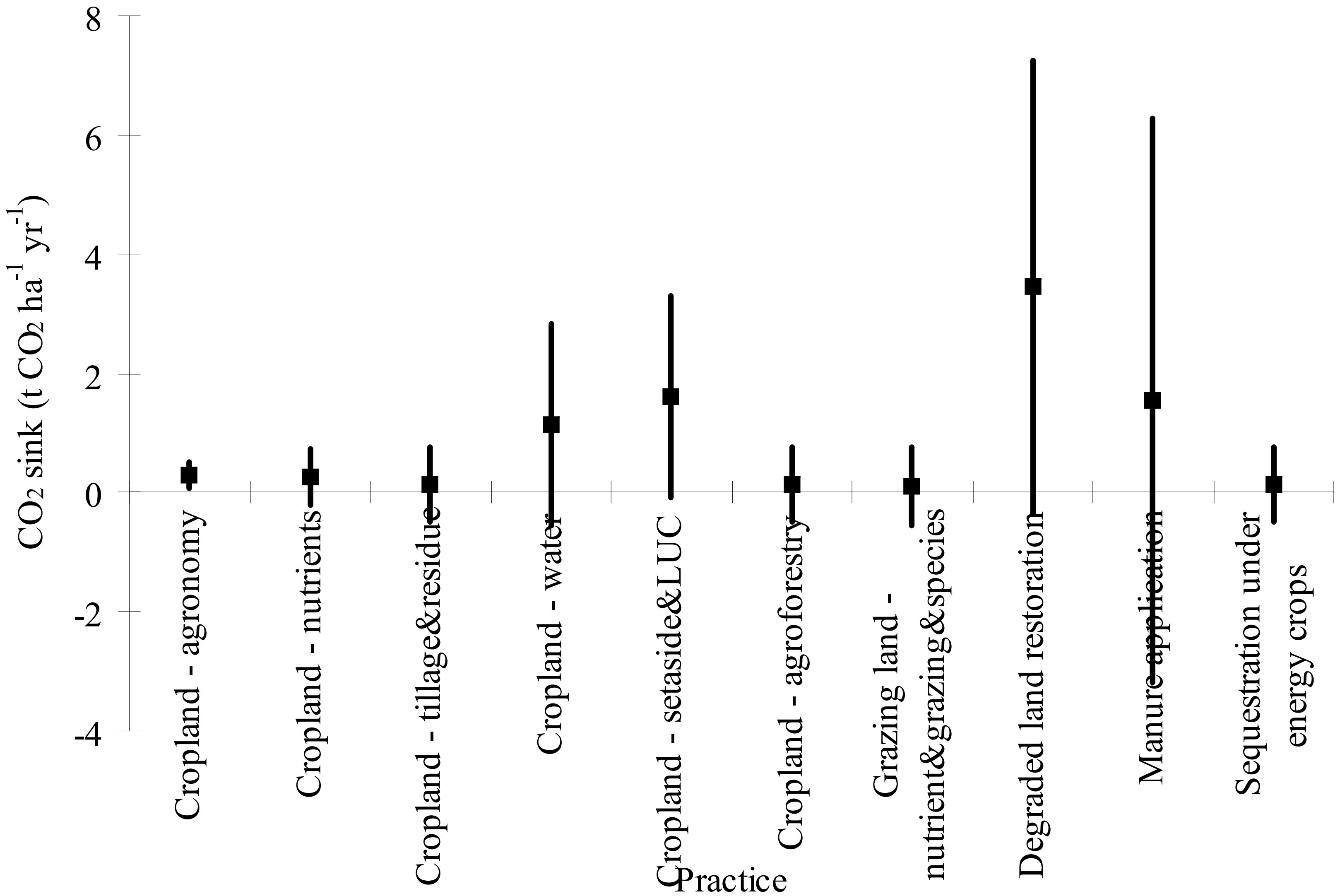
Per-area / per-animal mitigation potential

Climate zone	Activity	Practice	CO_2 (t CO_2 ha^{-1} y^{-1})			CH_4 (t CO_2-eq. ha^{-1} y^{-1})			N_2O (t CO_2-eq. ha^{-1} y^{-1})			All GHG (t CO_2-eq. ha^{-1} y^{-1})		
			Mean estimate	Low	High	Mean estimate	Low	High	Mean estimate	Low	High	Mean estimate	Low	High
Cool-dry	Croplands	agronomy	0.29	0.07	0.51	0.00	0.00	0.00	0.10	0.00	0.20	0.39	0.07	0.71
	Croplands	nutrient management	0.26	-0.22	0.73	0.00	0.00	0.00	0.07	0.01	0.32	0.33	-0.21	1.05
	Croplands	tillage and residue management	0.15	-0.48	0.77	0.00	0.00	0.00	0.02	-0.04	0.09	0.17	-0.52	0.86
	Croplands	water management	1.14	-0.55	2.82	0.00	0.00	0.00	0.00	0.00	0.00	1.14	-0.55	2.82
	Croplands	set-aside and LUC	1.61	-0.07	3.30	0.02	0.00	0.00	2.30	0.00	4.60	3.93	-0.07	7.90
	Croplands	agro-forestry	0.15	-0.48	0.77	0.00	0.00	0.00	0.02	-0.04	0.09	0.17	-0.52	0.86
	Grasslands	grazing, fertilizaltion, fire	0.11	-0.55	0.77	0.02	0.01	0.02	0.00	0.00	0.00	0.13	-0.54	0.79
	Organic soils	restoration	36.67	3.67	69.67	-3.32	-0.05	-15.30	0.16	0.05	0.28	33.51	3.67	54.65
	Degraded lands	restoration	3.45	-0.37	7.26	0.08	0.04	0.14	0.00	0.00	0.00	3.53	-0.33	7.40
	Manure / biosol	application	1.54	-3.19	6.27	0.00	0.00	0.00	0.00	-0.17	1.30	1.54	-3.36	7.57
	Bioenergy	soils only	0.15	-0.48	0.77	0.00	0.00	0.00	0.02	-0.04	0.09	0.17	-0.52	0.86
Cool-moist	Croplands	agronomy	0.88	0.51	1.25	0.00	0.00	0.00	0.10	0.00	0.20	0.98	0.51	1.45
	Croplands	nutrient management	0.55	0.01	1.10	0.00	0.00	0.00	0.07	0.01	0.32	0.62	0.02	1.42
	Croplands	tillage and residue management	0.51	0.00	1.03	0.00	0.00	0.00	0.02	-0.04	0.09	0.53	-0.04	1.12
	Croplands	water management	1.14	-0.55	2.82	0.00	0.00	0.00	0.00	0.00	0.00	1.14	-0.55	2.82
	Croplands	set-aside and LUC	3.04	1.17	4.91	0.02	0.00	0.00	2.30	0.00	4.60	5.36	1.17	9.51
	Croplands	agro-forestry	0.51	0.00	1.03	0.00	0.00	0.00	0.02	-0.04	0.09	0.53	-0.04	1.12
	Grasslands	grazing, fertilizaltion, fire	0.81	0.11	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.11	1.50
	Organic soils	restoration	36.67	3.67	69.67	-3.32	-0.05	-15.30	0.16	0.05	0.28	33.51	3.67	54.65
	Degraded lands	restoration	3.45	-0.37	7.26	1.00	0.69	1.25	0.00	0.00	0.00	4.45	0.32	8.51
	Manure / biosol	application	2.79	-0.62	6.20	0.00	0.00	0.00	0.00	-0.17	1.30	2.79	-0.79	7.50
	Bioenergy	soils only	0.51	0.00	1.03	0.00	0.00	0.00	0.02	-0.04	0.09	0.53	-0.04	1.12
Warm-dry	Croplands	agronomy	0.29	0.07	0.51	0.00	0.00	0.00	0.10	0.00	0.20	0.39	0.07	0.71
	Croplands	nutrient management	0.26	-0.22	0.73	0.00	0.00	0.00	0.07	0.01	0.32	0.33	-0.21	1.05
	Croplands	tillage and residue management	0.33	-0.73	1.39	0.00	0.00	0.00	0.02	-0.04	0.09	0.35	-0.77	1.48
	Croplands	water management	1.14	-0.55	2.82	0.00	0.00	0.00	0.00	0.00	0.00	1.14	-0.55	2.82
	Croplands	set-aside and LUC	1.61	-0.07	3.30	0.02	0.00	0.00	2.30	0.00	4.60	3.93	-0.07	7.90
	Croplands	agro-forestry	0.33	-0.73	1.39	0.00	0.00	0.00	0.02	-0.04	0.09	0.35	-0.77	1.48
	Grasslands	grazing, fertilizaltion, fire	0.11	-0.55	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.11	-0.55	0.77
	Organic soils	restoration	73.33	7.33	139.33	-3.32	-0.05	-15.30	0.16	0.05	0.28	70.18	7.33	124.31
	Degraded lands	restoration	3.45	-0.37	7.26	0.00	0.00	0.00	0.00	0.00	0.00	3.45	-0.37	7.26
	Manure / biosol	application	1.54	-3.19	6.27	0.00	0.00	0.00	0.00	-0.17	1.30	1.54	-3.36	7.57
	Bioenergy	soils only	0.33	-0.73	1.39	0.00	0.00	0.00	0.02	-0.04	0.09	0.35	-0.77	1.48
Warm-moist	Croplands	agronomy	0.88	0.51	1.25	0.00	0.00	0.00	0.10	0.00	0.20	0.98	0.51	1.45
	Croplands	nutrient management	0.55	0.01	1.10	0.00	0.00	0.00	0.07	0.01	0.32	0.62	0.02	1.42
	Croplands	tillage and residue management	0.70	-0.40	1.80	0.00	0.00	0.00	0.02	-0.04	0.09	0.72	-0.44	1.89
	Croplands	water management	1.14	-0.55	2.82	0.00	0.00	0.00	0.00	0.00	0.00	1.14	-0.55	2.82
	Croplands	set-aside and LUC	3.04	1.17	4.91	0.02	0.00	0.00	2.30	0.00	4.60	5.36	1.17	9.51
	Croplands	agro-forestry	0.70	-0.40	1.80	0.00	0.00	0.00	0.02	-0.04	0.09	0.72	-0.44	1.89
	Grasslands	grazing, fertilizaltion, fire	0.81	0.11	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.81	0.11	1.50
	Organic soils	restoration	73.33	7.33	139.33	-3.32	-0.05	-15.30	0.16	0.05	0.28	70.18	7.33	124.31
	Degraded lands	restoration	3.45	-0.37	7.26	0.00	0.00	0.00	0.00	0.00	0.00	3.45	-0.37	7.26
	Manure / biosol	application	2.79	-0.62	6.20	0.00	0.00	0.00	0.00	-0.17	1.30	2.79	-0.79	7.50
	Bioenergy	soils only	0.70	-0.40	1.80	0.00	0.00	0.00	0.02	-0.04	0.09	0.72	-0.44	1.89

