Impacts of climate change on land suitability for cereal crops in Ethiopia

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(1) Motivation

- Climate and soil define cropland suitability (CLS) in time and space
- Climate change will alter future cropland availability and quality
- These alterations threatens food security and socioeconomic stability, especially in smallholder farming systems
- Effective adaptation requires understanding both the current status and future changes

(2) Research questions

We conduct a detailed analysis to assess the current potential and projected changes in cropland suitability (CLS) for major cereal crops (teff, maize, sorghum, and wheat) in Ethiopia. We address three key research questions:

i. What is the currently suitable cropland extent for the major cereals?
ii. How will the current CLS change under a future climate?
iii. Which climatic factor dominantly drive the changes in CLS and where?

(3) Methods

Study area

The study focuses on the entire rainfed agriculture (RFA) region of Ethiopia (Fig. 1):

- Climate: semi-arid to hyper-humid
- Smallholder rainfed system
- Growing season: May – September

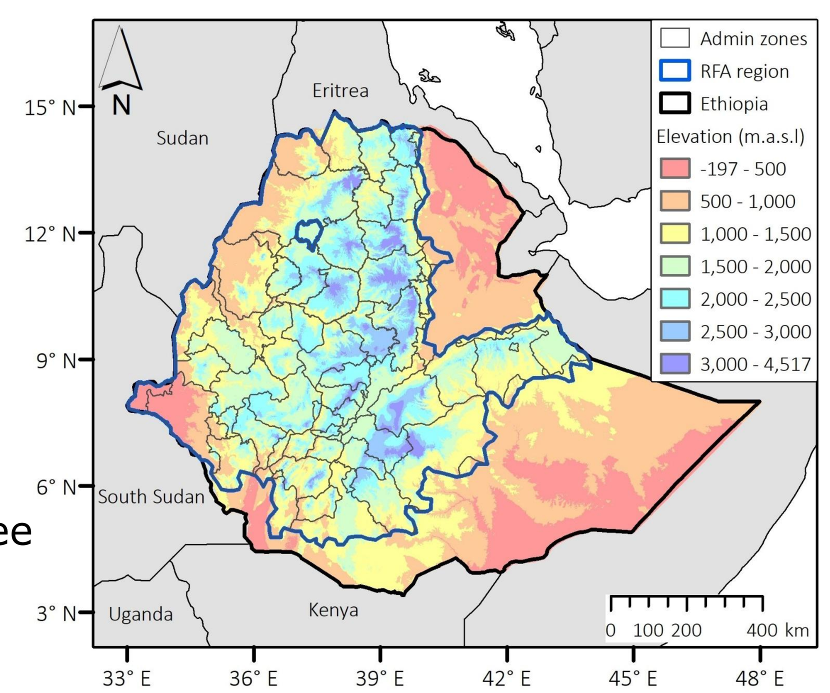

Fig. 1: The rainfed agriculture (RFA) region of Ethiopia (blue outline) and administrative zones (as of the year 2010) at which crop yield data is available

Data and model

Crop yield data from 62 zones along with three *climatic* and three *soil factors*, were used to develop the CLS model

The CLS model represents an envelope curve fitted to the *high (partial) yield responses* (PYR) for each factor (Fig. 2)

