The fourth dimension of crop nutrition:

soil carbon sequestration

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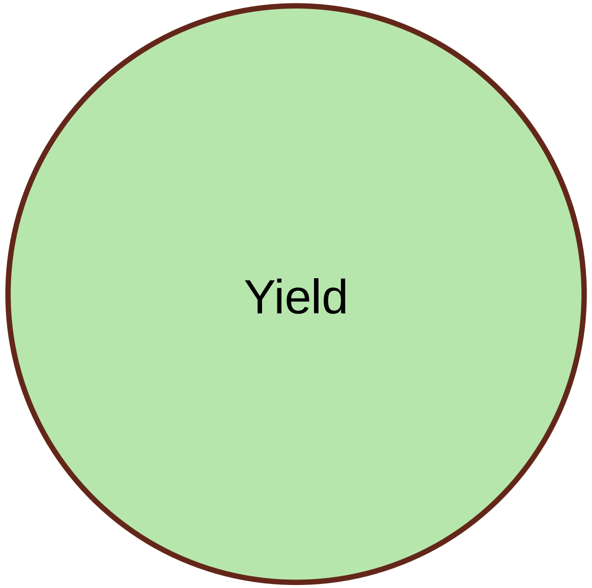
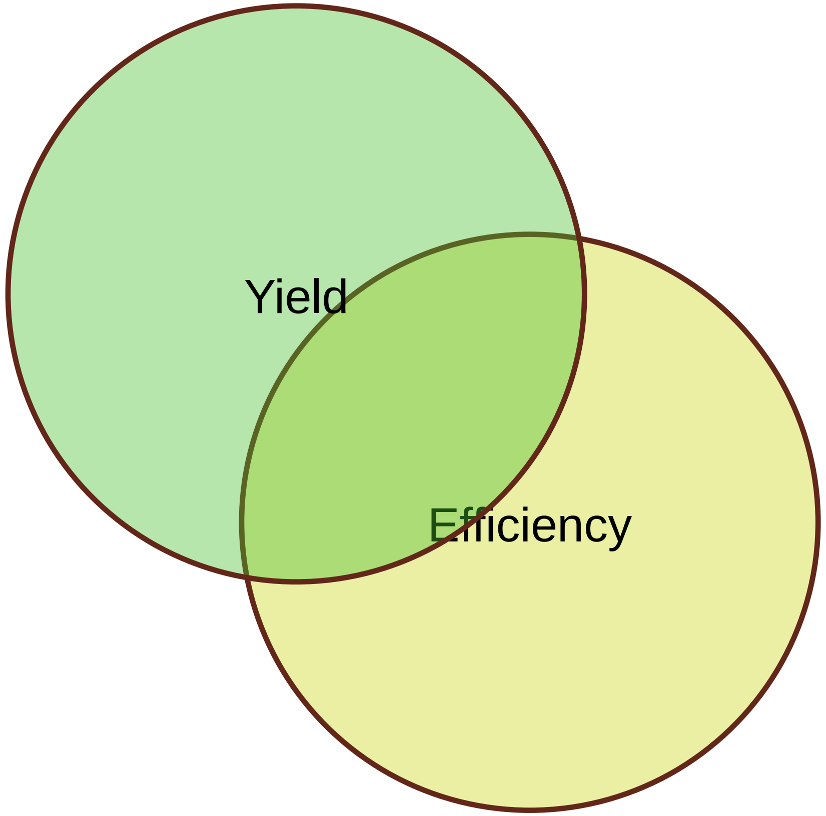
Optimal Nutrient management



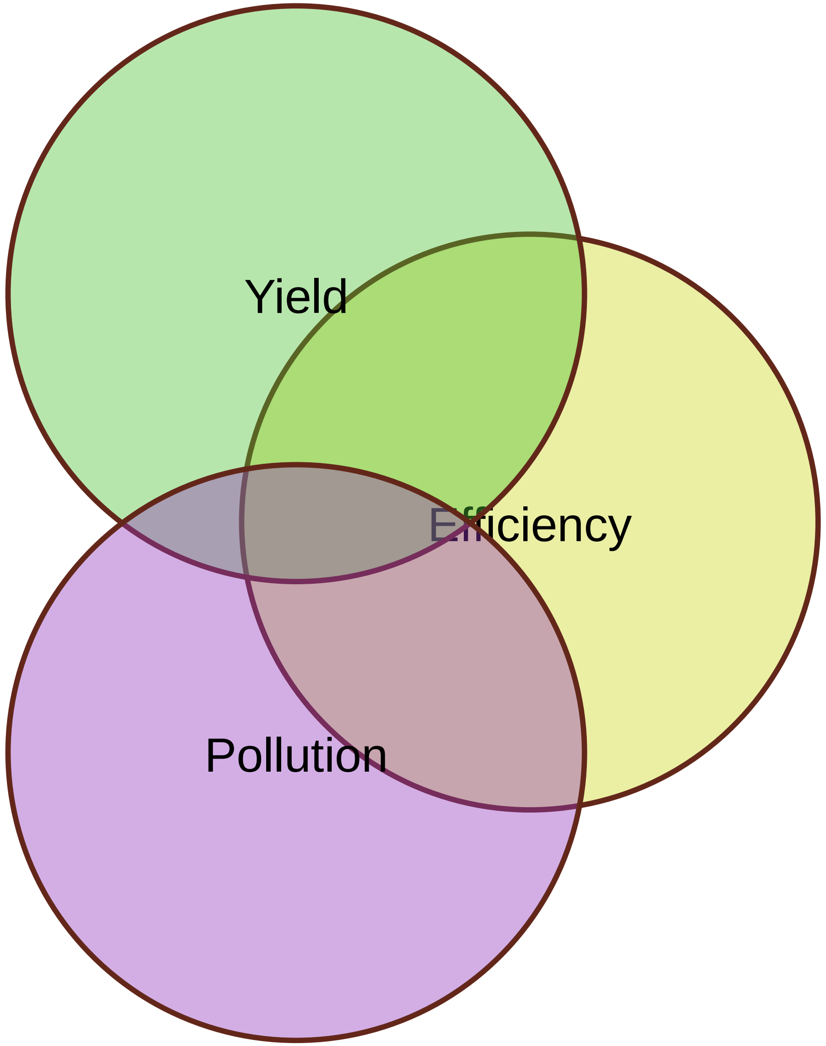
- Increase yield

Optimal Nutrient management



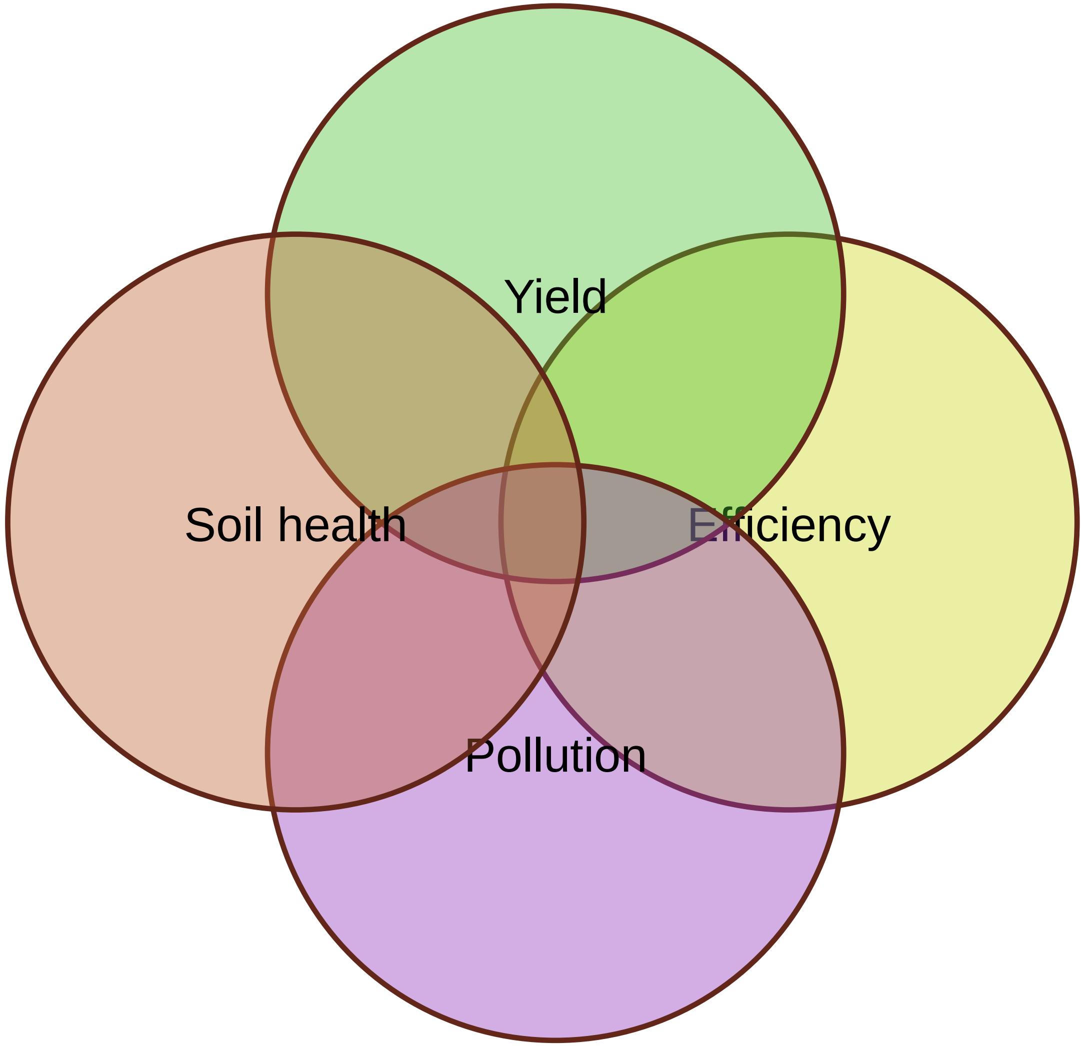
- Optimise yield
- Without excessive inputs

