State of Carbon in Soils and Agriculture: Linking North American Science to Global Efforts

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With: Alexander Hristov, Jane Johnson, Kate Lajtha, Vanessa Bailey and others

This presentation:

- How Agriculture and Soils fit into the scheme of things
- Main findings from SOCCR2 related to soils, including from chapters on:
  - Soils (including permafrost) (chapters 11-12)
  - Agriculture (Chapter 5),
  - Some on Grasslands, aquatic systems (Chapters 10, 13-16) where they relate to soils and agriculture
- Key uncertainties and controversies
- Carbon Management efforts in these realms
- International efforts in these realms

Leads on Chapters drawn from

Main chapters:

Agriculture

- **Jane M. F. Johnson**, USDA ARS
- **Alexander N. Hristov**, The Pennsylvania State University

Soils

- **Vanessa Bailey**, Pacific Northwest National Laboratory
- **Kate Lajtha**, Oregon State University

Other chapters:

Tribal Lands

- **Maureen I. McCarthy**, University of Nevada, Reno

Grasslands:

- **Elise Pendall**, Western Sydney University

Inland Waters:

- **David Butman**, University of Washington

Terrestrial Wetlands

- **Randall Kolka**, USDA Forest Service
- **Carl Trettin**, USDA Forest Service

Arctic and Boreal Carbon

- **Ted Schuur**, Northern Arizona University

Forests:

- **Christopher A. Williams**, Clark University
- **Grant Domke**, USDA Forest Service

Carbon Cycle Science in Support of Decision Making

- **Tristram O. West**, DOE

Who wrote SOCCR2 and for whom

A U.S. government report but CA and MX contributions

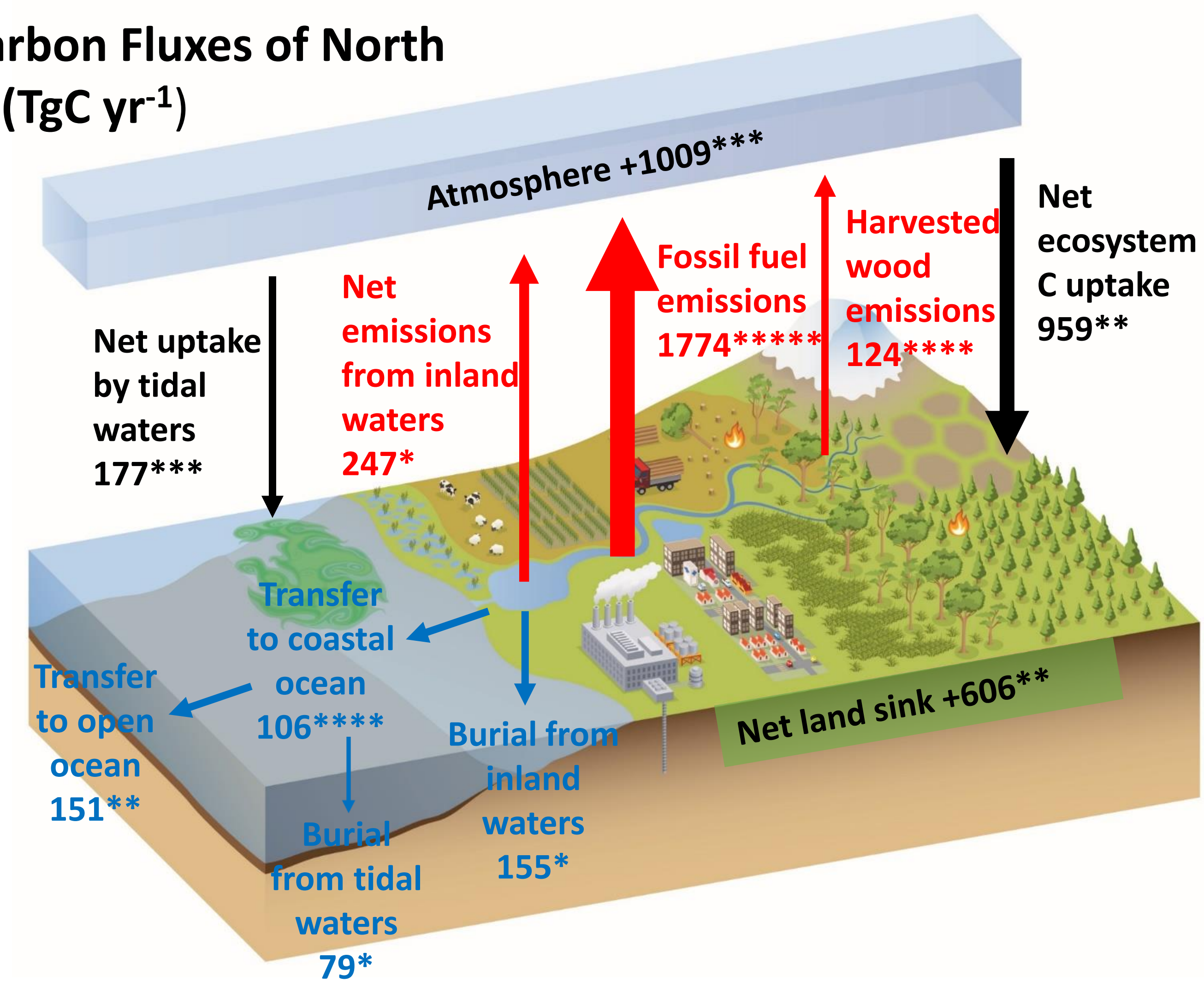
- Outline and organization **developed in consultation with leaders in the scientific community** in the US, Canada and Mexico
- **Written by experts who volunteered** via open calls
- **Mexican and Canadian** Carbon Program scientists helped via contributions from both countries **in supplying estimates and in writing sections of most of the chapters**, and supplying specialists for technical reviews
- **Written for decision makers** in the public and private sectors, scientists, educators
- **Purpose is to inform policy and decisions**, not to prescribe or recommend policy

Domain of The Second State of the Carbon Cycle Report.

In addition to the land masses and inland waters of Canada, Mexico, and the United States, SOCCR2 covers carbon dynamics in coastal waters, defined as tidal wetlands, estuaries, and the Exclusive Economic Zone (EEZ).

[Figure source: Christopher DeRolph, Oak Ridge National Laboratory.]

Major Carbon Fluxes of North America (TgC yr^{-1})



Soils

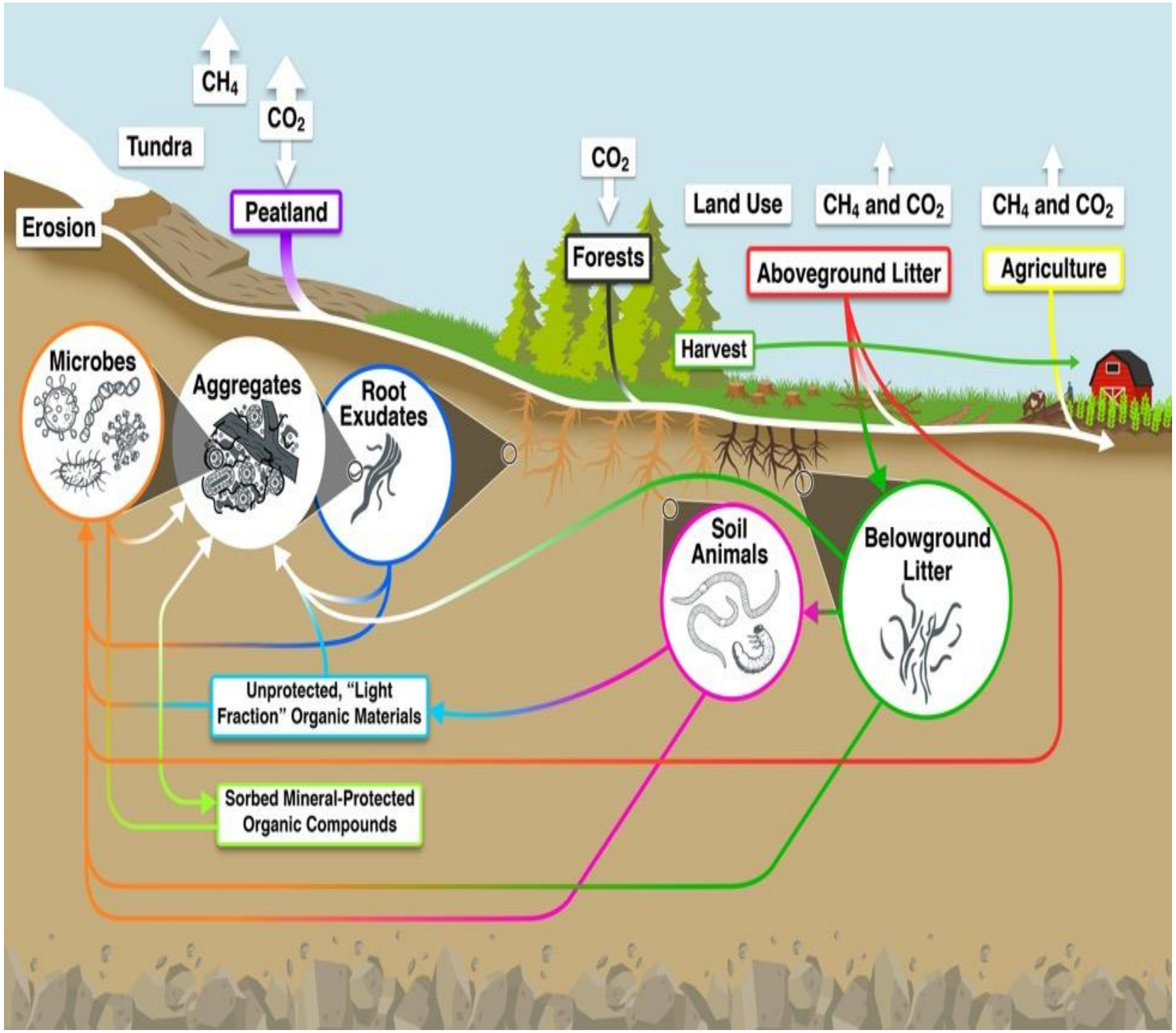
Chapter leads: Kate LAJTHA[1] and Vanessa BAILEY[2]
[1]Oregon State University
[2]Pacific Northwest National Laboratory

