Twelve years of soil monitoring in forests and grasslands to study changes in organic C stocks in topsoils under control of management intensity

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MAIN FINDINGS

- **Increase in soil organic carbon stocks in 0-10 cm in most grasslands and forests plots between 2011 and 2023**
- **Magnitude of soil organic carbon stock increase depends on the initial soil organic carbon stock**

INTRODUCTION & AIMS

Grasslands and forests play an important role in the global carbon (C) cycle and management intensity in grassland and forests influences the uptake and storage of C in soils.

However, long term studies on C stock changes in real world ecosystems and along land use gradients in forests and grasslands are rare. Therefore, it is unclear how management intensity and site conditions influence the long-term C storage.

Here we study the twelve year trends in soil organic C (SOC) stocks in 0-10 cm in 270 grassland and forest plots of the German Biodiversity Exploratories project.

Fig. 1: Location of the Biodiversity Exploratories. Picture: Soil sampling on a grassland plot.

MATERIAL & METHODS

- Soil sampling at 120 grassland and 150 forest plots of the German Biodiversity Exploratories Schwäbische Alb (ALB), Hainich-Dün (HAI) and Schorfheide-Chorin (SCH).
- The topsoil (0-10 cm) was sampled at 14 sampling points per plot with a split tube corer (Ø = 5 cm) in 2011, 2014, 2017, 2021 and 2023. A composite soil sample for each plot and year was prepared.
- Analysis of the SOC concentrations by dry combustion with a CN analyser (VarioMax, Elementar Hanau, Germany) and calculation of SOC stocks using the volume of the corer and the weight of dry soil.
- Forest management effects were studied using the SMI index (Schall and Ammer, 2013). In Grasslands, fertilization as nitrogen (N) per hectare was considered. Grazing livestock included cattle, sheep and horses, which were converted to livestock units.
- The annual SOC stock change (slope of SOC stocks for each plot) was calculated with a linear mixed effects model (R package: lme4). Piecewise Structural Equation Modelling (PSEM) was applied to evaluate the impact of grassland and forest management and soil properties (pH, clay content, dithionite extractable iron, Fe_d) on SOC stocks and their average annual changes.

