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Projected soil carbon dynamic in Hesse forests under climate change: sink or source by the end of the century?

Motivation

Forest soils represent a large carbon pool and therefore have a critical role in the global carbon cycle[1]. Changes in this pool due to climate change may potentially alter their sink capacity. To predict the future dynamic of soil organic carbon (SOC) and the mitigation potential of forests against climate change is crucial for decision-making and policy. To respond at these demands field observations[2] only are not enough and thus well-validated model are needed[3].

Approach

- Yasso20[4-5] model validation:
  a. 135 National Forest Soil Inventory sites (NFSI) of Hesse;
  b. 16 intensively monitored sites (Level-II).
- SOC projections (organic layer + mineral soil up to 90 cm depth) until 2099 using:
  a. No climate change;
  b. RCP 8.5 scenario (7 projections);
  c. RCP 8.5 + whole-tree harvest (i.e. total biomass harvest above ground) from 2025.
- Carbon input estimation:
  a. harvest residues and branch turnover from yield tables (dyn-ET[6]);
  b. litterfall by a newly statistical model (poster Heitkamp et al.),
  c. Fine root turnover proportional to foliage litterfall[7].

Results

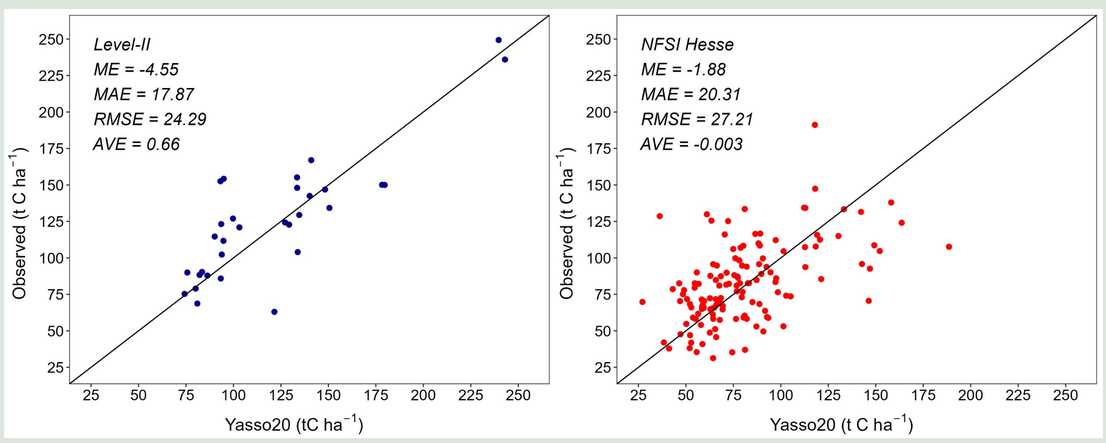

Figure 1: Comparison of measured (NFSI: n=135 sites and Level-II: n=16 sites) and modelled (Yasso20) soil carbon stocks of organic layer and mineral soil down to 90 cm soil depth. ME: bias, MAE: mean absolute error, RMSE: root mean square and, AVE: amount of variance explained.

- **Level II**: Yasso20 was well suited to predict SOC stocks of individual sites (AVE: 0.66, Fig. 1).
- **NSFI**: Low AVE (AVE: 0.00) indicated that SOC predictions for individual sites should be avoided → Uncertain projections due to incomplete inventory data to estimate C inputs and lack of observed time-series.
- Annual SOC stock changes were slightly underestimated by Yasso20 (0.18 ± 5.84 t C ha^{-1} a^{-1} Yasso20 vs. 0.31 ± 26.6 t C ha^{-1} a^{-1} NFSI II).

- **CON**: Without climate change, SOC stock is predicted to increase to 84.5 t C ha^{-1} by 2099 (Fig.2);
- **CC**: SOC stocks are estimated to increase until 2040 and to decline to 78.9 ± 21.9 t C ha^{-1} afterwards under RCP 8.5 scenario.
- **CC + whole-tree**: Considering country-wide whole-tree harvesting with climate change, a high SOC loss is predicted by the end of the century (to 74.8 ± 21.9 t C ha^{-1}).