1 Oregon State University

Soil Carbon Perspecitves and co-benefits

- **Soil carbon can be organic or inorganic (ie:carbonates), but the organic carbon can be more easily manipulated to accumulate and store carbon to keep it out of the atmosphere**
- **Rich, fertile soils are generally high in organic carbon**
- **Soil organic carbon stores nutrients that can promote plant and animal growth→uptake of C from the atmosphere**
- **Soil carbon tends to confer greater resilience to ecosystems in the face of changing climate and extreme weather events**
- **Soil carbon relies on inputs from plants and animals and is strongly influenced by the community of microorganisms in the soil, including bacteria, archaea, and fungi**
- **Effects of management and environment on soil carbon and health can be highly variable due to the many inherent differences in soil types**

Soils Chapter

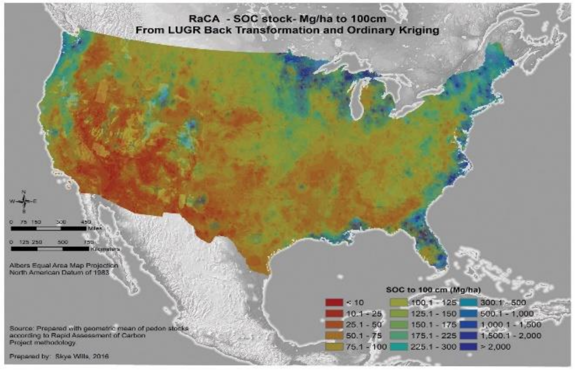


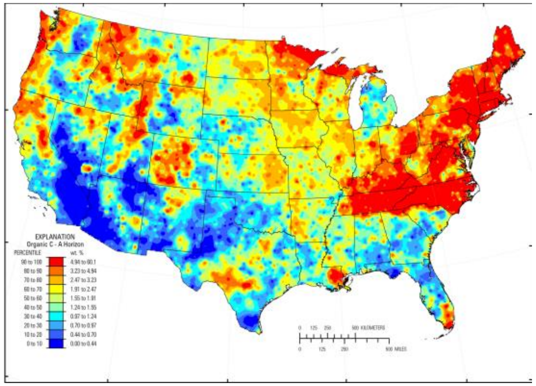
- C Cycling Processes
  - Inputs
  - Protection mechanisms
  - Rhizosphere
  - Macro- and mesofauna, microbes
  - Nitrogen
- C Losses
  - Gas fluxes, Erosion
- Indicators, trends, feedbacks
  - Soil C models
- Global, national, and regional
  - US, Mexico, Canada
- Land uses
  - Agriculture, forestry

Key Findings

Estimates for soil carbon stocks in the conterminous United States plus Alaska range from 142 to 154 petagrams of carbon (Pg C) to 1 m in depth. Estimates for Canada average about 262 Pg C, but sampling is less extensive. Soil carbon for Mexico is calculated as 18 Pg C (1 m in depth), but there is some uncertainty in this value.

Where did we get data?





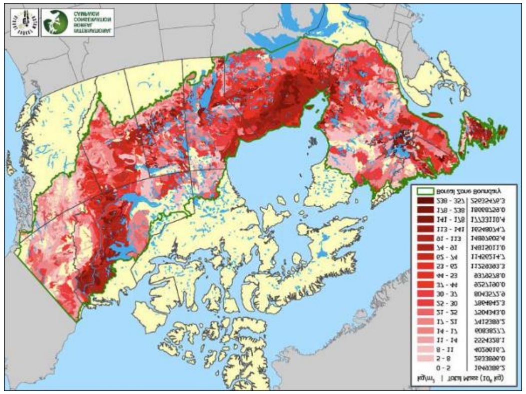


Table 12.1. Estimates of Soil Carbon Storage in the Conterminous United States in Different Land-Use Classes

Land Cover	Soil Organic Carbon to 1m, PgC			
	from RaCA	**Bliss et al., 2014**	**Sundquist et al., 2009**	**Other Estimates**
Forests & woodlands	20	13.1	25.1	28
Agriculture	13	13.4	27.4	
Shrublands		5.6	9.7	
Urban		3.3		1.9
Wetlands	14	8.9		13.5 – 11.5
Rangelands (+ pasture)	19	12.3	11.2	
Totals	65	57.2	73.4	

Table 12.4 Soil Carbon Storage in Canada		
Land Cover	**Soil Organic Carbon to 1m, PgC**	**Source of estimate**
Organic (Peat) Soils	147.1c, 137e	Tarnocai (2006), Kurz et al. (2013)
Agriculture	5.5	Tarnocai (1997)
Boreal Forest Region	208	Kurz et al. (2013)*
Upland Forest Soils	71	Kurz et al. (2013)
Totals	262.3	Tarnocai (2006)
*Includes some peat soils		

Table 12.3. Soil Organic Carbon Distribution in Mexico for Vegetation Types with Top Five Highest Total Soil Carbon Estimates

Vegetation Type	Area (M ha)	Soil Organic Carbon to 1m, TgC	% of total
Grazing lands	50	2,115	23
All Forest lands	194	5,000	54
Deciduous Dry Forest	14	690	8
Desert Microphyll Shrub	22	600	7
Medium Semi-Evergreen Forest	5	570	6
Oak Forest	11	564	6

From the National Institute for Statistics and Geography of Mexico for 2007 (from Paz Pellat et al., 2016).

Key Findings

Soil carbon stocks are sensitive to agricultural and forestry practices and loss of carbon-rich soils such as wetlands. Soils in North America have lost, on average, 20% to 75% of their original top soil carbon (0 to 30 cm) with historical conversion to agriculture, with a mean estimate for Canada of 24%.

Key Point of Contention: Does no-till improve C stocks?

