

Full model integration versus loose coupling – examples for assessing agricultural mitigation potential

Pete Smith

Professor of Soils & Global Change
School of Biological Sciences,
University of Aberdeen,
Scotland, UK

E-mail: pete.smith@abdn.ac.uk



Co-authors of the work

- Daniel Martino, Zucong Cai, Daniel Gwary, Henry Janzen, Pushpam Kumar, Bruce McCarl, Stephen Ogle, Frank O'Mara, Charles Rice, Steve Rose, Bob Scholes, Oleg Sirotenko, Mark Howden, Tim McAllister, Genxing Pan, Vladimir Romanenkov, Uwe Schneider, Sirintornthep Towprayoon & Martin Wattenbach

Outline

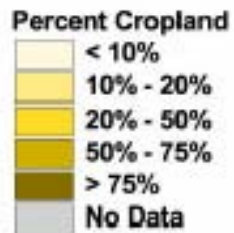
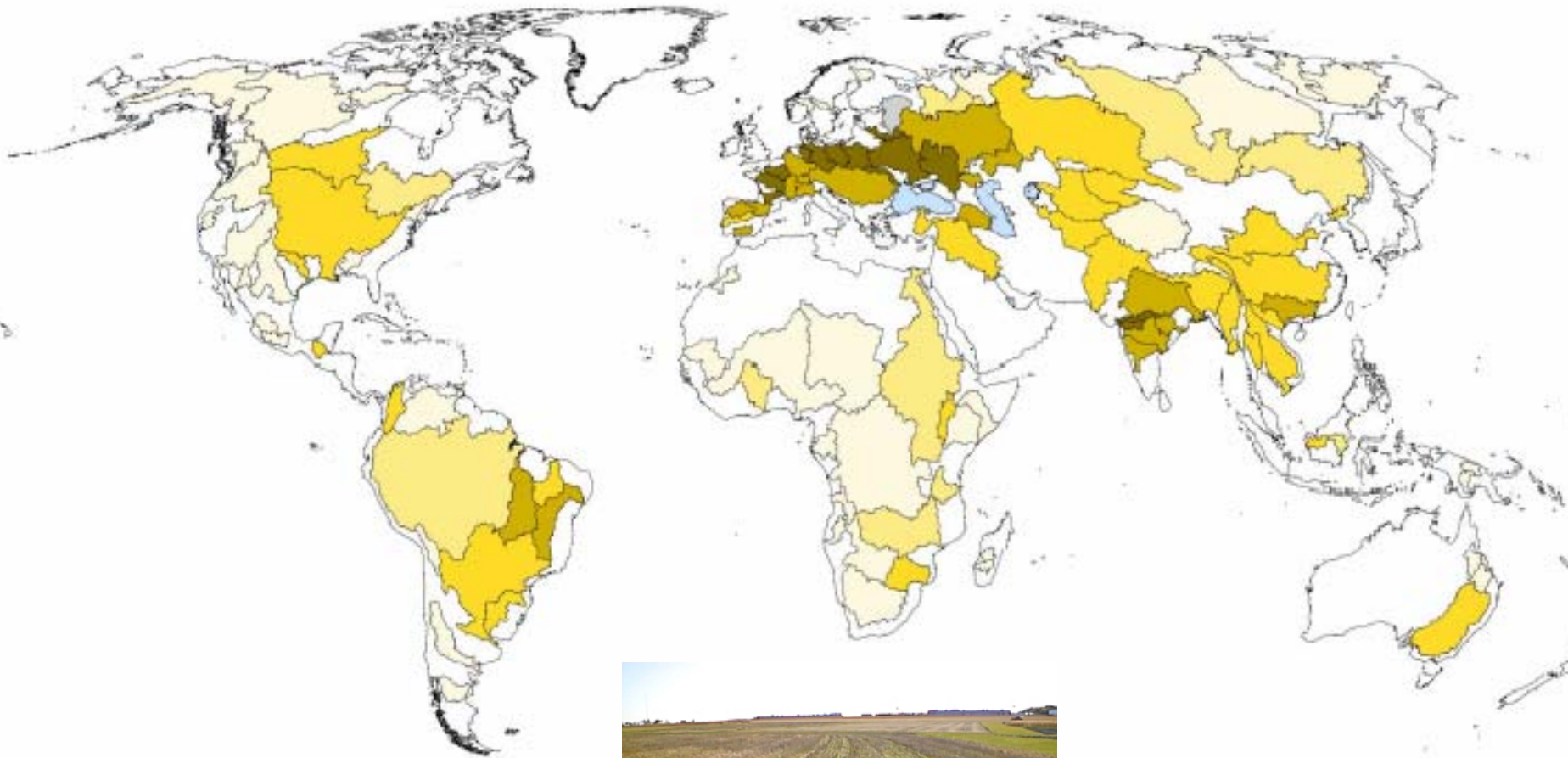
- Agricultural GHG emissions
- Global potential for agricultural GHG mitigation
 - Can use process models
 - Can use simpler models
- Comparing estimates from bottom-up (loosely coupled) vs. top-down (fully integrated) models
- Agriculture in the big picture
- Conclusions