RESULTS & DISCUSSION

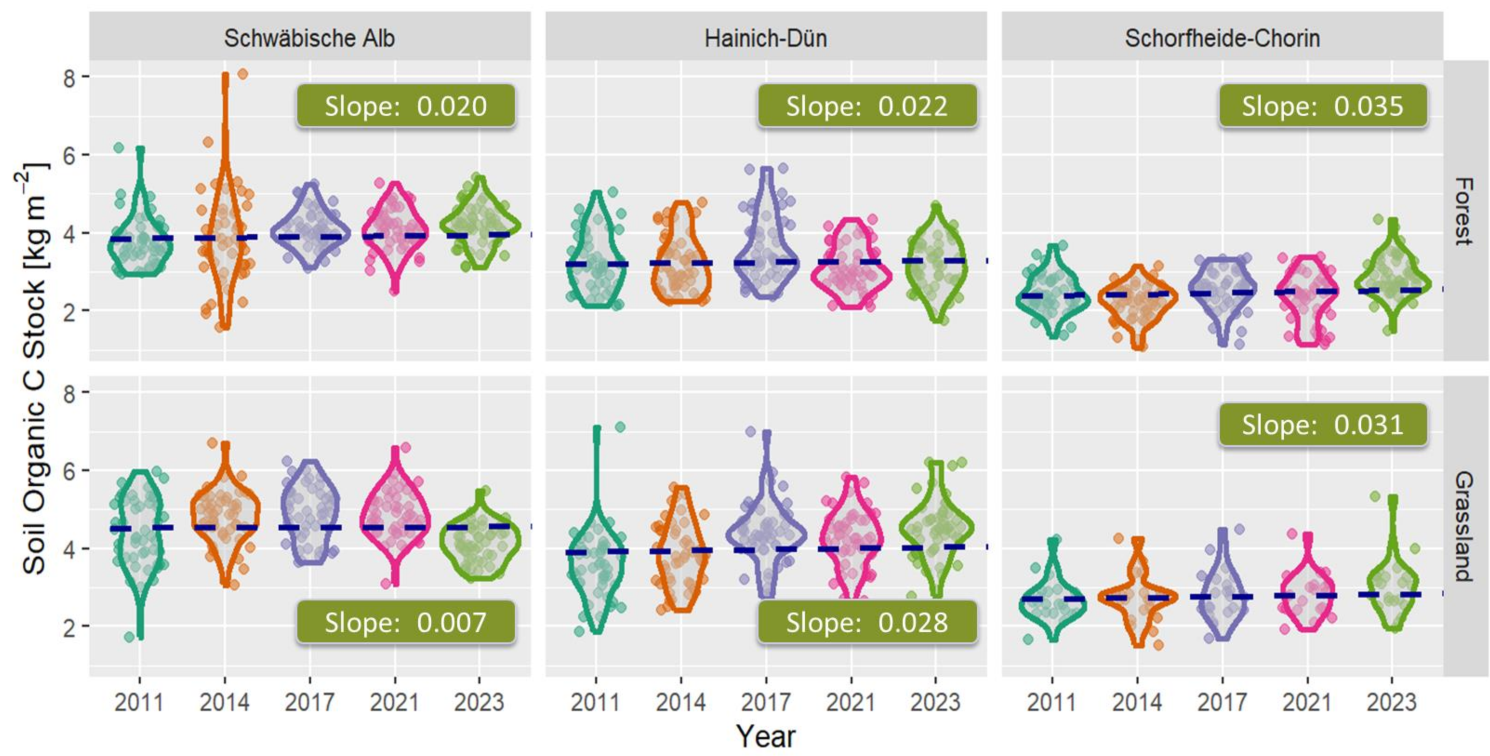

Fig. 2: Temporal changes (2011-2023) in soil organic carbon stocks in 0-10 cm in forest and grasslands of the Schwäbische Alb (ALB), Hainich Dün (HAI) and Schorfheide-Chorin (SCH).

Results of a linear mixed effects model are shown as dashed blue lines in the plot; the blue lines show the average slope of 50 plots per Exploratory and land use (Exception: Schorfheide-Chorin grassland n = 20)

- Lowest soil organic carbon (SOC) stocks in 0-10 cm in SCH. Highest SOC stocks in HAI and ALB (Fig. 2)
- Overall, SOC stocks have increased significantly in most of the forest and grassland plots during the 12-year period from 2011 to 2023 (p<0.01) (Fig. 2).
- No direct effect of land management on annual changes in SOC stocks. Annual changes in SOC stocks were strongly negatively correlated with the mineral soil OC stocks (Fig. 3 and 4). SOC stock change depended on how much C the soil has already absorbed, i.e. to what extent the maximum C storage capacity has been reached → C poor soils are less limited by saturation of the mineral surfaces (Manzoni & Cotrufo, 2024).