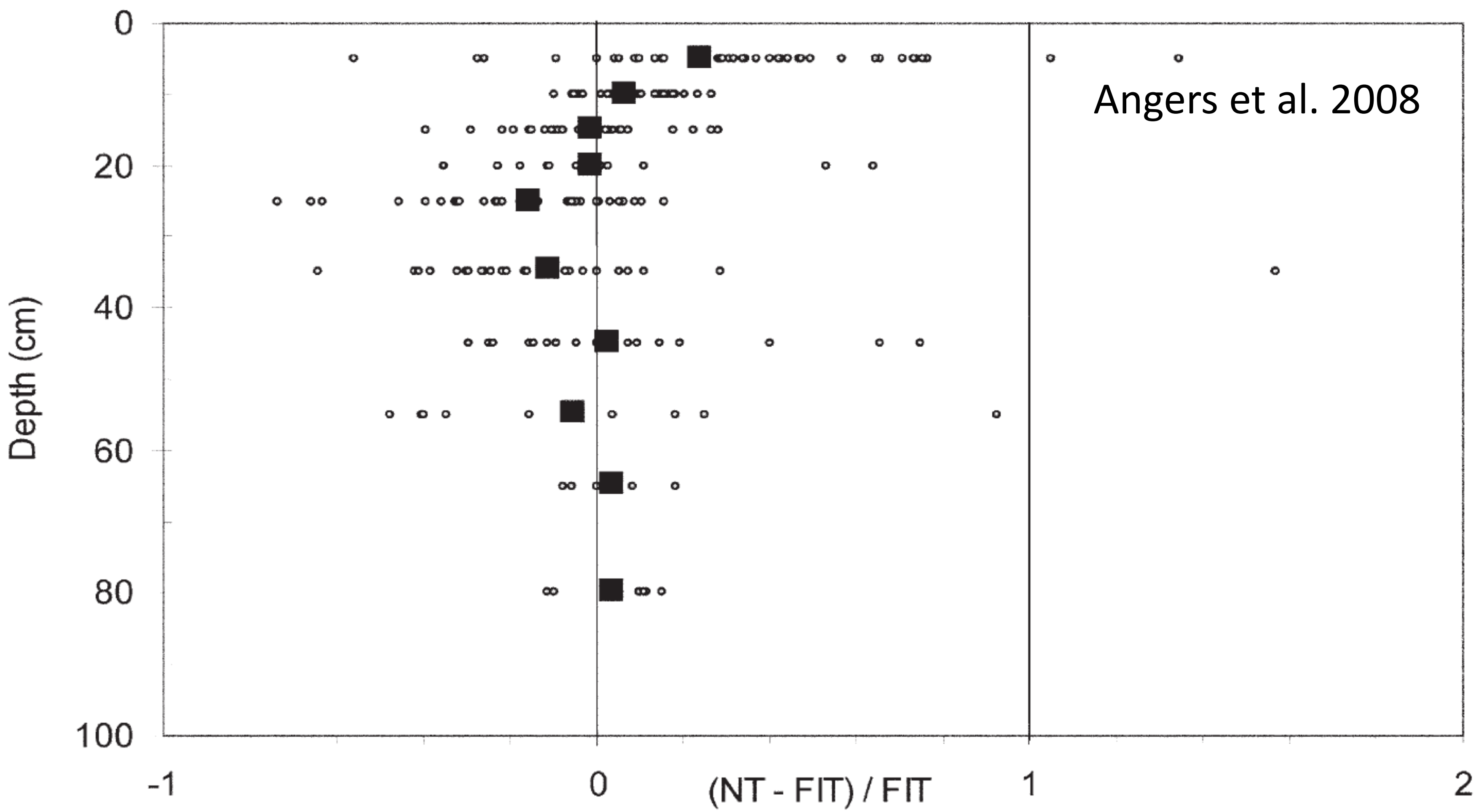
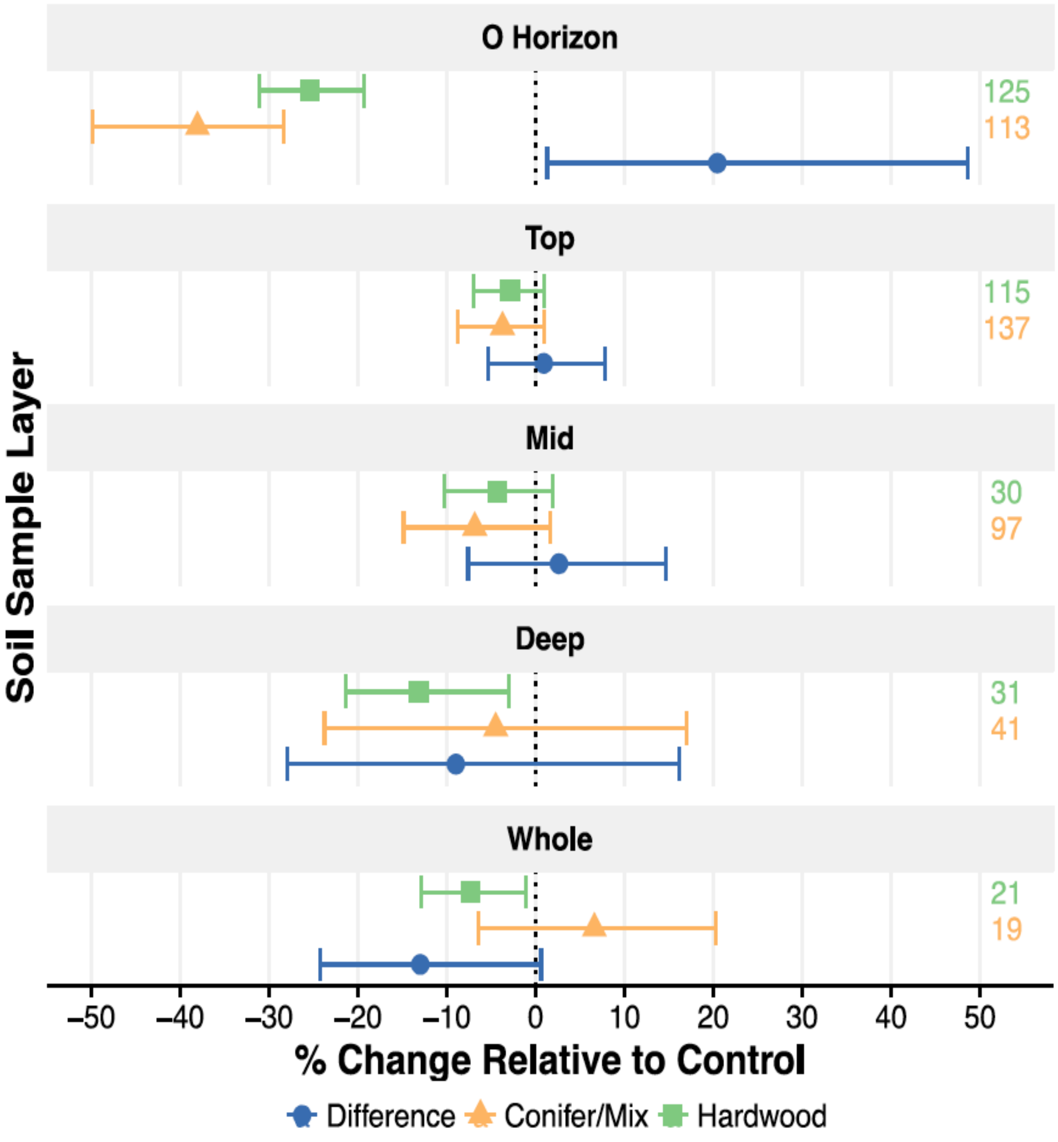


Fig. 1. Relative change in soil organic C content under no-till (NT) compared with full-inversion (FIT) as a function of soil depth. Data were generally not normally distributed (seven layers out of 10). The *P* values for the log-transformed data [log(ratio + 1)] were <0.001 for the 1- to 5- and 21- to 25-cm soil layers, 0.02 for the 6- to 10-cm layer, 0.01 for the 31- to 35-cm layer, and not significant (*P* > 0.05) at other depths. Large filled squares represent the geometric mean.

Key Point of Contention: Does repeat forest harvest deplete soil C stocks?

James & Harrison 2016



Key Findings

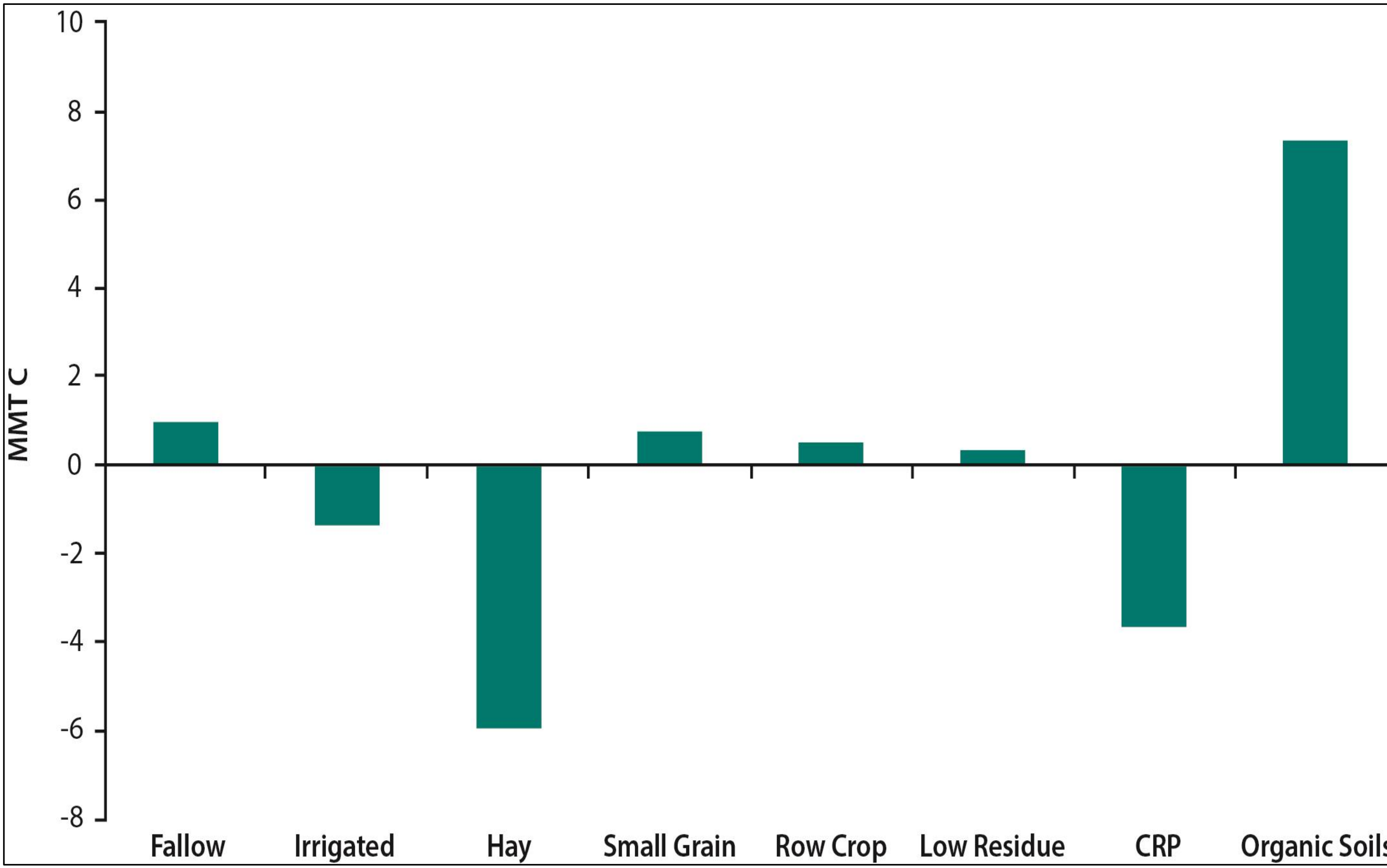
Evidence is strong for direct effects of increased temperature on loss of soil carbon, but warming and atmospheric carbon dioxide increases also may enhance plant production in many ecosystems, resulting in greater carbon inputs to soil. Globally, projected warming could cause the release of 55 ± 50 Pg C over the next 35 years from a soil pool of 1,400 ± 150 Pg C.