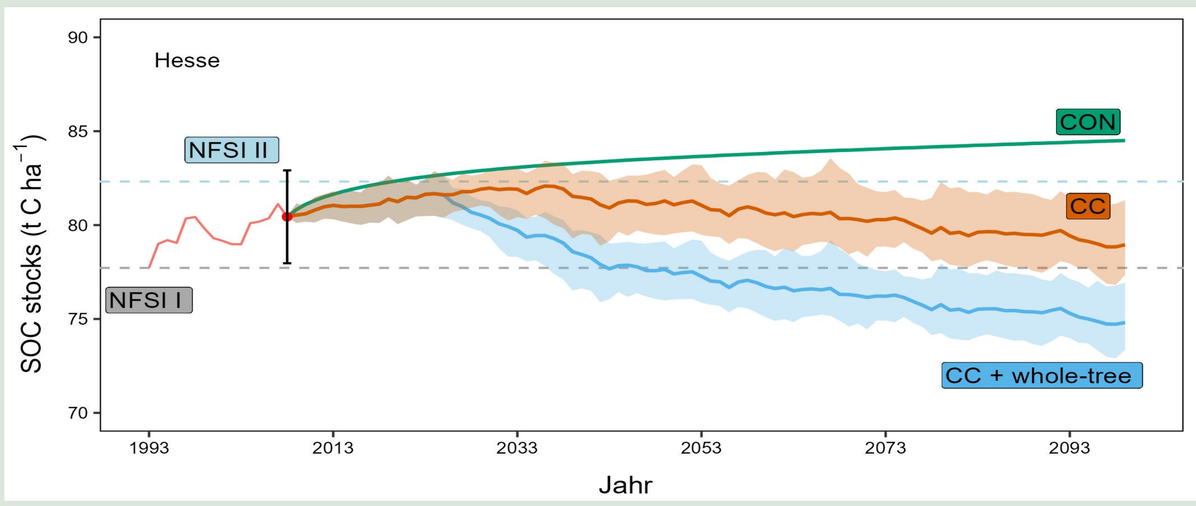

Figure 2: Mean carbon stocks for Hesse in the period from NFSI I and II (red line) and up to 2099. CON (green line): no future climate change based on repeated climate data 1960-1990, CC: climate change under RCP8.5 scenario, CC + whole-tree: climate change under RCP8.5 in combination with whole-tree harvest from the year 2025. Orange and blue area: Range of the seven climate scenarios of the RCP8.5.

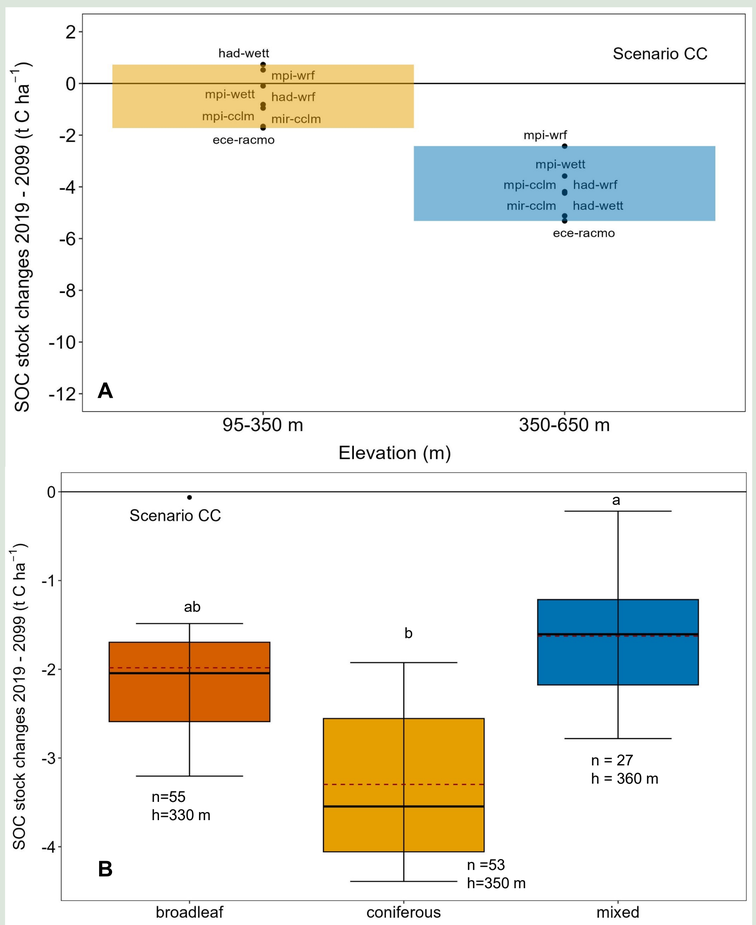

Figure 3: Organic carbon stock changes of Hesse in the organic layer + mineral soil down to a depth of 90 cm from 2019-2099 under (**A**) two different elevation classes: 95-350 m (n=94) and 350-650 m (n=41) and, (**B**) various forest types for the RCP 8.5 scenario. (**B**) Forest types with different letters are significantly different ($p < 0.05$, tested by ANOVA and the attended Tukey HSD test for each forest type group individually). h: is the median elevation among the sites.

Under climate change (**CC** Scenario, Fig. 3A and B) in Hesse:

- Moderate SOC losses observed in forest soils at high elevations (350-650 m).
- Below 350 m neither high C losses nor gains are predicted.
- Apart from the broadleaf forest stands, soils in coniferous forest at high elevation (h: 350 m) are predicted to lose significantly more C than in mixed forest.

Conclusions

- Current management practice and annual C inputs to forest soils in Hesse are insufficient to compensate for climate change effects (RCP 8.5), losing their sink function and likely turning into net-sources of CO_2 compared to the NFSI II.
- Under the RCP 8.5 scenario, the effect of whole-tree harvesting is of similar magnitude as the effect of climate change.
- The risk of becoming a net C source is higher in the Hessian forest soils with coniferous stands at high altitudes (> 350 m).

References: 1) Batjes, N.H., (1996), DOI: 10.1111/j.1365-2389.1996.tb01389. 2) Schrumpf, M. et al. (2011), DOI: 10.5194/bg-8-1193-2011. 3) Ziche D. et al. (2019), DOI: 10.1016/j.scitotenv.2018.07.327. 4) Liski J. et al. (2005), DOI: 10.1016/j.ecolmodel.2005.03.005. 5) Tuomi M. et al. (2011), DOI: 10.1016/j.envsoft.2011.05.009. 6) Albert M. et al (2022), DOI: 10.23765/afjz0002084. 7) Mao Z. et al (2019), DOI: 10.5194/bg-16-1955-2019.

Integrierter Klimaschutzplan Hessen 2025

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