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SESSION 2 – CLIMATE CHANGE – IMPACTS, ADAPTATION, MITIGATION

Climate change will limit the potential for intensification in Senegal

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Keywords Calibri : climate change, impact, yields, millet, intensification, adaptation.

1. Introduction

Agriculture in sub-Saharan Africa, largely rain-fed, is highly vulnerable to climate change. This study assesses how climate change may limit the potential for agricultural intensification, particularly for millet.

2. Materials and Methods Calibri

2.1. Study Area

Senegal with annual totals ranging from less than 200 mm in the northern Sahelian zones to over 1200 mm in the southern regions (Fig. 1).

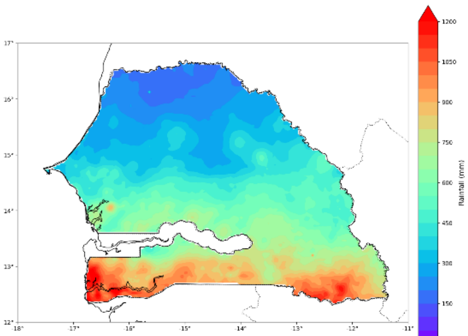

Figure 1:: Spatial distribution of mean annual rainfall in Senegal over the period 1991–2020

2.2. Climate data

18 CMIP6 models bias-corrected using the CDF-t method daily for the SSP5-8.5 scenario (Mbengue et al. 2025) for precipitation variables, Tmax, Tmin, Tmean, radiation.

2.3. Yield simulation model STICS

- ❑ Crop model : STICS (Brisson et al., 2009).
- ❑ Crop variety calibration and validation : Souna 3 millet (Sow et al., 2024),
- ❑ 3 simulations options :
- ▪ intensified yield without N stress,
- ▪ actual yield under combined water and nitrogen stress with 0 kg input
- ▪ potential yield without N stress and without water stress

- Sowing date: optimal sowing date for each pixel over the period 1985–2014 by selecting the date that maximizes yield.

3. Results and Discussion

3.1. Impacts of CC on intensification potential

The models estimate an optimal millet sowing window in Senegal between the 160th and 180th Julian days, with strong agreement across models (Fig. 2).

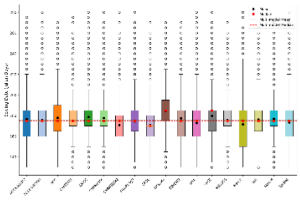

Figure 2: Spatial variation of optimal sowing dates in Senegal across cultivated area pixels, based on climate model forcings for the 1985–2014 period

Millet yield losses in Senegal could reach up to 32% by 2056–2085 without nitrogen stress, and 19% (Fig. 3) with nitrogen stress, highlighting that intensification increases both losses and inter-model variability.

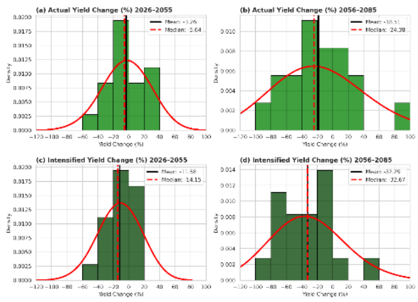

Figure 3: Distribution of projected millet actual and intensified yield change in Senegal for 2026–2055 and 2056–2085 relative to the 1985–2014 baseline, illustrating variability across different climate models.

Historically, intensification increased millet yields by a factor of 4.8, but climate change could reduce this potential to 2.9 by 2056–2085 or even eliminate it entirely in some scenarios (Fig. 4).

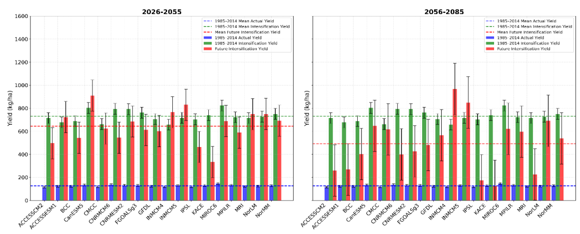

Figure 4: Average actual and intensified yield in Senegal during the historical period (1985–2014) and future climate in 2026–2055 and 2056–2085. The horizontal bars represent the multimodel mean.

The differences between climate models in future intensification potential are mainly driven by projected changes in rainfall and temperature. Drier and hotter projections significantly reduce this potential compared to the historical average (+478%), while wetter and cooler projections tend to increase it (Fig. 5).

