Co-benefits and trade-offs of agricultural soil carbon sequestration

WIMEK-Walailak webinar 29 February 2024

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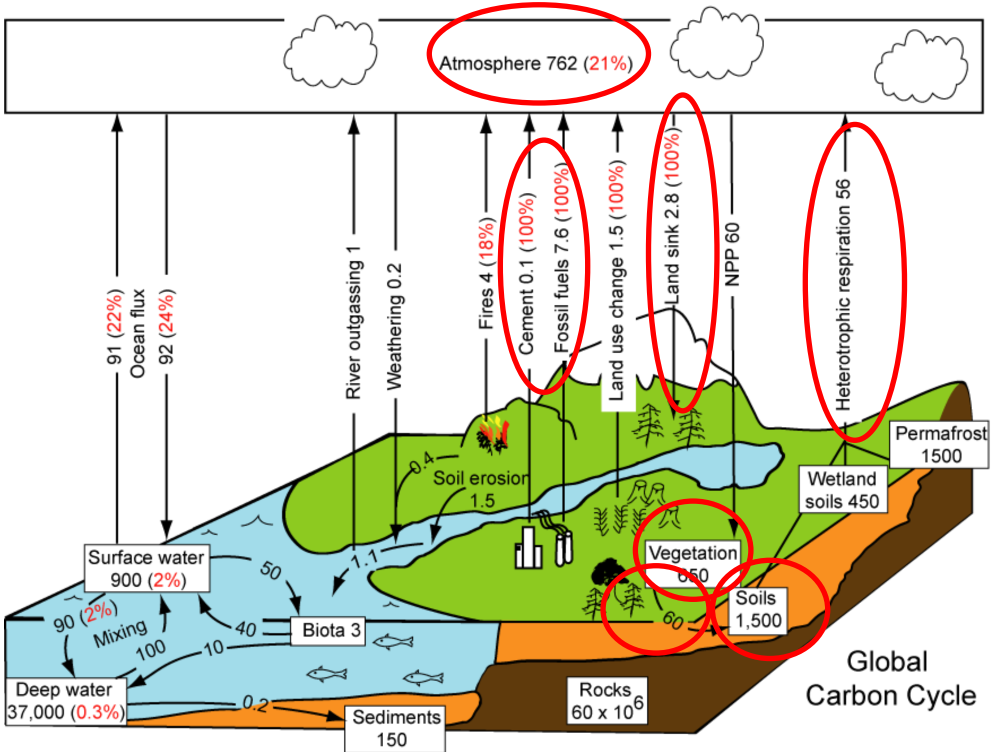
Contents

- Rationale behind agricultural soil carbon sequestration
- Case studies:
    - Soil Organic Carbon sequestration for climate change mitigation and food production
    - Enhanced Rock Weathering: storing carbon in inorganic form
- Take-home messages

Global Carbon Cycle

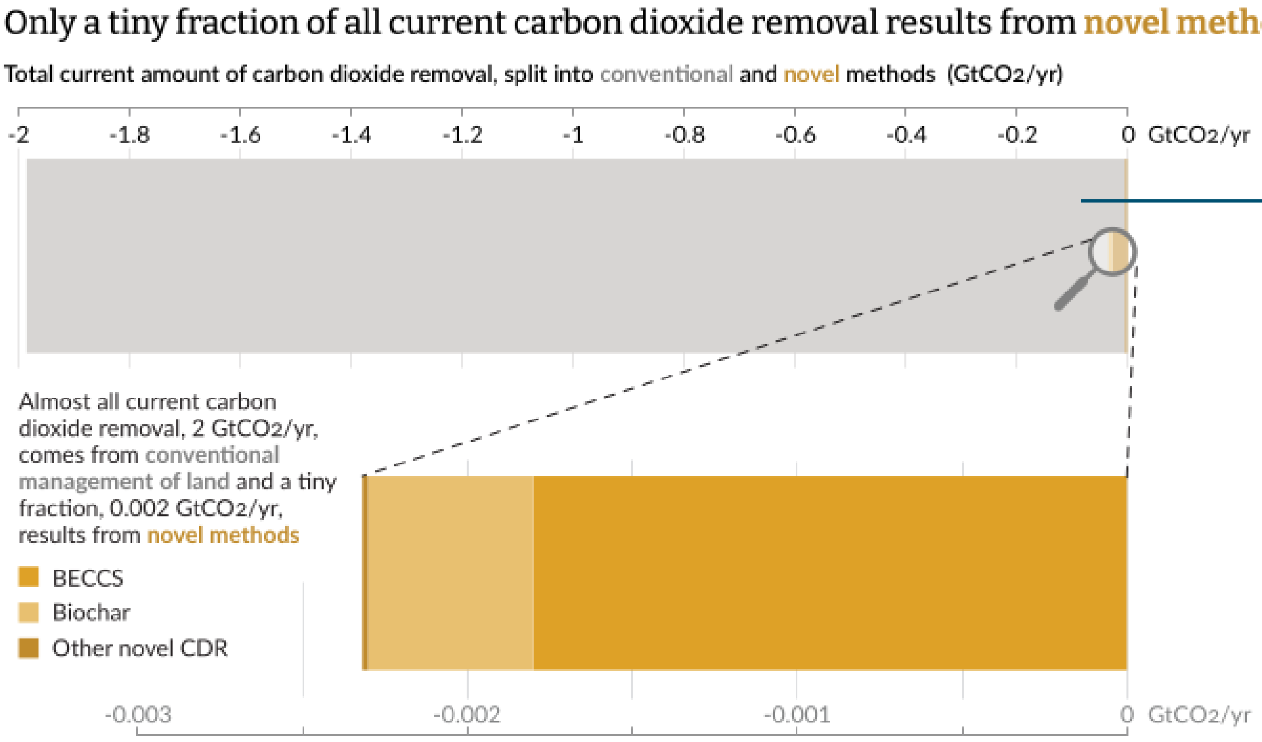


Pools in Pg C, Fluxes in Pg C y^{-1}

Chapin et al., Principles of Terrestrial Ecosystem Ecology, 2012

- Soils store more C than the vegetation and atmosphere combined
- Soil C inputs and losses are an order of magnitude higher than C emissions from fossil fuels and cement production
- A small change in the balance between inputs and losses can have a large impact on atmospheric CO_2 concentrations