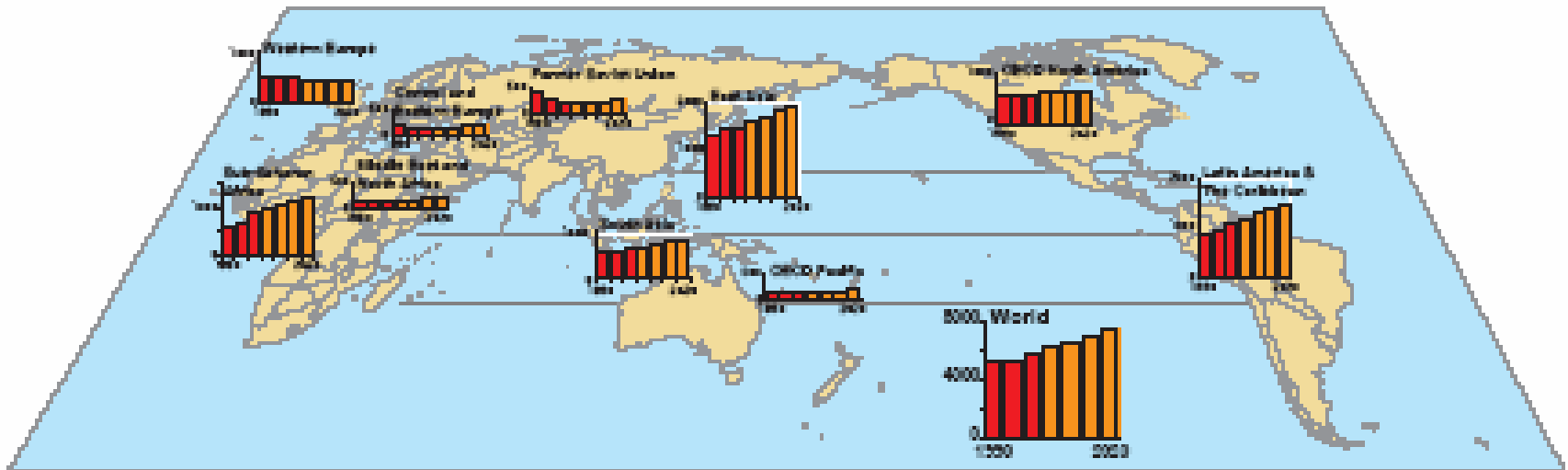
Agricultural GHG emissions



Distribution of croplands globally



Agricultural GHG emissions



CH₄ and N₂O emissions by world region, 1990-2020

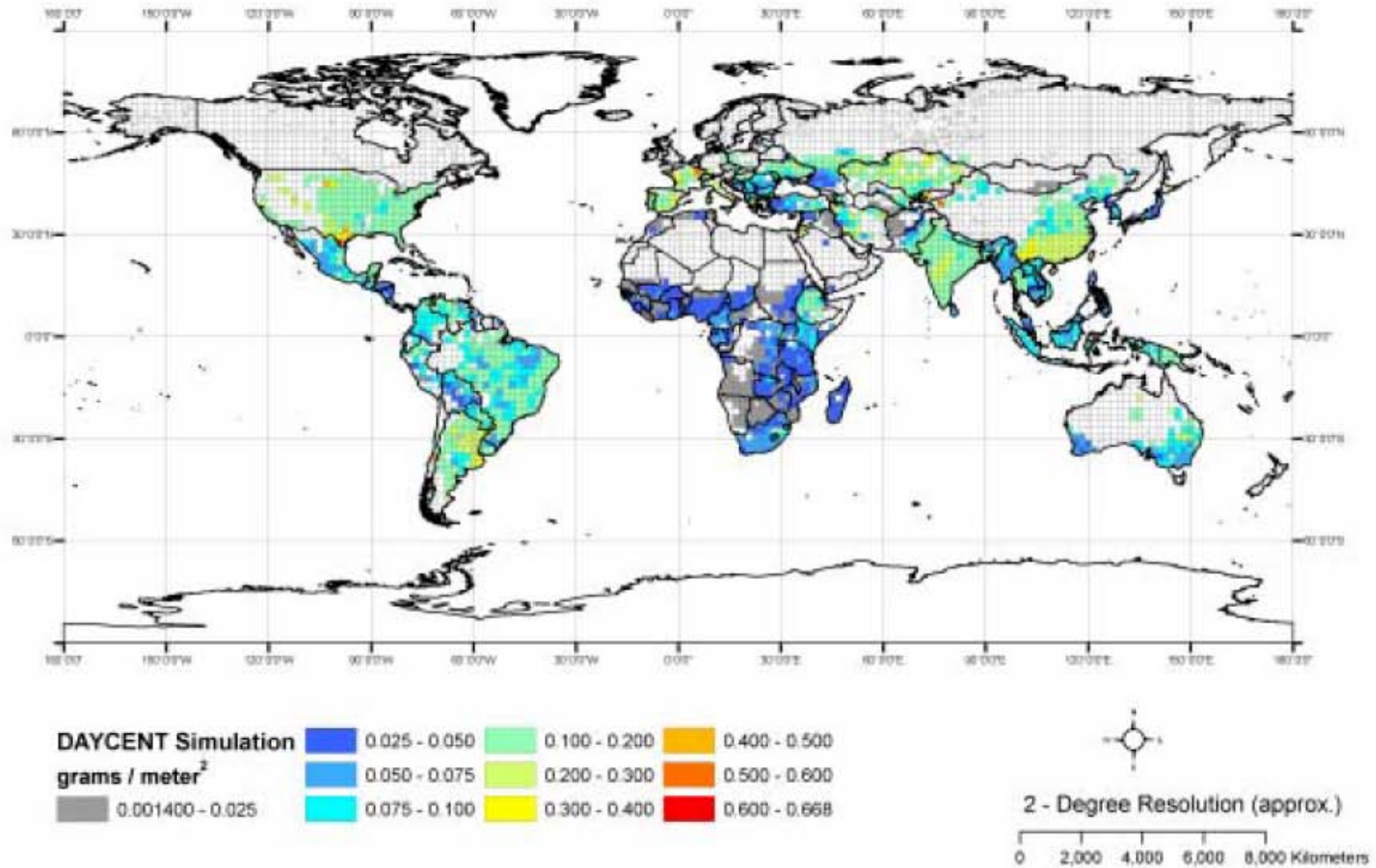


Global potential for agricultural GHG mitigation



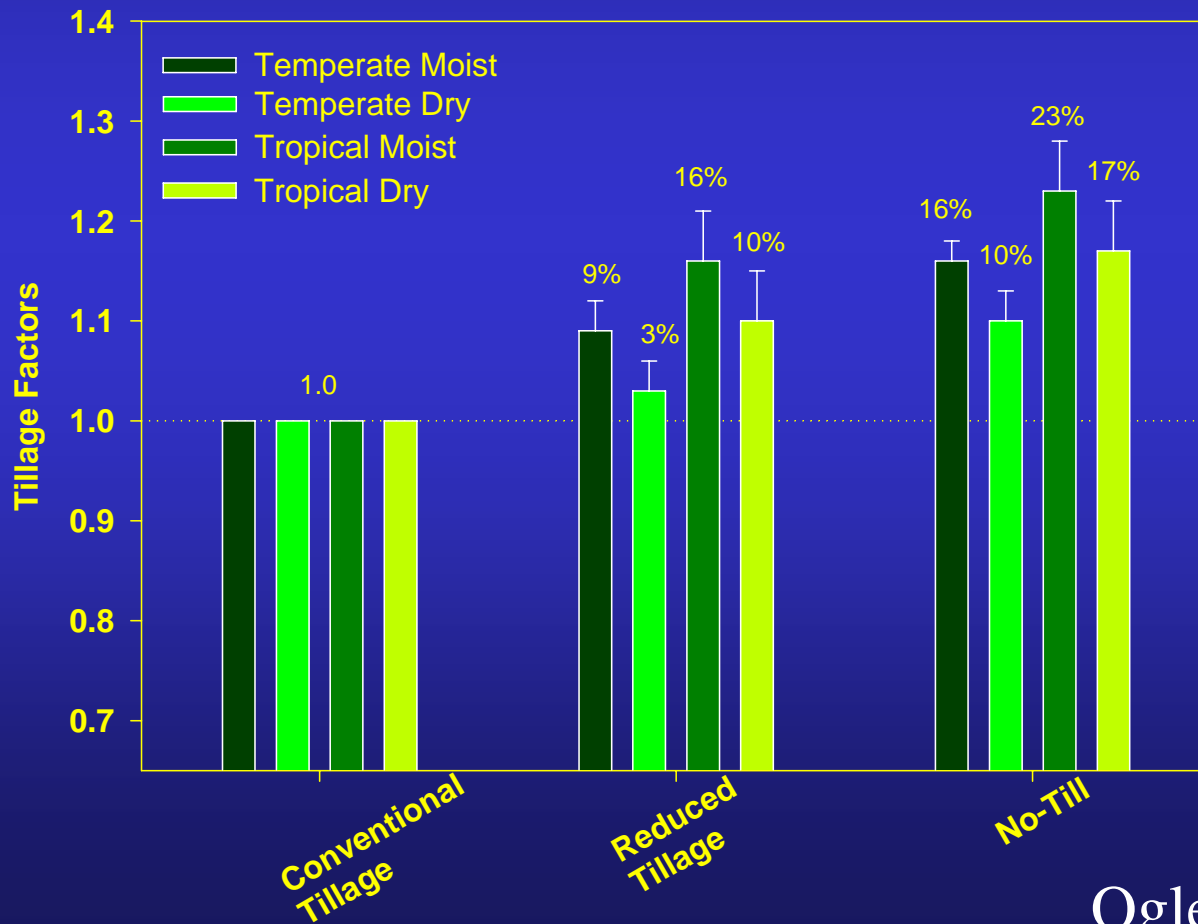
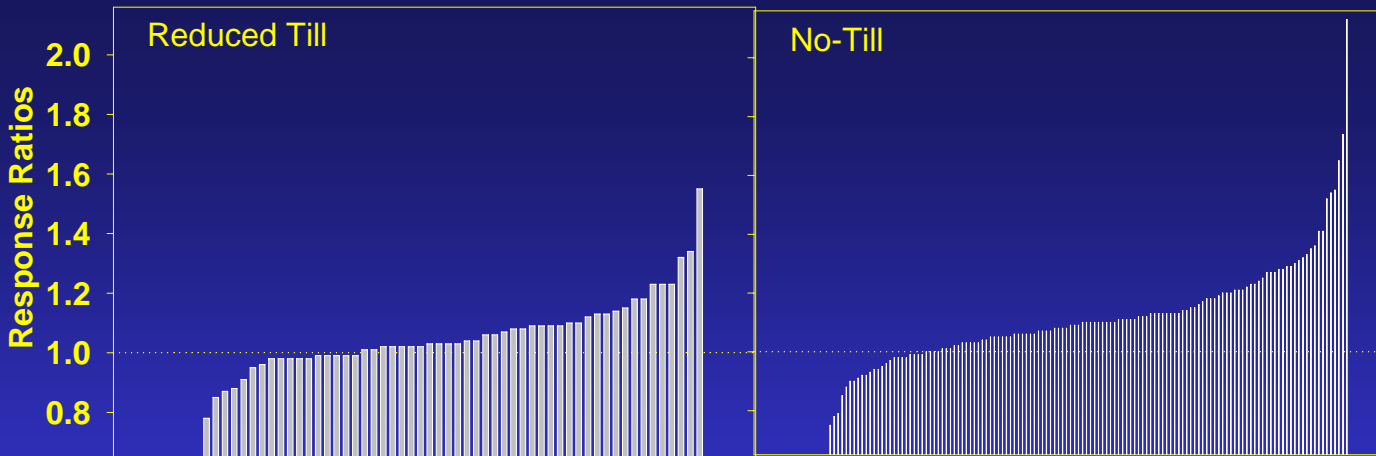
Process models, e.g. DAYCENT (US-EPA, 2006)

Figure Q-3: DAYCENT-NCEP Global Simulation: Maize N₂O Emissions: 1991-2000

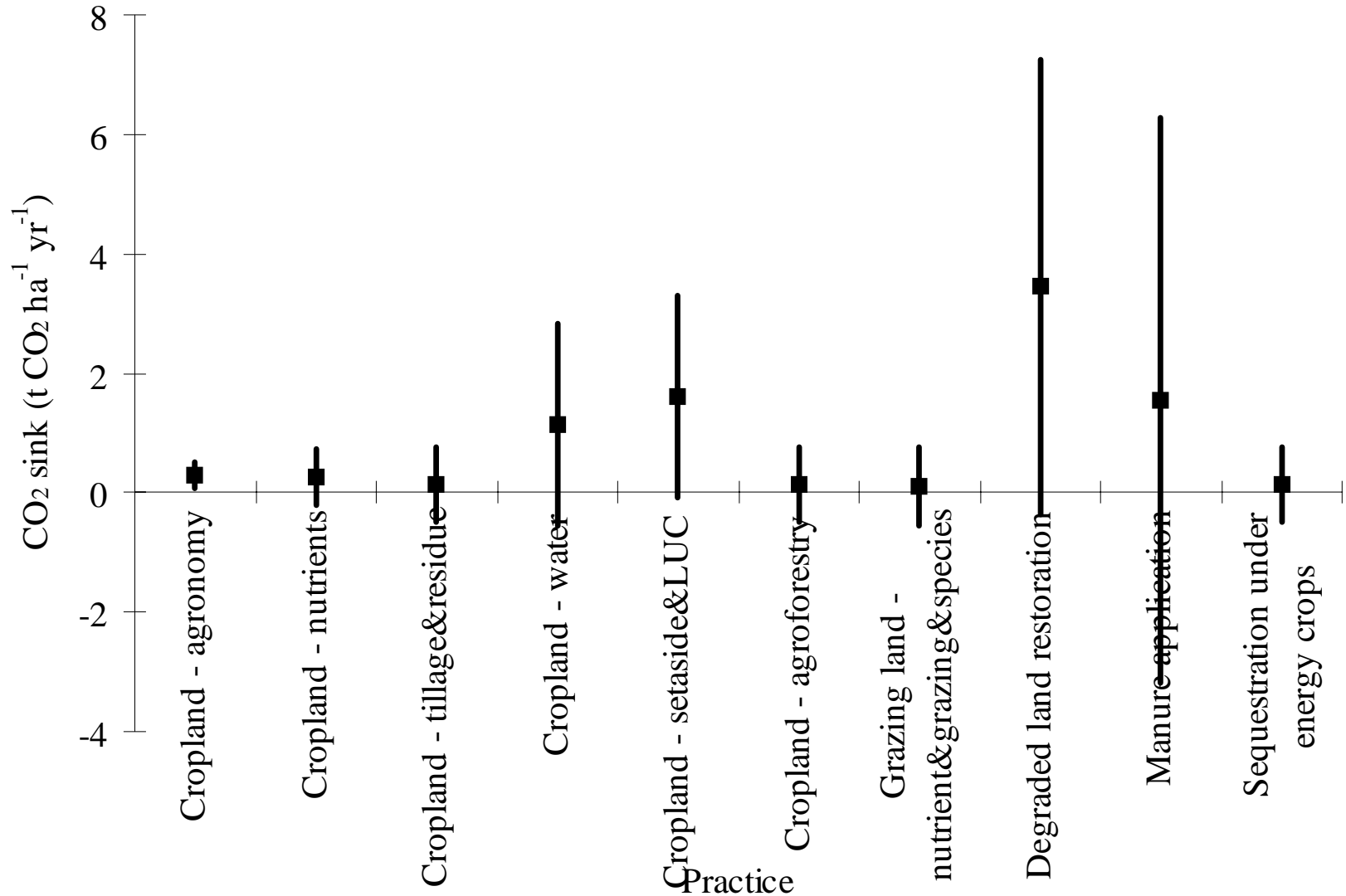


Method

- Database of over 200 experiments to derive per-area / per-animal mitigation efficiencies for >60 agricultural mitigation options, for four climate zones – for CO₂, CH₄ and N₂O
- Mean estimates and low and high 95% CI values derived from mixed effects modelling
- Applied to appropriate agricultural (crop, grass, livestock) areas / numbers in each climate zone in each region