For 14 practices, for 4 climate zones, for CO_2, N_2O & CH_4, estimates for mean and +/- 95%CI

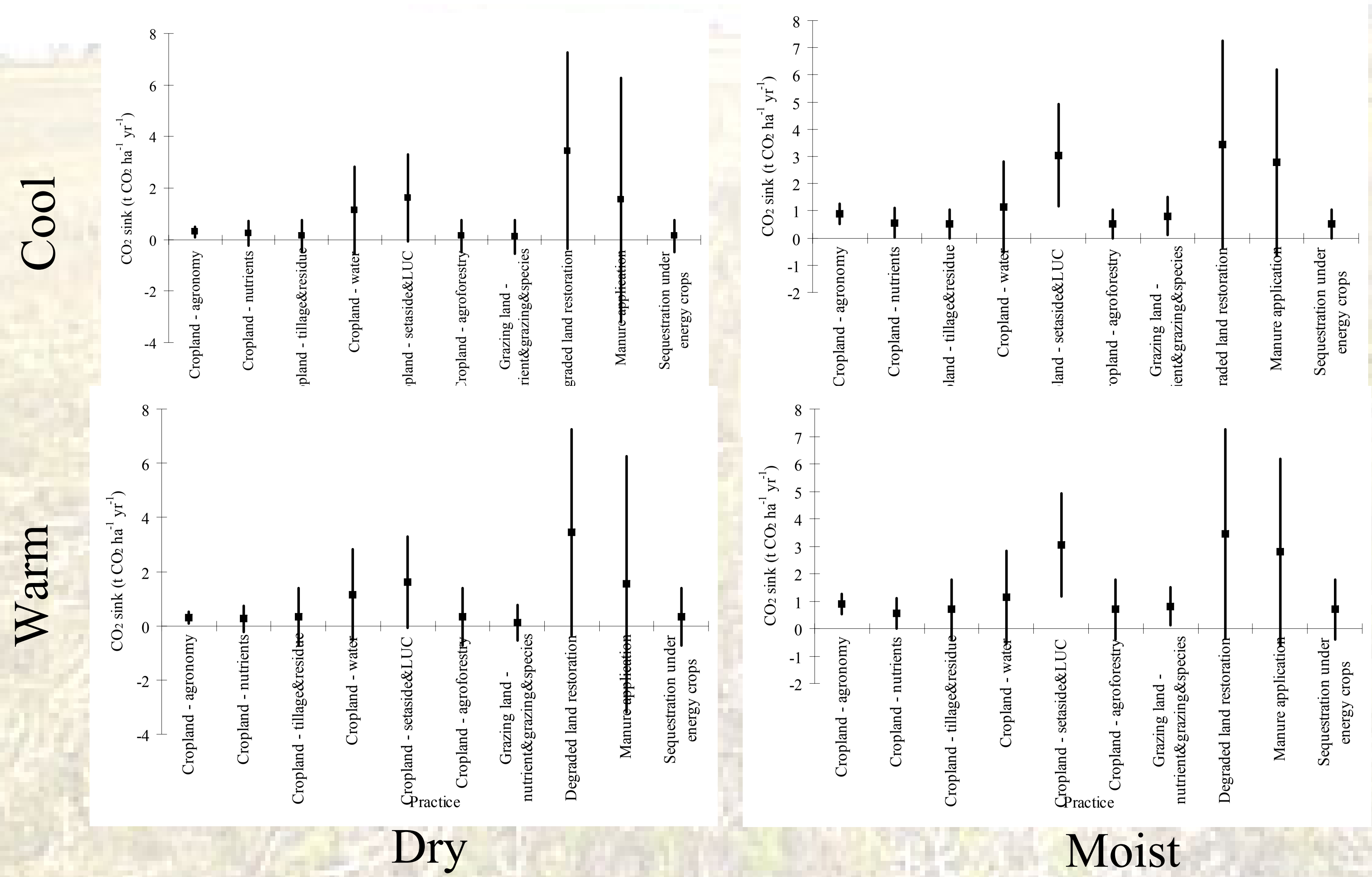
Smith et al. (2007a)

Soil C sequestration rates for cool dry climate



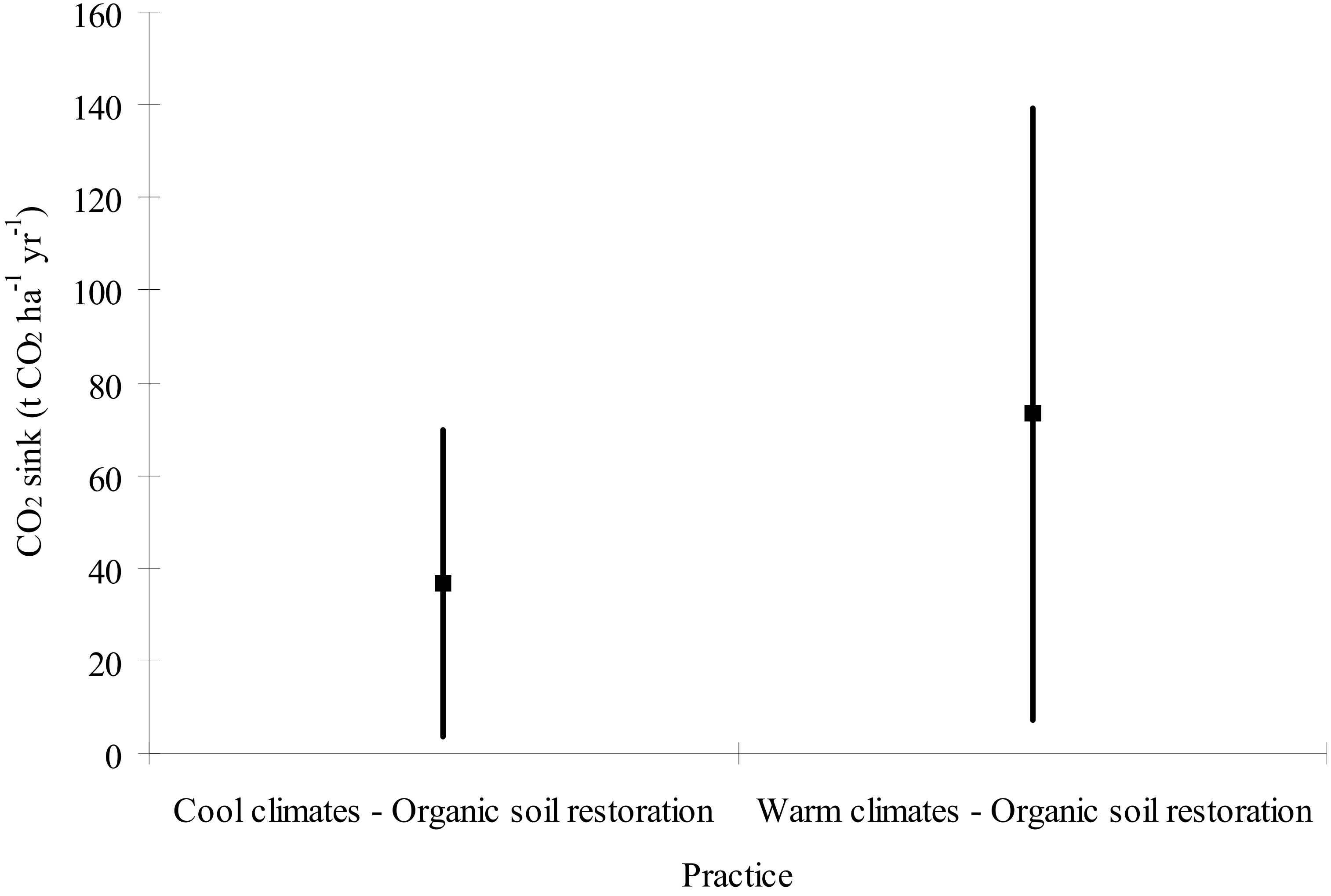
Data from: Smith et al. (2007a)