Current Carbon Dioxide Removal (CDR)



- Dominantly afforestation / reforestation
- Small part agricultural soil carbon sequestration

Smith et al., The State of Carbon Dioxide Removal, 2023

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Note: 1 Pg C y^{-1} = 3.664 Gt CO_2 y^{-1}

C sequestration related to land management

Forests

- Afforestration / reforestation
- Management of existing forests

Agriculture

- **Soil organic carbon (SOC) sequestration**

Agricultural SOC sequestration

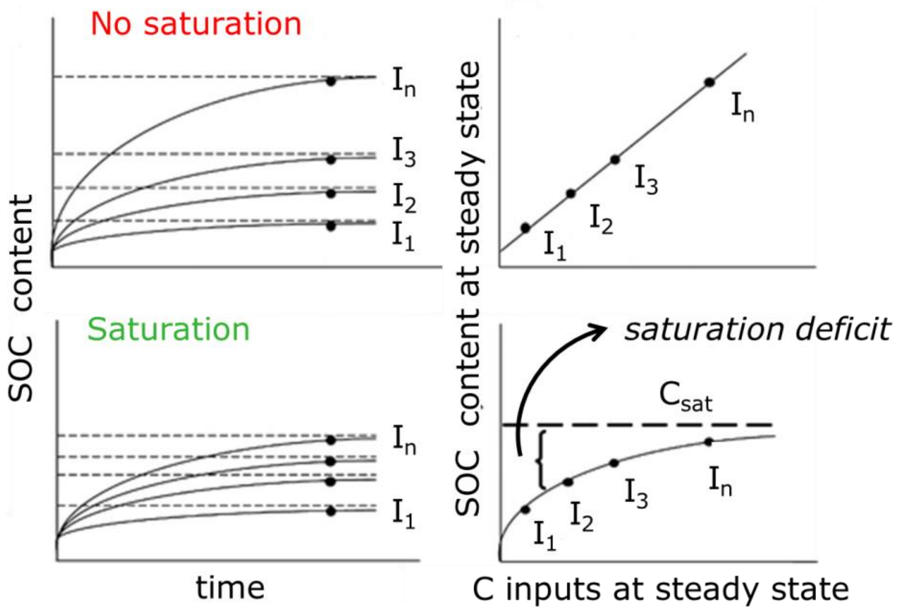
Global potential

- 0.6-9.3 Gt CO_2 y^{-1}

  (Smith et al., The State of CDR, 2023)

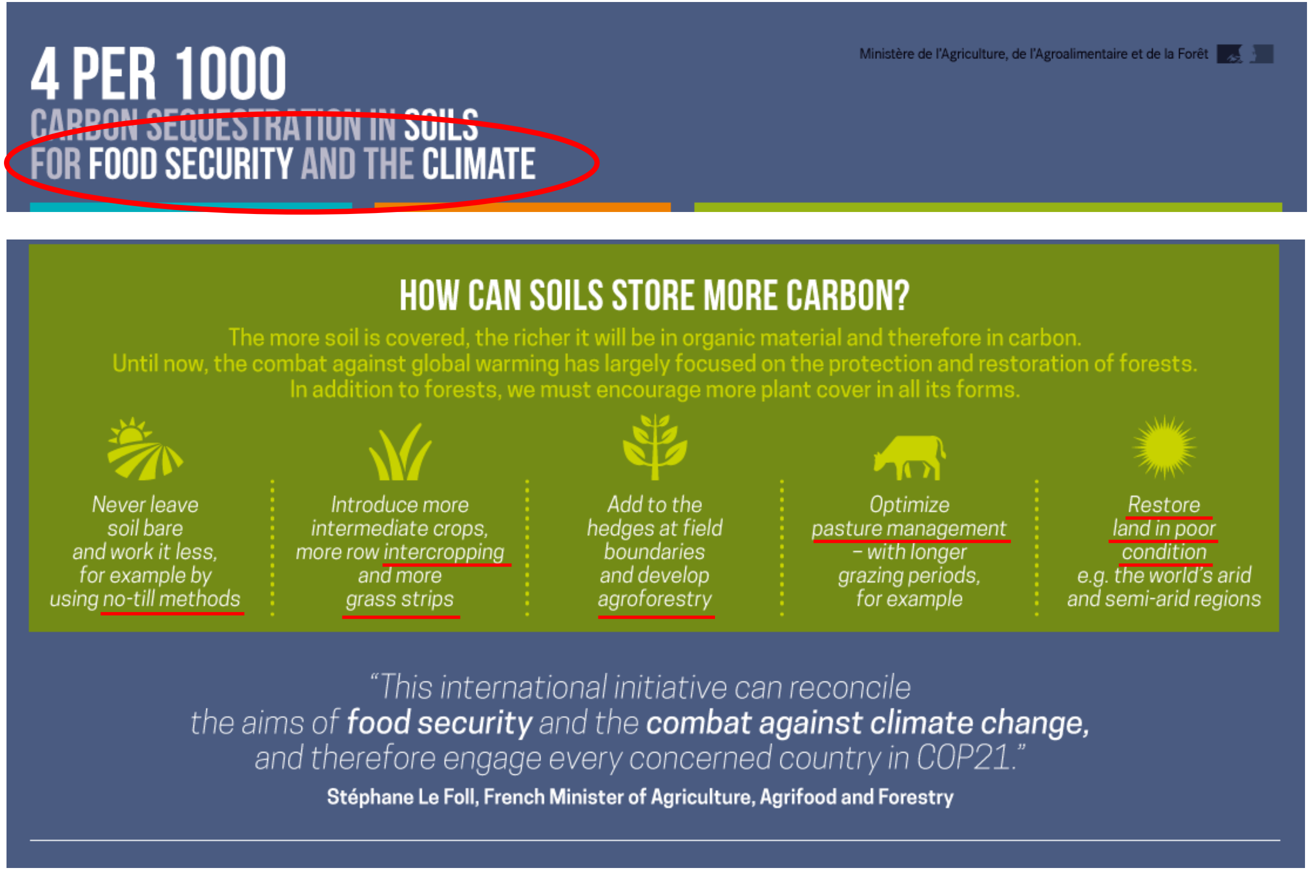
Yet, highly dependent on:

- **Durability** (or permanence): requires long-term continuation of land use and land management practices
- **Saturation**: is there a limit to the amount of SOC a soil can inherently store?



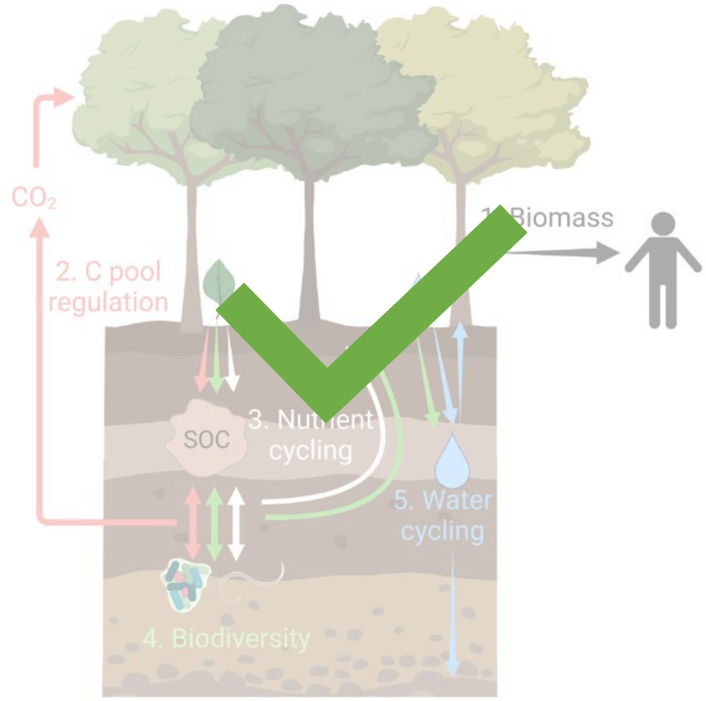
Adapted from Stewart et al., Biogeochemistry, 2007

Which management practices?

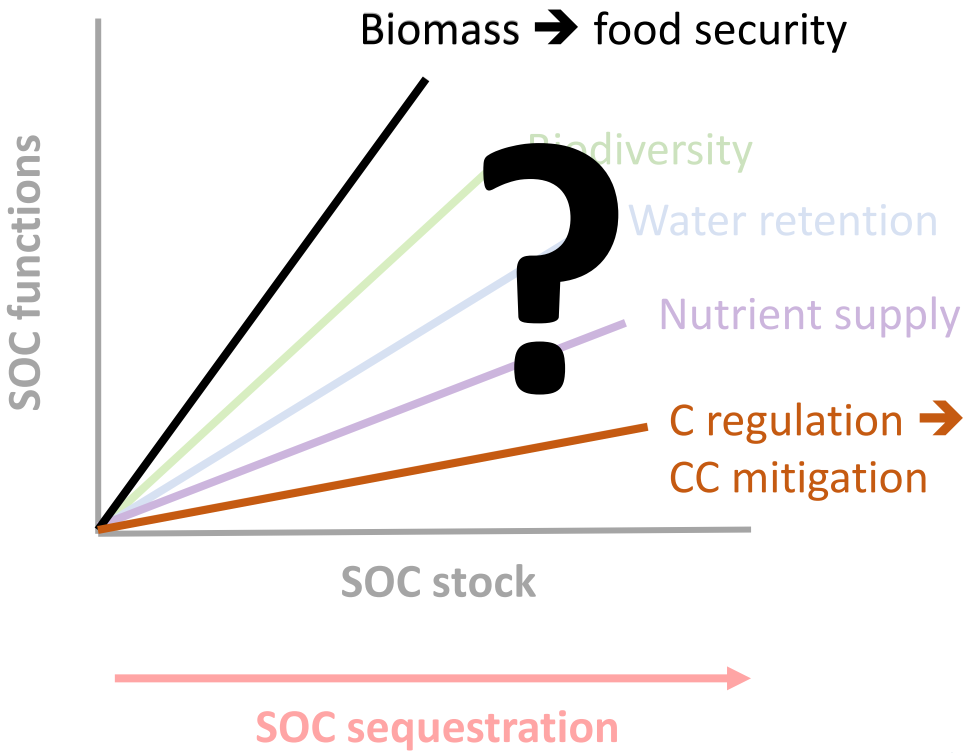


- No-till
- Intercropping
- Grass strips
- Agroforestry
- Grazing management
- Restoration of degraded land