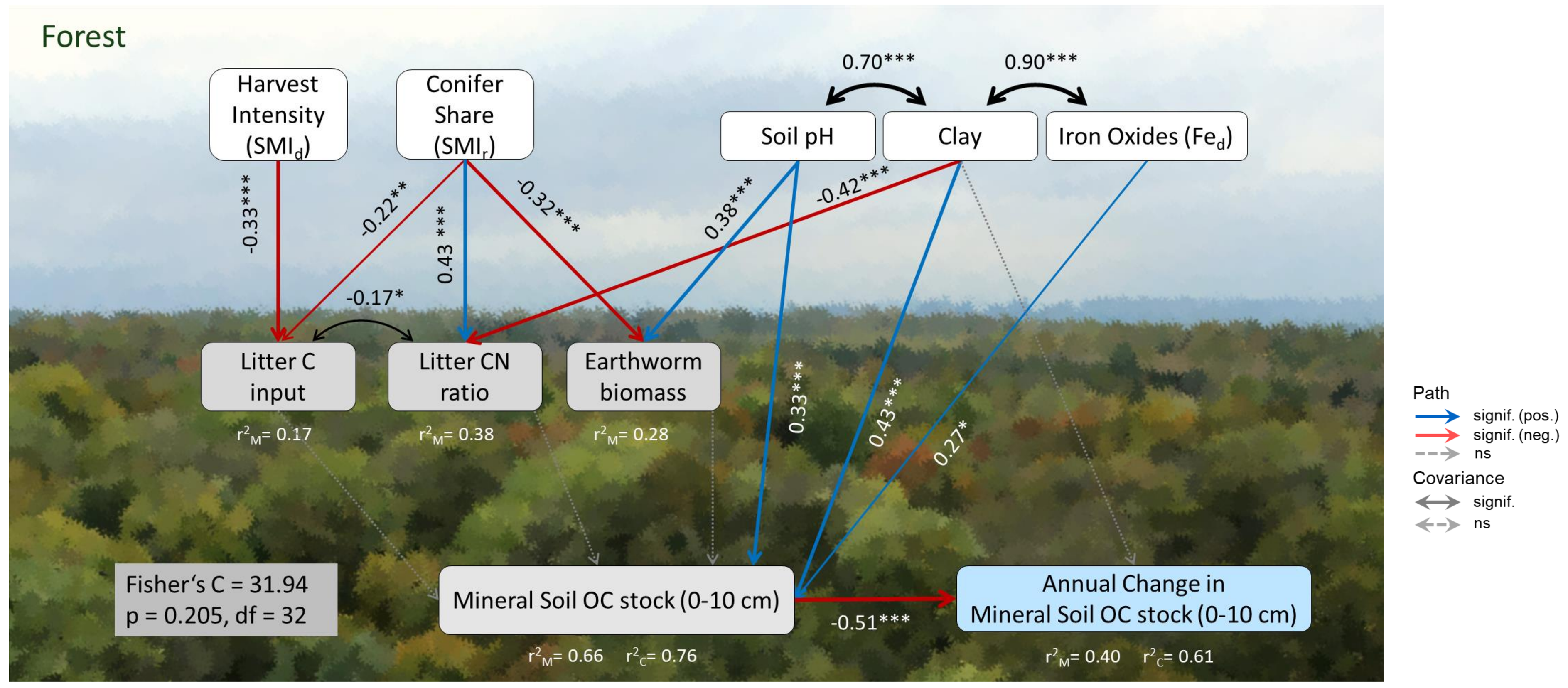

Fig. 3: Piecewise SEM showing the direct and indirect effects of harvesting, tree species selection, soil pH, clay, dithionite extractable iron (Fe_d), on the soil organic carbon stocks in 0-10 cm in forests; random factor = study region; values on arrows are standardized coefficients (β) with significance level (p<0.001 (***), p<0.01 (**), p<0.05 (*); variance explained by fixed effects = r^2_M, variance explained by fixed + random effects = r^2_C; Fisher's C and p-value indicate the goodness of fit of the model