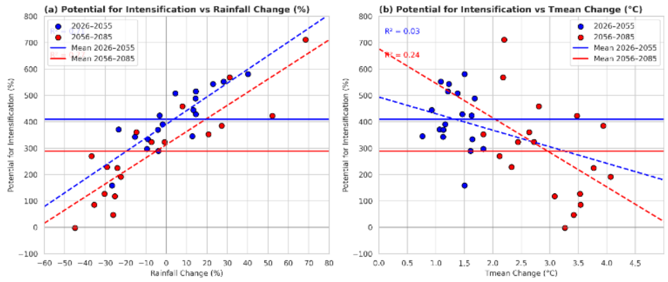

Figure 5: Evolution of intensification potential in Senegal, each blue (red) point in the scatter plot represents the spatial and temporal average of a climate model for the period 2026–2055 (2056–2085) compared to the historical period 1985–2014.

3.2. Impacts of climate change on potential yield

Potential yield in Senegal remains stable until 2055 but declines by 9% by 2056–2085, as heat and water stress increasingly affect crop performance (Fig. 6).

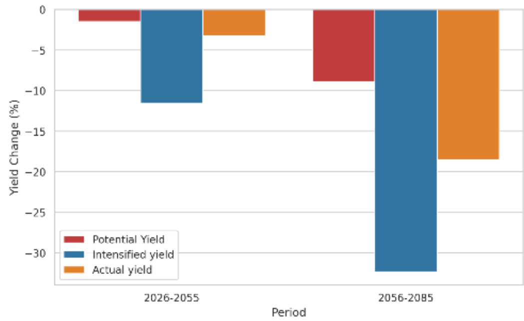

Figure 6: Losses in potential yield (without water and N stress), intensified yield (with water stress and without N stress) and actual yield (with water and N stress) in Senegal for 2026–2055 and 2056–2085 relative to the 1985–2014 baseline.

Hotter climate projections lead to a stronger decrease in potential yield, while milder projections have a more moderate impact (Fig. 7). This effect becomes particularly noticeable beyond a +3 °C increase in temperature where potential yield change ranges between -5% and -30%.

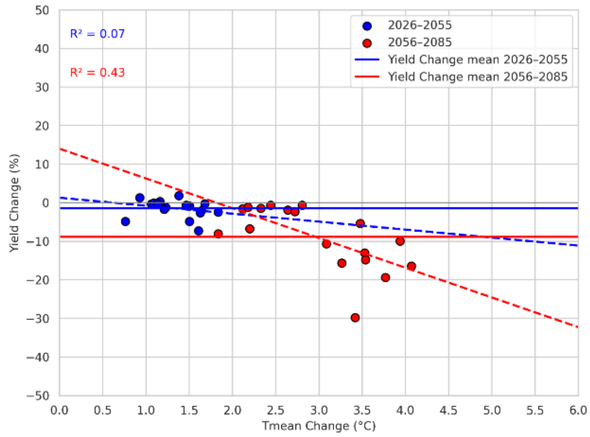

Figure 7: Relationship between potential yield change and mean temperature change in Senegal, each blue (red) point in the scatter plot represents the spatial and temporal average of a climate model for the period 2026–2055 (2056–2085) compared to the historical period 1985–2014

4. Discussion

Intensification is often seen as adaptive, but its effectiveness may decline under future climate due to greater sensitivity to rainfall variability and heat stress (Challinor et al., 2014; Müller et al., 2017). Rethinking it with climate-resilient strategies is crucial.

Conclusions

Future climate conditions challenge the effectiveness of intensification, mainly due to heat and water stress. Sustainable intensification, based on moderate inputs and climate-resilient practices, appears better suited for adaptation

Acknowledgements

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Multi-criteria evaluation of the Azodyn-Pea crop model: a step towards adapting pea to climate change in French conditions

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Keywords: legume crop model, global evaluation, sensitivity analysis, uncertainty analysis, abiotic stresses

Introduction

Grain legumes are key species for agroecological and dietary transitions due to their high nutritional value, but their adoption remains limited by unstable yields (Nemecek et al. 2008; Magrini et al. 2016). In the context of climate change, the development of robust crop models is essential to anticipate legume performance across diverse agro-environmental conditions (Marteau-Bazouni et al. 2024). Azodyn-Pea is a dynamic model (daily time step) specifically developed at the plot scale to simulate the functioning of pea crop (*Pisum sativum L.*) and to predict crop production (yield components and grain protein content). Azodyn-Pea formerly known as AFISOL (Jeuffroy et al. 2012) incorporates symbiotic nitrogen fixation and the impact of various abiotic stresses (soil compaction, water deficit, temperature stresses, frost, and nitrogen deficiency) as a function of genotype, management, climate and soil characteristics (Fig.1).