Key Findings

In particular, an estimated 5% to 15% of the peatland carbon pool could become a significant carbon flux to the atmosphere under future anthropogenic disturbances (e.g., harvest, development, and peatland drainage) and change in disturbance regimes (e.g., wildfires and permafrost thaw).

From Arctic Chapter: 5% to 15% of the SOC stored in permafrost zone is considered vulnerable to release to the atmosphere by the year 2100, and is likely to be up to an order of magnitude larger than the potential increase in carbon stored in plant biomass due to warming.

Soil Carbon Fluxes for Major Cropping Systems in the United States. Values, in million metric tons of carbon (MMT C)



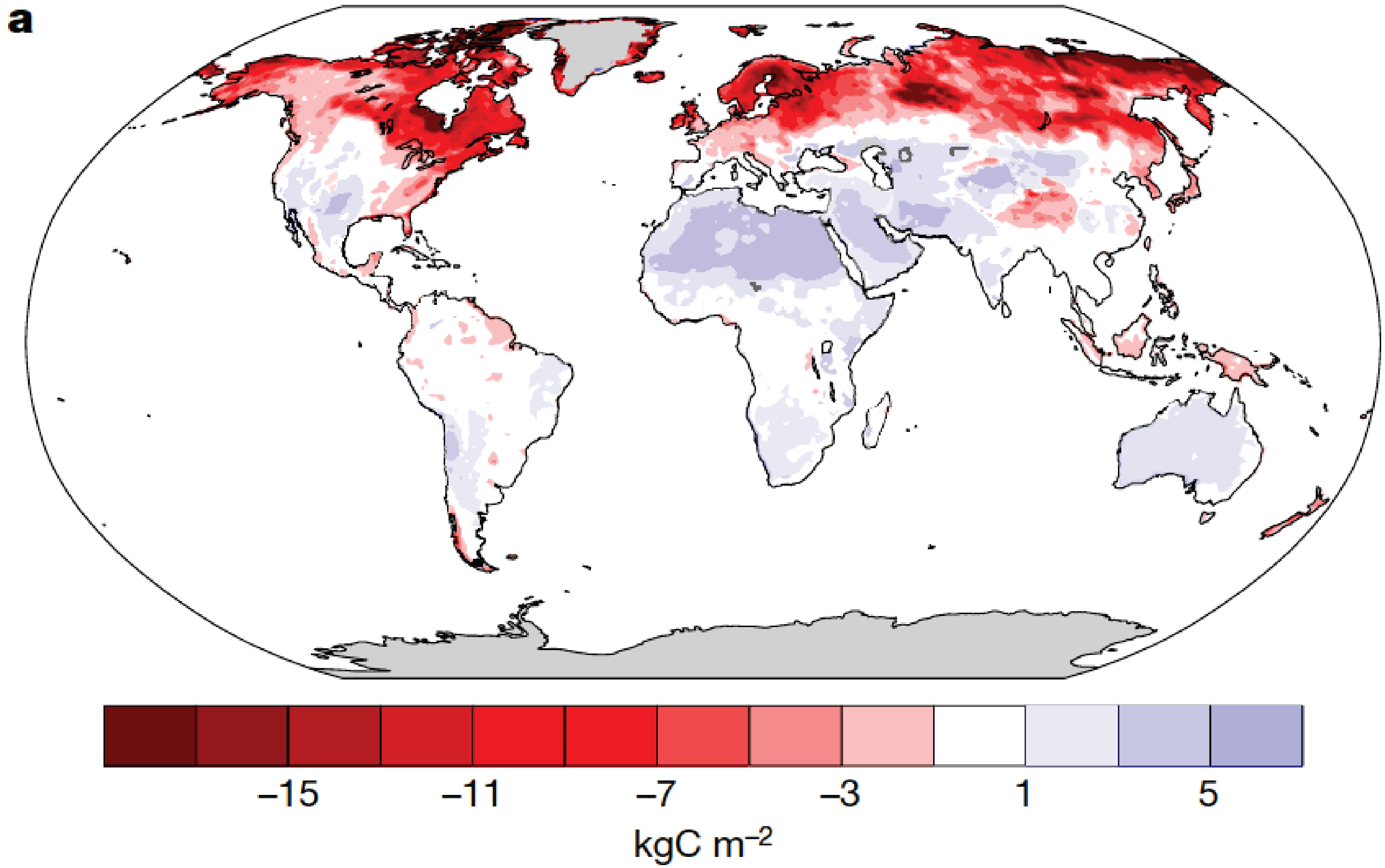
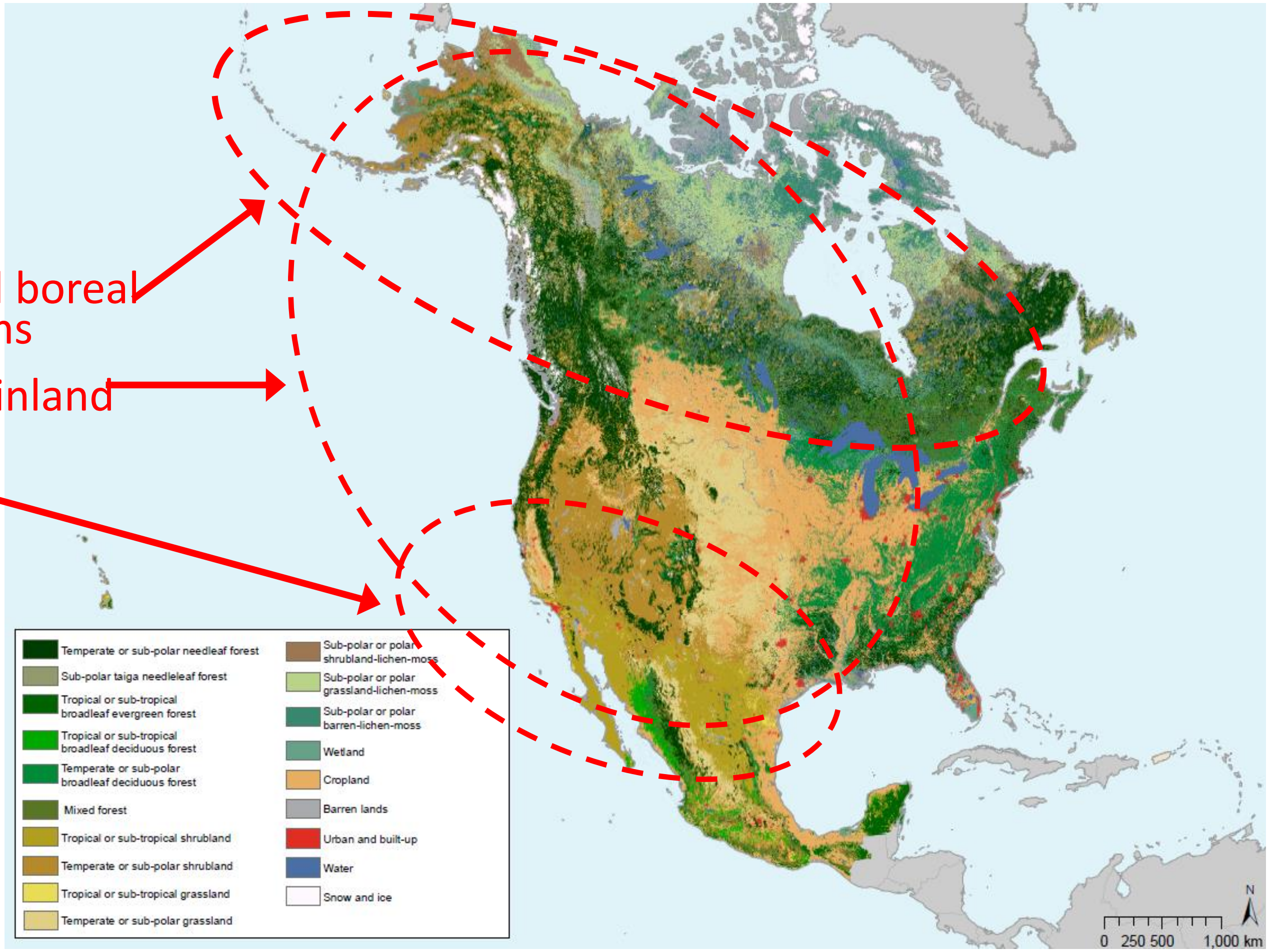