Optimal Nutrient management



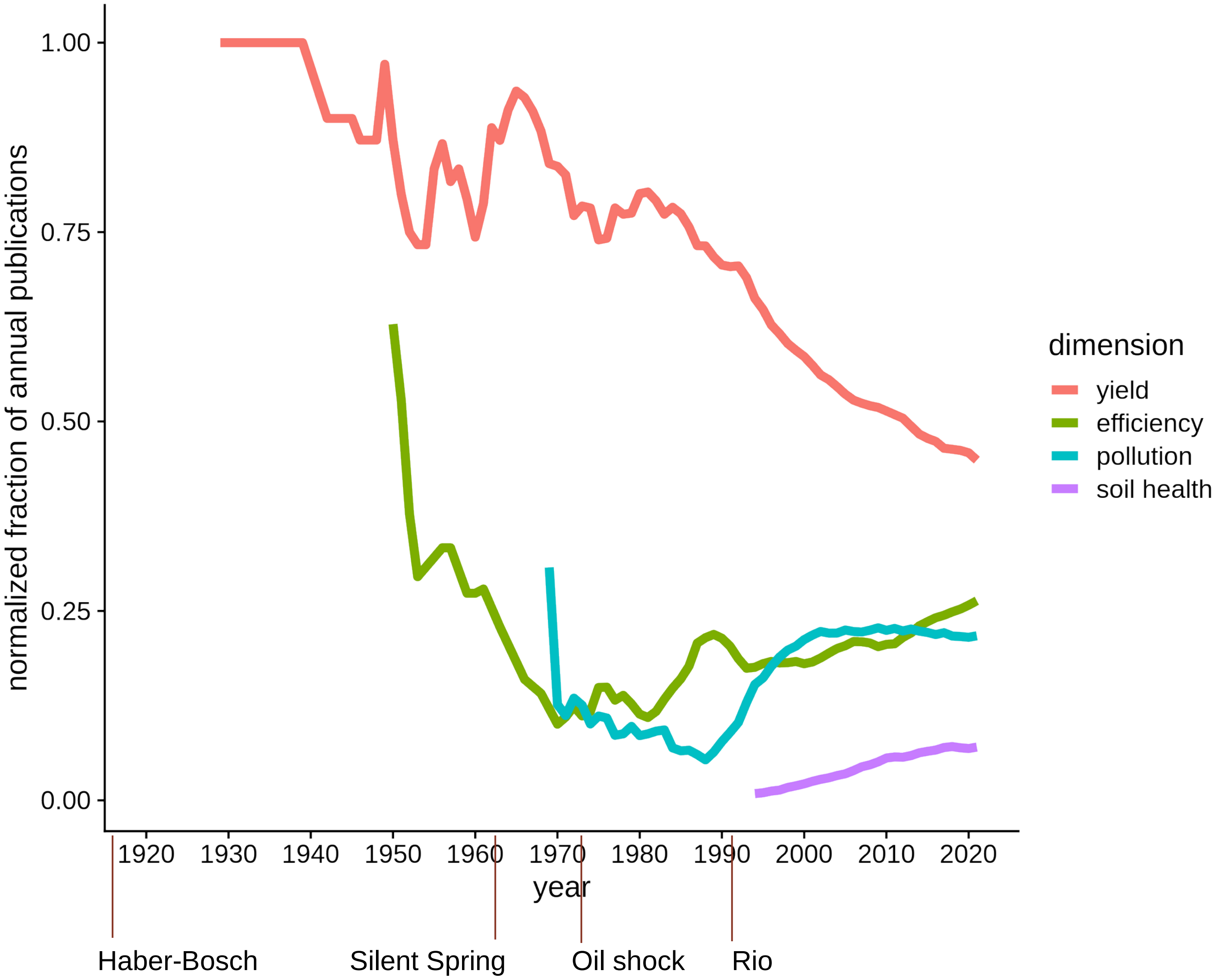
- Optimise yield
- Without excessive inputs
- While limiting off site water- and air-pollution

Optimal Nutrient management



- Optimise yield
- Without excessive inputs
- While limiting off site water- and air-pollution
- While also increasing soil organic matter

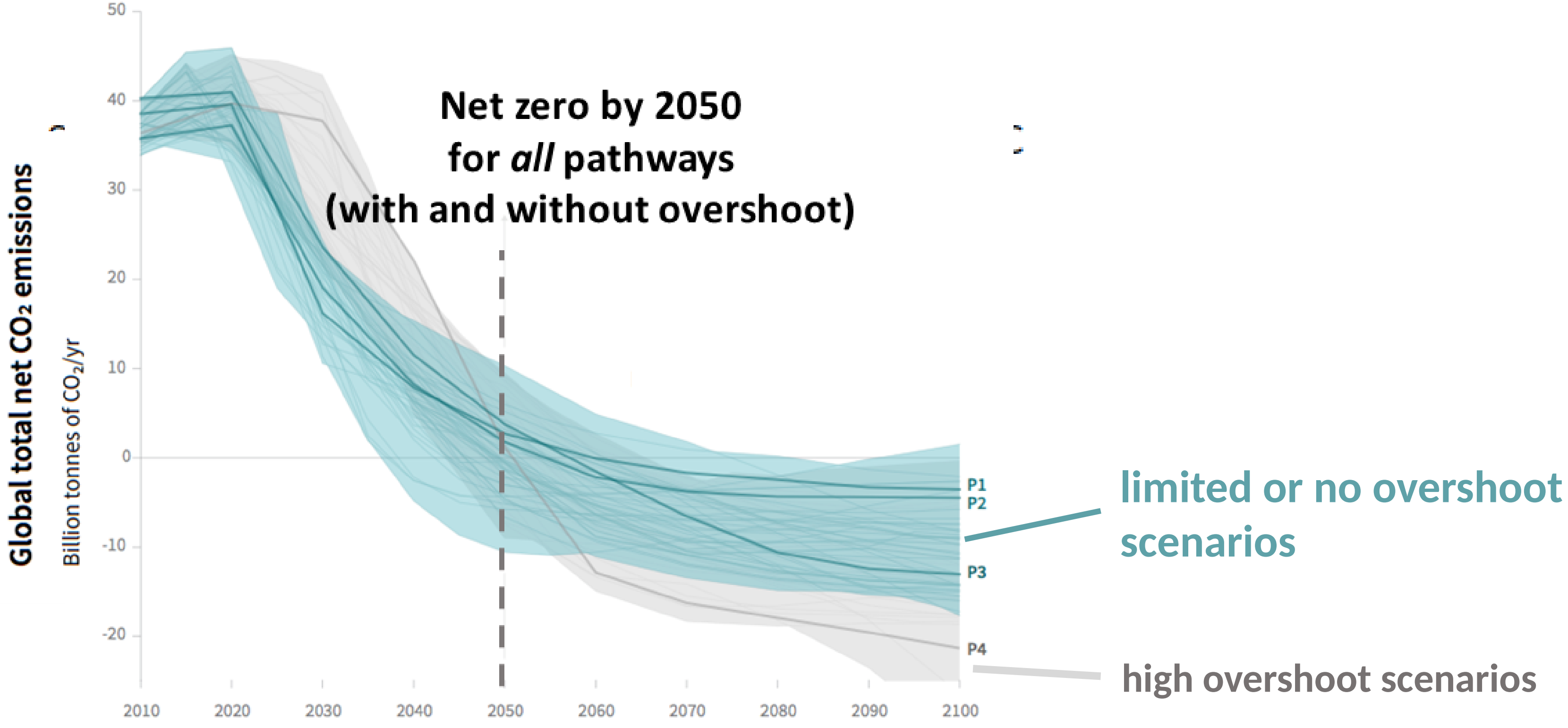
Fertilizer publications over time



- Web of Science publications
- 5-year rolling mean
- Search terms: Fertilizer +
  - Yield
  - Efficiency
  - Pollution / Environment
  - Soil Health / Soil Organic Carbon / Soil Carbon