Soil C sequestration rates in different climates



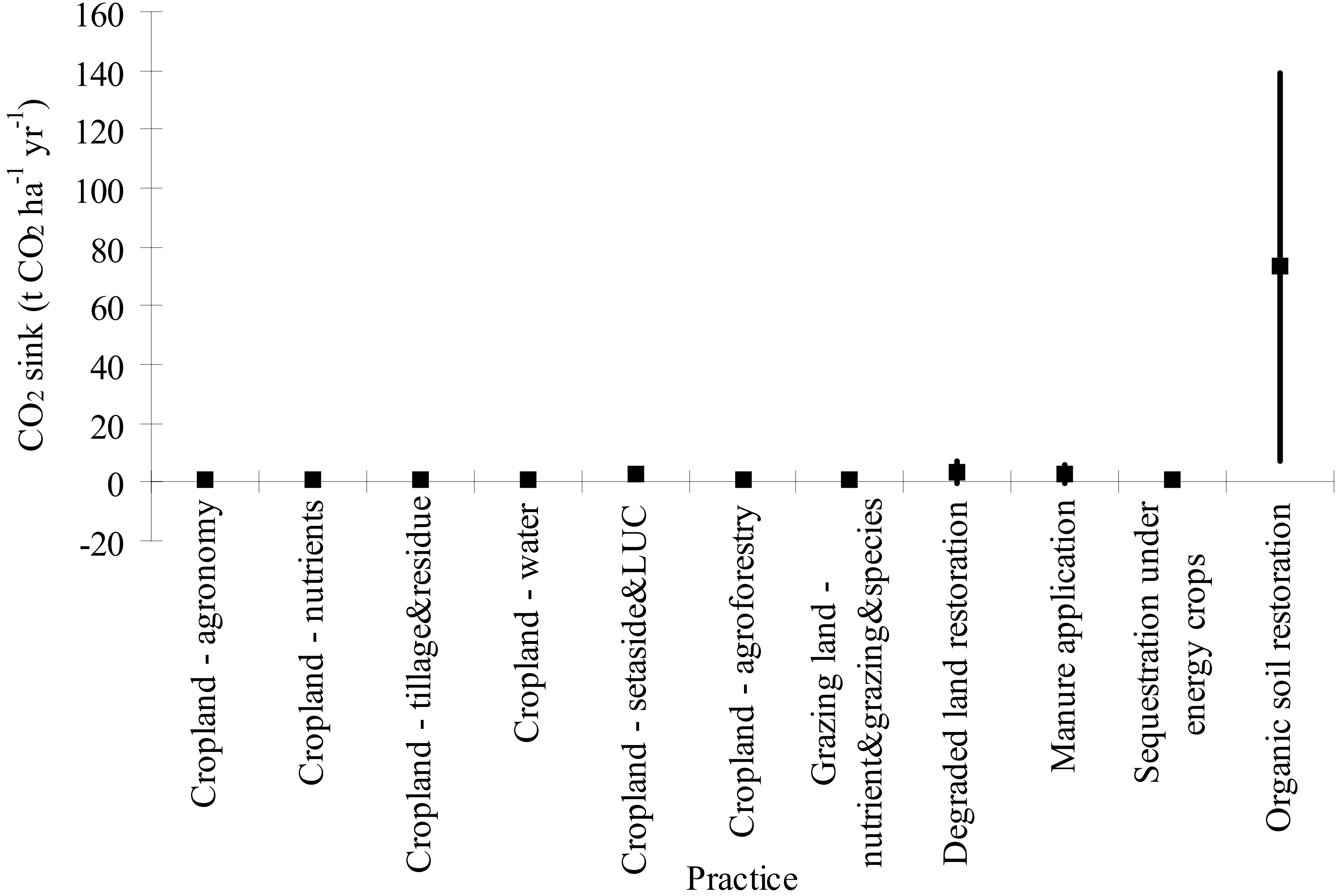
Data from: Smith et al. (2007a)

Soil C emission reduction rates for organic soil restoration



Data from: Smith et al. (2007a)

Organic soil restoration vs. mineral soil sequestration



Data from: Smith et al. (2007a)

Method

- Database of over 200 experiments to derive per-area / per-animal mitigation efficiencies for >60 agricultural mitigation options, for four climate zones
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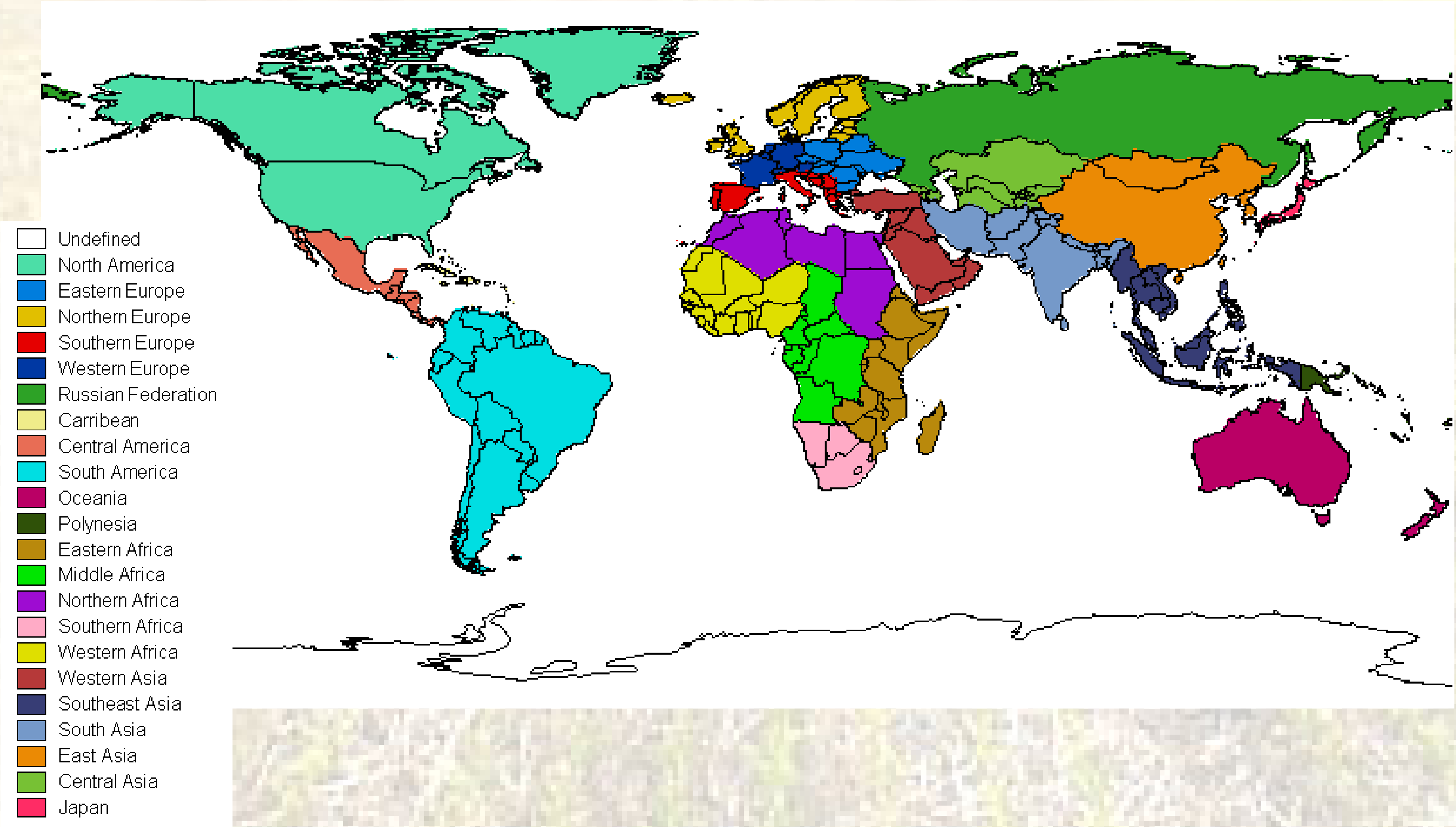
- Applied to appropriate agricultural (crop, grass) areas in each climate zone in each region