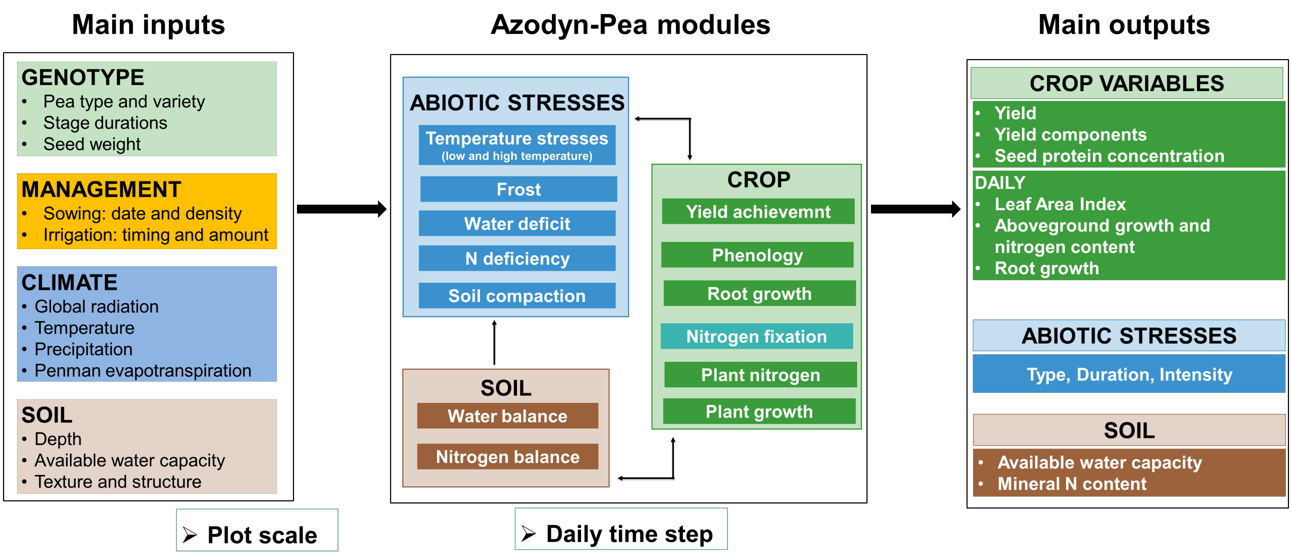

Figure 1: Diagram of the Azodyn-Pea crop model (Soil-Plant system), implemented on the VLE platform by the RECORD team (INRAE Toulouse)

Why evaluate Azodyn-Pea ?

Azodyn-Pea has never been subject to a global evaluation, which is essential before it can be used as a decision-support tool or for scenario testing (Ahmed et al. 2020). This study aims to evaluate the model's accuracy, robustness, and behavior across a wide range of agro-environmental conditions in France, in order to define its domain of validity and identify key levers for its improvement.

How will Azodyn-Pea be evaluated ?

This work proposes the first multi-criteria evaluation of Azodyn-Pea by combining four complementary steps:

- Comparison between simulated and observed outputs: for the three output categories across diverse agro-environmental conditions.
- Uncertainty analysis: to quantify the robustness of model predictions and identify areas of high variability.
- Global sensitivity analysis: using the eFAST method (Fourier Amplitude Sensitivity Test), based on output variance decomposition (first-order index = direct effect of each input, total sensitivity index = combined effect of each input including interactions, and grouped input index = joint effect of related inputs), to rank the influence of uncertain inputs on both dynamic and final outputs.
- Machine learning: based on the simulated/observed comparison matrix, Random Forest and Gradient Boosted Model will be fitted to identify and rank the importance of input variables on model outputs.

All the steps of the evaluation are based on an independent experimental dataset covering 3 500 agro-environmental conditions including pea genotype (incl. the type spring or winter), management practices, climate and soil type. Model outputs (dynamic and final outputs) will be analyzed in three categories: crop characteristics, abiotic stresses affecting the crop, and soil water and nitrogen balances. Performance is assessed using classical statistics (RMSE, rRMSE, EF, R^2) and complemented by graphical representations.

Perspectives

First, this study should help identify the strengths and weaknesses of the Azodyn-Pea model in simulating pea crop across a wide range of agro-pedoclimatic conditions. Identifying important inputs will guide priority improvements to the model, particularly in terms of genotypic response to abiotic stresses. Second, this evaluation will help define the most suitable contexts for operational use of the model as a decisions-support tool for adapting peas to climate change. Finally, by combining classical sensitivity analysis with machine learning approaches, this study will contribute to methodological advances for robust crop model evaluation.