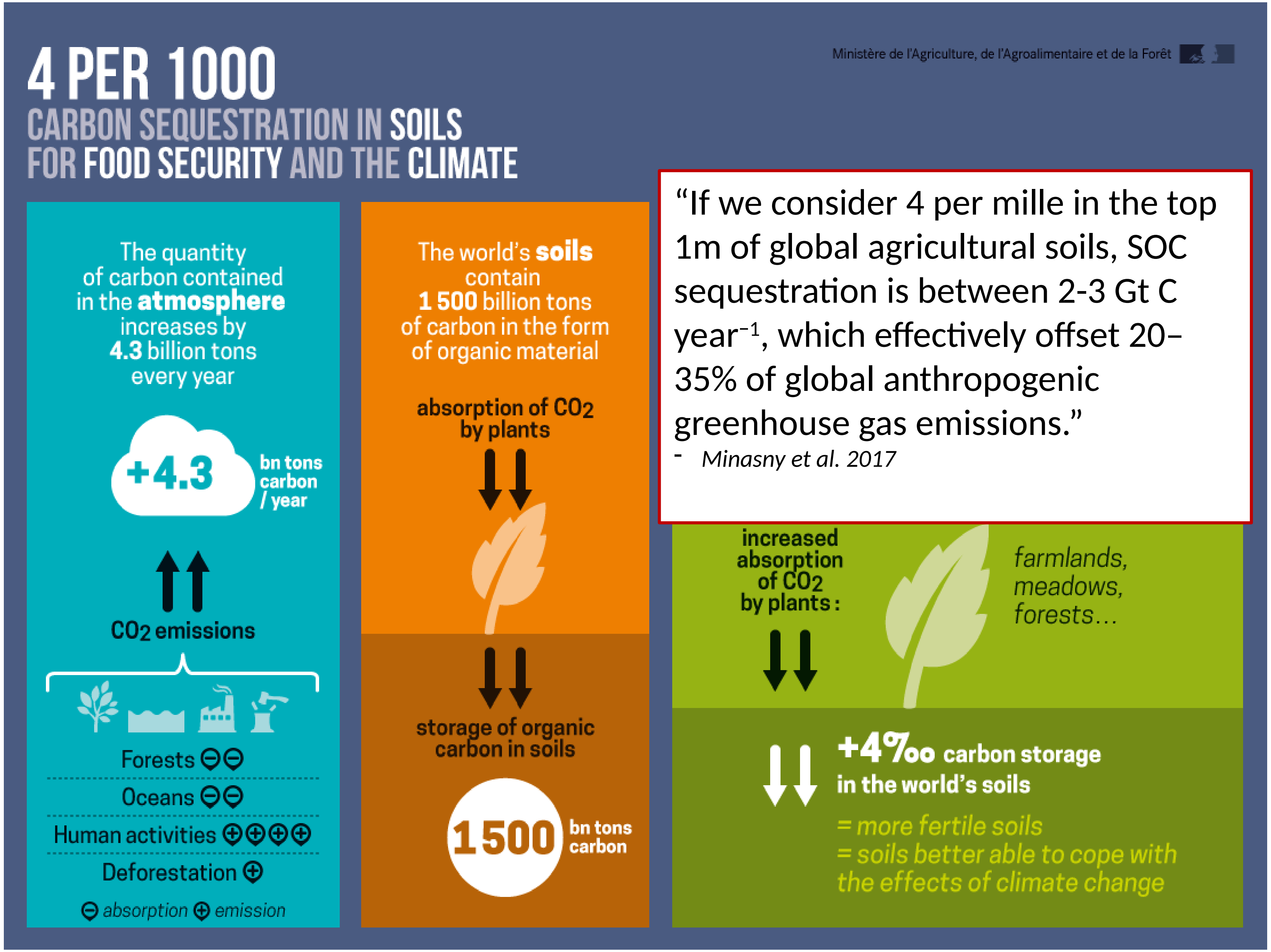
Why Soil Carbon Sequestration?

- CO_2 Emission pathways for meeting 1.5°C
  - Available carbon-budget shrinking
  - Emissions reduction no longer sufficient in coming years
  - NETS also needed now to bring down emissions rapidly enough



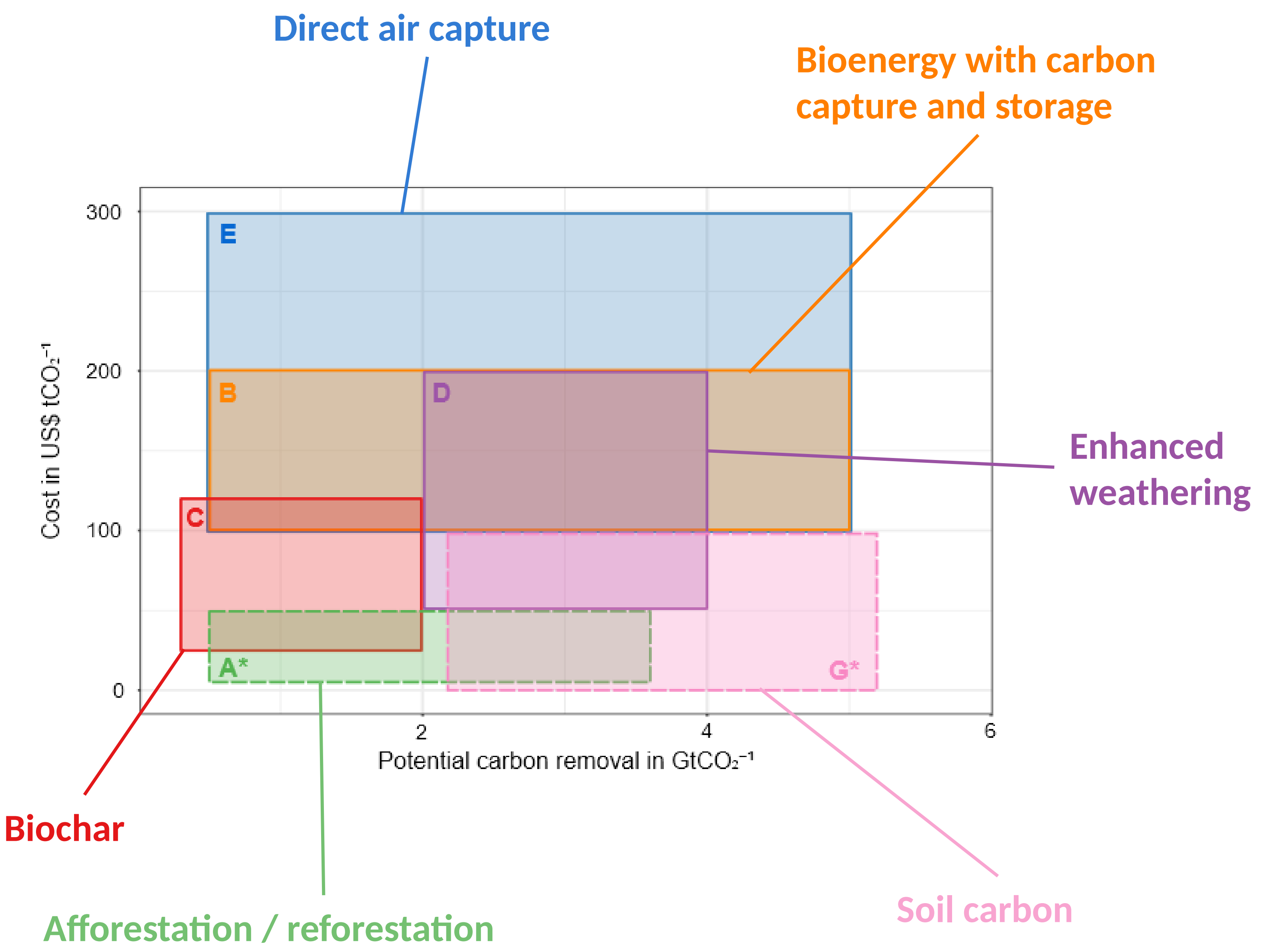
Source: IPCC Special Report on Global Warming of 1.5°C

- SOC 3x more carbon than atmosphere
- 8x more CO_2 exchanged between soil and atmosphere than total anthropogenic emissions.
- Soil carbon sequestration (SCS) promoted as both scalable and affordable



"If we consider 4 per mille in the top 1m of global agricultural soils, SOC sequestration is between 2-3 Gt C year^{-1}, which effectively offset 20–35% of global anthropogenic greenhouse gas emissions."