Smith et al. (2007a, 2008)

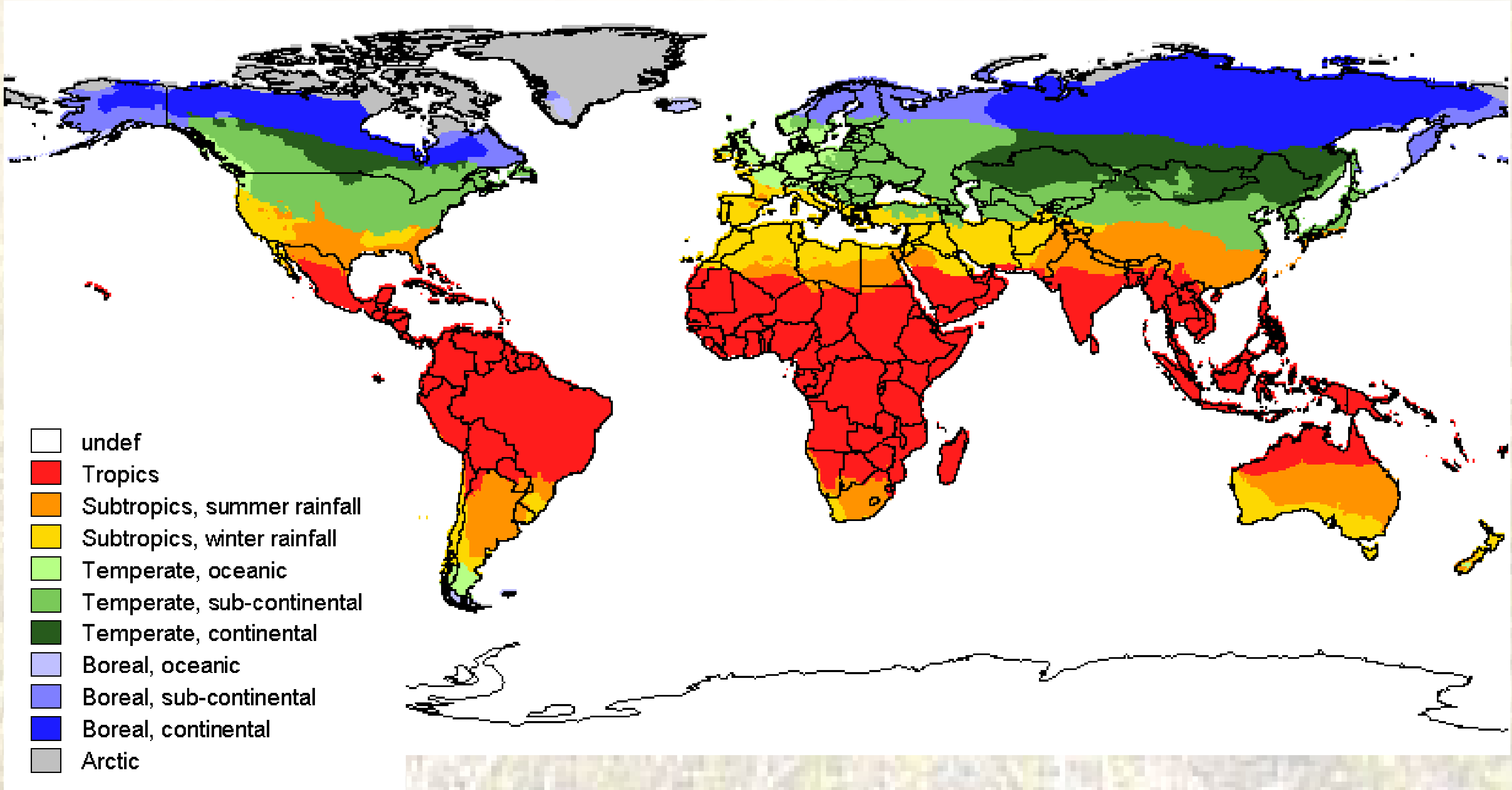
IPCC AR4 Agricultural GHG Mitigation

FAO AEZ Database (e.g. showing regions)



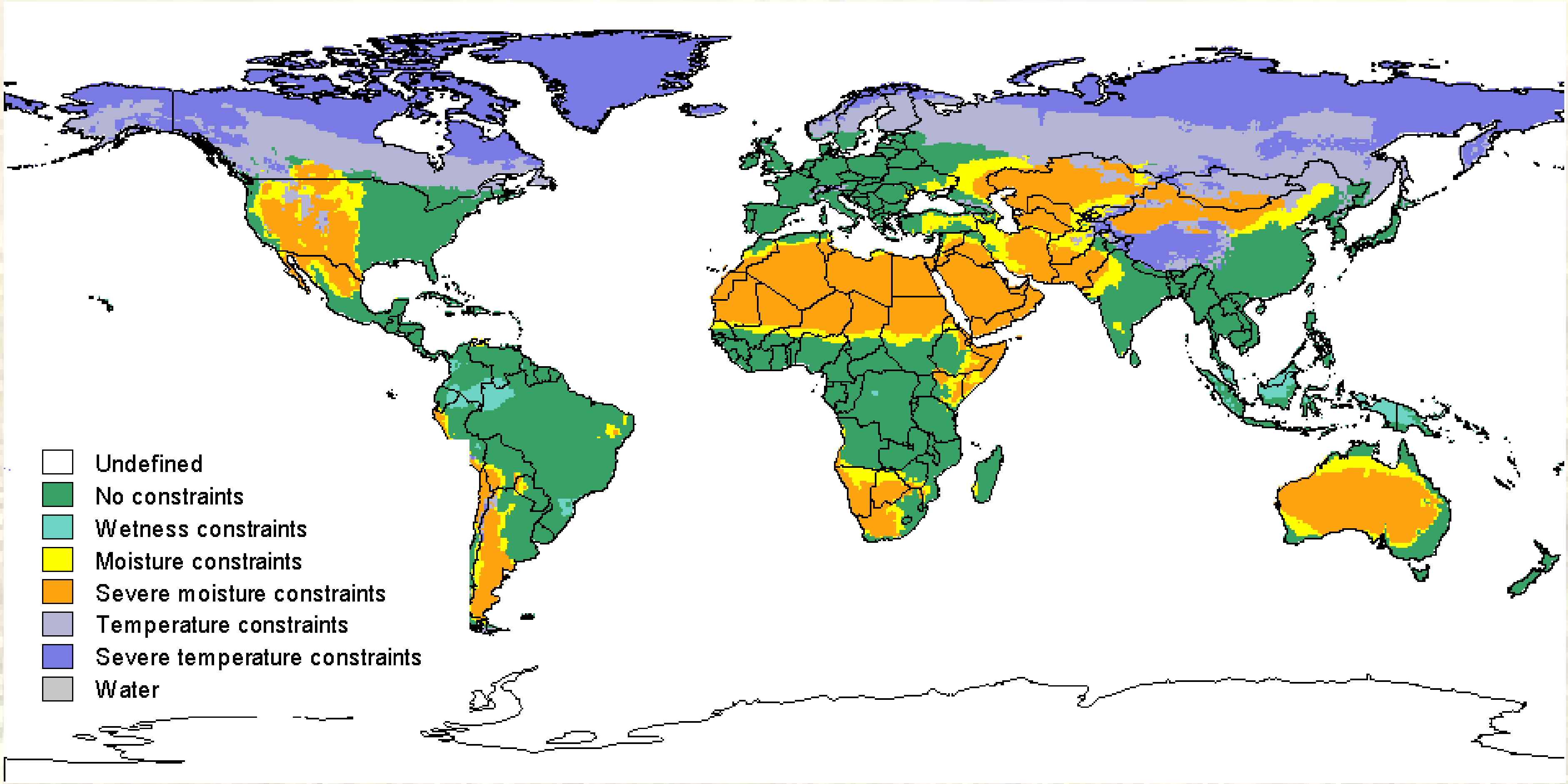
IPCC AR4 Agricultural GHG Mitigation

FAO AEZ Database (e.g. showing thermal climate)