Benefits(?) of global SOC sequestration



Kopittke et al., Critical Rev. Env. Sci. Tec., 2022



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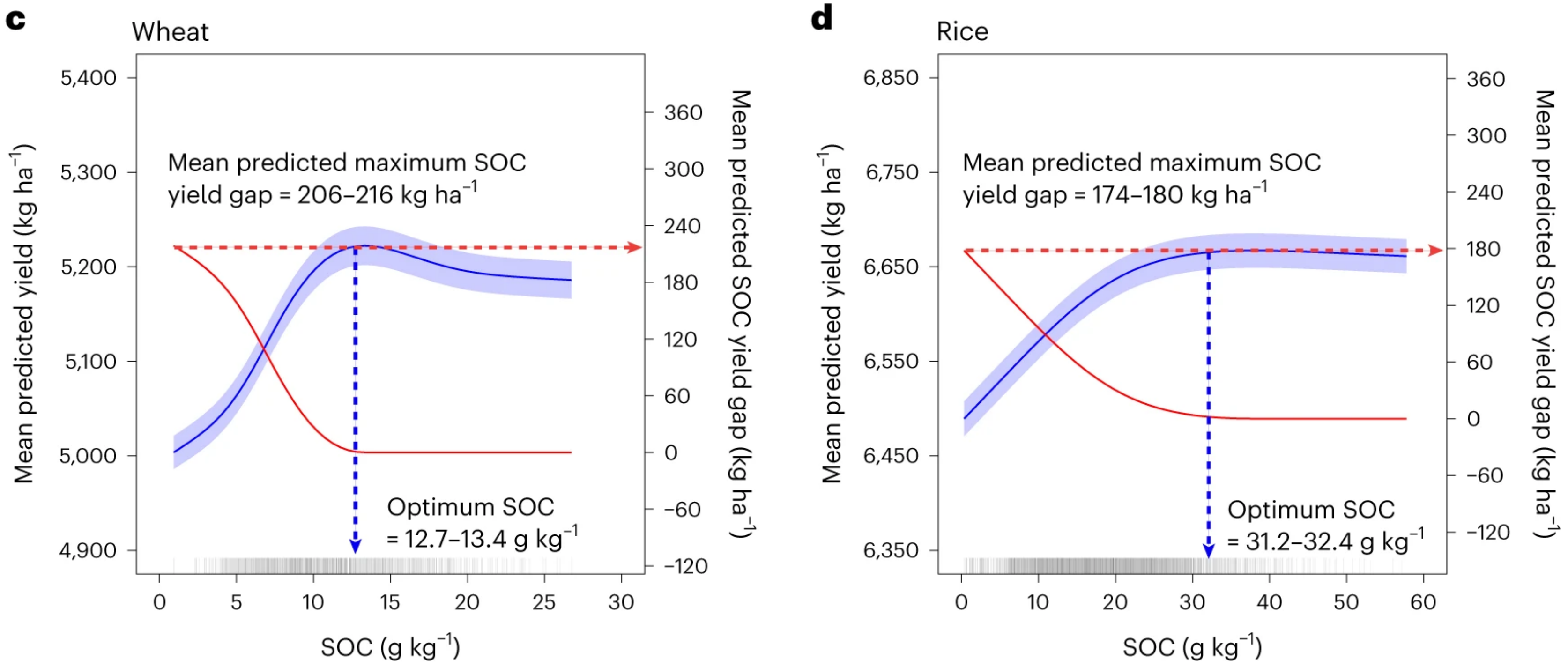
Synergies or trade-offs: it depends…



Ma et al., Nature Geoscience, 2023

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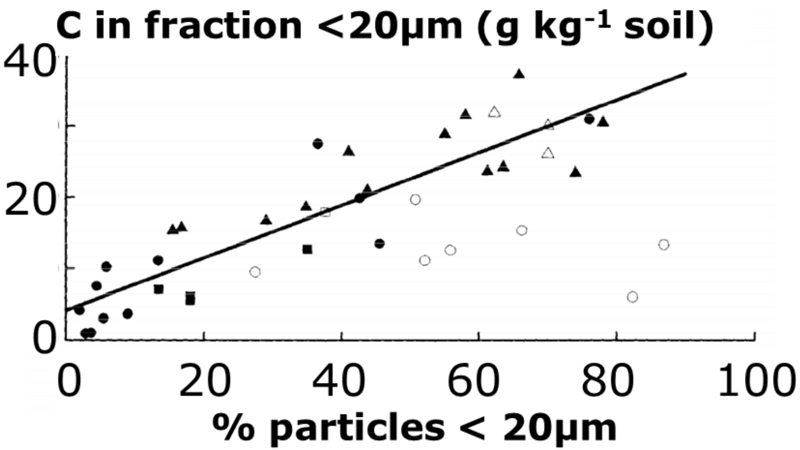
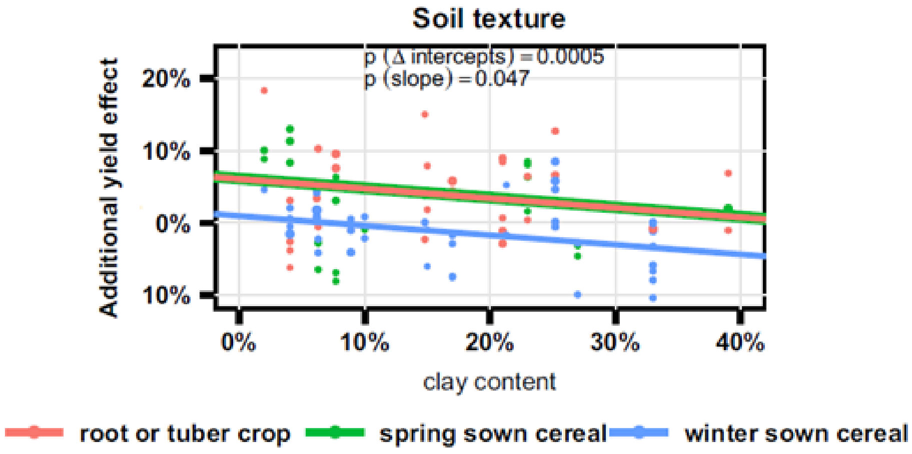
Direction of benefits can be opposite