Figure 19.10. Potential vulnerability of soil carbon stocks to climate warming based on a meta-analysis of 3 **warming experiments:** predicted changes in soil carbon stocks by 2050, under a 1ºC rise in global average soil surface

From Crowther et al., 2016: Quantifying 6 global soil carbon losses in response to warming. *Nature* **540**, 104-108. 7

Critical Knowledge Gaps Overall include Soils

- Arctic and boreal ecosystems
- Soils and inland waters
- Mexico



Agriculture

Chapter leads Jane Johnson, ARS, and Alex Hristov, Penn State
(Several slides from AGU presentation by Benjamin Runkle ARS)

Agriculture: some important perspectives

- Agriculture overall is a net source of carbon to the atmosphere- primarily from
  - Soil disturbance, land degradation and land conversions (mostly CO_2)
  - Excessive Fertilizers—N_2O
  - Manure management (N_2O, CO_2, CH_4)
  - Enteric CH_4 (from ruminant livestock such as cows and sheep)
- Food waste also adds to the problem
- Producers and land managers influenced not just by policies and regulations, but by the public and markets that influence profits
- Good yields and sustainable, resilient systems usually have the lowest carbon footprint

Key Findings

Predictions of global soil carbon change in Earth System Models through this century range from a loss of 72 Pg C to a gain of 253 Pg C with a multimodel mean gain of 65 Pg C. ESMs projecting large gains do so largely by projecting increases in high-latitude soil organic carbon that are inconsistent with empirical studies that indicate significant losses of soil carbon with predicted climate change.

Key finding 1: Bottom-up emissions estimates

Agricultural GHG emissions (CO_2e) in 2015 were:

- US: 567 Tg
- Canada: 60 Tg
- Mexico: 80 Tg

Major agricultural non-CO_2 emission sources:

- nitrous oxide (N_2O) from cropped and grazed soils
- enteric methane (CH_4) from livestock

Table 5.1. Greenhouse Gas Fluxes from North American Agriculture (Teragrams of Carbon Dioxide Equivalent per Year)

Emission Source	Canada[a]	United States[b]	Mexico[c]	Total by Source
Enteric Fermentation	25	166.5	43.3	234.8
Manure Management	8	84.0	25.7[f]	117.7
Agricultural Soil Management	24[d]	295.0	0	318.0
Rice Cultivation	0	12.3	0.2	12.5
Liming, Urea Application, and Others	3	8.7	7.5[g]	19.2
Field Burning of Agricultural Residues	0	0.4	1.3	1.7
Crop Residues	NR[e]	NR	1.9	1.9
Total by Country[h]	60	566.9	79.9	705.8

Not including land use change

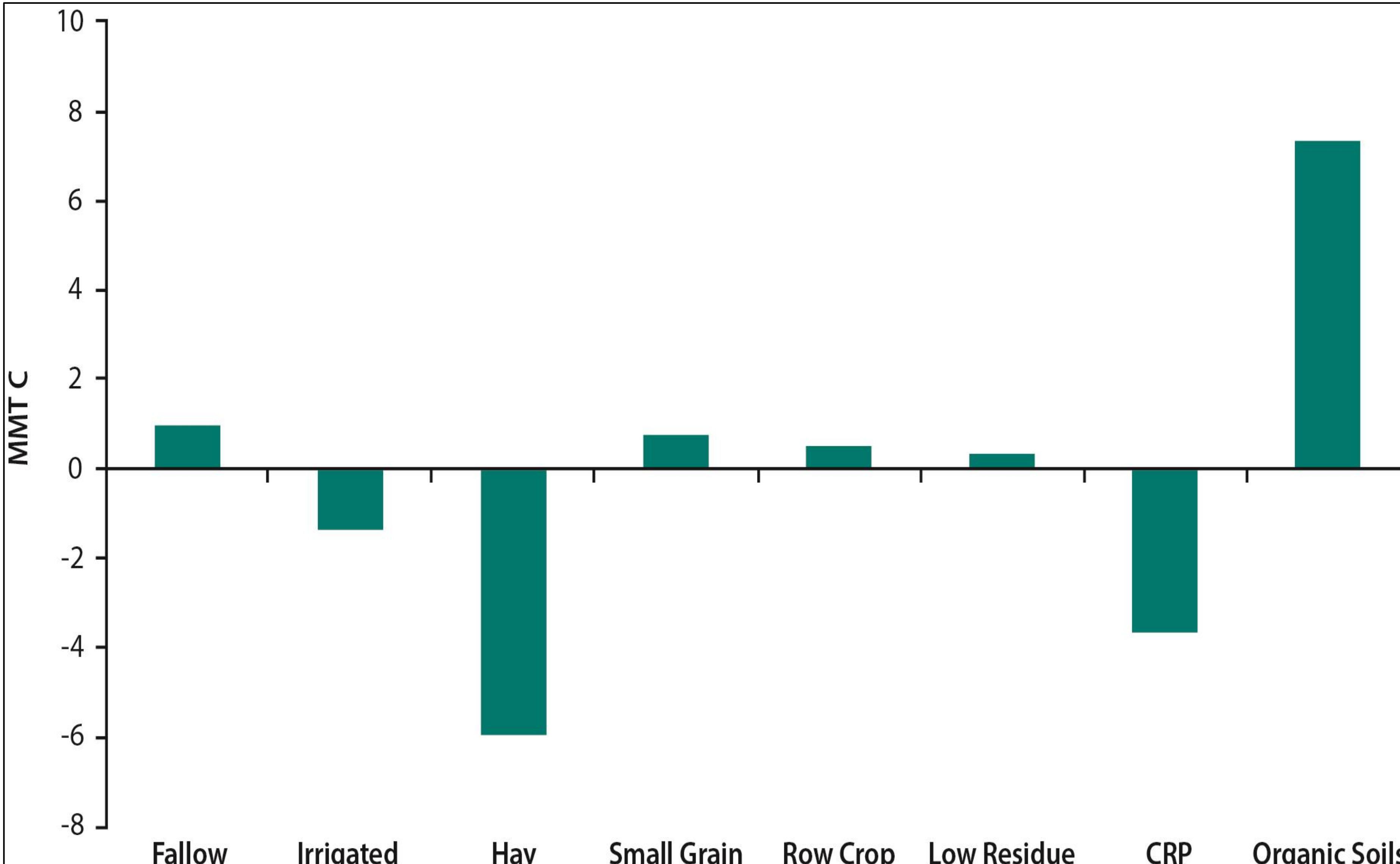
Key finding 2: Human decisions are key

- Agricultural carbon budgets and net emissions are directly affected by human decision making.
- Trends in food production and agricultural management, and thus carbon budgets, can <u>fluctuate significantly</u> with changes in global markets, diets, consumer demand, regional policies, and incentives (*very high confidence*).

Key finding 3: Soil stocks

- **Most cropland carbon stocks are in the soil, and are controlled by cropland management practices.**
- **Practices that can increase soil carbon stocks include:**
  - **maintaining land cover with vegetation (deep-rooted perennials; cover crops),**
  - **protecting the soil from erosion (using reduced or no tillage), and**
  - **improving nutrient management.**
- **Management-related carbon stock changes have strong environmental and regional differences, and respond to changes in management practices (*high confidence, likely*).**

Soil Carbon Fluxes for Major Cropping Systems in the United States. Values, in million metric tons of carbon (MMT C)



Key finding 4: Need N Management

North America's growing population can achieve benefits such as reduced GHG emissions, lowered net GWP, increased water and air quality, reduced CH_4 flux in flooded or relatively anoxic systems, and increased food availability:

- By optimizing nitrogen fertilizer management to sustain crop yields and reduce nitrogen losses to air and water (*high confidence, likely*).
- But high spatial and temporal variability
- Need to match crop needs to N fertilizer applications

Liu and Greaver, 2009

Key finding 5: CH_4 reductions

Strategies are available to mitigate livestock enteric and manure CH_4 emissions.