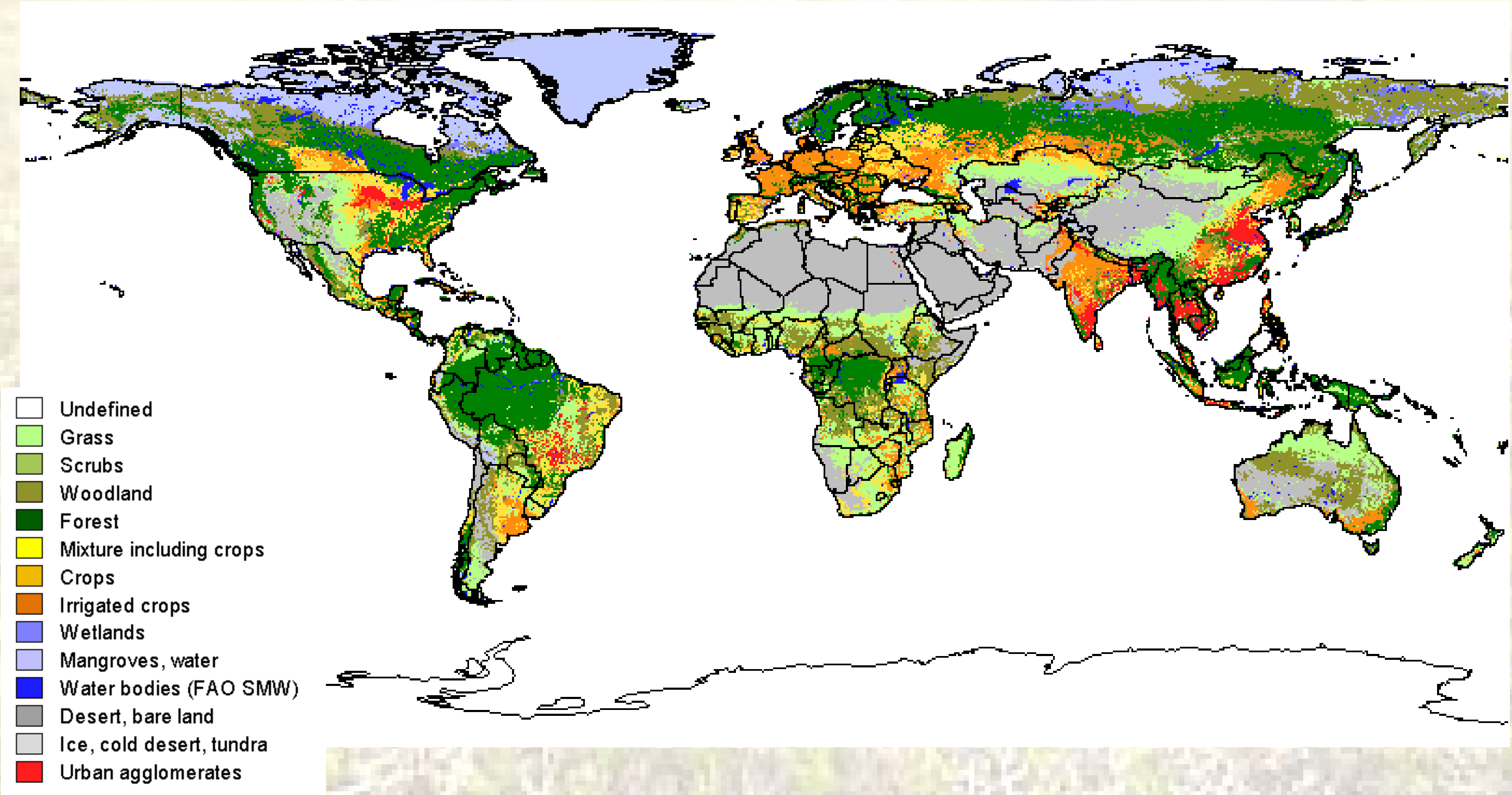
IPCC AR4 Agricultural GHG Mitigation

FAO AEZ Database (e.g. showing production constraints)

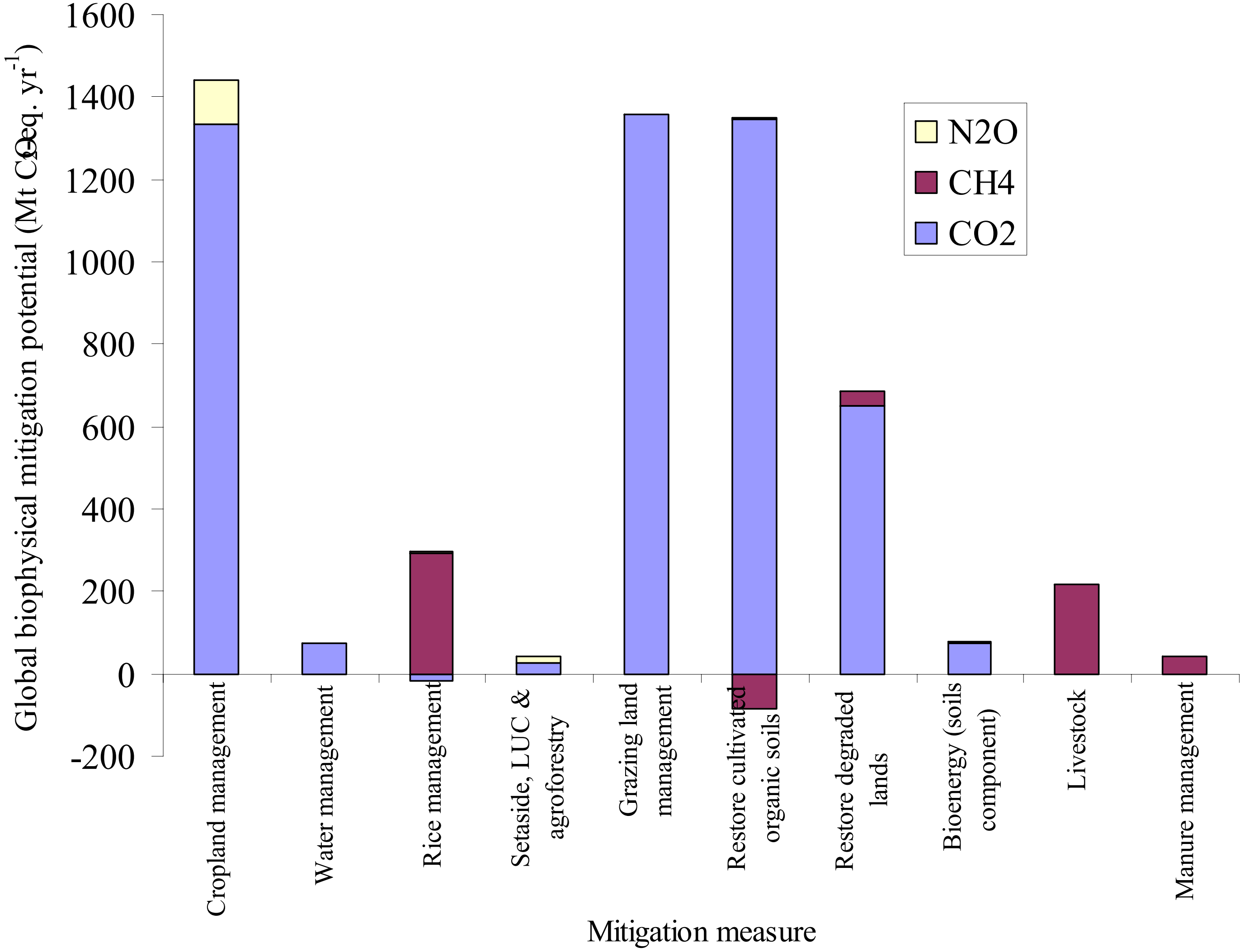


IPCC AR4 Agricultural GHG Mitigation

FAO AEZ Database (e.g. showing land cover)