- *Minasny et al. 2017*



Fuss et al. 2018 *Env. Res. Lett.*

How changing SOC affects nutrient cycling

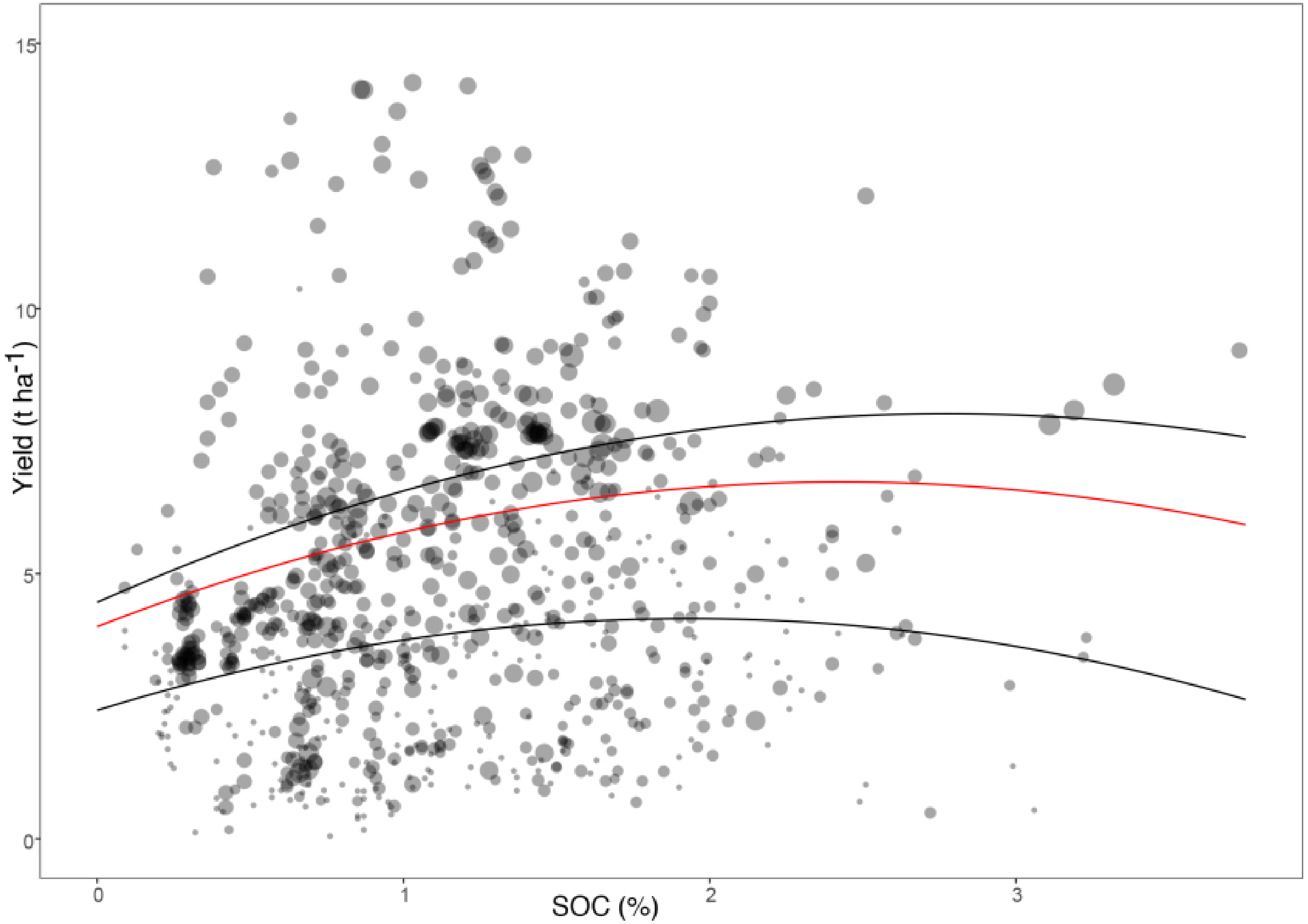
- Impacts of *building* SOC
- Impacts of *having* more SOC
- Impacts of carbon management

Impacts of *building* SOC on nutrient cycling

- SOM stoichiometry
- 0.55 Mg C ha^{-1} yr^{-1} (Minasny 2017) =
  - 50 kg N ha^{-1} yr^{-1}
  - 3 kg P ha^{-1} yr^{-1}
  - On *all* agricultural land (including grasslands)
- Substantial increase in nutrient demand
  - Unless, somehow, we can deliver these extra nutrients “for free”
  - Reduced leaching
  - Increased fixation

Impacts of *having* more SOC on nutrient cycling

- Yield
- Leaching
- Erosion

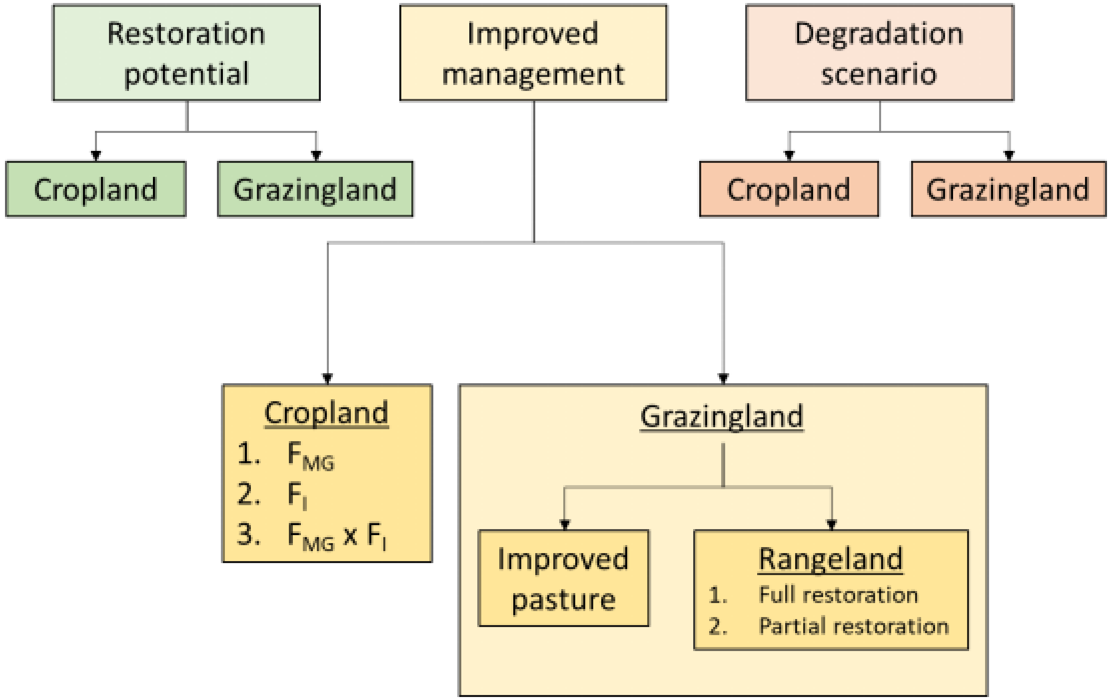


Impacts of carbon management on nutrient cycling

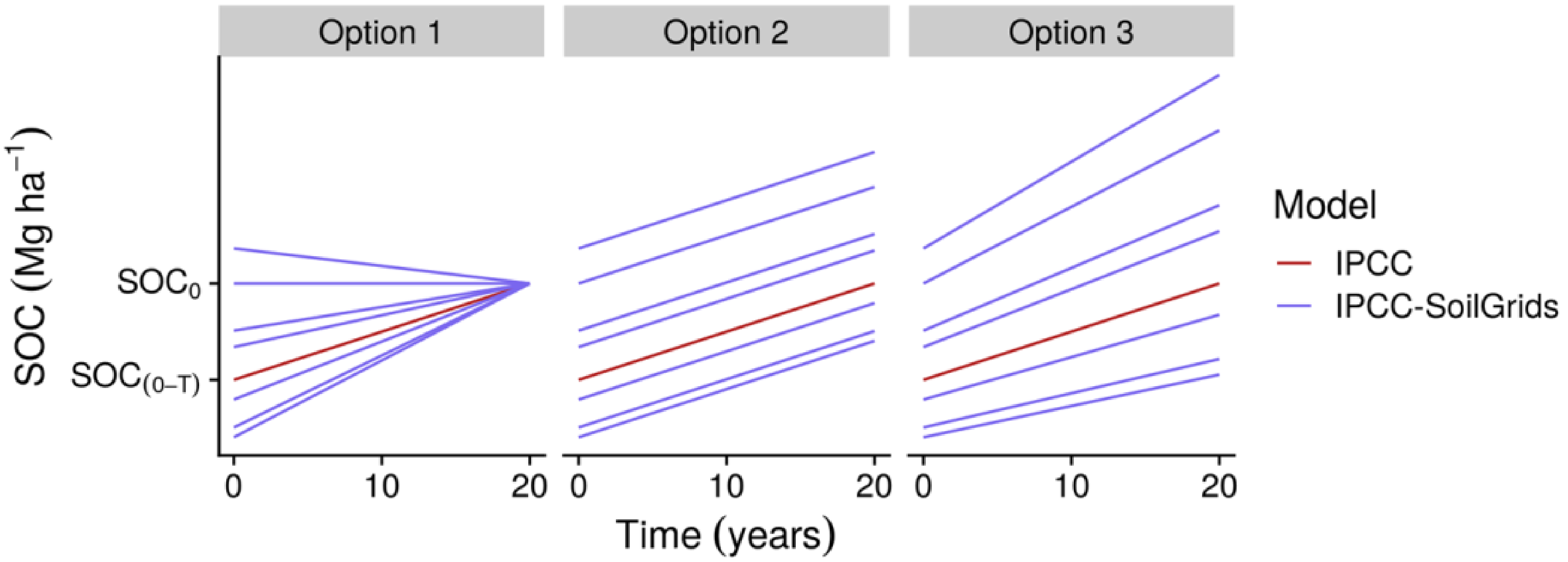
- Nutrient demand for additional biomass
- N fixation (if legumes added to mix)
- Change in crop yield
- Nitrogen use efficiency of organic amendments
- Change in leaching (cover crops and reduced tillage)