- Promising and readily applicable technologies can reduce enteric CH_4 emissions from ruminants by 20% to 30%. (e.g., increasing forage digestibility, increasing corn or legume vs grass silage, feed additives)
- Other mitigation technologies can reduce manure CH_4 emissions by 30% to 50%, on average, and in some cases as much as 80%. (e.g., changed composting and treatment, covers, digestion and capture)

Methane mitigation strategies have to be evaluated on a production-system scale to account for emission tradeoffs and co-benefits such as improved feed efficiency or productivity in livestock (*high confidence, likely*).

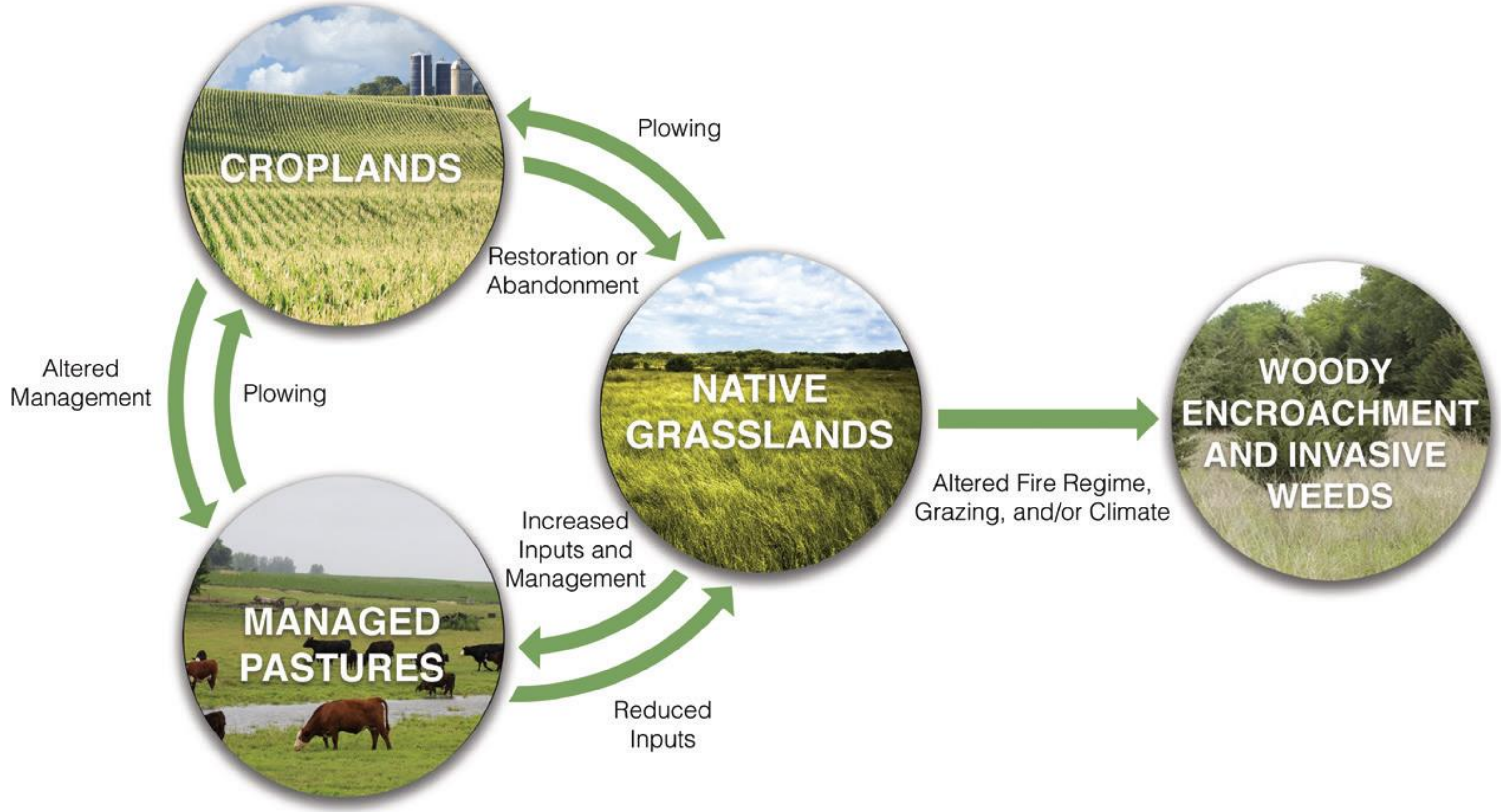


Figure 10.1. Management Activities and Their Effects on Grassland Carbon Cycling. Reduced fire frequency in mesic native grassland has allowed woody vegetation such as *Juniperus virginia* to expand and has been associated with rapid increases in carbon stocks in vegetation and soils (McKinley and Blair 2008). Other observed management impacts include lower carbon density in agricultural lands compared with grasslands (Zhu et al., 2011) and the rapid accumulation of soil carbon in intensively managed pastures in the southeastern United States (Machmuller et al., 2015). In addition, the rate of carbon uptake by croplands in the Great Plains is 30% lower than that of grasslands (Wylie et al., 2016).

Key Point of Contention: Is livestock grazing good or bad for soil carbon and soil health & GHGs

- There is general agreement among experts that for grasslands, some grazing is better than exclusion of grazers for soil carbon
- Intensive management so that high stocking rates for short periods in a multi-paddock system can increase soil carbon rapidly
- Management and stocking levels need to adapt to weather conditions such as droughts.

- Important interactions between grazers, soil carbon, and species distribution
- Grain-fed versus grass-fed differences in enteric methane

Key finding 6: Feedbacks on CH_4

- Projected climate change likely will (*high confidence*):
  - increase CH_4 emissions from livestock manure management
  - it will have a lesser impact on enteric CH_4 emissions.
- Potential effects of climate change on **agricultural soil carbon stocks** are difficult to assess because they will vary according to the nature of the change, onsite ecosystem characteristics, production system, and management type (*high confidence*).

Paddy Rice, Methane and Nitrous Oxide

- Still many unknowns about the influence of soil and environmental factors in methane and nitrous oxide from paddy rice systems
- New varieties have increased productivity while decreasing emissions
- Intermittent flooding—optimization of timing and duration of drainage

Perspectives

- Whole farm modeling is still challenging
- Need for systems-level research
- Climate-smart agriculture is a unique opportunity for projects that maintain food supplies and fight climate change

Some strategies to reduce agricultural greenhouse gases

Grazing & livestock management

Fig. 5.3 & 5.4 Hristov *et al.*

- **Reduce enteric CH_4 emissions from ruminants by 20% to 30% and from manure by 30% to 80% via feed and management**
- **Cost-benefit evaluations are still needed**

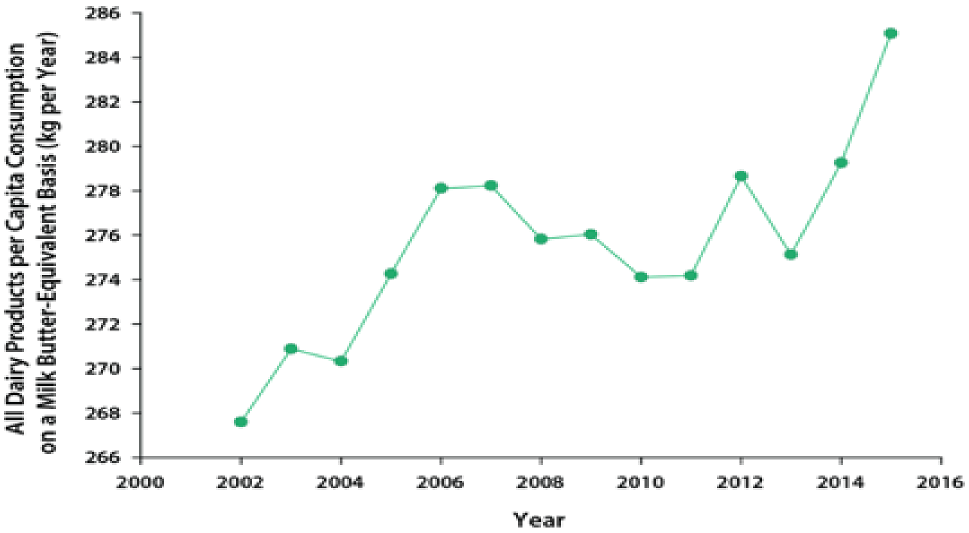
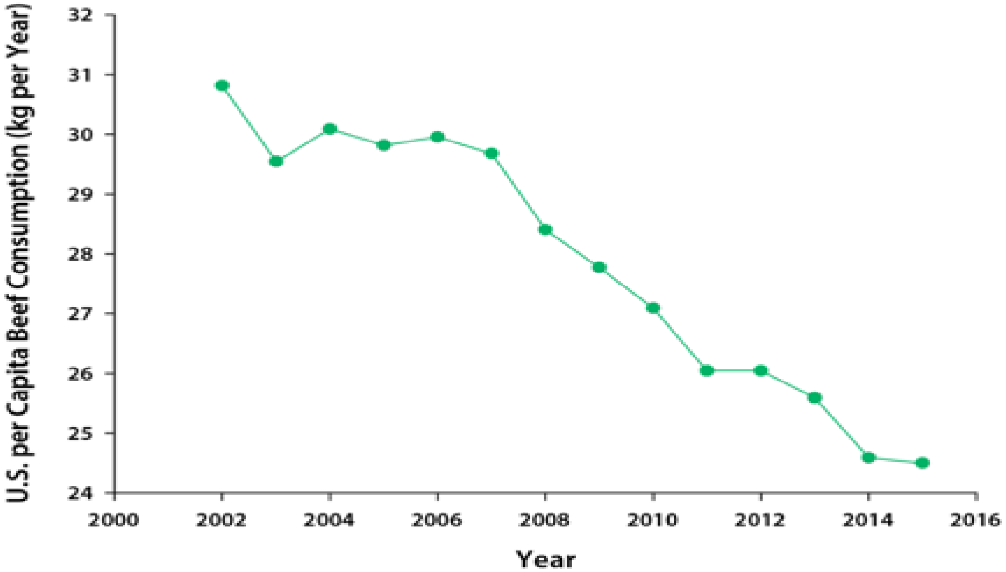
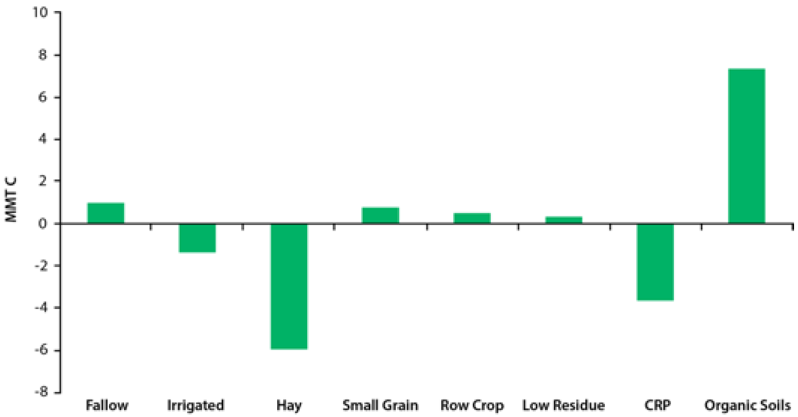