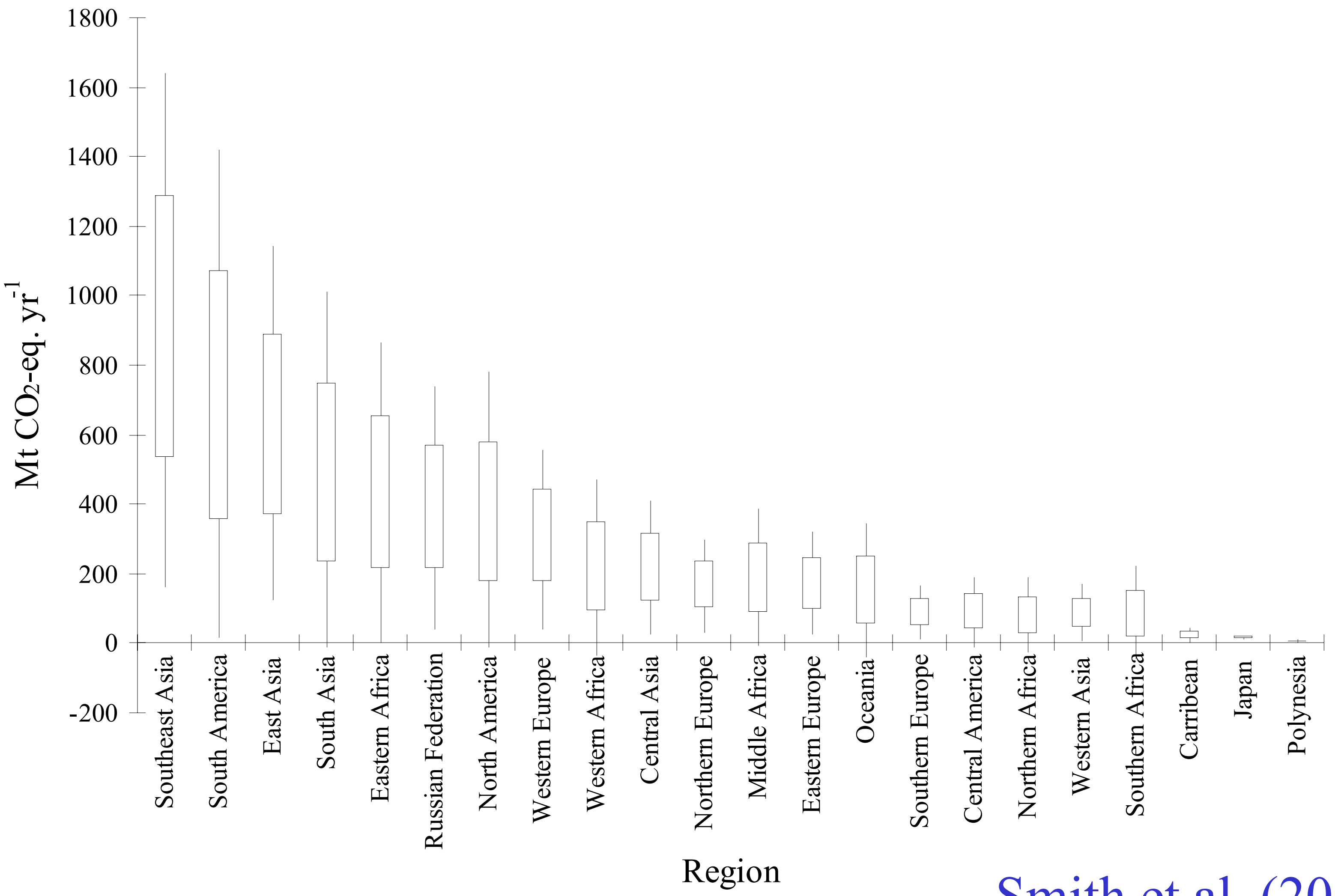


Global mitigation potential in agriculture



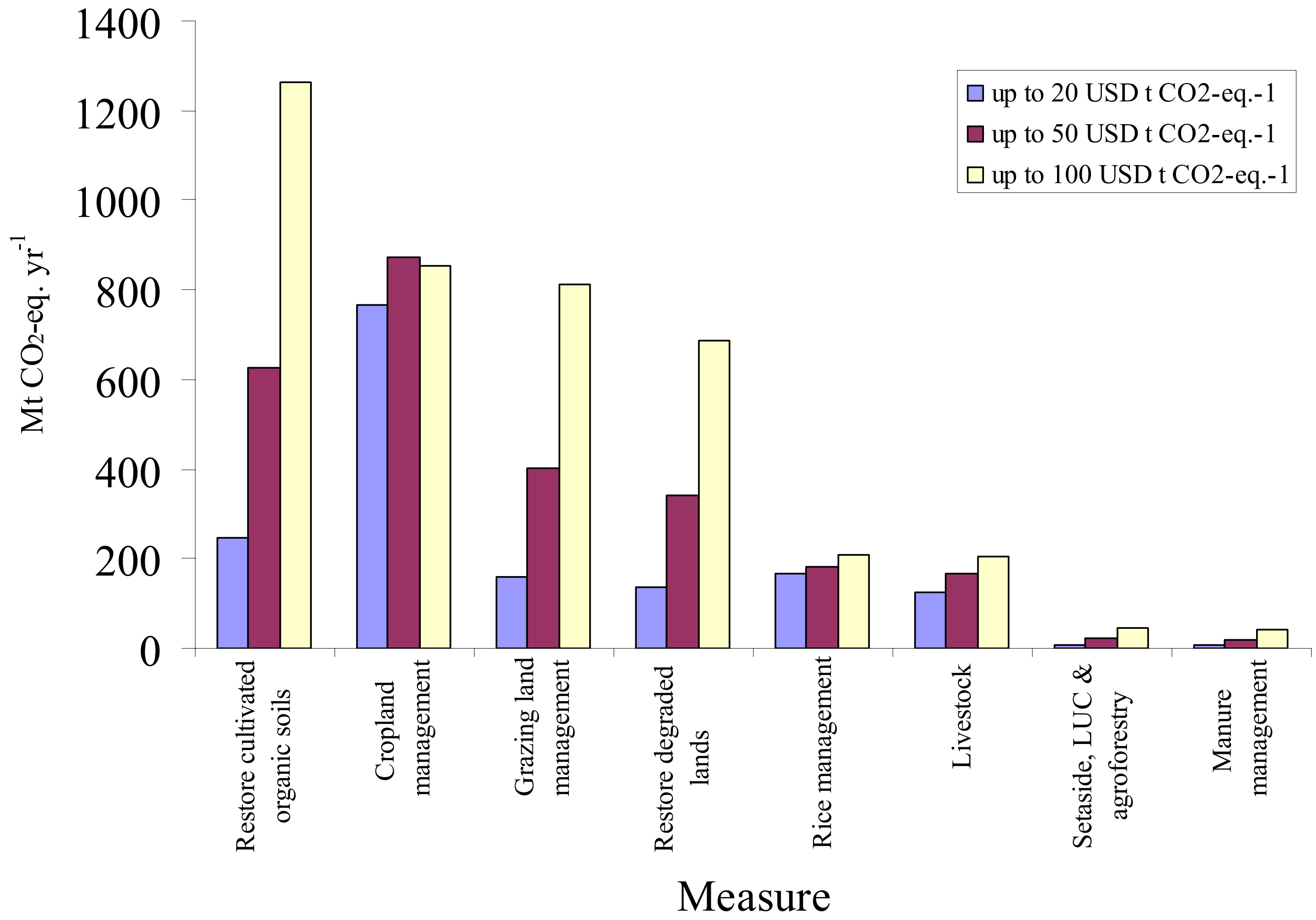
Smith et al. (2007a)

High and low estimates of the mitigation potential in each region



Smith et al. (2007a)

Effect of C price on implementation



Smith et al. (2007a)

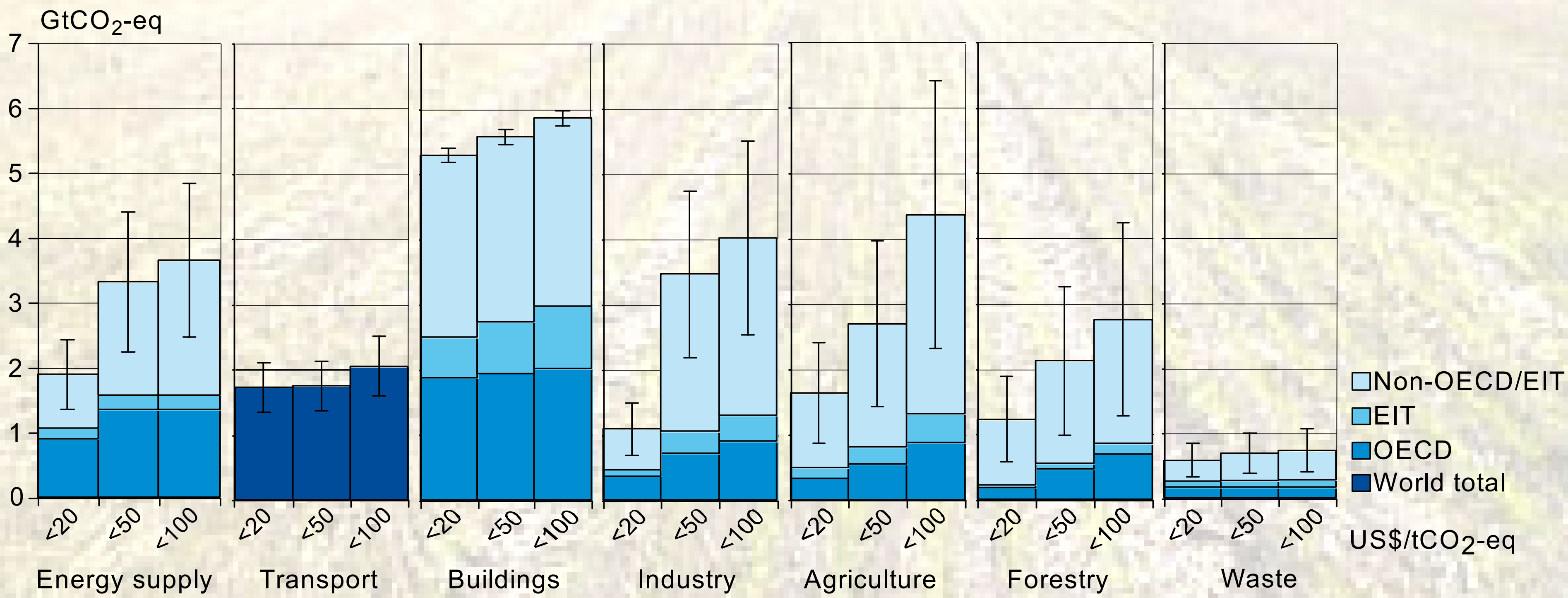
Global mitigation potential in agriculture (Mt CO_2-eq. yr^{-1})