Potential for SCS: **Soils Revealed**

- https://soilsrevealed.org/
- Current SOC based on
  - Machine learning applied to WOSIS database + envirnmental covariates
  - 250 m resolution, globally
  - Change over recent past using UNFCCC method + land cover change from ESA-CCI
- Future Scenarios, forward projected from current stocks using modified IPCC Tier 1 method
  - Climate x Soil x Land Cover x Management x Inputs x Degradation



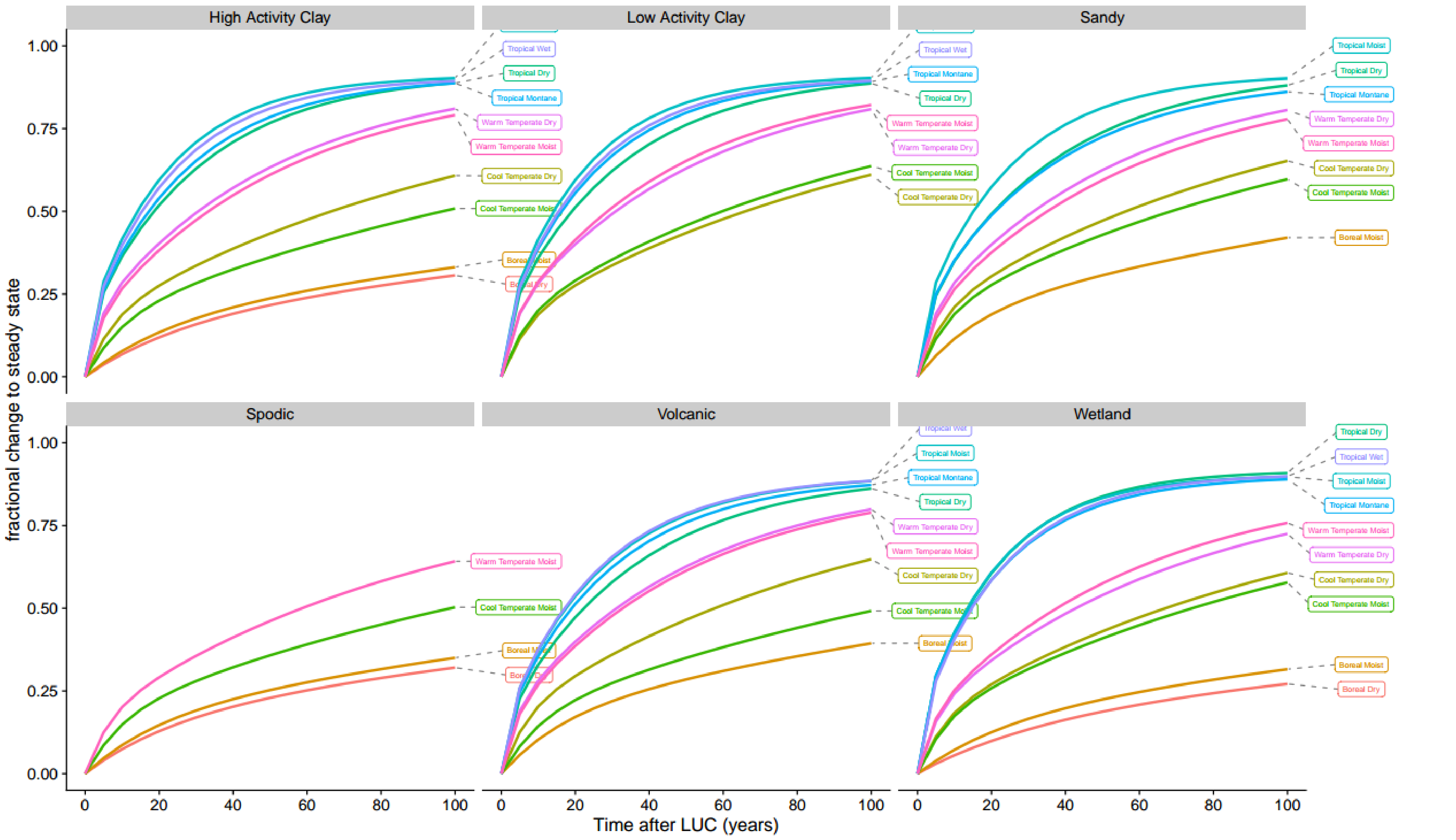
Integrating high resolution SOC baseline with low resolution IPCC method



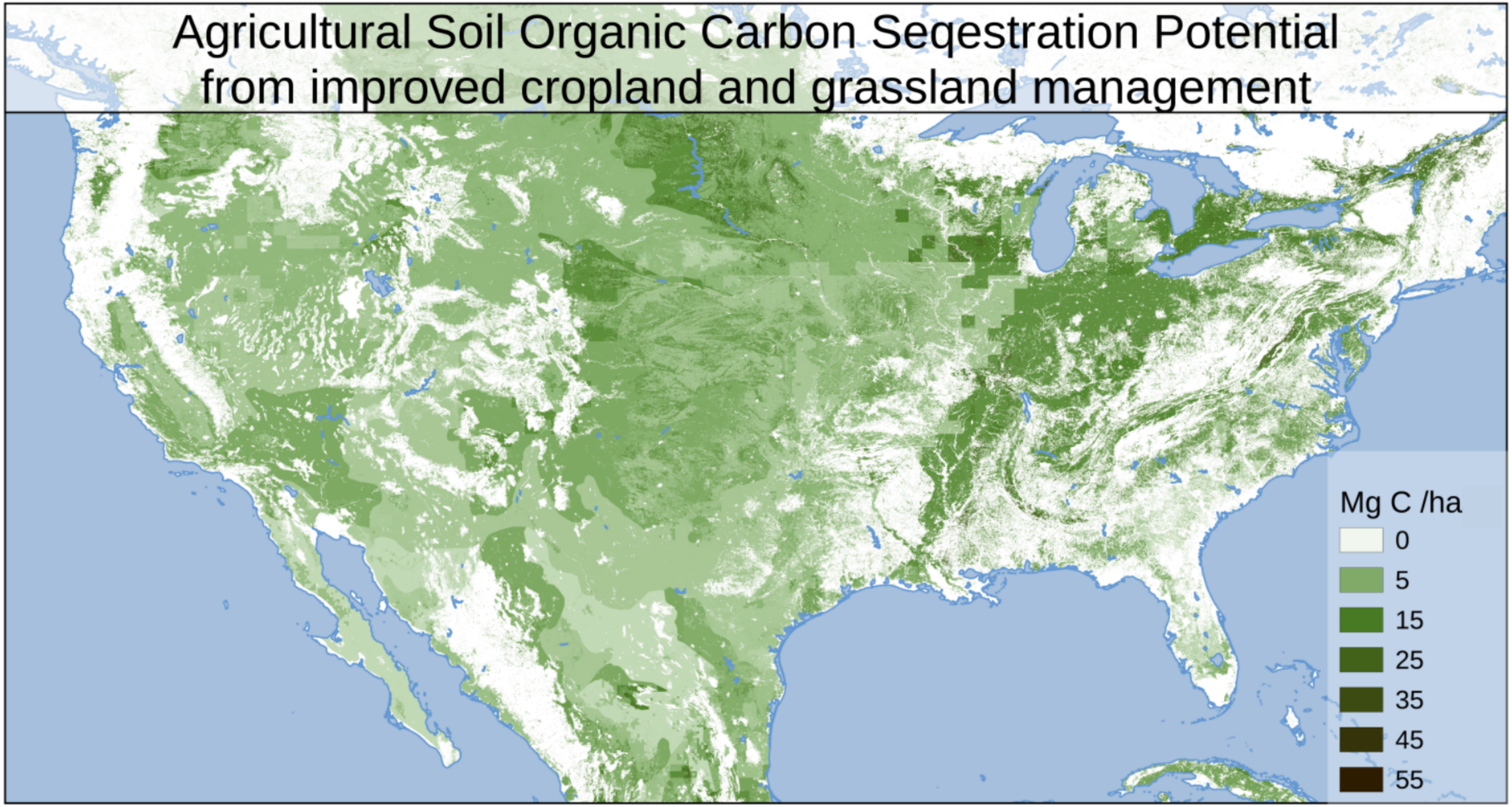
Possible methods for integrating the IPCC SOC model with a high resolution SoilGrids-derived baseline map of initial SOC stocks.

