Global soil organic carbon changes with reforestation/afforestation

AUTHORS

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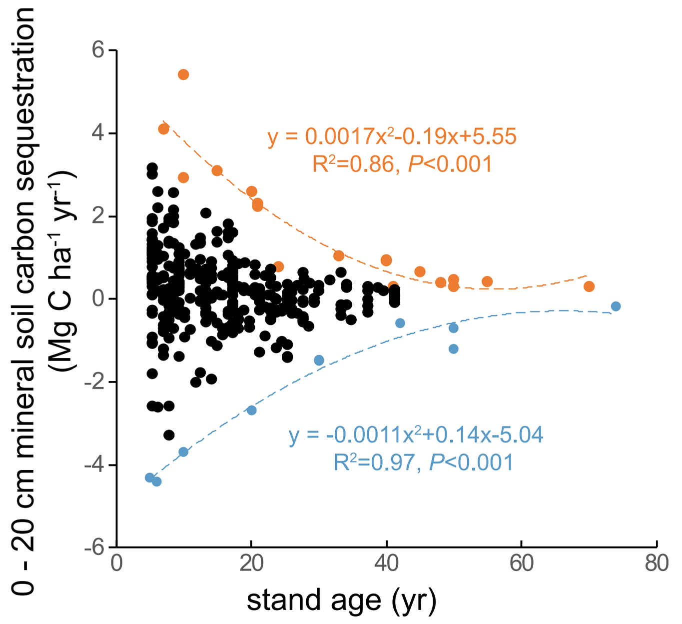
Introduction

Study	Region	Method	Relationship
Janssens et al., 2003	Europe	Inventory/Flux	ΔC stock= 0.43×(AGB+BGB) (Whole profile, Mg C ha^{-1})
Nave et al., 2018	United States	Inventory	C stock= 18.6 + 0.23 Years (0~10cm, Mg C ha^{-1}, R^2 = 0.06) C stock= 21.7 + 0.04 AGB (0~10cm, Mg C ha^{-1}, R^2 = 0.01)
Cook-Patton et al., 2020	Global	Sites	0.42 (0~30cm, Mg C ha^{-1}yr^{-1})
Pan et al., 2011	Global	Model/Sites/ Inventory	0.46~0.50 (0~100cm, Pg C yr^{-1})
Deng et al., 2014	China	Sites	ΔC stock= 9.27+ 0.21×Years (0~20cm, Mg C ha^{-1}, R^2=0.23) C stock=30.65+0.33×Years (0~20cm, Mg C ha^{-1}, R^2=0.08)



Land use is the second largest ***source*** of anthropogenic carbon emissions (*Friedlingstein et al.*,2025) , while ***reforestation*** can increase terrestrial carbon sinks, and soil has huge potential for carbon sequestration in ***natural climate solutions*** (*Bossio et al.*, 2020). The global estimated soil organic carbon density changes (ΔSOCD) are often limited to the **surface** with high uncertainty. It might be due to soil carbon does not always increase in afforestation/reforestation.

1. What are the main factors governing afforesetation/reforestation soil orgainc carbon (SOC) dynamics?
2. How to quantify the relationships between ΔSOCD and environmental variables?

Method

Equivalent soil mass (ESM) method:

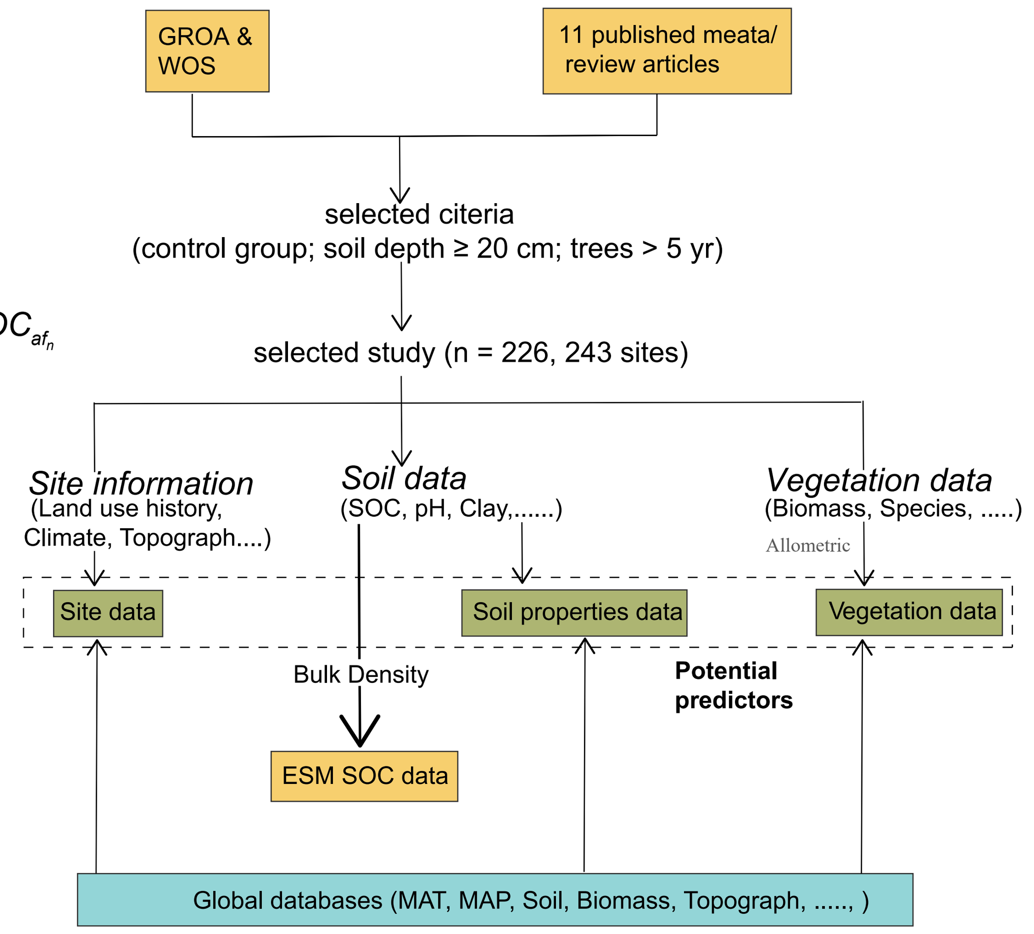
$$SOCD_{corr} = SOCD_{af} + \frac{\left(\sum_{i=1}^{n} BD_{bf_i} \times D_{bf_i} - \sum_{i=1}^{n} BD_{af_i} \times D_{af_i}\right)}{BD_{af_n} \times D_{af_n}} \times SOC_{af_n}$$