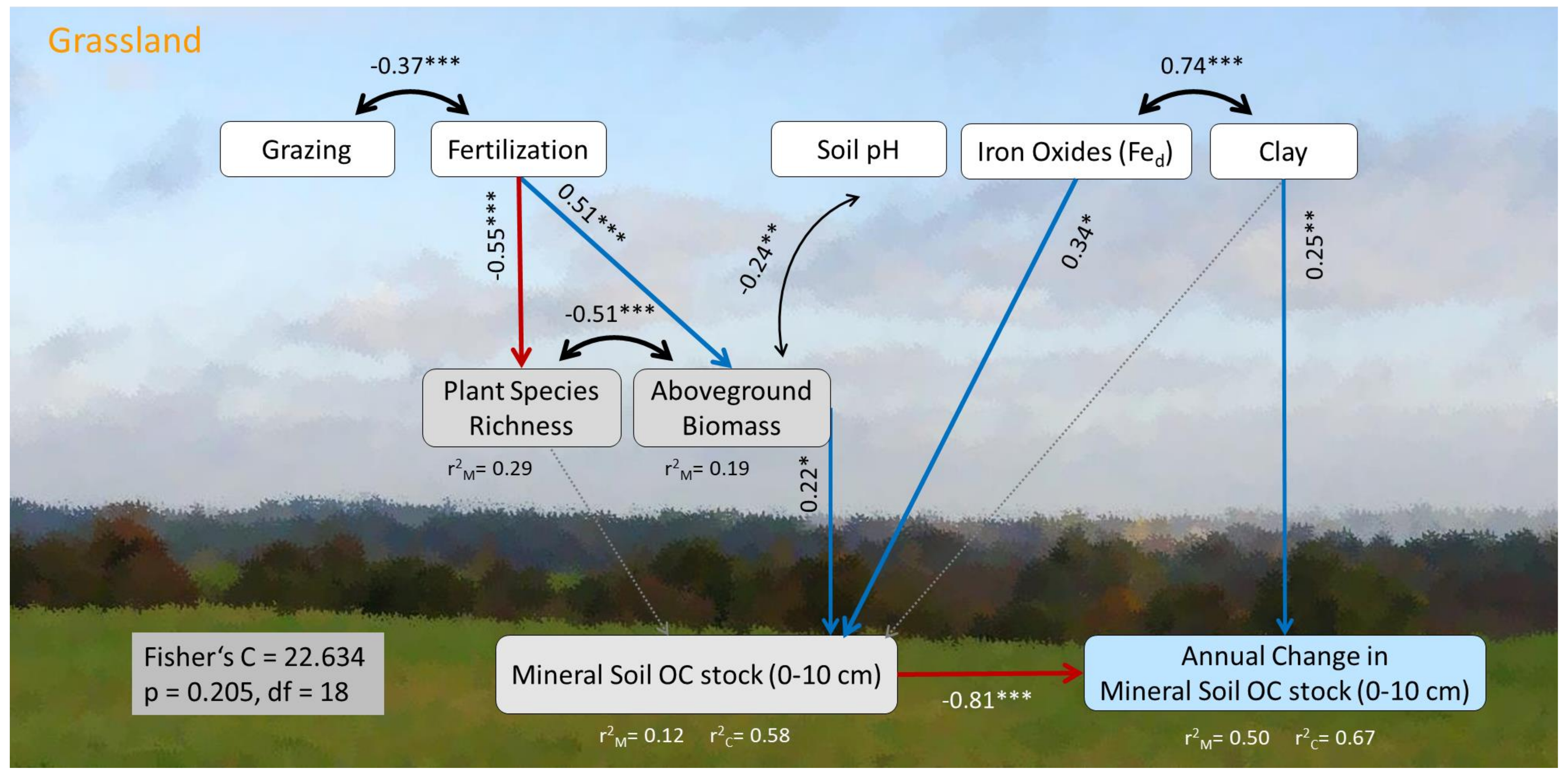

Fig. 4: Piecewise SEM showing the direct and indirect effects of grazing, fertilization, soil pH, clay, dithionite extractable iron (Fe_d), on the soil organic carbon stocks in 0-10 cm in grasslands; random factor = study region; values on arrows are standardized coefficients (β) with significance level (p<0.001 (***), p<0.01 (**), p<0.05 (*); variance explained by fixed effects = r^2_M, variance explained by fixed + random effects = r^2_C; Fisher's C and p-value indicate the goodness of fit of the model.

CONCLUSIONS

- SOC stocks in 0-10 cm increased over the period 2011-2023, probably due to global change factors (e.g. extended vegetation period due to increasing temperature, nitrogen deposition, elevated CO_2) → **If studying long-term land management effects on SOC stocks global change factors need to be considered.**
- In both ecosystems the annual change in SOC stocks were higher at sites with lower initial SOC stocks while the initial SOC stocks were mainly driven by abiotic site conditions → **Soils with higher SOC stocks could be increasingly SOC saturated. C sequestration potential of C poor soils might be higher than that of C rich soils.**

REFERENCES

- Manzoni, S. and Cotrufo, M. F. (2024): Mechanisms of soil organic carbon and nitrogen stabilization in mineral-associated organic matter – insights from modeling in phase space. Biogeosciences, 21, 4077–4098, https://doi.org/10.5194/bg-21-4077-2024
- Schall, P. and Ammer, C. (2013): How to quantify forest management intensity in Central European forests. European Journal of Forest Research 132 (2013): 379 - 396.