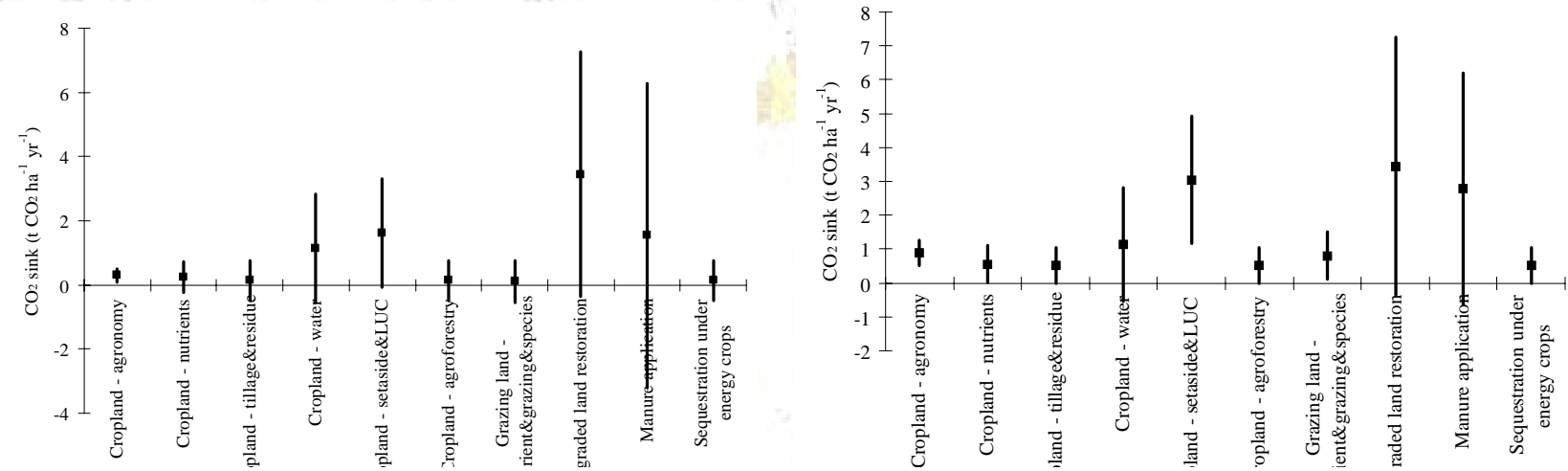
Soil C sequestration rates for cool dry climate



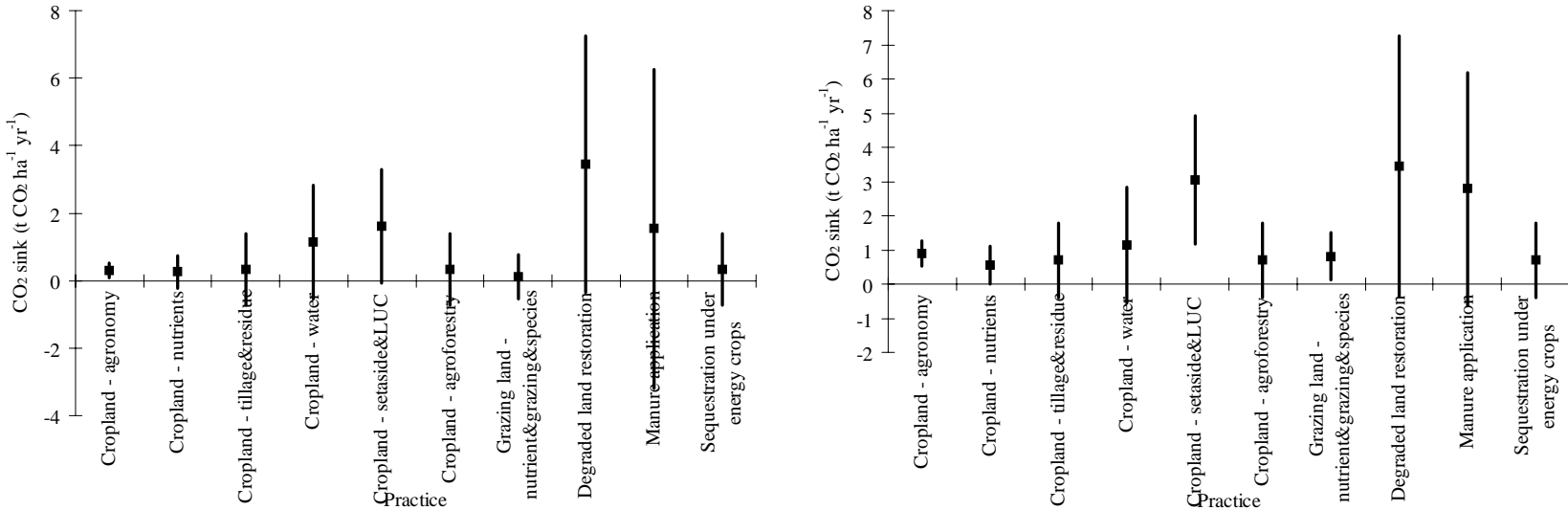
Data from: Smith et al. (2007a)

Soil C sequestration rates in different climates

Cool

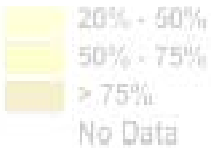


Warm



Dry

Moist



Data from: Smith et al. (2007a)

Per-area / per-animal mitigation potential

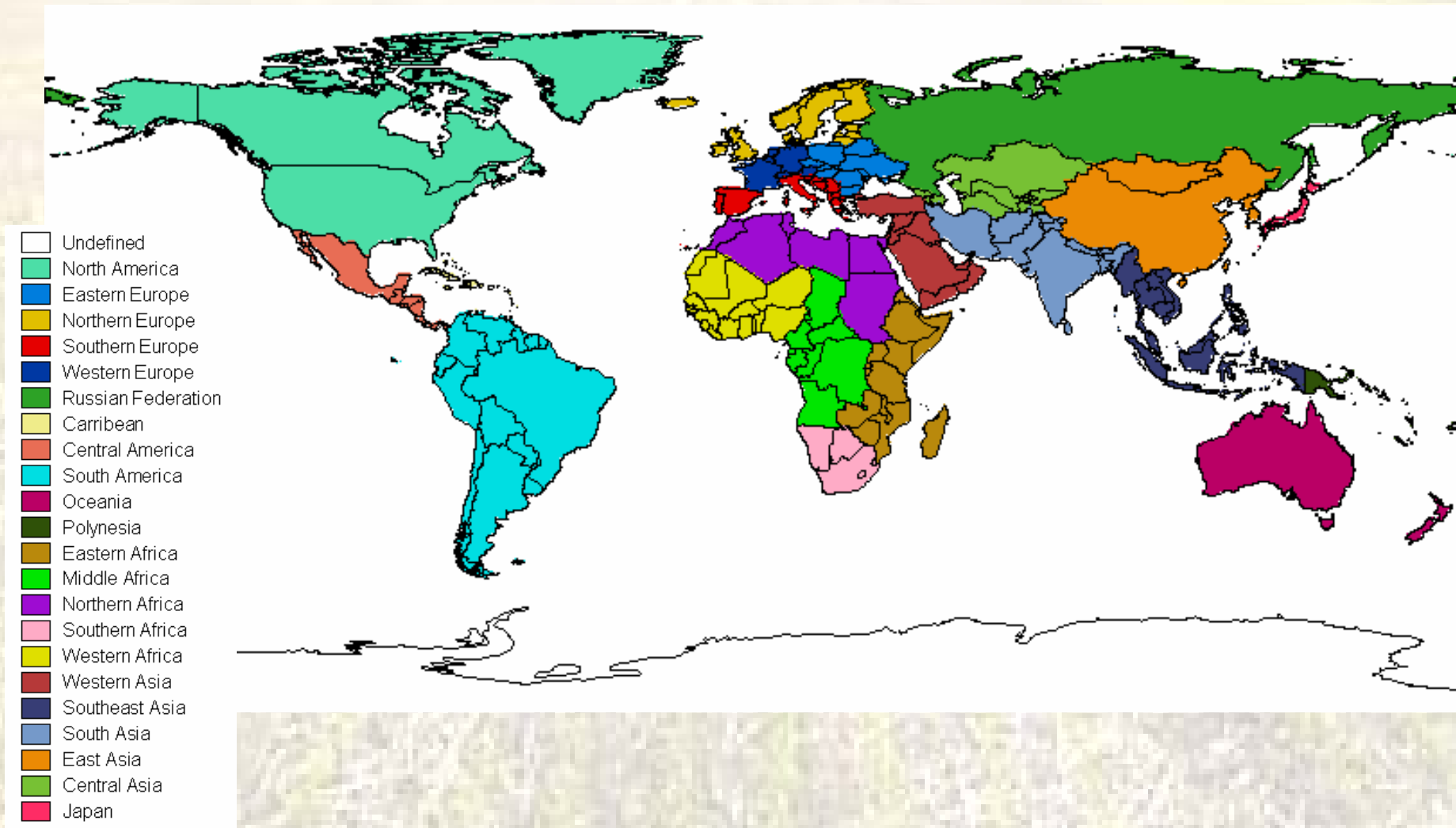
Climate zone	Activity	Practice	CO ₂ (t CO ₂ -ha ⁻¹ y ⁻¹)			CH ₄ (t CO ₂ -eq. ha ⁻¹ y ⁻¹)			N ₂ O (t CO ₂ -eq. ha ⁻¹ y ⁻¹)			All GHG (t CO ₂ -eq. ha ⁻¹ y ⁻¹)		
			Mean estimate	Low	High	Mean estimate	Low	High	Mean estimate	Low	High	Mean estimate	Low	High
Cool-dry	Croplands	agronomy	0.29	0.07	0.51	0.00	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, fertilization, 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 / biosolids	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, fertilization, 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 / biosolids	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, fertilization, 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 / biosolids	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, fertilization, 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 / biosolids	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 CO₂, N₂O & CH₄, estimates for mean and +/- 95% CI