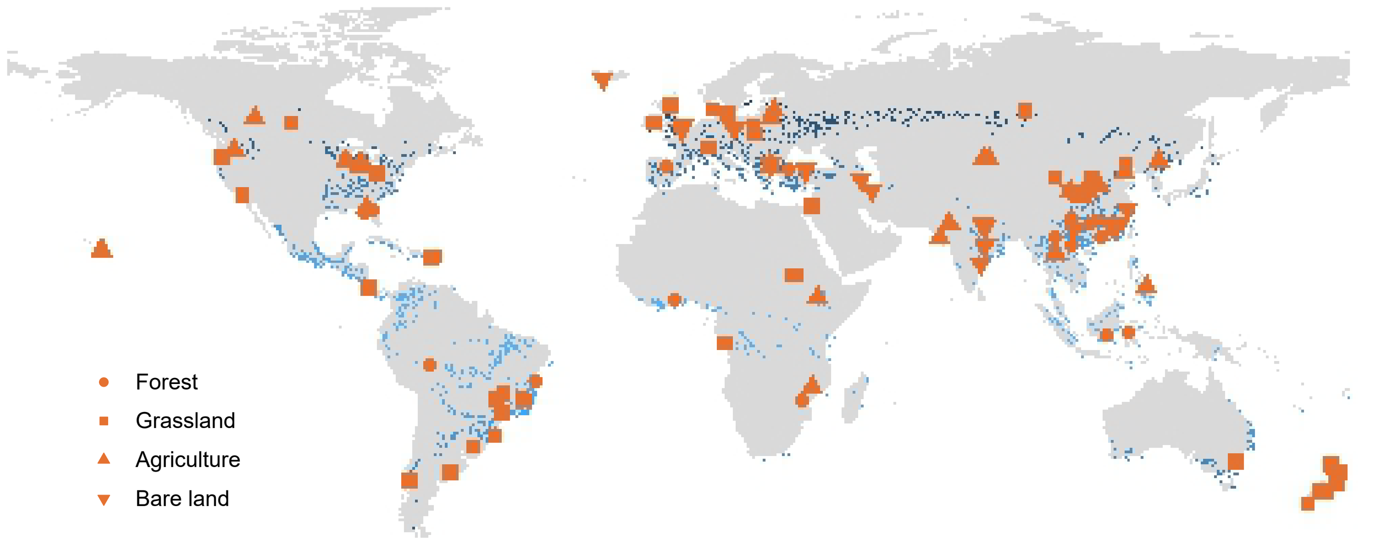
Natural log-transformed response ratio:

$$\ln RR = \ln(\bar{X}_f / \bar{X}_c) = \ln \bar{X}_f - \ln \bar{X}_c$$

Weighting functions:

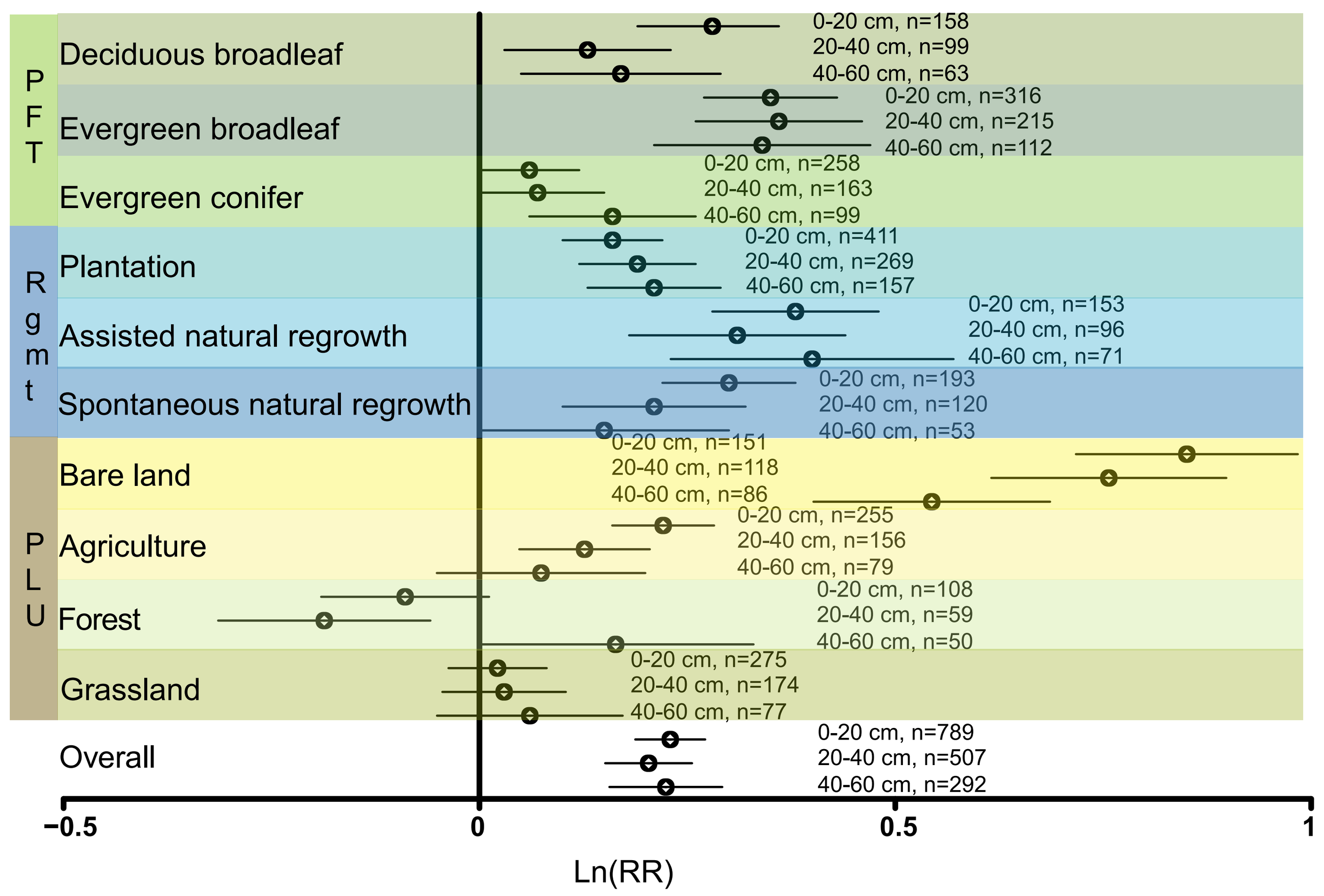
$$W_i = \frac{N_c \times N_f}{N_c + N_f}$$