Photo by Matthias Zomer from Pexels



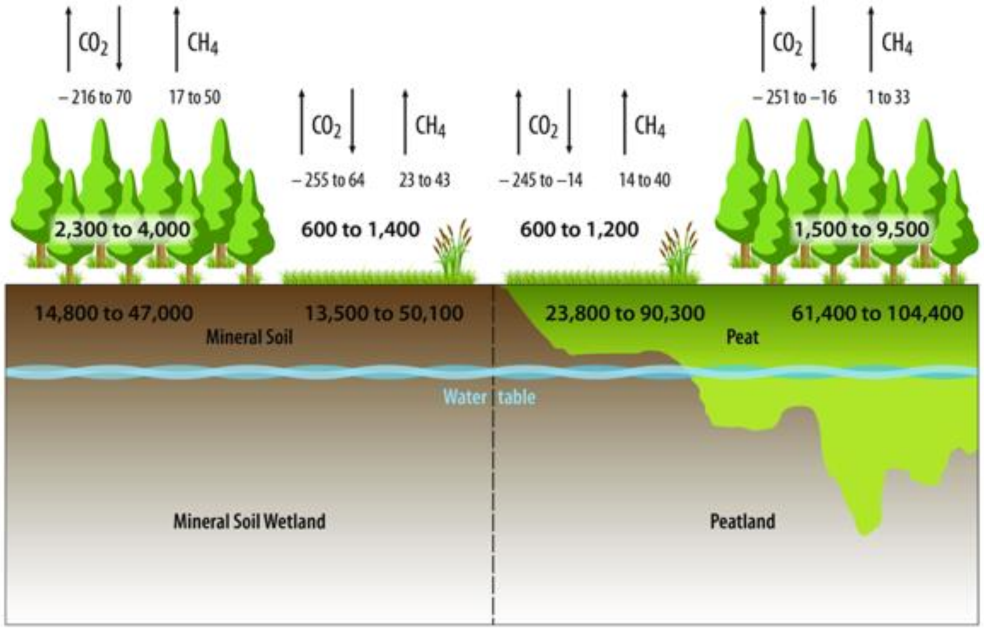
Agriculture cropland & waste management

- **Deeply-rooted crops, cover crops, perennials**
- **Restoration of drained wetlands, or covert from upland crops to paddy rice**
- **Improved nutrient management, especially N**
- **Reduce food waste**



Wetland restoration or creation

- Wetlands store significant C
- Minimize impacts, restore & create
- Careful, wetlands are source of CH_4 emissions



Sustainable management through traditional knowledge

- Successful efforts on tribal lands provide examples

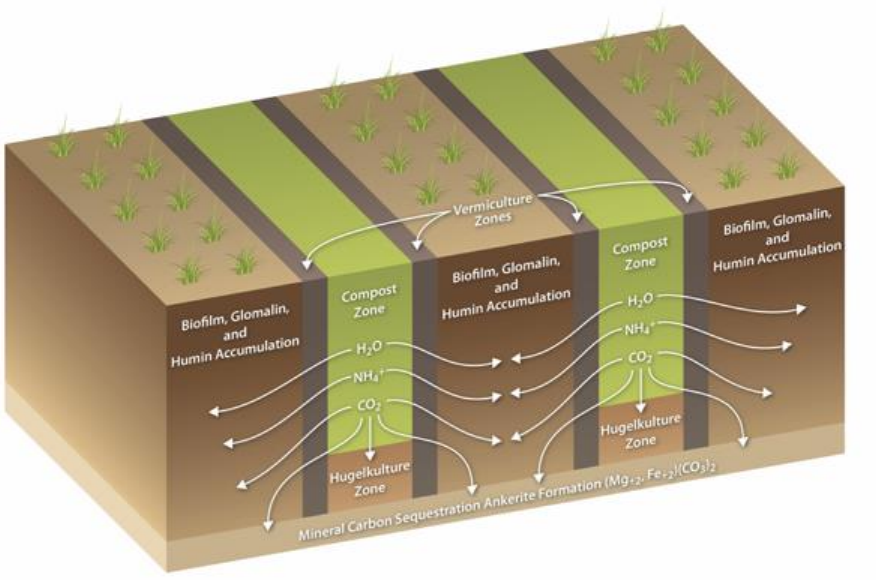


Fig. 7a, b McCarthy *et al.*

Microbiome manipulations to reduce GHGs?

- Can we manipulate the soil microbiome to increase carbon use efficiency and carbon storage?

- Can we manipulate the rumen microbiome to increase decrease enteric methane emissions

- What are the potential interactions between livestock, plant and soil microbiomes, and what are the trade-offs/co-benefits – disease resistance, water quality, food safety?

- Can we produce more food from perennial crops and how will this affect the soil microbiome?

International groups we participate in on carbon-agriculture-climate-soils (illustrative, not exhaustive)

- Global Research Alliance on agricultural greenhouse gases (GRA)
- Coordination of International Research Cooperation on Soil CArbon Sequestration in Agriculture (CIRCASA)-EU based
- International Soil Modeling Consortium (ISCN)-focus on soil structure, strongly dependent on carbon
- International Soil Carbon Network (ISMC)-partnering with CCIWG, CIRCASA, participation from
- 4 per mil initiative—focus on increasing soil carbon storage to offset carbon emissions
- Climate and Clean Air Coalitions (CCAC)
- CarboNA https://www.nacarbon.org/carbona/index.htm?
- Programa Mexicana de Carbono (PMC) http://pmcarbono.org/pmc/

Networks-Soils

- International Soil Carbon Network https://iscn.fluxdata.org/
  - Facilitates data sharing,
  - Assembles databases,
  - Identifies gaps in data coverage, and
  - Enables spatially explicit assessments of soil carbon in context of landscape, climate, land use, and biotic variables
  - Also partnering with CIRCASA
- International Soil Modeling Consortium https://soil-modeling.org/
  - A total of 573 members make up the ISMC community as of 4th Feb 2019.
  - All continents are represented by their soil modeling expertise.
  - Currently, 39 models are uploaded to the model platform with 23 categories.
  - The soil meta data repository is starting off with 6 meta data sets.
  - The second biannual ISMC conference attracted 140 soil scientists, from 22 countries and was co-sponsored by 3 soil research outlets.