Smith et al. (2007a)

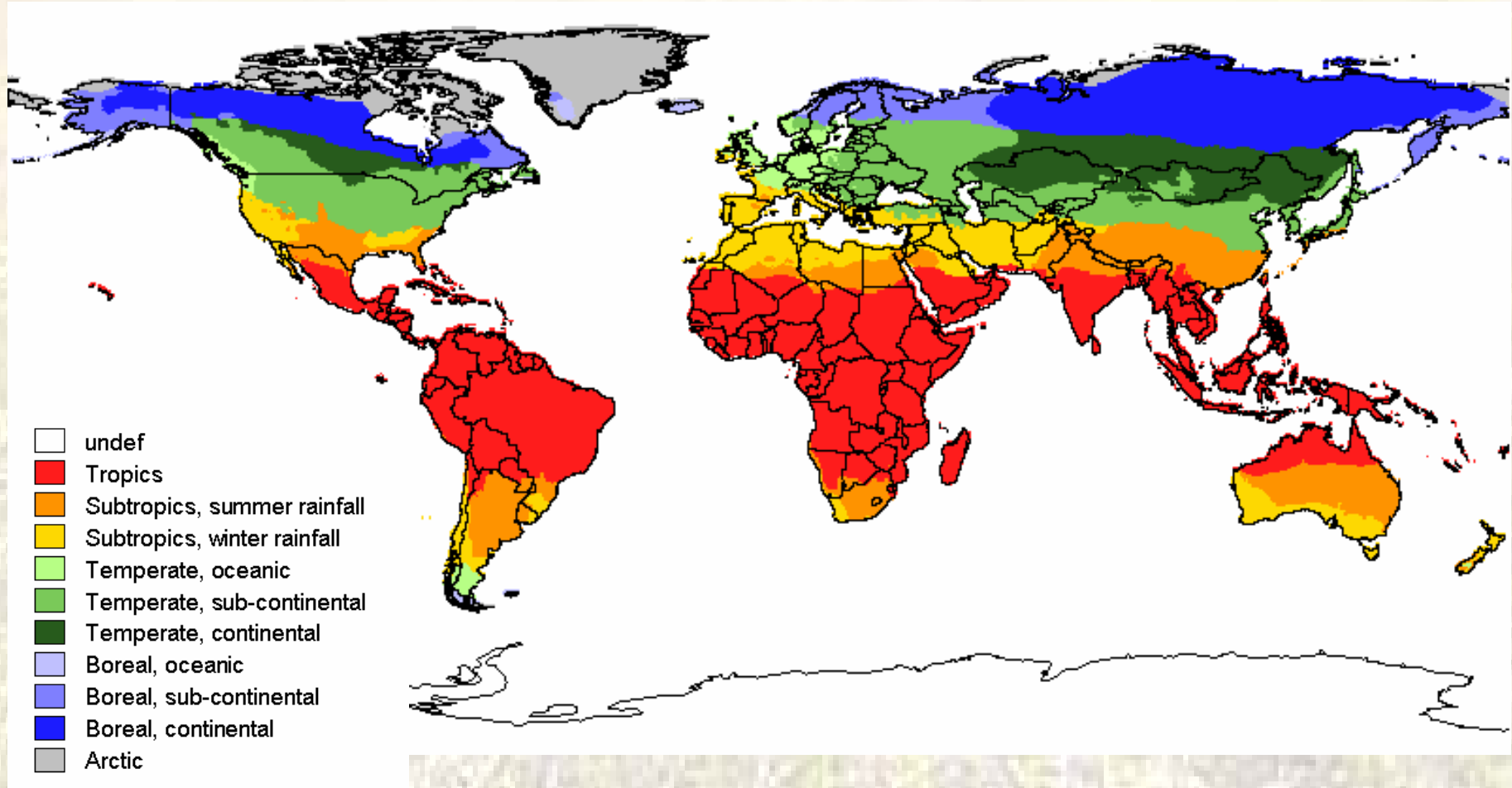
IPCC AR4 Agricultural GHG Mitigation

FAO AEZ Database (e.g. showing regions)