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Estimating global soybean yield under multiple climate change projections using a process-based model MATCRO-Soy

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Keywords : CMIP6 global climate models, future projections, process-based crop model, soybean yield, uncertainty

Introduction

Soybean is an important global C3 crop and is particularly sensitive to climatic variability. Rising temperatures and changing precipitation patterns may reduce yields by decreasing soil moisture and shortening the effective growing period, which is critical for soybean development (Zhao et a., 2017). However, increased CO_2 levels could enhance photosynthetic efficiency in C3 plants and may partially compensate for yield losses due to the increased temperature (Lu et al., 2021). These opposite effects of the climate change factors make it challenging to predict future yields, but this also emphasizes the importance of reliable models to evaluate the effects of climate change and recommend strategies for decision-makers. Since climate changes cannot be reproduced in field experiments, process-based crop models have become an essential tool for assessing potential impacts. Utilizing multiple Global Climate Models (GCMs) and ensemble techniques is crucial to capture a broader range of climate variability, thereby increasing the robustness of projections and reducing uncertainty in crop yield forecasts (Silva and Giller, 2021). A major source of uncertainty arises from the choice and number of climate models used as inputs, with different models offering various projections of climate change effects. In this study, we quantify global soybean yield changes using an ensemble of multiple GCMs with a process-based model (MATCRO-Soy).

Materials and Methods

We simulated soybean growth responses across major soybean-producing regions, focusing on the physiological mechanisms that drive yield variability. The simulation was conducted using MATCRO-Soy, a process-based, eco-physiological model that integrates leaf-level photosynthesis and water-use efficiency to simulate soybean growth and development. This model has been calibrated using experimental data and validated against historical yield data at the global, country, and grid-cell levels (Yusara et al., 2025). Future soybean yields were projected by simulating yield responses under three SSP scenarios (SSP126, SSP370, and SSP585) using the CMIP6 (Coupled Model Intercomparison Project Phase 6) ensemble of 16 bias-corrected GCMs. The simulations included baseline data from 2000 to 2014 and future projections for the periods 2015–2039, 2040–2069, and 2070–2100. We calculated key parameters including mean yield, standard deviation (SD), first quartile (Q1), median (Q2), and third quartile (Q3). The uncertainty in soybean yield projections was quantified by analyzing the variation between different GCMs and SSP scenarios, providing insights into the robustness of future yield projections.

Results and Discussion

The global soybean yield projections under the 16-GCM ensemble show noticeable variation between different SSP scenarios. Figure 1 illustrates the temporal variation in global productivity, showing the median yield change for each scenario along with the standard deviation to indicate uncertainty. For SSP126, global yield changes remain near the baseline for the near term (2015–2039), with slight variations among models. However, yield projections under SSP370 and SSP585 diverge more significantly, with a downward trend that accelerates toward the end of the century particularly under the highest emission scenario (SSP585). When comparing the full ensemble with a subset of 5 representative GCMs, the uncertainty in yield projections was reduced. The subset captures the central tendency of global yield changes, but it does not account for the extreme probabilities when compared to the high number of GCMs.

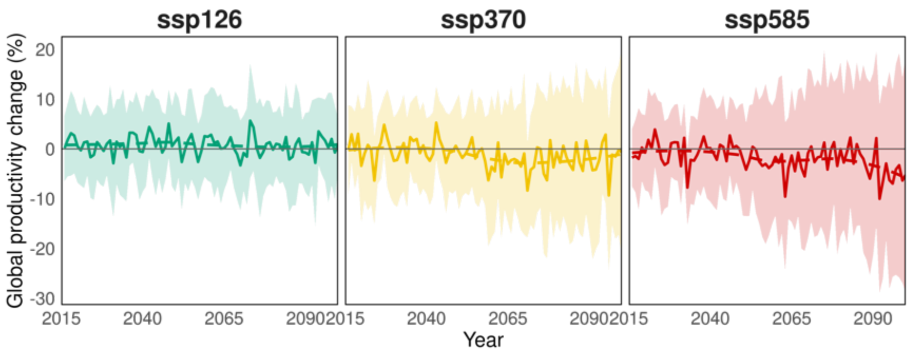

Figure 1. Mean of ensemble 16 GCMs (solid line) and standard deviation (dashed colored range) for ssp126 (green), ssp370 (yellow),and ssp585 (red) of simulated global soybean yield change (%) compared with baseline (2000-2014)

Spatial variability in yield projections suggests that soybean productivity may respond differently among regions under future climate scenarios, highlighting the need for region-specific adaptation strategies. This variation highlights the significance of accurately parameterizing physiological processes, including photosynthesis and water regulation, in process-based models to enhance projection accuracy across diverse climate conditions. Refining key model parameters and linking them with empirical evidence will advance the ability to assess the impact of climate change. Further analysis will explore the robustness of these projections and the role of regional adaptation strategies in mitigating yield loss.

Conclusions

The ensemble of yield projections based on the 16 GCMs underscores the substantial uncertainty in future crop productivity. These findings indicate that using multiple GCMs enhances the reliability of global soybean yield projections. The observed variability in projections emphasizes the necessity for further refinements in model parameterization and continued efforts to reduce uncertainty in the climate change projections. Future analyses will include over 30 GCMs for a more comprehensive assessment of crop yield uncertainty and its implications for global food security. These improvements will result in more robust predictions of crop yield under changing climate, on which future-proof strategies can be developed for the crop production.