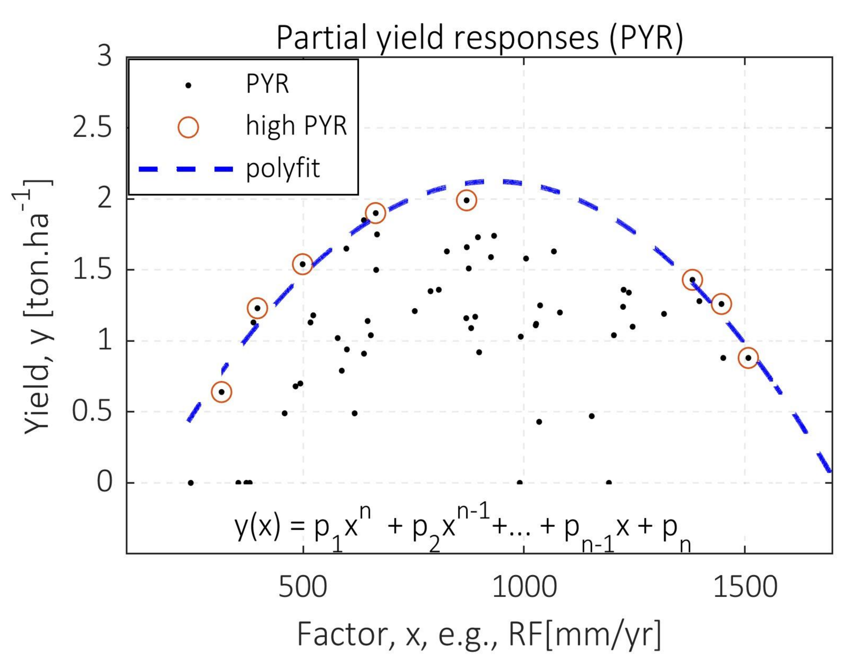

Fig. 2: Functional relationships between crop yield and individual suitability factors -- growing season total rainfall (RF), mean temperature (Tm), and solar radiation (Rad), soil pH, sand-to-clay ratio (S2C), and soil organic carbon (SOC) were established

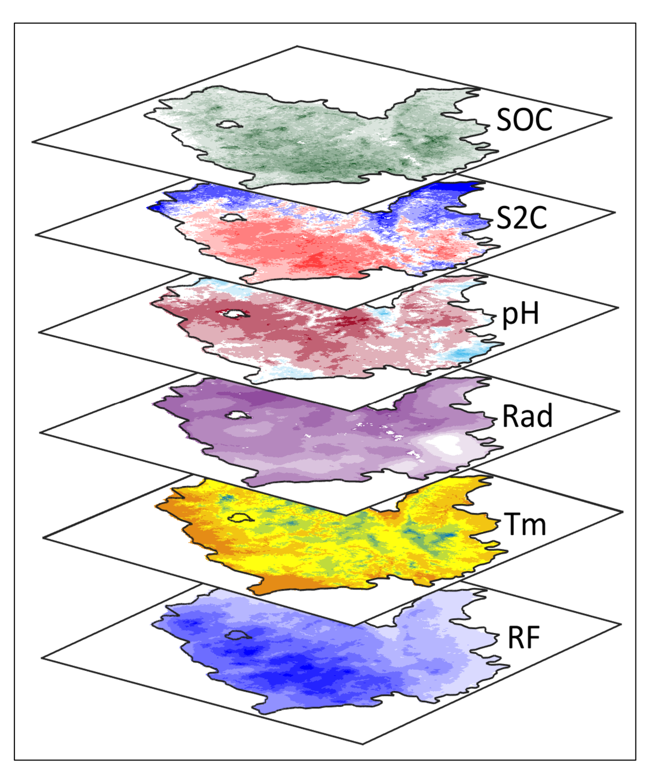

Fig. 3: The model was applied to CLS gridded datasets of climatic and soil factors to calculate PYR at a 5 × 5km resolution, using mean climate conditions from the period 1981–2010

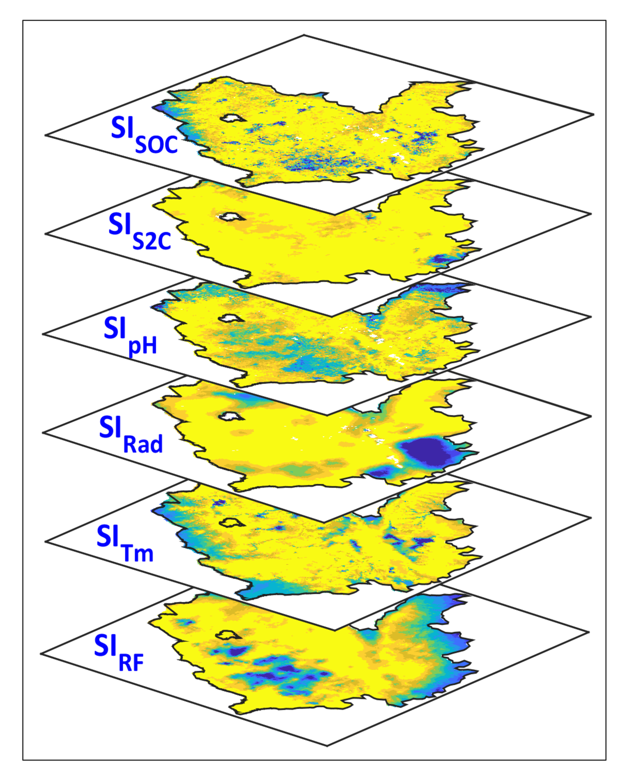

Fig. 4: The computed PYR was normalized to represent partial suitability indices, with values ranging from 0 (blue, unsuitable) to 1 (yellow, highly suitable)