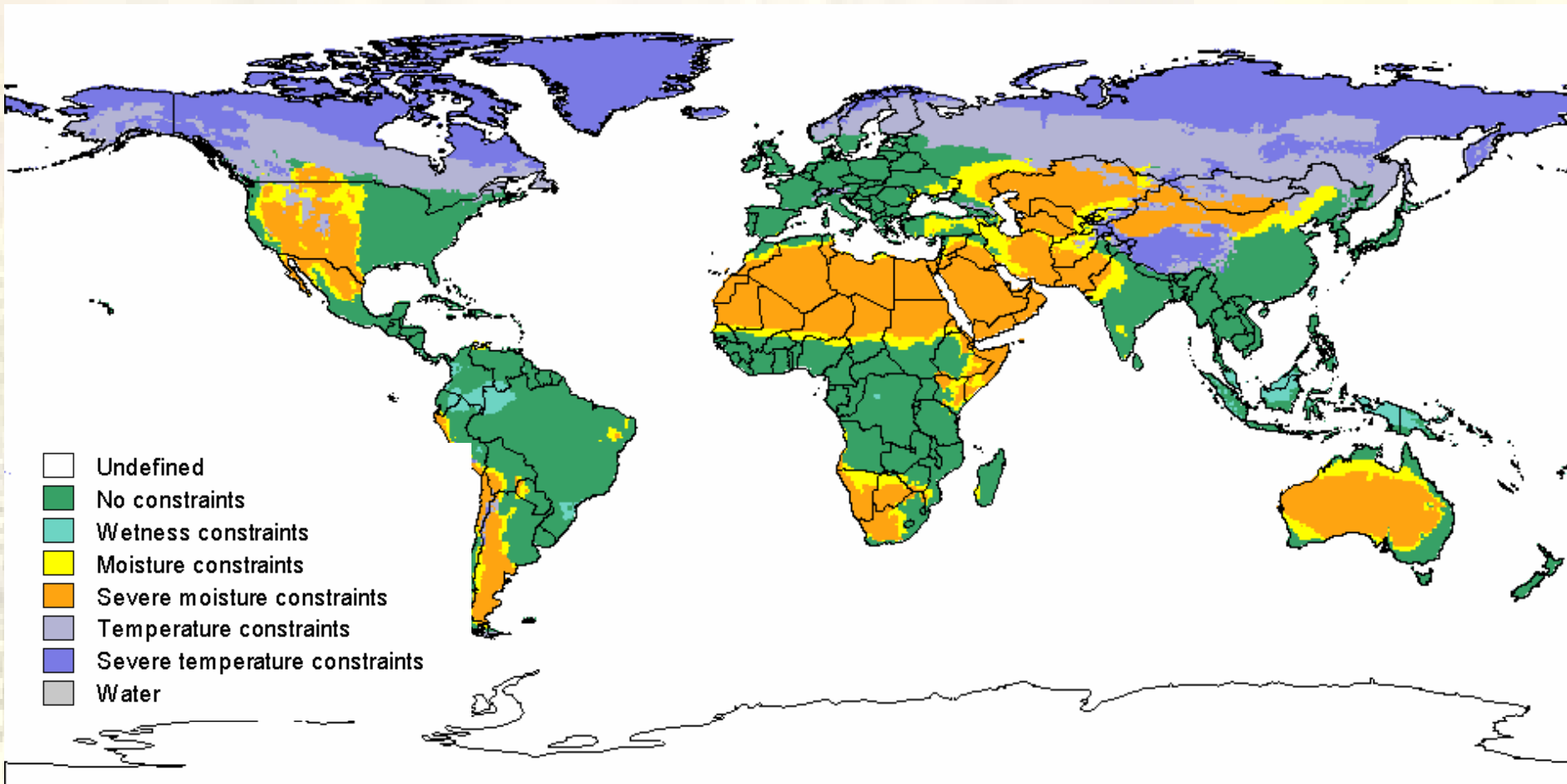
IPCC AR4 Agricultural GHG Mitigation

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



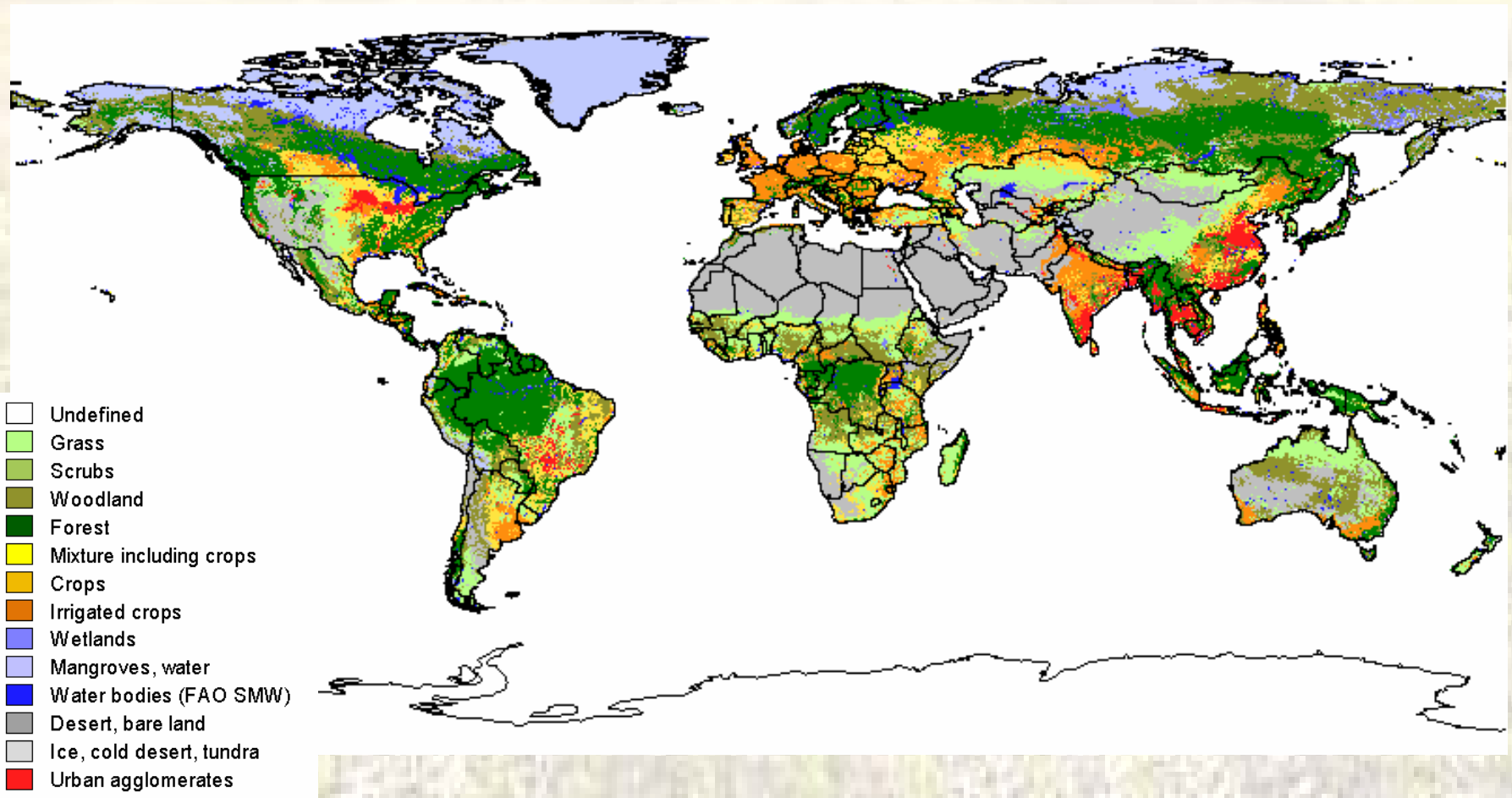
IPCC AR4 Agricultural GHG Mitigation

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

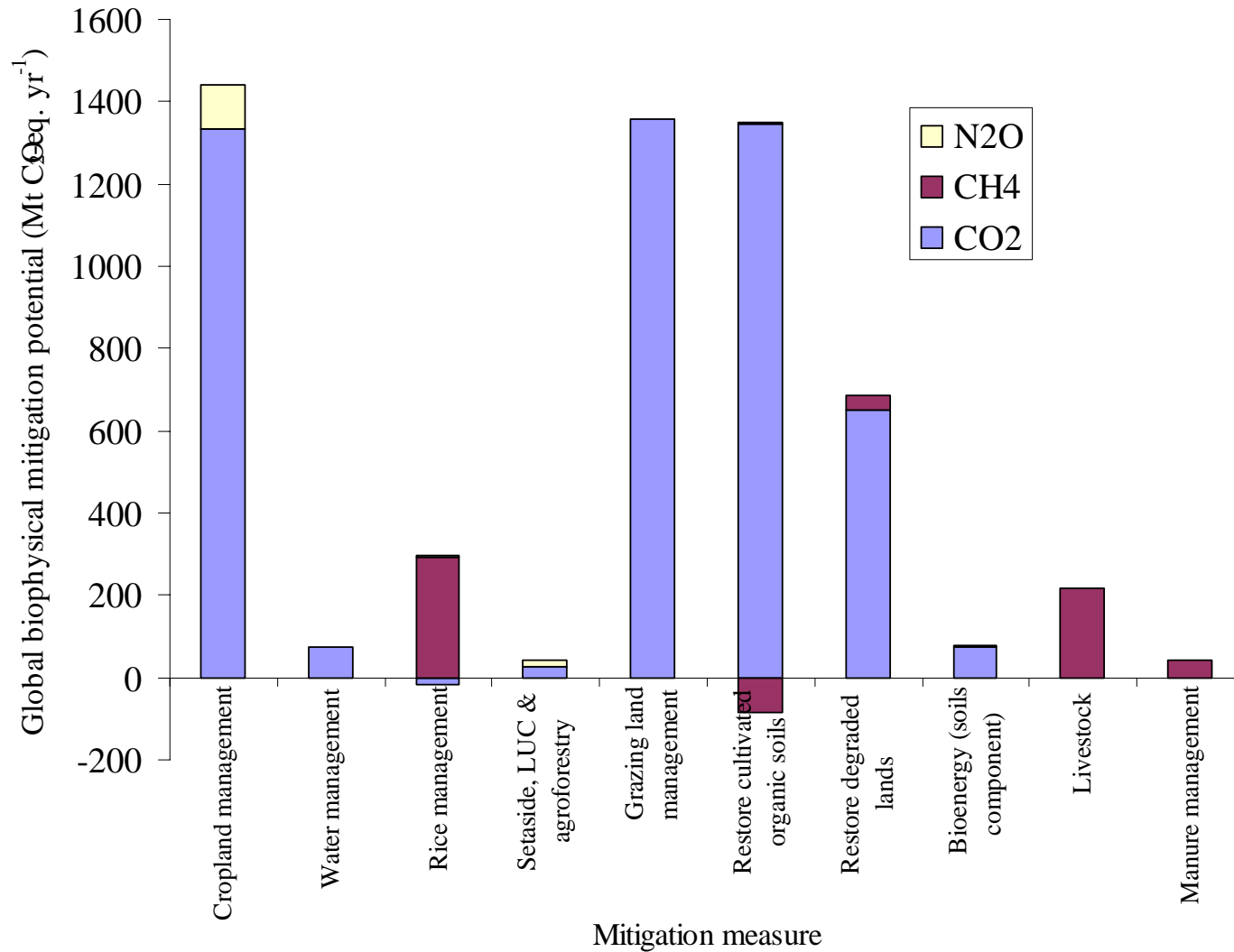


IPCC AR4 Agricultural GHG Mitigation

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

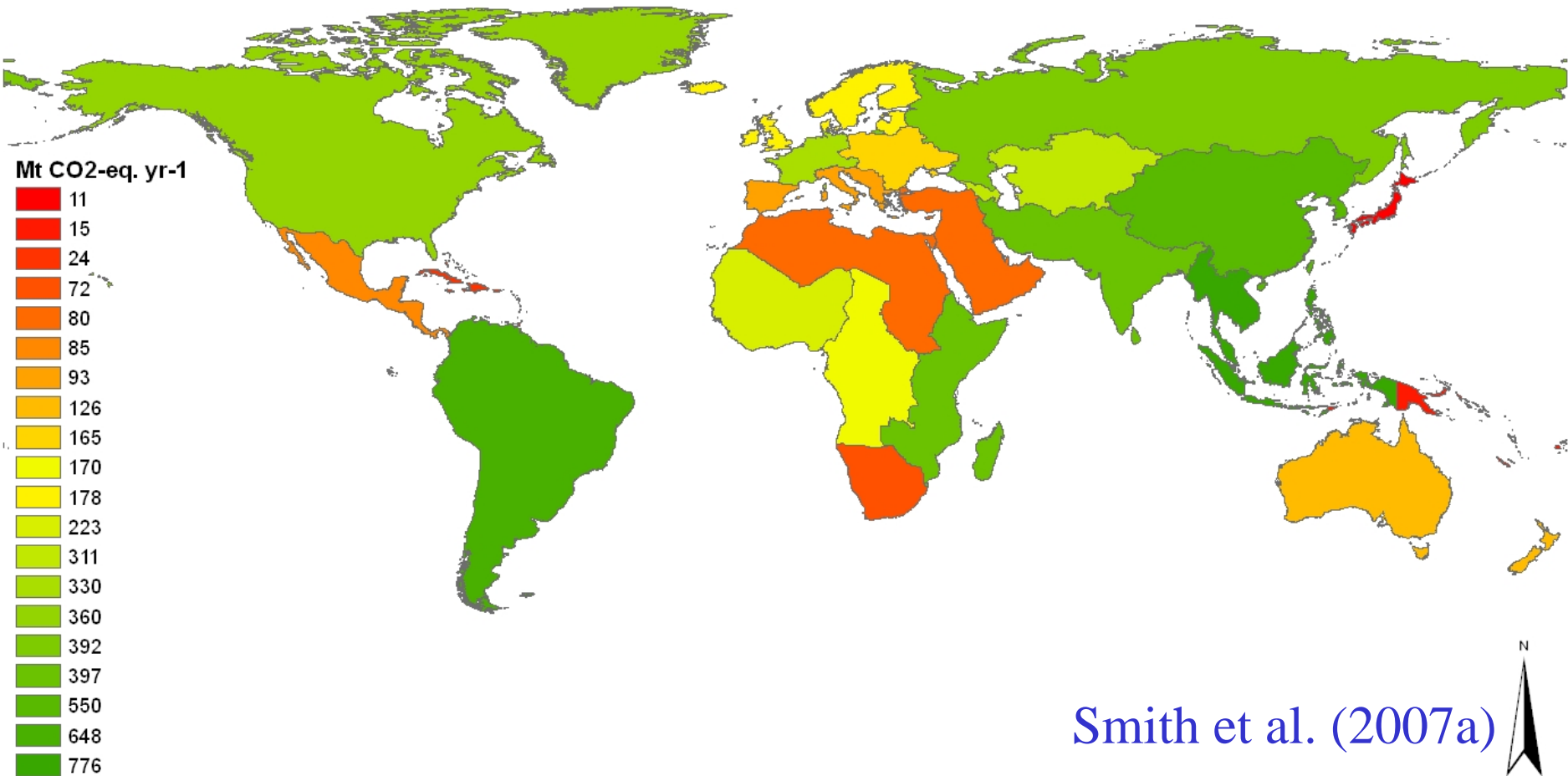