SOC storage increases with clay content



Hassink, Plant and Soil, 1997

Yield benefit decreases with clay content



Hijbeek et al., Plant and Soil, 2017

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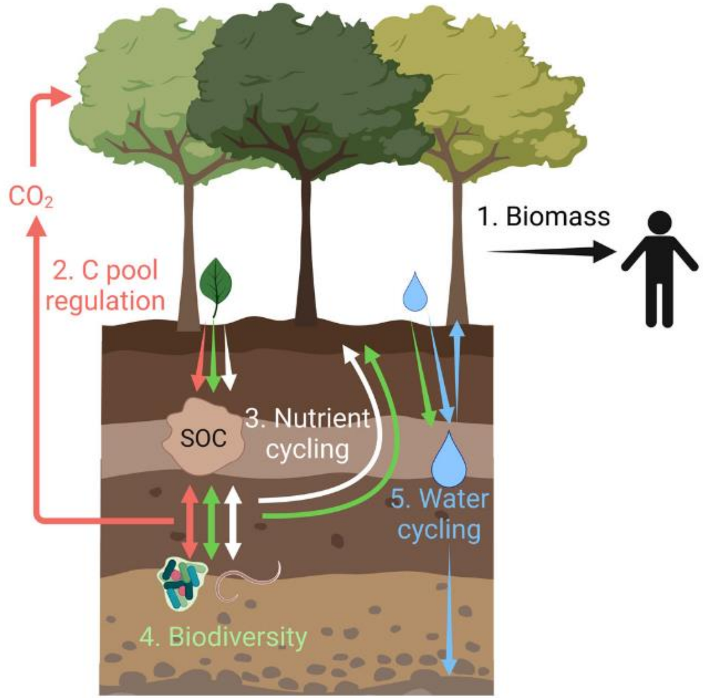
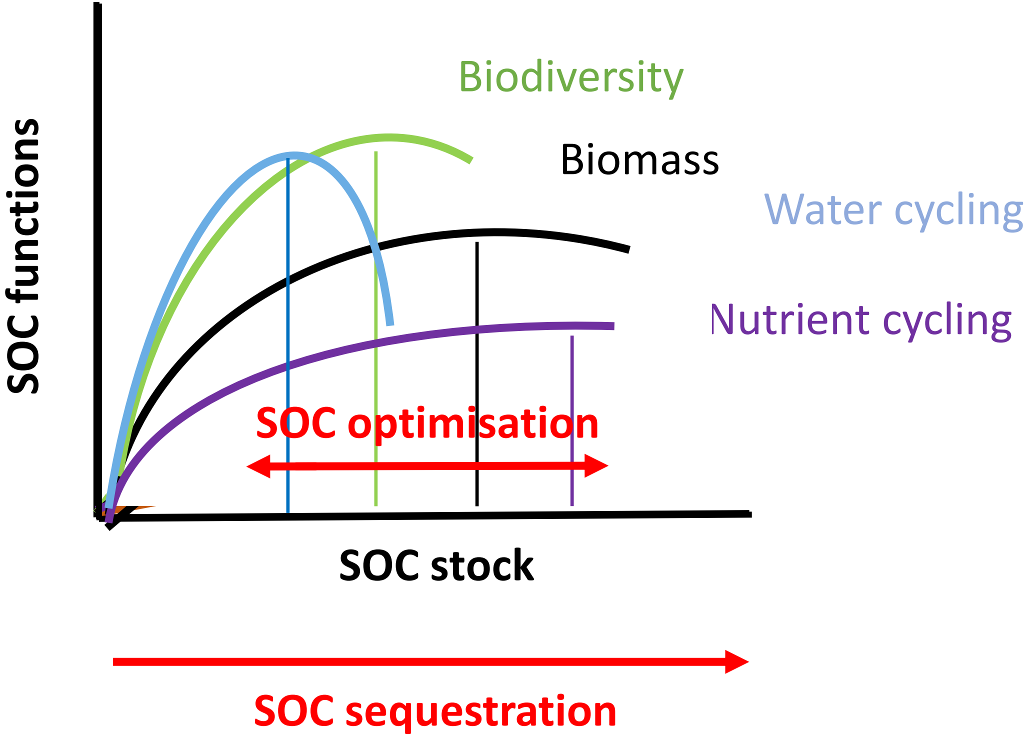
The full picture is more nuanced



Kopittke et al., Critical Rev. Env. Sci. Tec., 2022



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Potential of soil-based Carbon Dioxide Removal

Method	Route of CDR*	TRL	Cost at scale ($/t$CO_2$)	Mitigation potential (GtCO_2/yr)	MRV	Example hazards	Example co-benefits
Enhanced rock weathering	(Geochemical capture via spreading crushed silicate rocks on land or ocean) -> (Storage in minerals or as bicarbonate)	3-4	50 - 200	2-4	Capture: low, no Storage: low, no	Mining impacts; air quality impacts of rock dust when spreading on land. Heavy metal contamination, especially nickel and chromium, from some rock types.	Reduced soil acidity and increased nutrient supply, which can enhance plant growth and soil carbon sequestration.
Afforestation/ Reforestation	(Biological capture via trees) -> (Storage in trees)	8-9	0 - 240	0.5-10	Capture: high, yes Storage: high, yes	Reversal of CDR through wildfire, disease, pests. Reduced catchment water yield and lower groundwater level if species and biome are inappropriate. Finite carbon carrying capacity of land; capacity may be reduced under climate change.	Enhanced employment and local livelihoods, improved biodiversity, improved renewable wood products provision, soil carbon and nutrient cycling. Possibly less pressure on primary forest.
Biochar	(Biological capture via cropping and forestry residues, organic wastes, or purpose-grown crops) -> (Storage in biochar)	6-7	10 - 345	0.3-6.6	Capture: high, yes** Storage: med, yes**	Particulate and greenhouse gas emissions from biochar production; biodiversity and carbon stock loss if from unsustainable biomass harvest.	Increased crop yields; reduced non-CO_2 emissions from soil; resilience to drought.
Soil carbon sequestration	(Biological capture via various agricultural practices and pasture management) -> (Storage in soils)	8-9	-45 - 100	0.6-9.3	Capture: med, yes Storage: low, yes	Increased nitrous oxide emissions due to higher levels of organic nitrogen in soil. Finite capacity of soil to protect organic matter; capacity may be reduced under climate change.	Improved soil quality, resilience and agricultural productivity.
Peatland and wetland restoration	(Biological capture via rewetting and revegetation) -> (Storage in soils)	8-9	Insufficient data	0.5-2.1	Capture: low, yes Storage: low, yes	Increased methane emissions.	Increased productivity of fisheries, improved biodiversity, soil carbon and nutrient cycling.
Agroforestry	(Biological capture via trees) -> (Storage in trees)	8-9	Insufficient data	0.3-9.4	Capture: med, yes Storage: med, yes	Trade-offs with agricultural crop production.	Enhanced employment and local livelihoods, variety of products, improved soil quality, more resilient systems.