Acknowledgements

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Simulation-based evaluation of drought risk and adaptation strategies for major crops in Taiwan

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Keywords: Resilient crop production; water resources; drought yield index

Background

Climate change has exerted varying degrees of impact on global agricultural production, thereby influencing international agricultural trade. In Taiwan, the pursuit of international trade agreements may further affect domestic crop prices. To ensure sustainable agricultural development and national food security, strategies are needed to promote import-substitution crops and improve crop quality under environmentally sustainable principles. Although annual rainfall in Taiwan has shown little long-term change, the frequency of extreme precipitation events has increased, leading to greater risks of drought and flooding. Rising temperatures also accelerate crop growth stages and increase evapotranspiration, resulting in higher irrigation demands. Since agricultural water accounts for about 70% of Taiwan's total water use, with irrigation comprising nearly 90% of that, crop production is highly vulnerable to water scarcity. Identifying resilient adaptation strategies and suitable alternative crops under local conditions is critical for maintaining production stability.

Methods

This study employed the DSSAT crop modeling framework to evaluate drought risks by integrating environmental, crop, and management factors. Using reconstructed climate data from 1980 to 2020, simulations were conducted for eight major crops under extreme drought scenarios, comparing *rainfed (no irrigation) and automatic irrigation* conditions. To quantify production risks, a novel drought yield index (DYI) was developed, which simultaneously reflects both drought severity and crop yield performance.

Results

The drought yield index provided a simplified yet robust approach for interpreting yield outcomes across multiple climate scenarios. Simulation results showed that yield reductions under drought stress varied significantly among crops and regions, with certain crops demonstrating higher tolerance to water stress. The DYI enabled direct comparison of crop suitability across different locations and management strategies.

Conclusion

The proposed droughty yield index offers a practical tool for assessing production risks under drought conditions and supports evidence-based decision-making for crop selection. In areas with high drought risk, farmers can adopt more drought-tolerant crops, thereby enhancing the resilience of Taiwan's agricultural system under climate change.

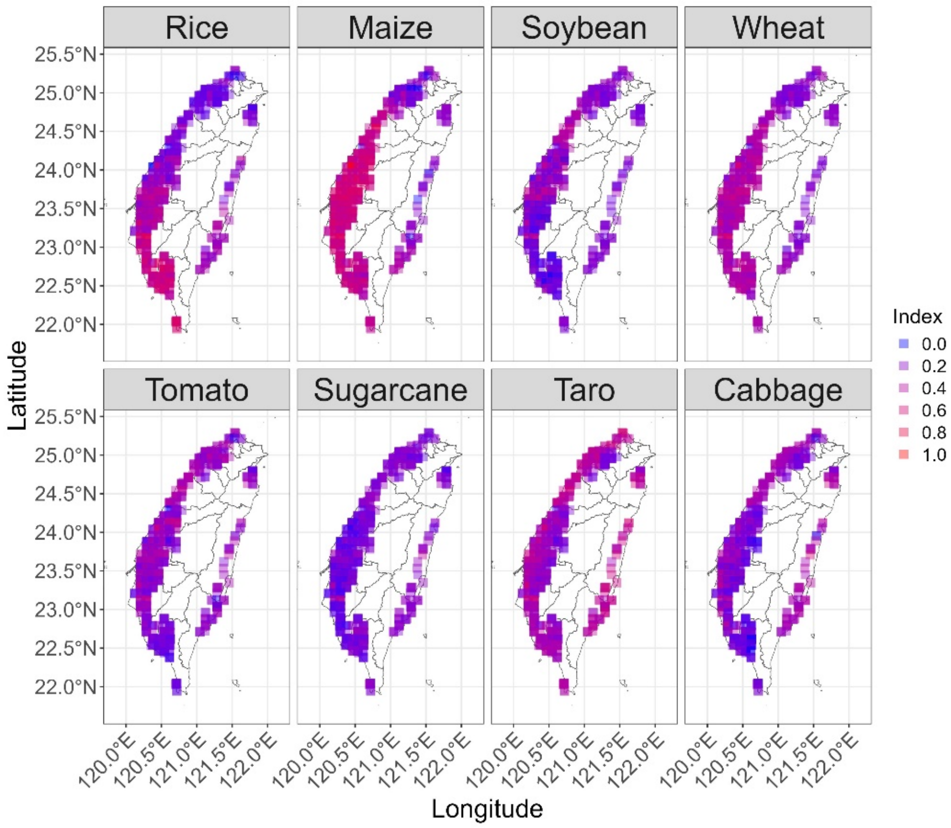

Figure 1. The average Drought Yield Index of different crops in Taiwan.