Result

1. Meta - analysis

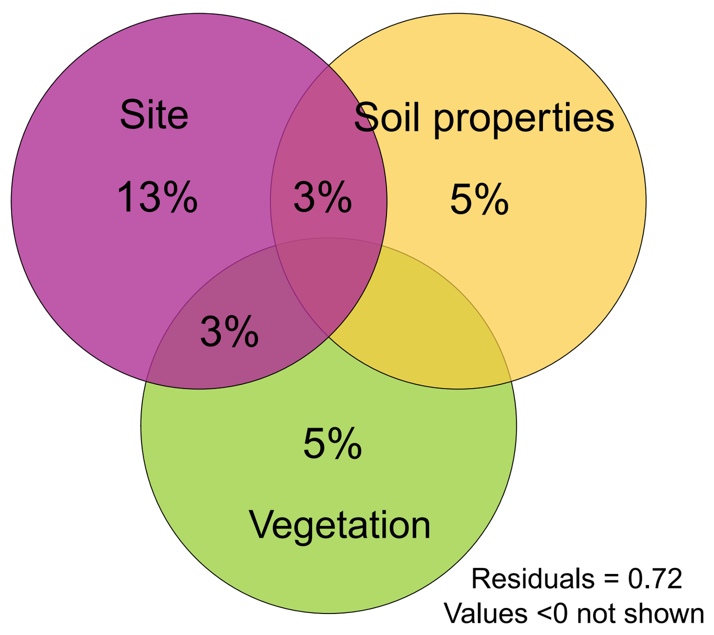


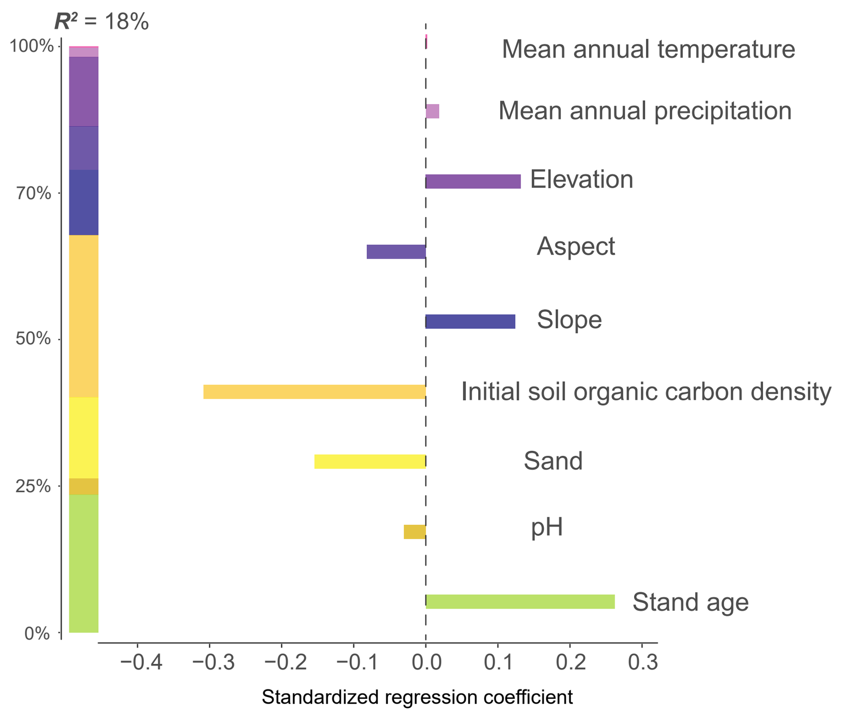
a. ***Evergreen broadleaf forests*** demonstrate superior capacity for soil carbon sequestration compared to coniferous forests, which show little effects.

b. All ***forest restoration approaches*** (e.g., natural regeneration, artificial plantation) contribute positively to SOC storage at 0-60 cm depth, though plantation systems demonstrate relatively weaker soil carbon sequestration effects than alternative approaches.

c. Afforestation/reforestation on agriculture and bare lands leads to significant increases in soil organic carbon density across different soil depths (ranging from **7%** to **85%**), representing a critical pathway for enhancing soil carbon sinks.