Smith et al., The State of Carbon Dioxide Removal, 2023

Durability of soil-based Carbon Dioxide Removal

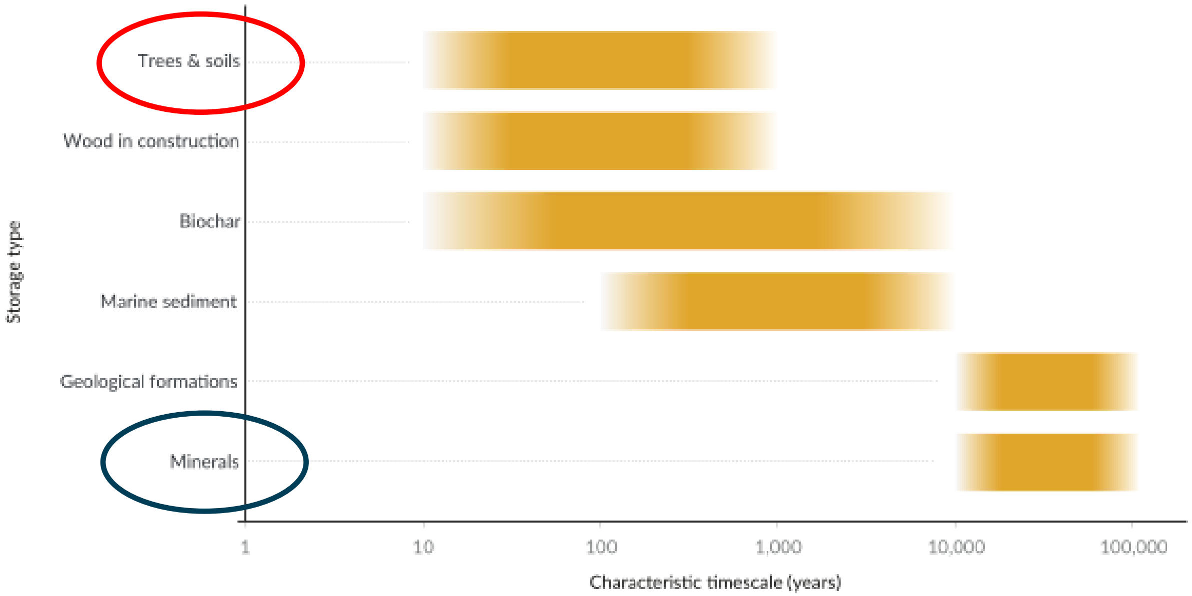
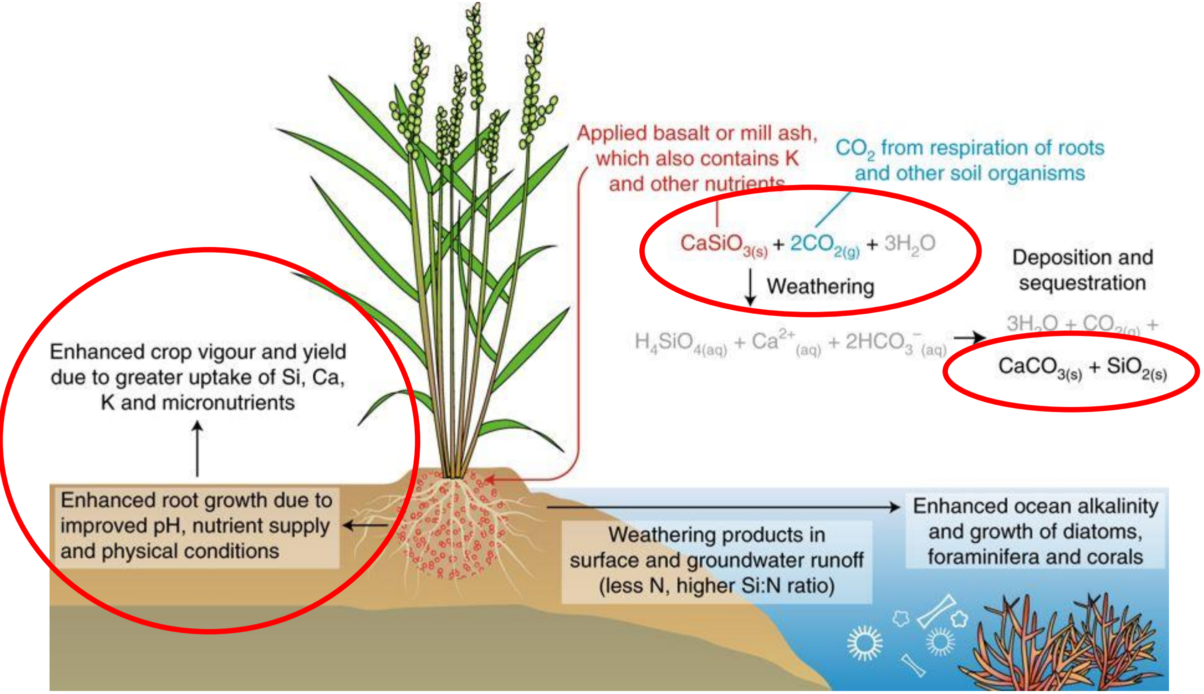


Figure 1.3. *The durability of different carbon storage pools ranges from decades to tens of millennia. Note that these timescales are indicative, assuming no premature disturbance. Source: IPCC WG3 AR6 Chapters 7 & 12*[13,19].