Adaptation of old and modern durum wheat cultivars to climate change in Mediterranean rainfed systems

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Crop modelling; Climate scenarios; Genotype × environment × management; Yield stability; Grain quality

Introduction

Durum wheat (Triticum turgidum ssp. durum) is a key crop in Mediterranean rainfed systems, where rising temperature and rainfall fluctuations threaten yield stability (Asseng et al., 2015). Contemporary semi-dwarf cultivars, carrying the Rht1 gene, produce higher yields but have reduced grain protein, while old tall varieties flower later and retain higher protein (Motzo and Giunta, 2007). Grasping their response to climate change is vital for breeding and management in marginal environments.

Materials and Methods

Field trials were carried out in Sardinia (2013–2017) with 10 durum wheat varieties (five old, five modern). Recorded phenology, yield and protein were employed to calibrate (2014–2015) and validate (2016–2017) the CERES-Wheat model (DSSAT v4.8). Long-term simulations (1980–2100) were performed using five CMIP6 GCMs, three SSPs (1-2.6, 3-7.0, 5-8.5), and varying nitrogen inputs (from 40 to 100 kg N ha^{-1}). Model accuracy was evaluated with RMSE and d-index.

Results and Discussion

Model calibration and testing showed strong accuracy for anthesis and maturity (RMSE 3–6 d; d ≥ 0.93) and moderate concordance for grain yield (RMSE ≈ 1.2 DM t ha^{-1}). Climate forecasts indicated gradual warming (+1.3 to +4.5 °C) and decreasing precipitation under high-emission scenarios.

Modern varieties advanced anthesis by roughly 30 days by 2100 but kept a steady grain-filling period, achieving yields up to 5.9 t DM ha^{-1} under high input (Fig. 1). Under low input, they exhibited smaller yet still positive yield gains. Older cultivars stayed largely insensitive to emission scenarios, producing stable but lower yields (~2.8 t DM ha^{-1}; Fig. 1), with a modest reduction in filling duration.

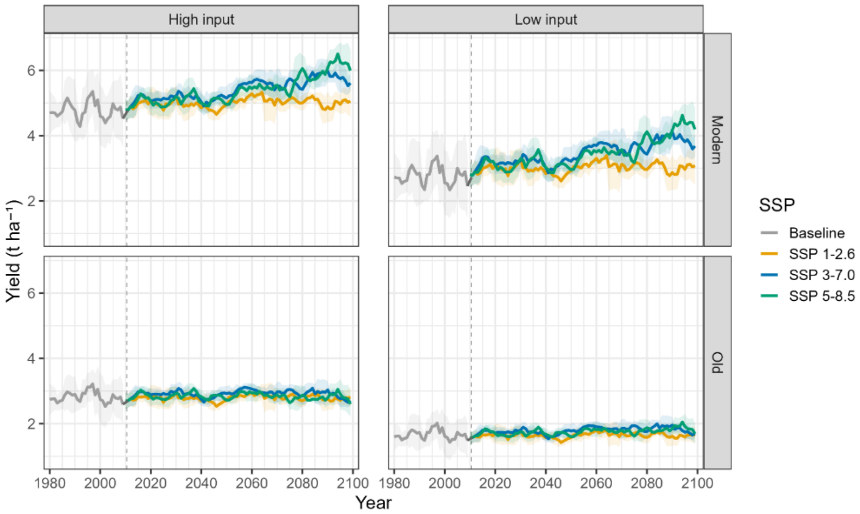

Figure 1. Simulated grain yield (t DM ha^{-1}) of modern and old durum wheat cultivars under high- and low-input management. Results are shown for the baseline period (1980–2010) and for three climate scenarios (SSP1-2.6, SSP3-7.0, SSP5-8.5) projected up to 2100. Shaded areas indicate variability across five CMIP6 GCMs.

Grain protein content was unchanged by climate scenarios, remaining about 14 % in old and ~10 % in modern cultivars (Fig. 2). This highlights a persistent genetic gap linked to breeding history rather than climate conditions. Overall, the results confirm that modern cultivars deliver higher productivity and greater adaptability, while older germplasm still holds value for grain quality.