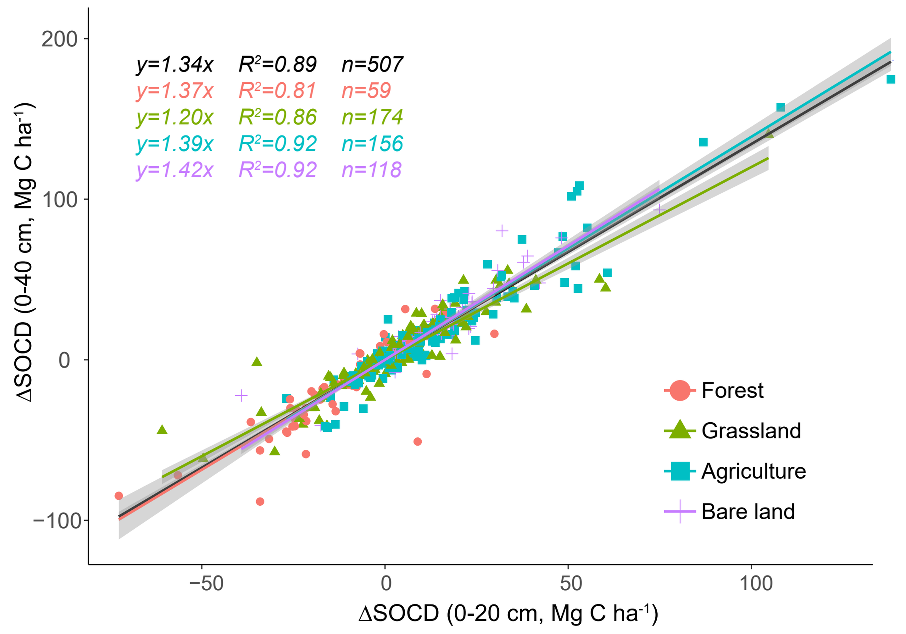
2. Factors driving surface ΔSOCD



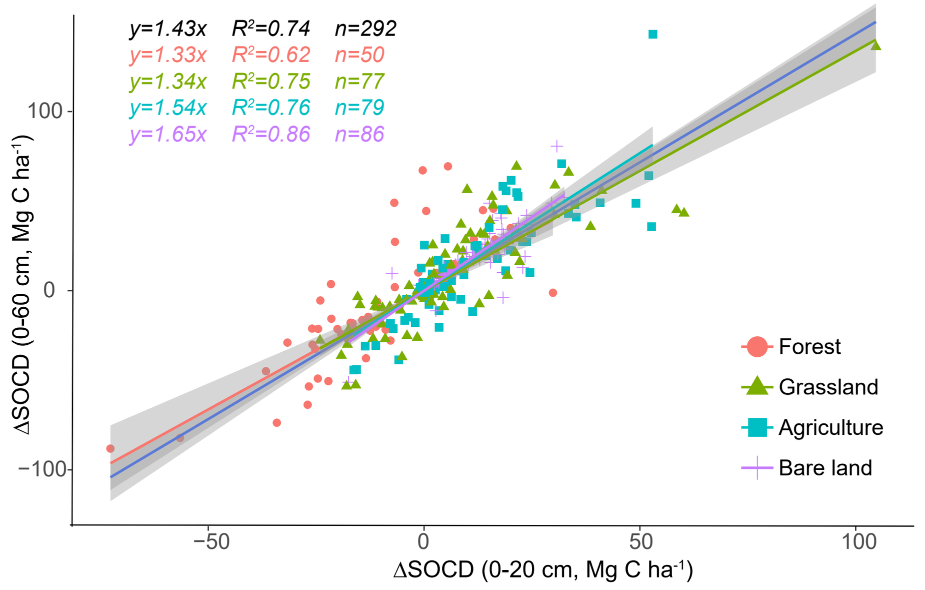


Site information well accounted for ΔSOCD variations compared to soil and vegetation data, with ***categorical variables*** (such as land use and restoration approaches) demonstrating stronger explanatory capacity. Among standardized regression, ***initial soil organic carbon density***, ***stand age***, and ***topograph*** variables exhibited superior explanatory power for ΔSOCD dynamics relative to climatic factors.

3. Correlation between surface ΔSOCD and deeper layers



depth (cm)	0-20			
	Δ SOCD (MgC ha^{-1})		$R_{\Delta SOCD}$ (Mg C ha^{-1} yr^{-1})	
	slope	R^2	slope	R^2
20-40	0.34	0.35	0.55	0.49
20-60	0.43	0.20	0.71	0.23
0-40	1.34	0.89	1.55	0.88
0-60	1.43	0.74	1.71	0.63



a. The 0-20 cm layer dominated ΔSOCD across the 0-60 cm profile, accounting for a predominant proportion of net carbon source-sink effects. However, surface-layer dynamics cannot be directly extrapolated to predict trends in deeper soil horizons (20-60 cm).

b. Afforestation/reforestation on bare lands and agriculture induced substantial soil carbon sequestration, with SOC changes in the 20-60 cm depth exceeding ***50%*** of the variation observed in surface soils (0-20 cm), it highlights the critical role of subsoil carbon pools in soil carbon assessments.

Conclusion

1. Soil carbon accumulation after afforestation/reforestation is strongly influenced by ***plants function types***, where ***broadleaf species*** accelerate soil carbon gains more rapidly than conifer. ***Previous land use*** and ***restoration approaches*** significantly govern surface-layer ΔSOCD.

2. Soil ***clay-silt content*** plays a critical role in the physical protection and stabilization of SOC, with regions characterized by ***lower initial soil carbon density*** exhibiting greater carbon sequestration potential. Assessments of soil carbon sink must be based on extended **temporal scales** (exceeding the rapid growth phase of trees), as short-term observations may fail to capture the full soil carbon sequestration potential.

3. When estimating afforestation/reforestation soil carbon sequestration potential, incorporating **subsoil** contributions (e.g., 20–60 cm depth) is essential to avoid underestimating carbon sink.

Finally, linear regression models exhibit limited explanatory power for ΔSOCD due to their inability to account for multi-factor interactions. Future methodologies should prioritize advanced approaches (e.g., machine learning, process-based modeling) to enhance predictive performance, particularly for large-scale and deep soil carbon estimations.

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