Global mitigation potential in agriculture

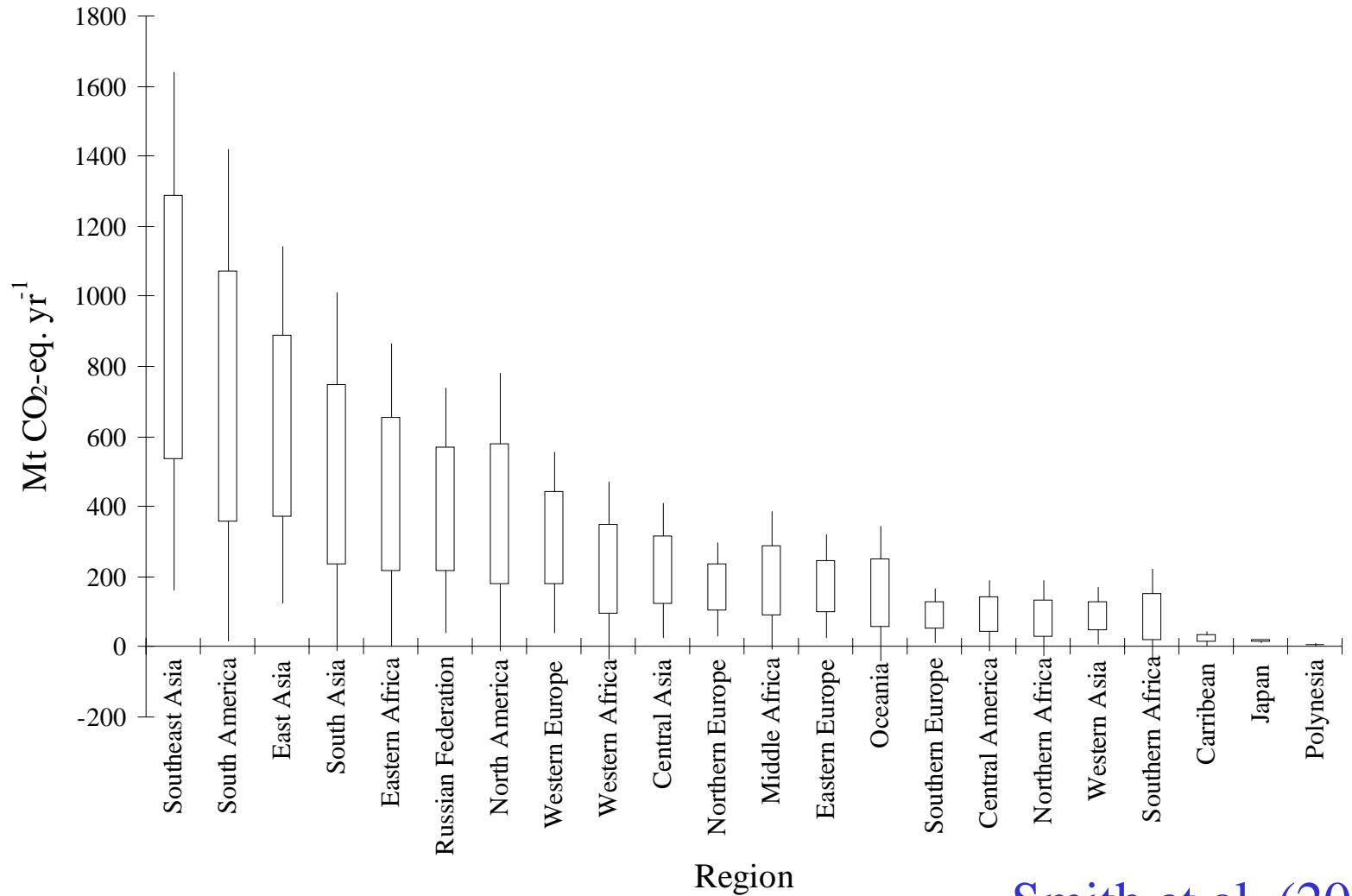


Regional breakdown of mitigation potential

Mean biophysical mitigation potential

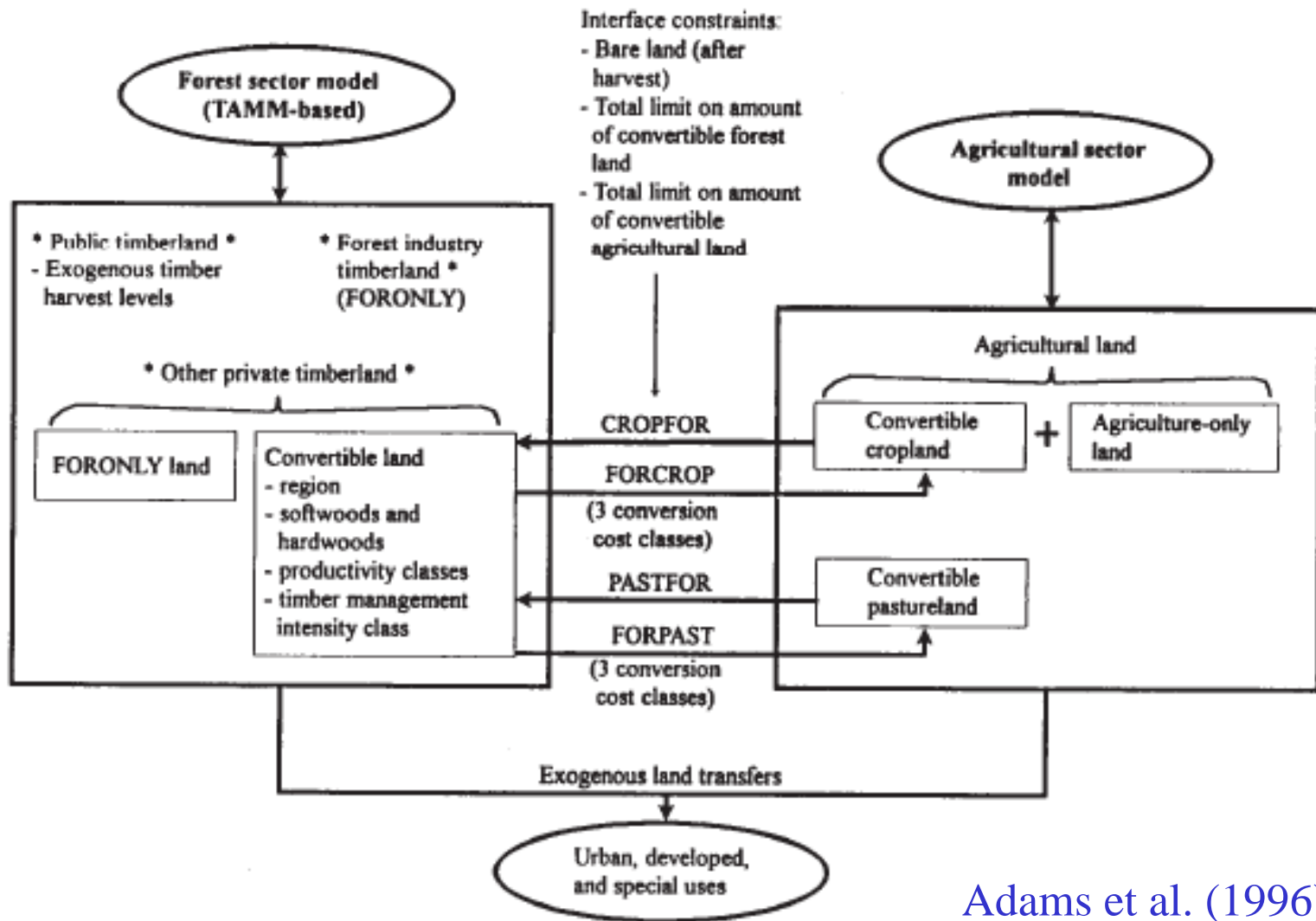


High and low estimates of the mitigation potential in each region



Smith et al. (2007a)

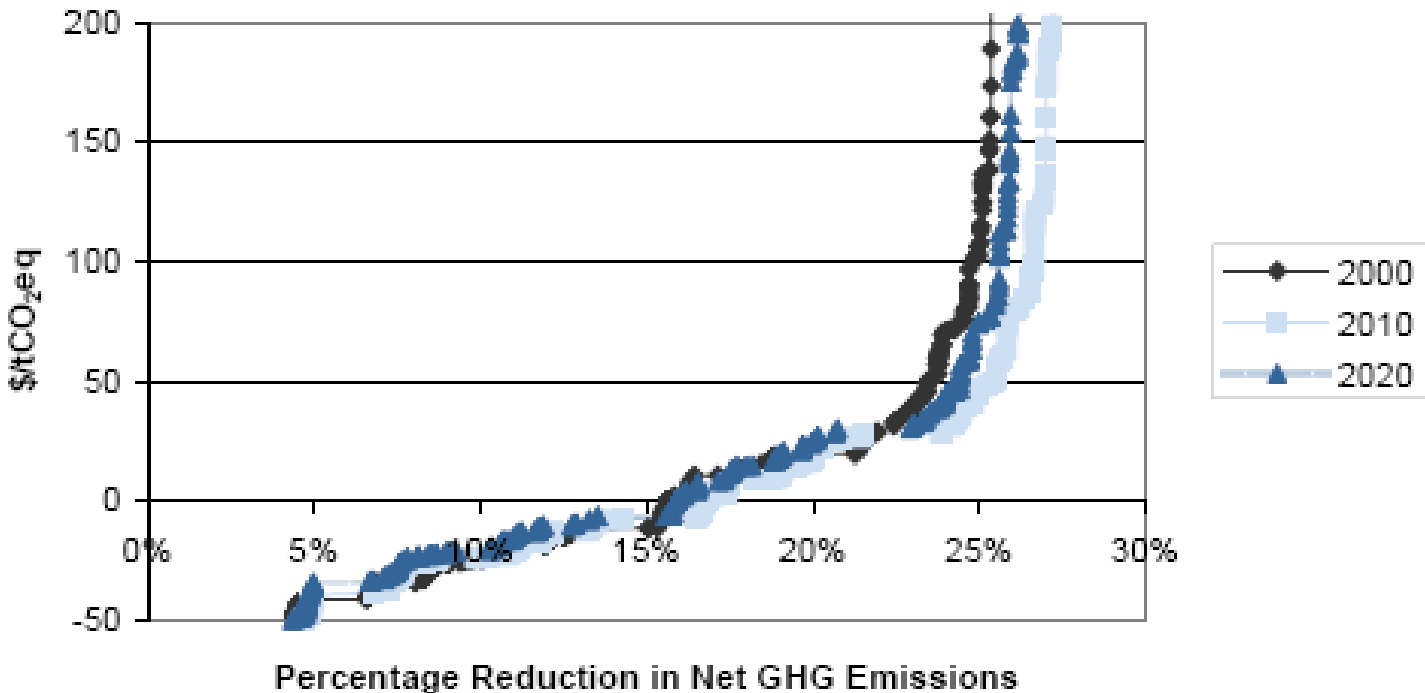
The Forest and Agricultural Sector Optimization Model (FASOM)



Adams et al. (1996)