	Price range (USD t CO_2-eq. $^{-1}$)			
Scenario	**0-20**	**0-50**	**0-100**	**0->>100 (technical potential)**
B1	1925	2384	3149	5480
A1b	1982	2439	3254	5670
B2	2047	2495	3330	5844
A2	2119	2549	3330	5957

Over 70% of the potential is in developing countries

Smith et al. (2007a, b)

Global economic mitigation potential for different sectors at different carbon prices



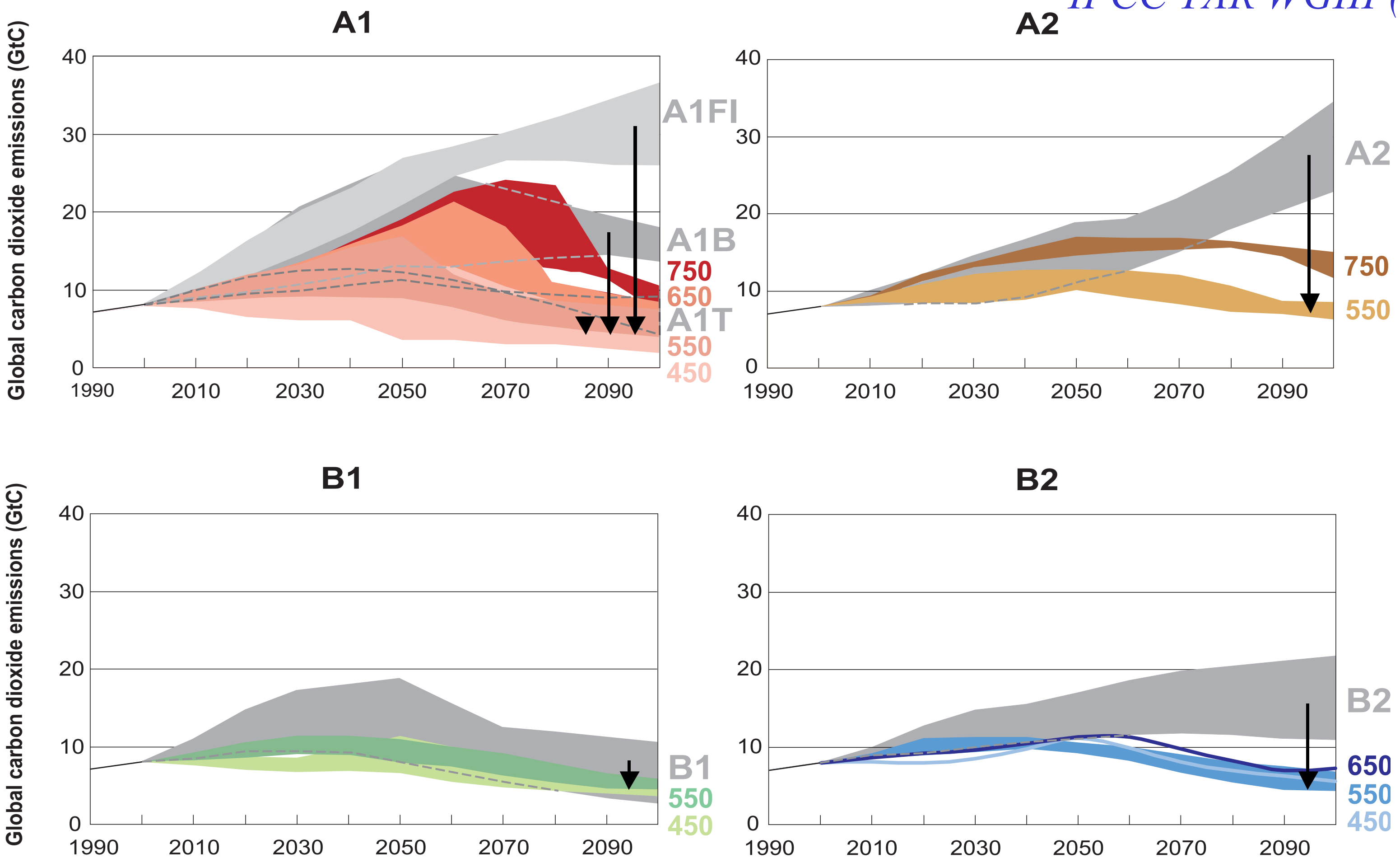
IPCC WGIII (2007)

How important is this C sequestration potential?

- Even at 100 USD t CO_2-eq.$^{-1}$, sequestration potential is 3100-3300 Mt CO_2-eq. yr^{-1}
- This is equivalent to less than 1000 Mt C yr^{-1} or <1 Pg per year
- Atmospheric CO_2-C is increasing at a rate of 3.2 Pg C yr^{-1} so soil C sequestration can mitigate less than 1/3 of this increase and less than 1/7 of fossil fuel C emissions
- So is it worth using C sequestration at all?

The energy / emission gap under different SRES scenarios

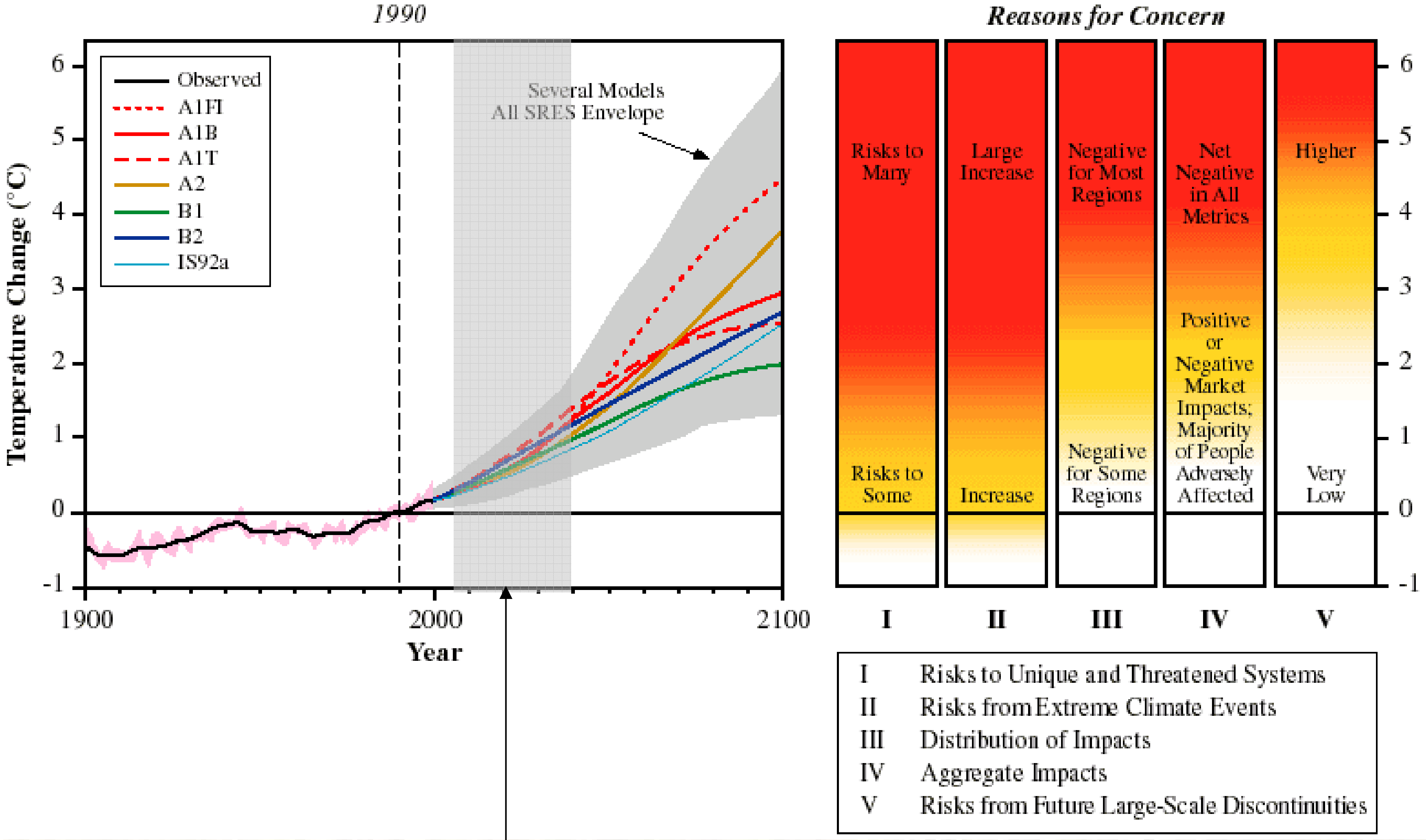
IPCC TAR WGIII (2001)



- Current yearly atmospheric C increase = 3.2 ± 0.1 Pg C y^{-1}
- Emission gaps of up to 25 Pg C y^{-1} by 2100

Smith (2004)

Why use sequestration?