Mineral rock dust

Smith et al., The State of Carbon Dioxide Removal, 2023

Principle of Enhanced Rock Weathering (ERW)



Beerling et al., Nature Plants, 2018

- Consumption of CO_2 via weathering of minerals added to soils
- The formed inorganic carbon may remain in the soil or leach out to oceans and form minerals
- But: what about co-benefits and trade-offs?

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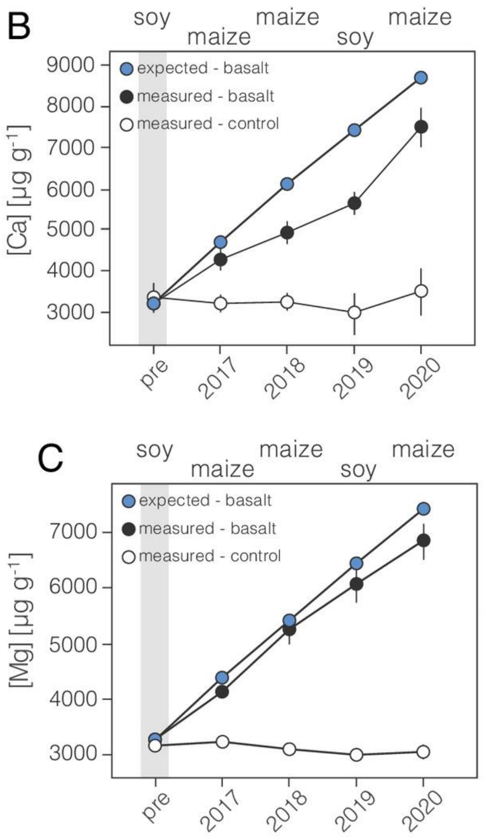
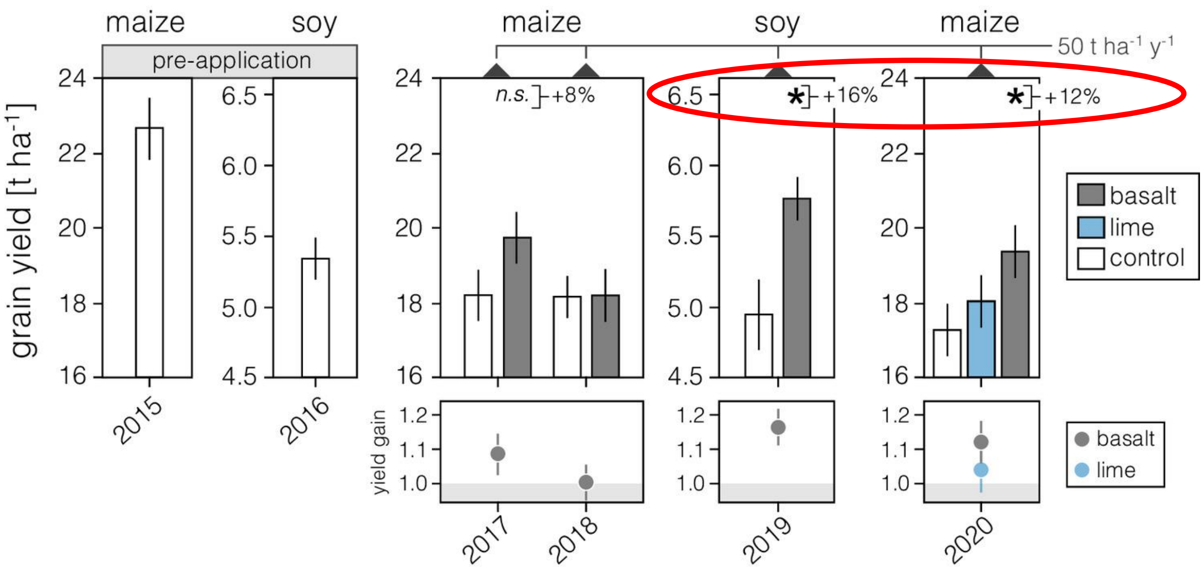
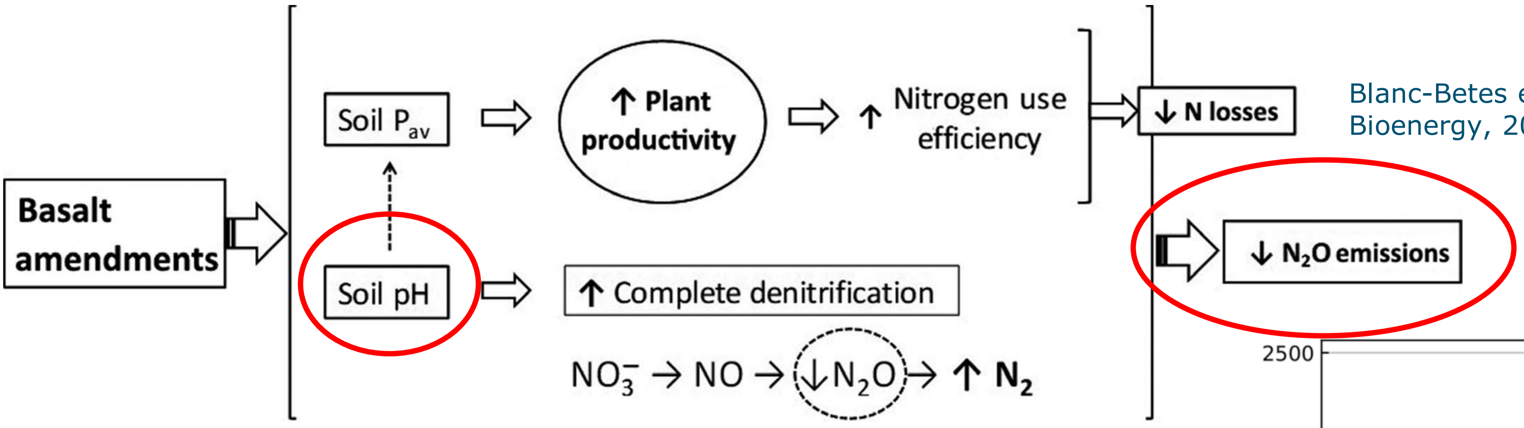
Co-benefits of ERW: increased nutrients & yield