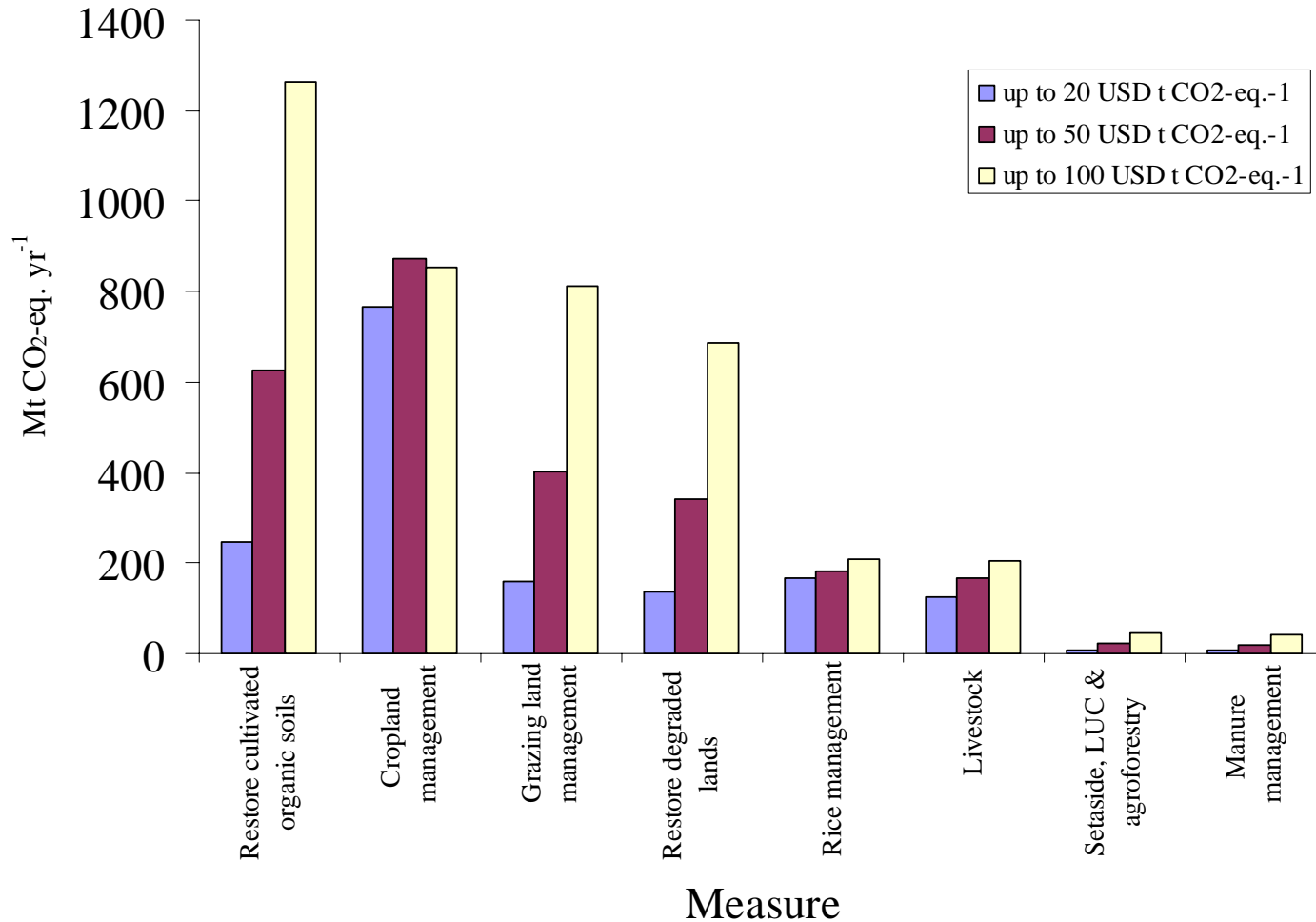
The Forest and Agricultural Sector Optimization Model (FASOM)

Figure 1-8: Global MAC for Net Greenhouse Gas Emissions from Croplands, Holding Area Constant, Allocating Adoption of Mitigation Strategies to the Three Most Effective Options Only, 2000–2020



Uses MAC and entry price to calculate penetration of mitigation practice at a given C price

Effect of C price on implementation



Global mitigation potential in agriculture (Mt CO₂-eq. yr⁻¹)

Scenario	Price range (USD t CO ₂ -eq. ⁻¹)			0->>100 (technical potential)
	0-20	0-50	0-100	
B1	1925	2384	3149	5480
A1b	1982	2439	3254	5670
B2	2047	2495	3330	5844
A2	2119	2549	3330	5957

Additional mitigation from agriculture

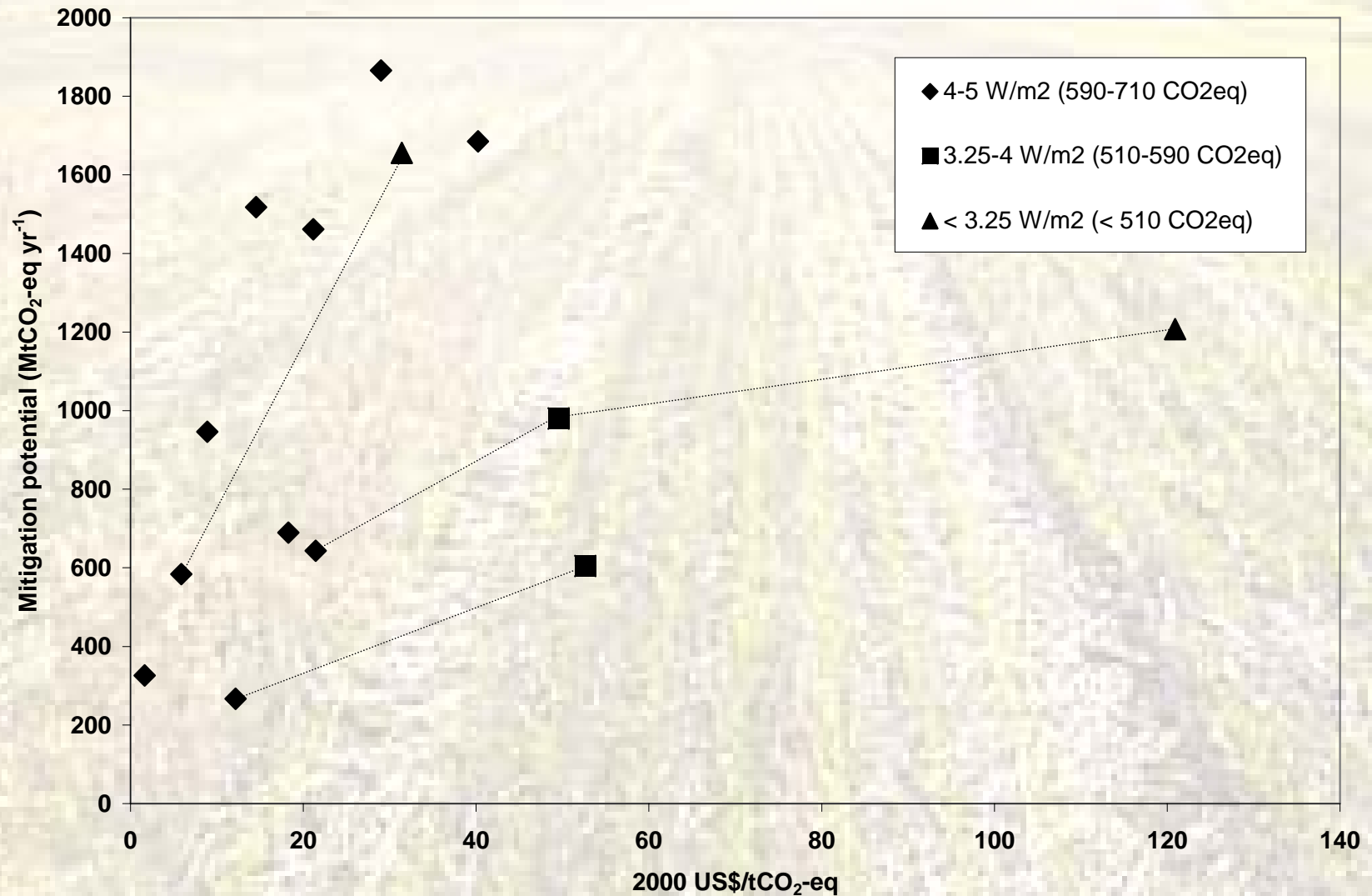
- **Feed-stocks for bio-energy** (residues, dung and dedicated energy crops).
- The economic mitigation potential for agricultural bio-energy in 2030 is estimated to be 70-1260, 560-2320 and 2720 Mt CO₂-eq. yr⁻¹ at prices up to 20, 50 and above 100 USD t CO₂-eq.⁻¹, respectively (5-90% of all other measures together).
- Additional mitigation of 770 Mt CO₂-eq. yr⁻¹ could be achieved by 2030 by **improved energy efficiency** in agriculture