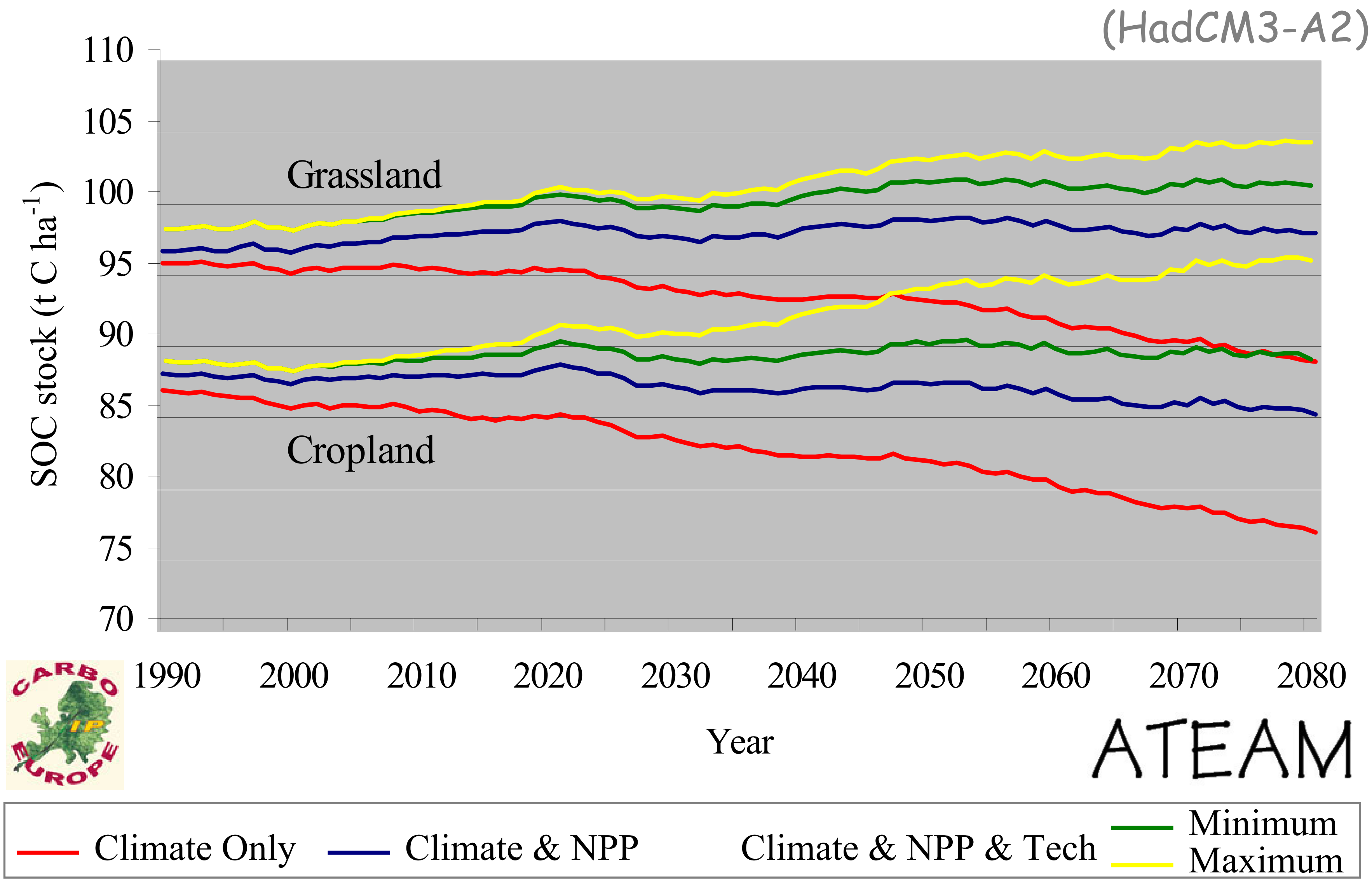


Critical period determining trajectory

IPCC (2001)

Response of soil C sinks to future climate change

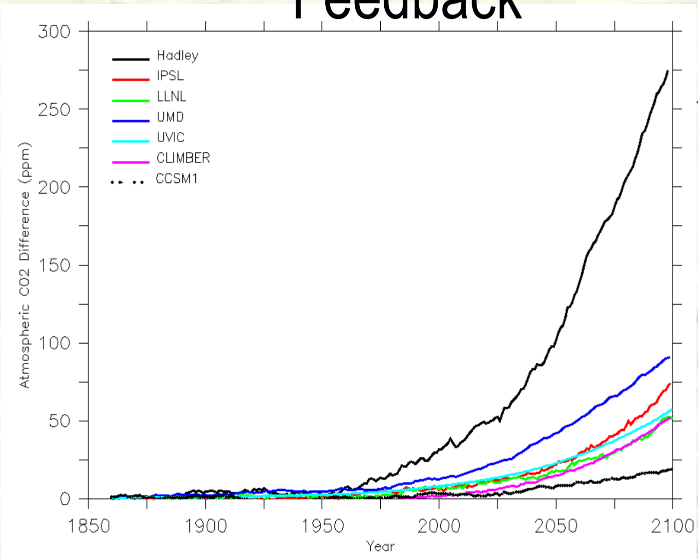
Uncertainty in cropland & grassland SOC stock changes due to climate, NPP & technology change



J.U. Smith *et al.* (2005)

Vulnerability of the Carbon Cycle in the 21st century

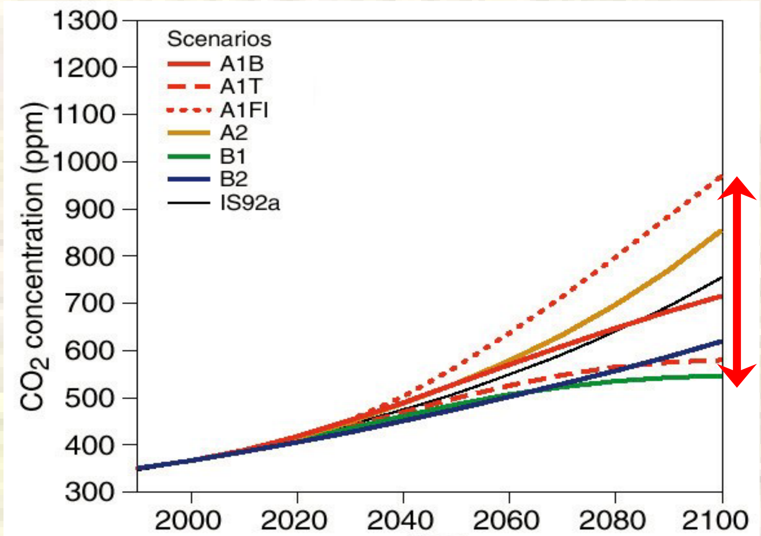
Uncertainty of the Biospheric-Carbon-Climate Feedback



Up to ~ 250 ppm

Friedlingstein et al. 2006

Uncertainty on Anthropogenic Carbon Emissions



Up to ~ 450 ppm

IPCC SRES 2000

Global Carbon Project

Slide courtesy of Pep Canadell, GCP

Earth System Science Partnership

Conclusions

- Soil C sequestration is a globally significant climate mitigation measure
- Soil C sequestration is cost competitive with climate mitigation measures in other sectors
- But - soil C sequestration is not permanent and is of limited duration (due to sink saturation)
- Response of soil C sinks to future climate change remains uncertain
- Protecting large soil C stocks (e.g. peatlands) is very important for avoiding emissions


Thank you for your attention