Overall suitability index (SI)

$$SI = SI_{RF} * SI_{TM} * SI_{Rad} * SI_{soil}$$

SI_{soil} is a weighted sum of SI_{pH}, SI_{S2C} & SI_{SOC}

Future CLS was computed considering multiple GCM projections of rainfall and temperature under SSP1-2.6, SSP2-4.5 and SSP5-8.5

Climate sensitivity of CLS

based on local sensitivity analysis:

$$\Delta SI = \beta_{RF}\Delta S_{RF} * \beta_{Tm}\Delta S_{Tm} \qquad \beta_{ratio} = \frac{\beta_{RF}}{\beta_{Tm}}$$

β_{RF} and β_{Tm} are rainfall and temperature sensitivity

(4) Results

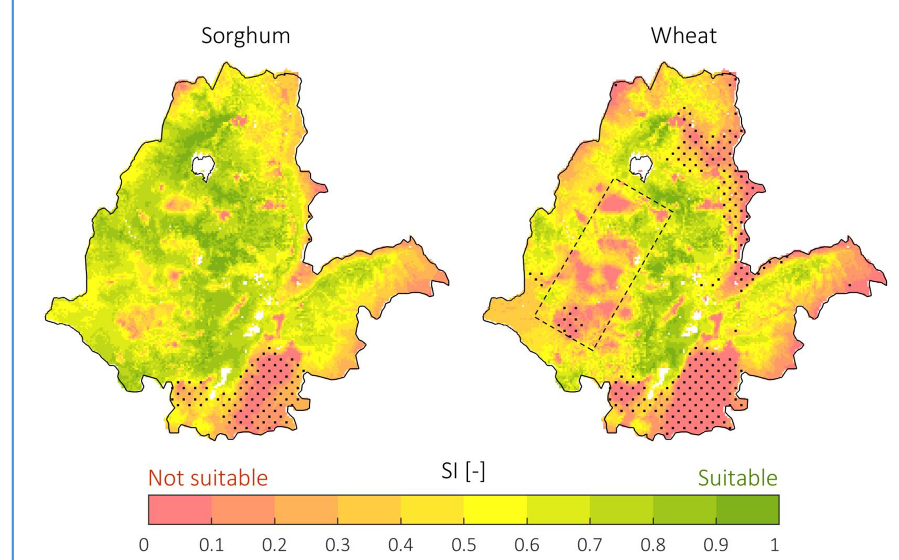

Fig.5: Suitability (SI) maps for the sorghum and wheat

Current cropland suitability

- Sorghum is the most versatile crop (63 % of the RFA region is suitable), followed by teff (54 %), maize (51 %) and wheat (29 %)
- Low suitability for teff and wheat in humid regions (Fig. 5, rectangle)
- Radiation limitation (too high/low) in some parts of RFA (stippled areas)

The future growing season climate is projected to be warmer and mostly wetter compared to the reference period 1981-2010. How do these changes affect the future CLS?

Climate change impacts

Climate change drives altitudinal shifts in suitable croplands toward the highlands (Fig. 7, left), thus, lowland areas lose suitability while highland areas gain suitability (Fig. 6)

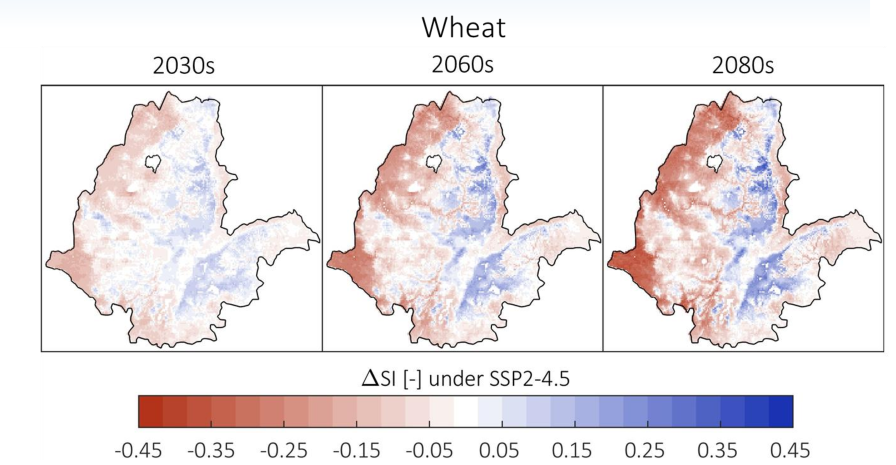

Fig.6: Projected changes in wheat SI across the RFA region under the intermediate emission scenario