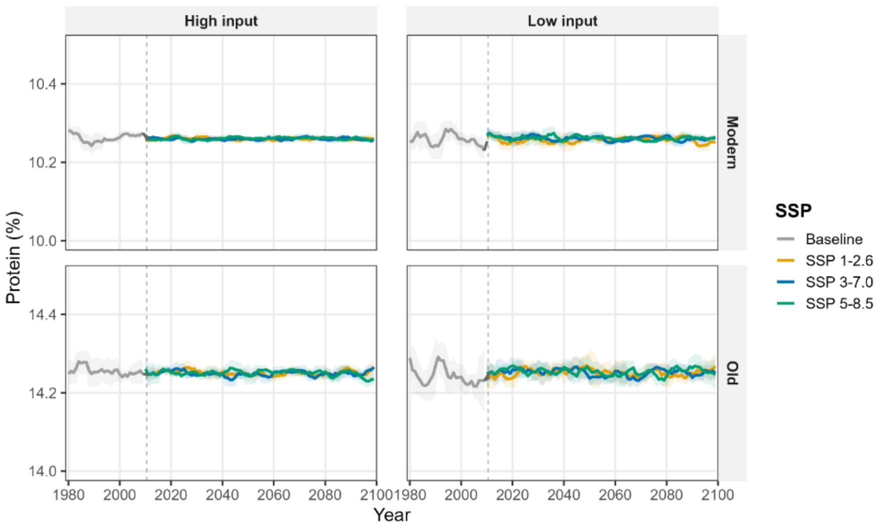

Figure 2. Simulated grain protein concentration (%) of modern and old durum wheat cultivars under high- and low-input management. Results are shown for the baseline period (1980–2010) and for three climate scenarios (SSP1-2.6, SSP3-7.0, SSP5-8.5) projected up to 2100. Shaded areas indicate variability across five CMIP6 GCMs.

Conclusions

Contemporary cultivars showed higher productivity and an ability to adjust to climate change, while traditional varieties exhibited consistent yet reduced yields together with higher grain protein levels. These divergent responses highlight the need to incorporate genotype × environment × management interactions when assessing durum wheat adaptation in Mediterranean rain-fed systems. Future breeding ought to merge early anthesis with enhanced post-anthesis assimilate allocation, while responsive nitrogen management and water-saving practices will be essential to maintain both yield and quality under future climates.

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Climate Change Impacts on African Legume Yields: A Meta-Analysis of Crop Model Projections

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Keywords: legumes, climate change, crop models, adaptation, yield projectionsIntroduction Calibri pt 10

Materials and Methods

We conducted a systematic review and meta-analysis following PRISMA guidelines (Moher et al., 2009). Peer-reviewed studies published before 2024 were sourced from Scopus and Web of Science using climate and agriculture-related search terms adapted from prior syntheses (Aggarwal et al., 2019; Challinor et al., 2014; Hasegawa et al., 2022). Studies were included if they reported crop yield projections under climate change in Africa, using process-based models, with or without adaptation and CO_2 fertilization. From over 8,000 records, 35 legume-focused studies met inclusion criteria. Data extracted included baseline and projected yields, temperature and precipitation changes (ΔT, ΔP), CO_2 fertilization status, and adaptation measures. Where ΔT or ΔP were missing, site-specific deltas were retrieved from WorldClim based on study location and scenario.

Yield change (%) was calculated as:

$$\Delta Y = (\frac{Y_{future}}{Y_{baseline}} - 1) \times 100$$

For adaptation scenarios, the benefit was calculated as:

$$\Delta Y_{adapt} = (\frac{Y_{adapt} - Y_{no\_adapt}}{Y_{no\_adapt}}) \times 100$$

We used generalized additive mixed models (GAMMs) to assess the effects of ΔT, ΔP (as smooth terms), CO_2, and adaptation (as fixed factors) on yield change, including random intercepts for study ID, crop, and country to account for heterogeneity. Non-linear fits and bootstrap confidence intervals (n = 500) were used to visualize climate-yield relationships. All analysis was conducted in R using the mgcv and gamm4 packages.

Results and Discussion

3.1 Screening and Data Coverage

From 8,197 records, 100 studies met inclusion criteria; 35 focused on legumes, contributing 47 unique legume crop records across ten species. Groundnut (n = 14), soybean (n = 11), and common bean (n = 9) were most represented.

Studies were concentrated in Nigeria, Kenya, Ghana, and South Africa. While legume-focused studies have grown, they remain a minority relative to cereals.

3.2 Yield Responses to Temperature and Precipitation

Results show yield responses across a range of ΔT and ΔP values, stratified by CO_2 fertilization and adaptation status. For legumes under CO_2 fertilization, yields were stable across temperature changes (Figure 1), with only slight declines. Adaptation consistently improved yields, aligning with known CO_2-enhanced physiological performance of C_3 crops.

For precipitation, legume yields rose with increased rainfall up to ~15–20% before declining, indicating threshold effects. Without CO_2 fertilization, yield patterns were more variable. Surprisingly, non-adapted scenarios outperformed adapted ones, likely due to inconsistencies in adaptation application or the loss of CO_2 benefits.

In maize, a C_4 crop with limited CO_2 responsiveness, yields declined steadily with temperature increase. Adaptation offered only minor benefits. Precipitation trends mirrored this: adaptation under fertilized scenarios offered small gains; without fertilization, yields were flat or declined.

3.3 Adaptation Strategy Effectiveness

Using only paired simulations, we quantified strategy-specific benefits. Irrigation showed the largest gains (+44%), followed by bundled practices (+36%) and cultivar improvements (+27%). Early planting yielded smaller average benefits (+6%), while fertilizer use had negligible effect due to legumes' nitrogen fixation (Vanlauwe et al., 2019).