International agreements

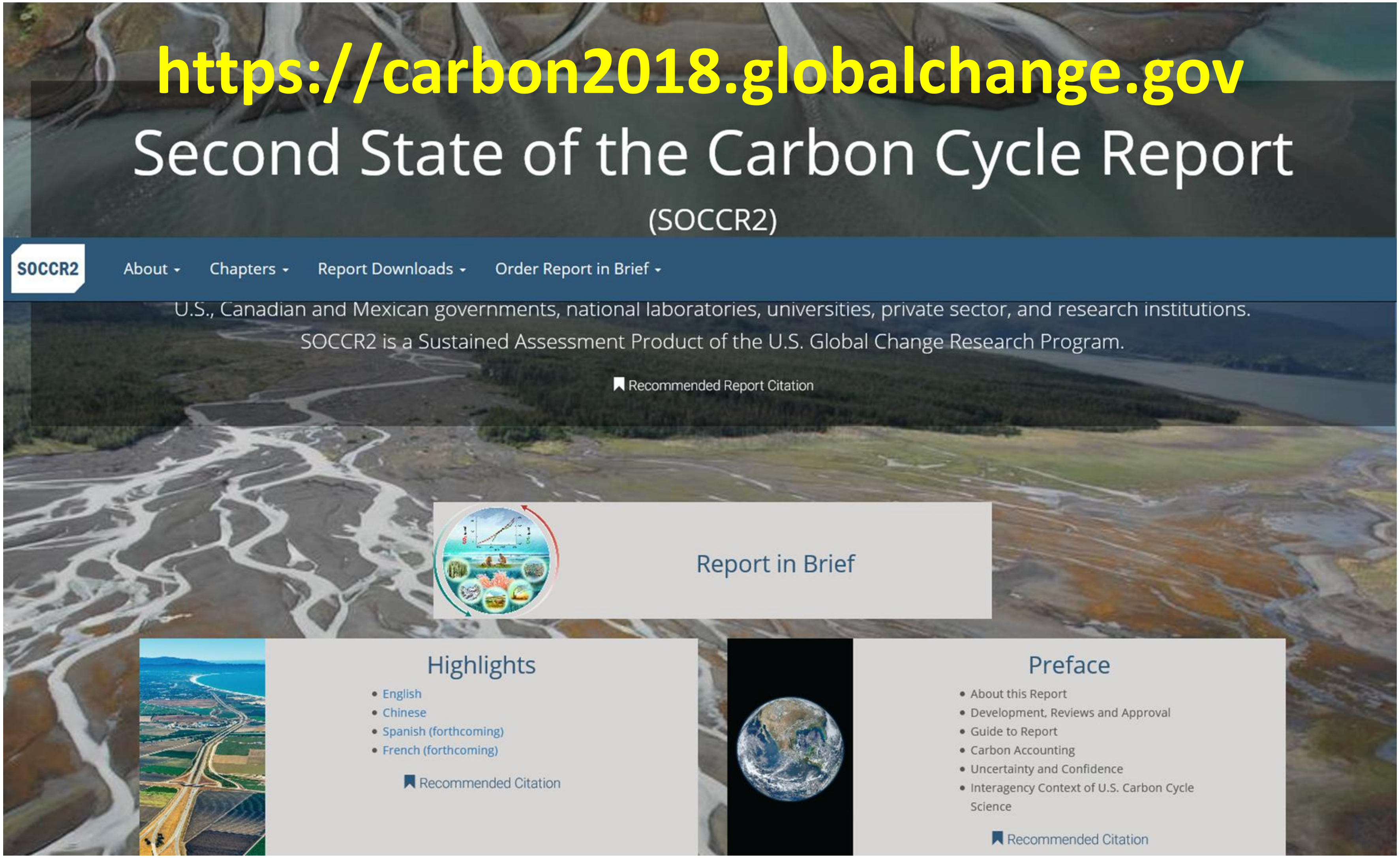
- **Global Research Alliance on agricultural greenhouse gases** https://globalresearchalliance.org/
  - About 50 countries, 6 continents, NGO partners-CGIAR, World Bank, etc.
  - 4 Research Groups (RGs): Livestock, Croplands, Paddy Rice, Integrated (cross-cutting)
  - Flagship Projects
    - **Soil Carbon Sequestration**
    - **Enteric Fermentation**
    - **Inventories**
    - **Nitrogen Cycle**
    - **Reducing GHG in Rice Systems**
    - **Circular Bioeconomy**
- **Climate and Clean Air Coalition** http://ccacoalition.org/en
  - Focus on short (and medium)-lived GHGs—methane and black carbon primary interest
  - Agriculture related projects-
    - **Livestock and Manure management**
    - **Paddy Rice Production**
    - **Enteric fermentation**
    - **Open agricultural burning**

Other international initiatives

- Coordination of International Research Cooperation on Soil CArbon Sequestration in Agriculture (CIRCASA) https://www.circasa-project.eu/
  - Partnering with GRA, Global Soil Partnership
  - Partnering with FACCE-JPI (European Commission's Joint Programming Initiative in Food and Climate Change and Environment)
  - Partnering with CGIAR's CCAFS and WLE programs

- 4 per mil initiative—focus on increasing soil carbon storage to offset carbon emissions https://www.4p1000.org/
  - Launched at COP 21
  - 35 member countries
  - Aims to demonstrate that agricultural soils can play a crucial role in food security and climate change
  - Calls on partners to implement practical actions to increase soil carbon storage

https://carbon2018.globalchange.gov



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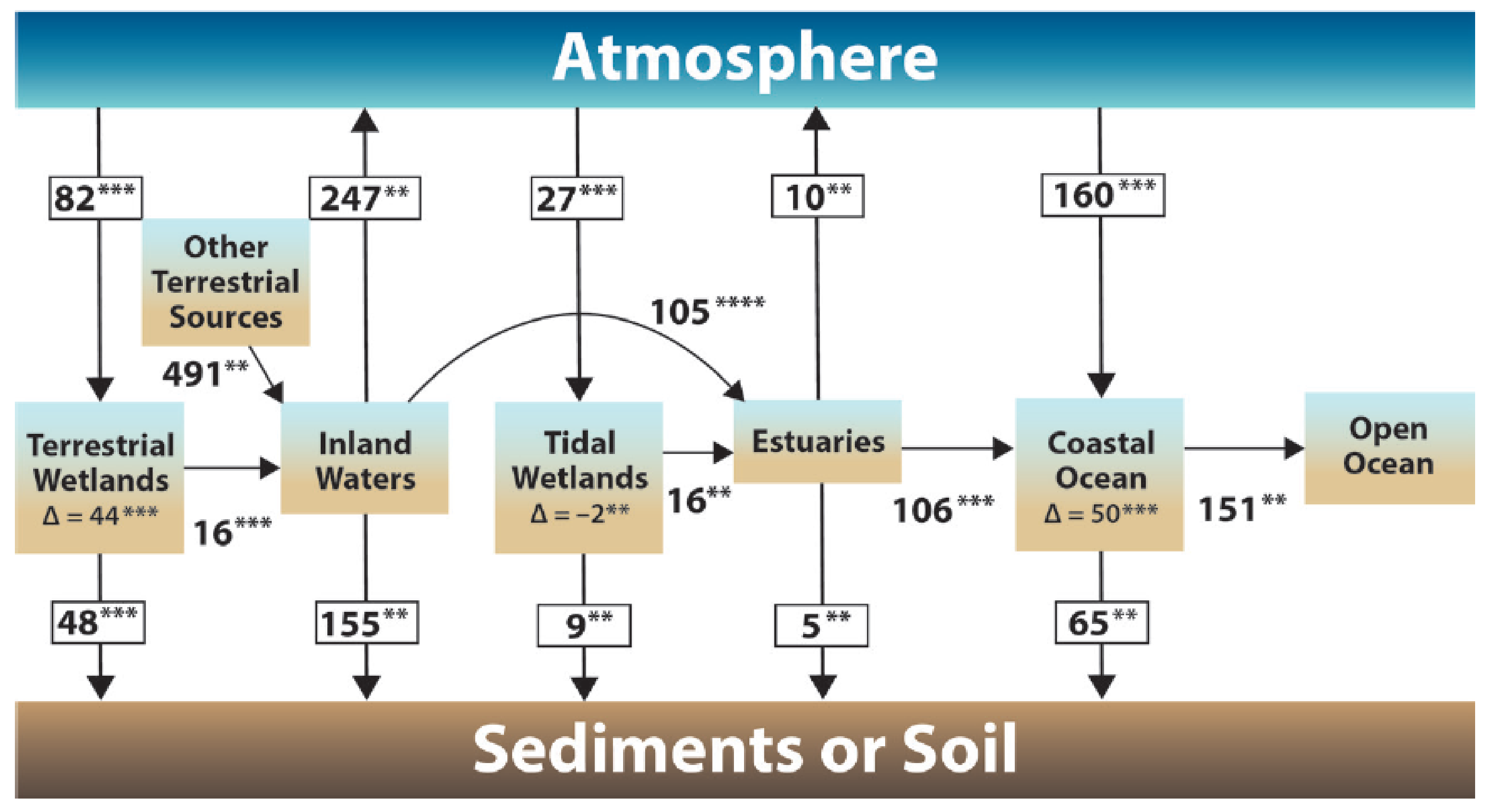
The end

Total Carbon Budget of North American Aquatic Ecosystems (Tg C yr^{-1})



95% confidence actual value is within 25% (****), 50% (***), or 100% (**) of reported value