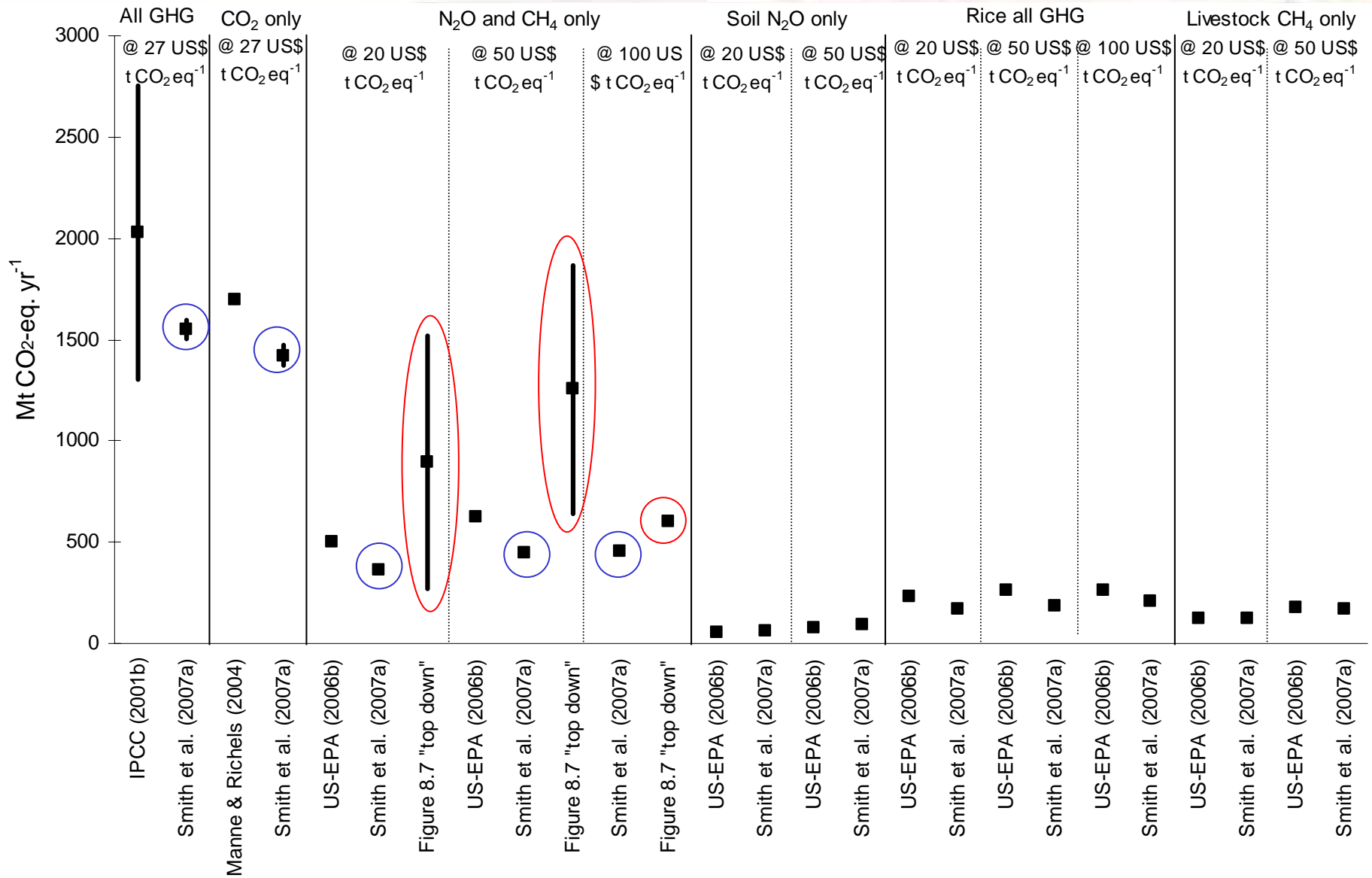
Comparing estimates from bottom-up (loosely coupled) vs. top-down (fully integrated) models



Compares well with top-down EMF-21 outputs



Other global estimates of economic potential



There is significant mitigation potential at a range of C prices

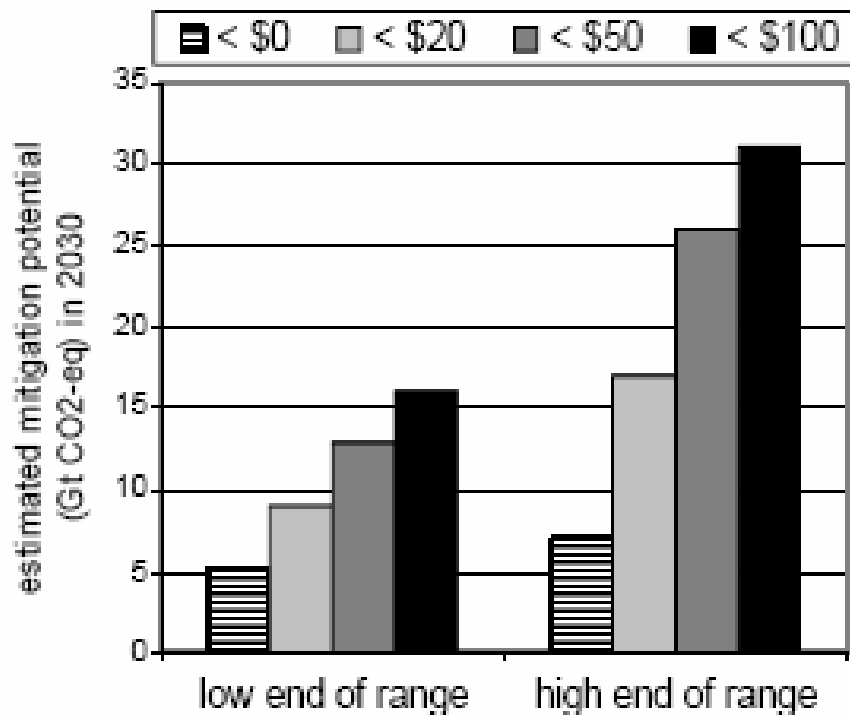


Figure SPM 5A:
Global economic potential in
2030 estimated from bottom-up studies
(data from Table SPM 1)

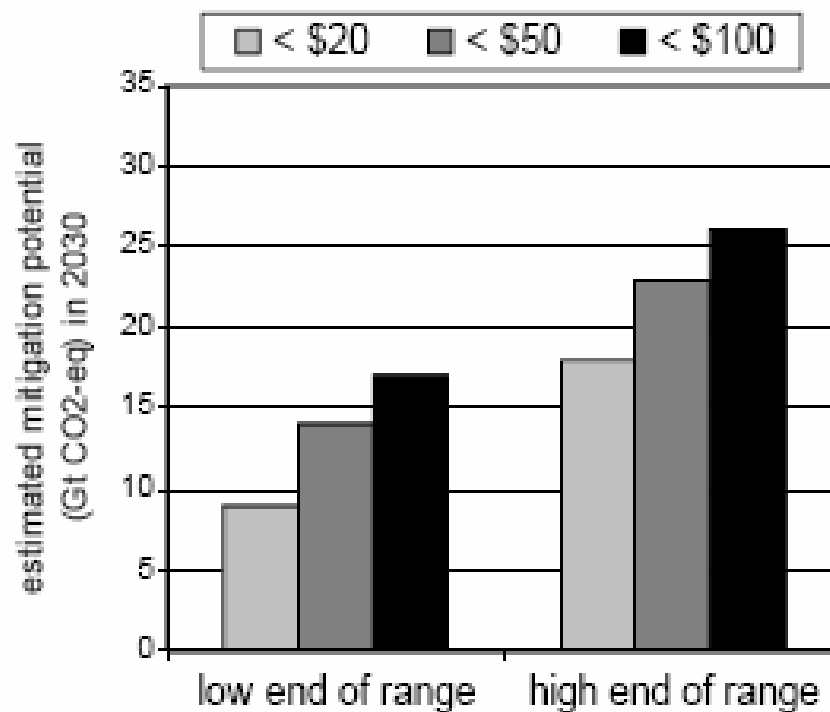


Figure SPM 5B:
Global economic potential in
2030 estimated from top-down studies
(data from Table SPM 2)



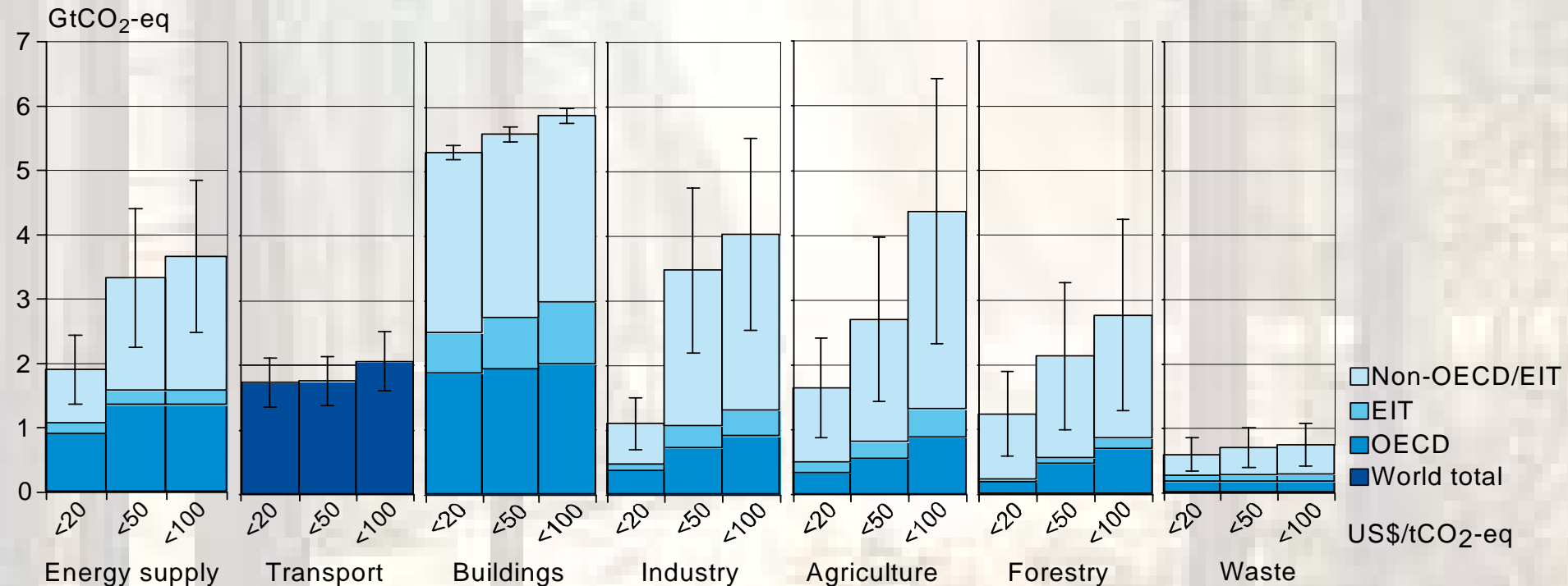
Agriculture in the big picture



How important is this mitigation potential?

- Even at 100 USD t CO₂-eq.⁻¹, mitigation potential is 3100-3300 Mt CO₂-eq. yr⁻¹
- This is equivalent to less than 1000 Mt C yr⁻¹ or <1 Pg per year
- Atmospheric CO₂-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 agricultural mitigation at all?

Global economic mitigation potential for different sectors at different carbon prices



Conclusions

- Agriculture offers a globally significant slice of climate mitigation
- Agricultural mitigation options are cost competitive with climate mitigation measures in other sectors
- Climate mitigation to stabilise atmospheric CO₂ concentrations at between 500 and 700 ppm will cost 0-3% of global GDP (a lot of money!)
- The cost of not mitigation climate change are estimated to cost *at least 5% of global GDP each year*, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage *could rise to 20% of GDP or more* (Stern, 2006; that is even more money!!)
- To mitigate or not to mitigate – it really is a no brainer



Thank you for your attention