- Option 1 final SOC value defined by the IPCC method
- Option 2 change at same rate of change as IPCC method.
- Option 3 multiply initial SOC by the same modifying factors as IPCC method.

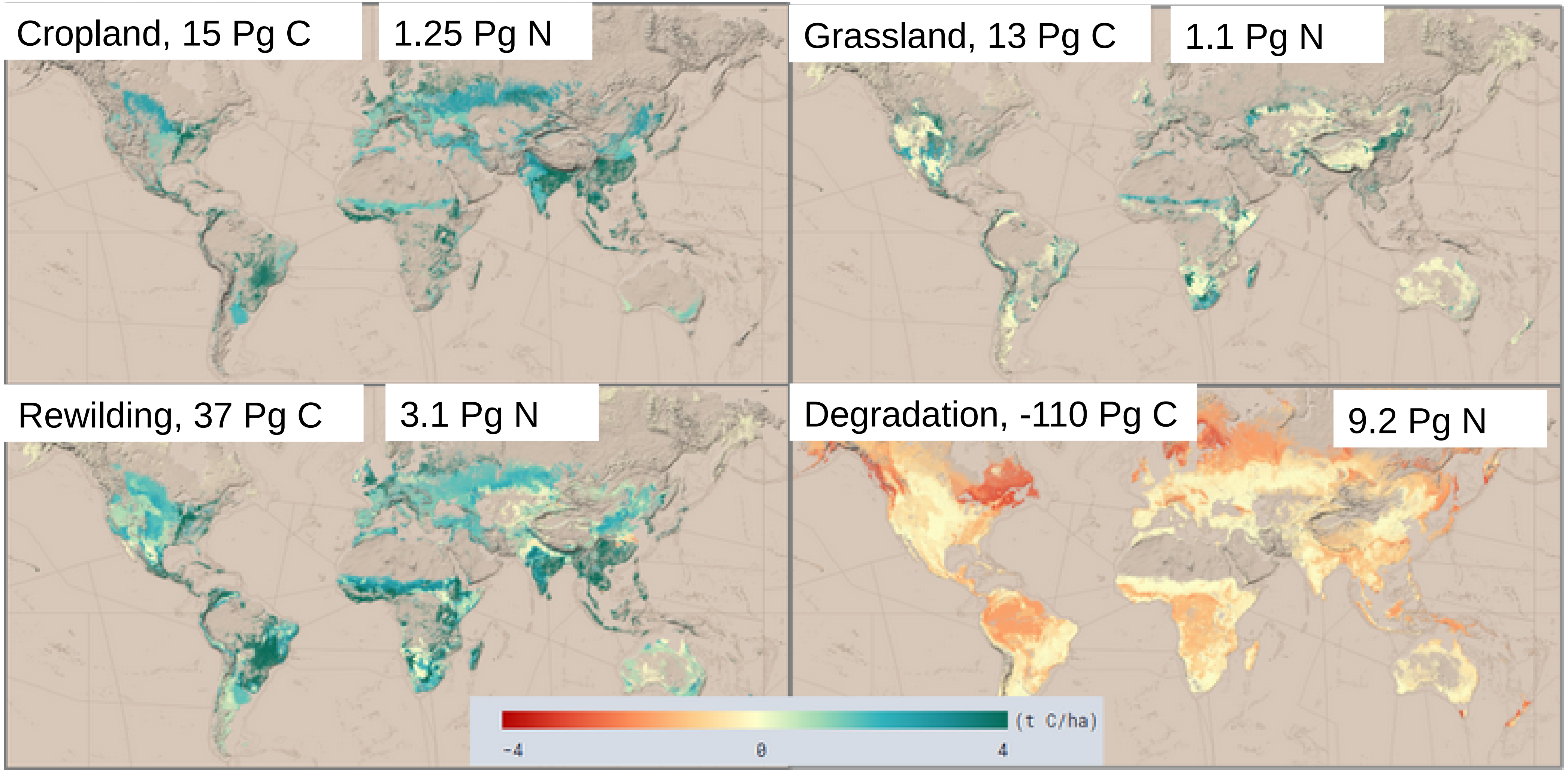
Convert to non-linear using RothC + climate x soil



Soils Revealed: 250 m resolution of sequestration



Global potential for SOC change (30 cm depth)



SOC sequestration rates by country

- Potential sequestration rates vary dramatically across the globe
- driven by a combination of different response factors in different climate zones and different reference SOC stock values
- Annual sequestration rates for improved cropland scenario range from 0.1 - 0.2 tC ha-1 yr-1 in countries dominated by arid and semi-arid climates to 0.8 - 1.0 tC ha-1 yr-1 in moist temperate climates.
- Similar patterns are seen for grassland restoration scenarios.