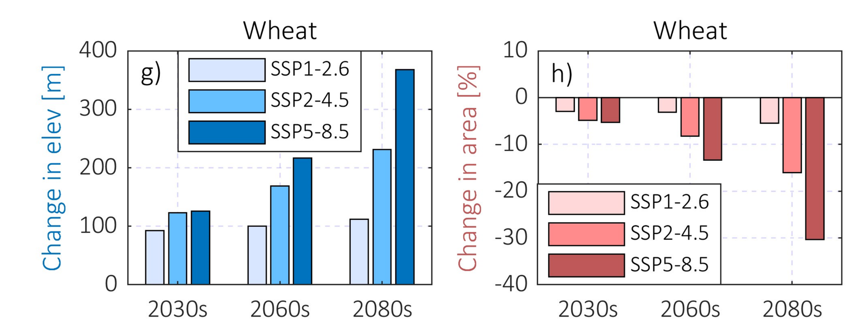

Fig.7: Projected altitudinal (left) and areal changes (right) in suitable wheat croplands

Currently suitable wheat cropland areas are projected to decrease by ~30% (high emission) and ~17% (intermediate emission) by the end of the century (Fig. 7 right)

Climate sensitivity of CLS

- The changes in CLS across the major parts of the RFA region are dominated by temperature warming (Fig. 8)
- Sensitivity to rainfall is higher in the semi-arid and hyper-humid regions

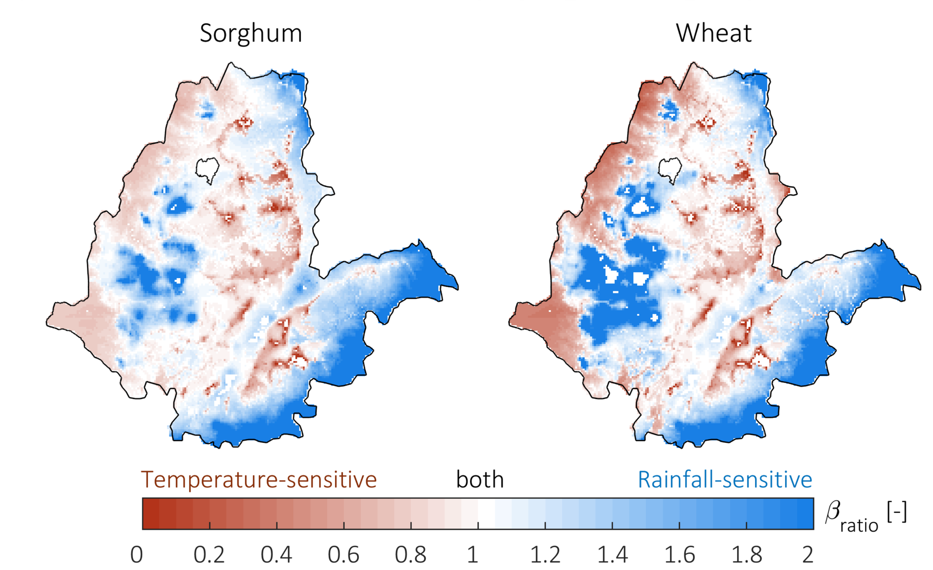

Fig.8: Maps of climate sensitivity ratio for sorghum and wheat crops. CLS is rainfall-sensitive if $\beta_{ratio} > 1$, and temperature-sensitive if $\beta_{ratio} < 1$

(5) Conclusions

- Current CLS offers potential for intensification of cereal production in Ethiopia
- Climate change may shift cropland from low to high altitudes, reducing lowland suitability
- National adaptation plans must consider measures to mitigate and adapt to these shifts

Full paper:

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Project page

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