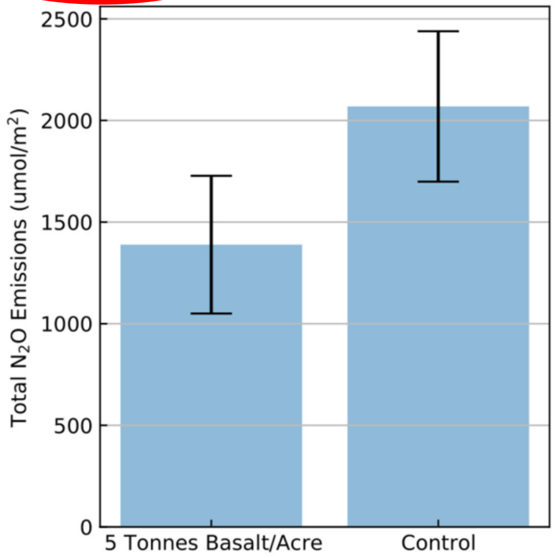


Beerling et al., PNAS, 2024

Co-benefits of ERW: reduced N_2O emissions

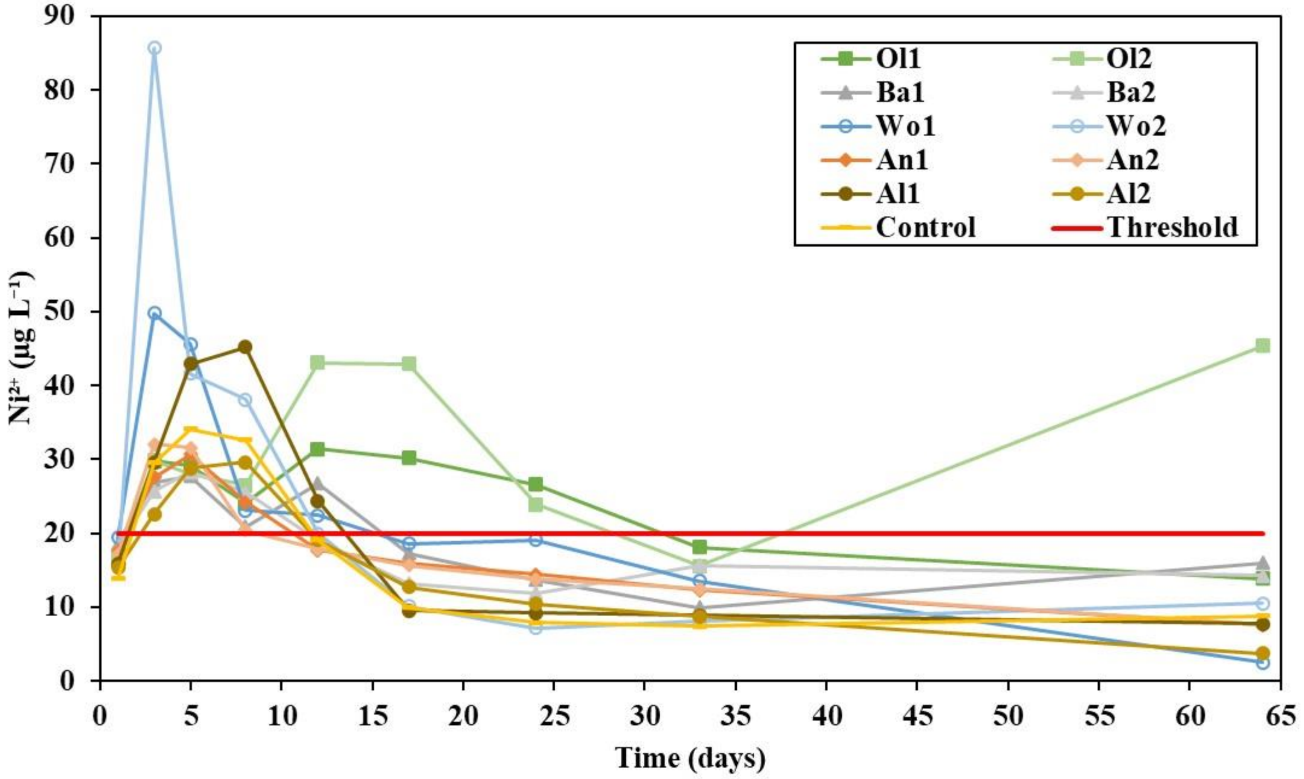


Blanc-Betes et al., Glob. Change Biol. Bioenergy, 2020



Chiaravalloti et al., Front. Clim., 2023

Trade-offs of ERW: enhanced Ni release



Te Pas, Hagens et al., Front Clim., 2023

Take-home messages

- High C sequestration potential in both conventional (SOC sequestration) and novel (biochar, ERW) agricultural CDR methods
- But: understanding and constraining the co-benefits and trade-offs are key to assess the full potential of each method

Acknowledgements

Emily te Pas MSc

PhD candidate at
Soil Chemistry, WUR

Dr Gabriel Moinet

Soil Biology, WUR

Our current long-term ERW experiment in the vicinity of Wageningen

Thank you for your attention!

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