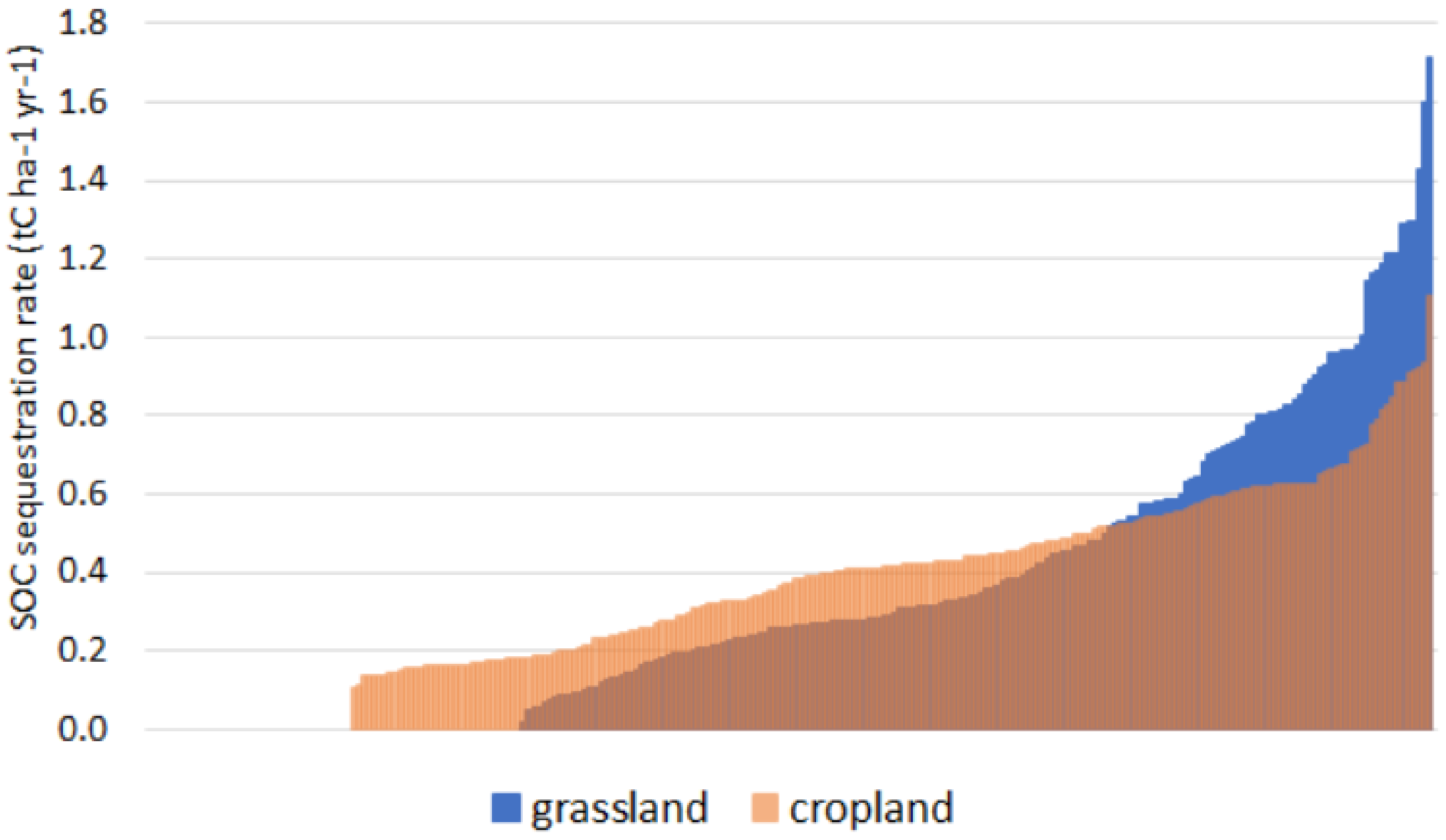
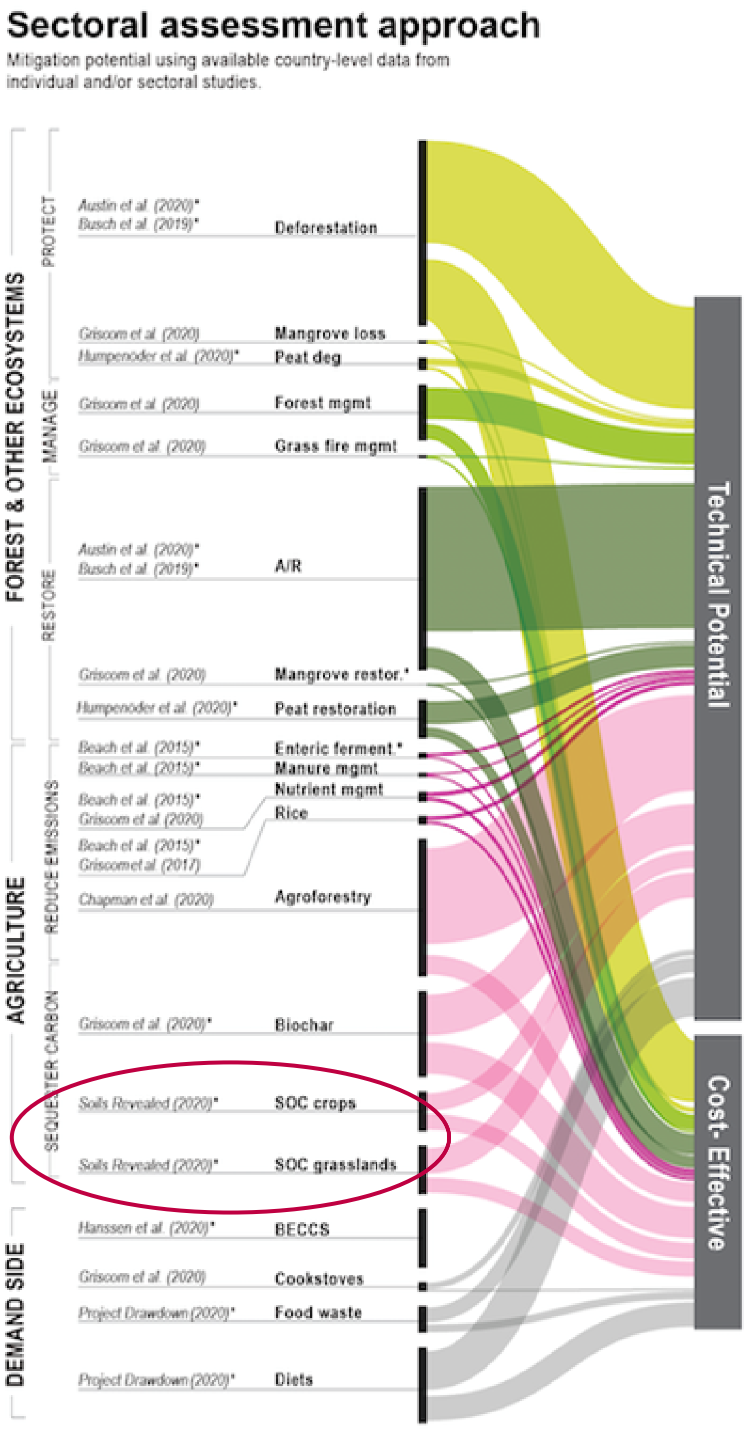


Figure 2. Mean country-level SOC sequestration rates for improved cropland (tillage x inputs) and grassland management scenarios. Out of the 249 nations defined in this analysis, there are 40 countries without appreciable cropland and 73 countries without appreciable grassland area.

Global CDR pathways

- Preliminary results
- Combine bottom-up sectoral assessments + top-down IAM
- Resource allocation avoids double counting
- SOC ~ 10% of cost-effective potential (excluding BECCS)
- Biochar from crop residues slightly higher (assumes biomass crops used for bioenergy).



Roe et al. (unpubl. In review, 2021)

FAST-GHG

- Fertilizer And Soil Tool (for agricultural GHGs)
- Scalable management options
  - Maize, soybean and wheat in Continental US
  - Improved tillage, cover cropping and nitrogen fertilizer management
- Initially developed for Walmart Project Gigaton
  - Aggregated supply chain with little farm-specific information
  - Default factors per State and County
  - Low barrier to entry
  - Flexible: enhanced results when more data available
  - Transparent documentation, scientifically rigorous, open source
- Cornell team: Dominic Woolf, Peter Woodbury, Christina Tonitto
- External panel: TNC, EDF

Methods

- Challenging topics considered
  - Leakage
  - Permanence
  - Additionality
  - Verifiability
  - Changing carbon and nitrogen dynamics over time
- C and N mass balance
  - SOM, OM additions, fertilizer additions, leaching & volatilisation, crop uptake, harvest
- Emission factors from comprehensive meta-analysis and literature review
- Default state and county data on soils (SoilGrids), climate (CRU), yield and N rate (USDA)

https://d-woolf.shinyapps.io/FAST-GHG/

FAST-GHG™

Fertilizer And Soil Tool for GreenHouse Gases

A FAST calculator for climate-change mitigation in agriculture

Select state

Alabama

Select county

Barbour

Select crop

- ○ Maize
- ○ Wheat
- ● Soybean

Cover crop type

- ○ None
- ● Legume
- ○ Non-legume
- ○ Mixed

Tillage practice

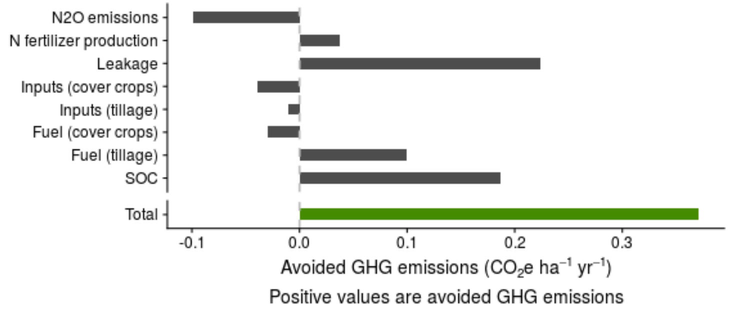
- ○ Conventional
- ○ Reduced-till
- ● No-till

Nitrogen fertilizer practice(s)

- ☐ Model-based optimization
- ☑ Variable Rate Application
- ☐ Improved Timing
- ☐ Other

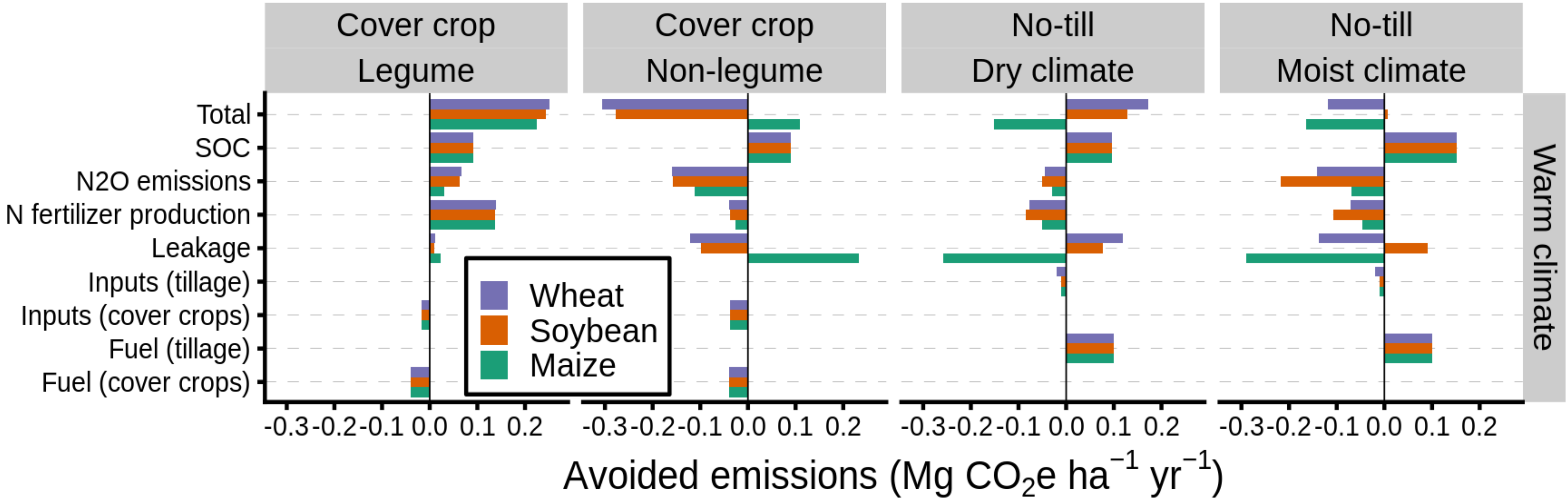
☐ Show advanced inputs

Results | Calculations | About | FAQs



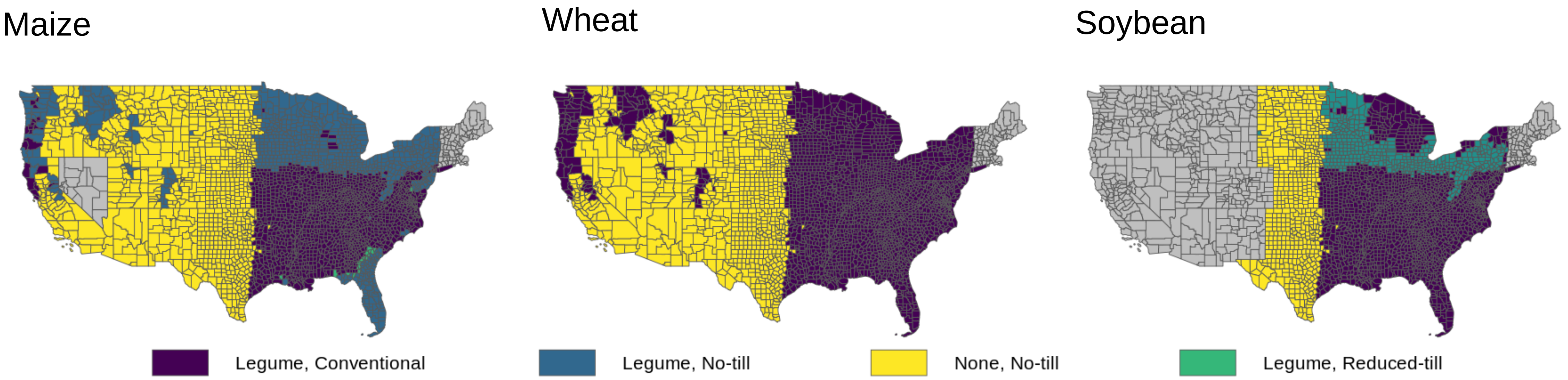
This management results in a net **decrease** in greenhouse gas emissions of **0.37 Mg CO_2-eq ha^{-1} yr^{-1}**, relative to a baseline with no soil-health or fertilizer optimization practices.

Results - facet bar chart



- Reduced N-leaching not sufficient to compensate N locked into new SOM
- N impacts typically larger than C
- High sensitivity to changes in crop yield + high uncertainty
- Net GHG impact of SOC sequestration can be positive or negative (over 100 years)
- Need to select combination of practices with highest benefit (BMP)

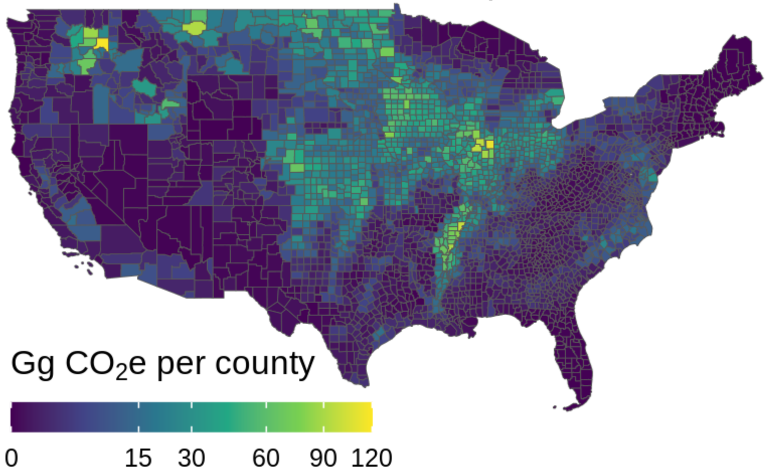
Best Management Practices



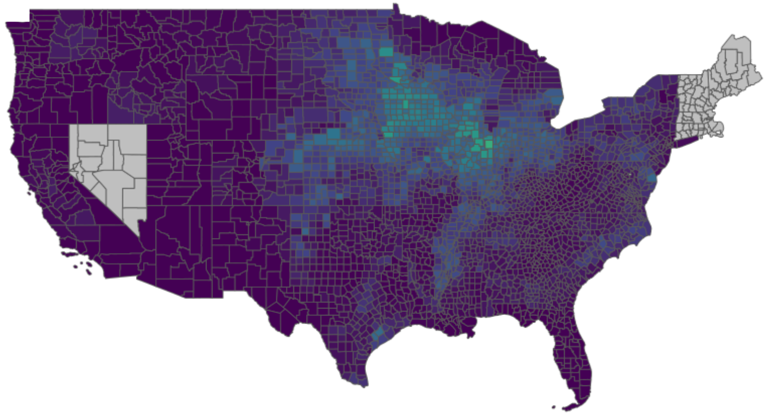
- Cover crops not recommended in dry climates
  - Lower yield
  - Compete for water
- No-till preferred in drier climates
  - Increase yield
  - Conserve moisture
- Legume cover crops typically preferred over non-legume

Results - mitigation per county

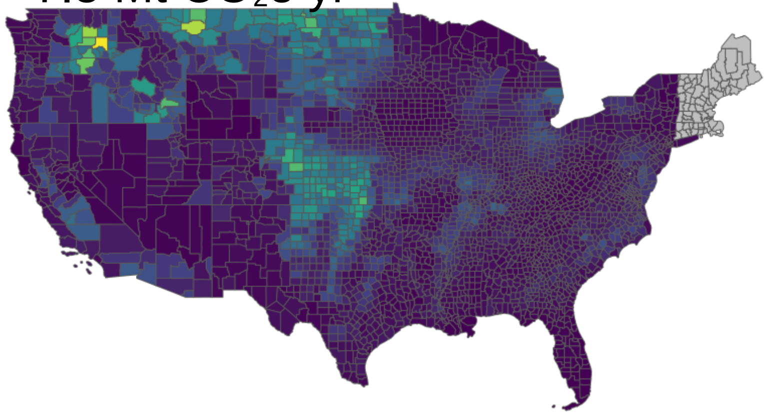
Total 23.4 +/- 4.2 Mt CO_2e yr^{-1}



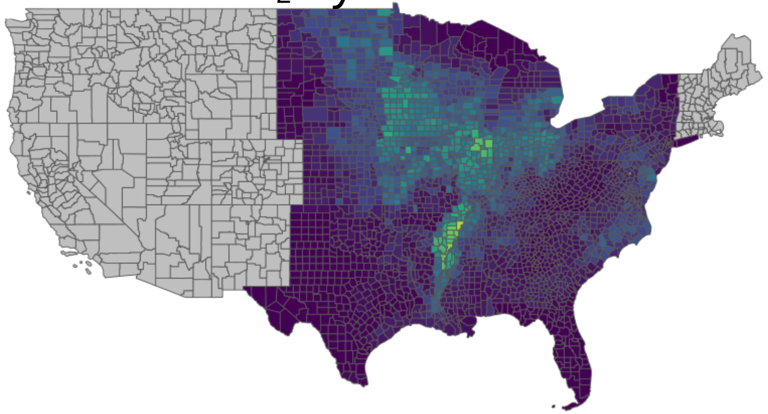
Maize 5.8 Mt CO_2e yr^{-1}



Wheat 7.5 Mt CO_2e yr^{-1}



Soybean 10.1 Mt CO_2e yr^{-1}



Conclusions

- Plus ça change, plus c'est la même
  - We still need to focus on yield and NUE
- Land-sharing vs land sparing
  - Net GHG typically lower with intensification (“sparing”) rather than “sharing”
- But, multiple interactions between carbon sequestration and nutrient cycling impact fertilizer requirements
- Regenerative agriculture can offset around
  - 5% of USA agriculture emissions
  - 0.5% of USA emissions
  - Less than 50% of this from SOC
- Although C sinks are limited they are essential for net zero

Acknowledgements

Soils Revealed:

- Funding: TNC
- Project partners: Cornell, Woodwell Climate Research, ISRIC

FAST-GHG:

- Funding:
  - Cornell Atkinson Center for Sustainability (Project Gigaton)
  - Cornell Institute for Digital Agriculture (development of spatial dynamic SOC model)
- PI's: Dominic Woolf, Peter Woodbury, Christina Tonitto
- External advisory board: TNC, EDF

Thank You!

- Questions