3.4 GAMM Results

The GAMM confirmed that adaptation significantly improved legume yield outcomes (average +18.31%, $p < 0.001$). ΔP showed a significant non-linear effect ($p = 0.006$), while ΔT and CO_2 had no significant linear effects, reinforcing the value of modelling non-linear and interaction effects. High variance across crop-study-country combinations underscores the context-specific nature of yield responses.

3.5 Protein Yield Trends

Digestible protein supply followed similar trends to yield: stable or rising under CO_2-fertilized, adapted conditions, with modest declines in high warming or low precipitation scenarios. Unfertilized scenarios consistently showed lower protein outputs.

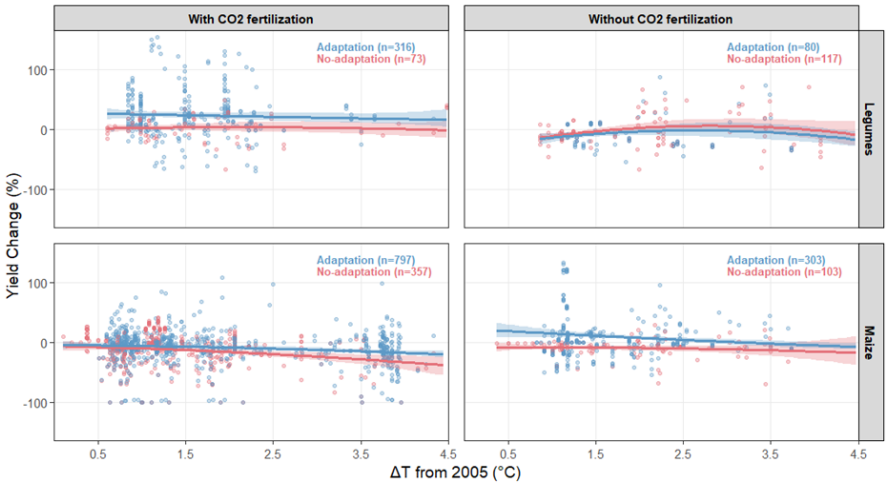

Figure 1 Percentage yield change as a function of local temperature change (ΔT) for legumes and maize, with and without adaptation and CO_2 fertilization. Shaded bands represent 95% confidence intervals based on 500 bootstrap replicates. Results are shown separately for scenarios with CO_2 fertilization and without and stratified by adaptation status. Extreme outliers are omitted for visual clarity.

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Calibrating WOFOST-Potato for subtropical environments to explore irrigation strategies under future climates

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Climate change, Solanum tuberosum, Global sensitivity analysis, Differential Evolution, crop model calibration

Introduction

Food security under climate change requires adaptation of crop management. Potato (*Solanum tuberosum* L.) is gaining importance for food and nutrition in subtropical regions, which are particularly vulnerable to extreme climate events. Crop Growth Models (CGMs), such as WOFOST, are essential tools to assess trade-offs between yield, resource use, and environmental impact under future climate conditions. To support sustainable intensification, CGMs must be evaluated for their suitability in target environments and, if necessary, adapted or recalibrated. This study presents a structured, quantitative approach to inform and calibrate WOFOST-Potato for subtropical environments, with a focus on irrigation strategy design.

Materials and Methods

The quantitative approach combines time-dependent sensitivity analysis to identify key parameters with an evolutionary algorithm for subsequent optimisation. We first conducted a time-dependent global sensitivity analysis (GSA) to identify the most influential parameters in WOFOST-Potato under subtropical conditions. The analysis aimed to inform data collection and model calibration (Liu et al., 2025). In parallel, a three-season field experiment was conducted in Gujarat, India, using short-duration drought treatments to simulate water stress. After identifying the most influence parameters considering the seasonal dynamic, we used differential Evolution (DE) algorithm to search the parameter values based on three output variables, i.e., development stage, leaf area index and tuber dry weight. Although full model optimisation is ongoing, we present preliminary simulations using the current parameter set. Model performance was evaluated using observed phenology and LAI data, and quantified by root mean square error (RMSE).

Results and Discussion

Time-dependent GSA identified two key growth-related parameters, initial seed tuber weight and maximum temperature for photosynthesis, as having strong influence on canopy growth and yield (Figure 1-A). These findings informed the selection of parameters for calibration and prioritised data collection during the field experiment. The model predicted emergence approximately 3–5 days earlier and tuber initiation later than observed (Figure 1-B), suggesting that the current thermal time settings may not be suitable for subtropical environments. This points to the need to recalibrate base temperature or thermal time requirements for early developmental stages. The model also significantly underestimated LAI development and canopy duration (Figure 1-C). This may be due to the assumption that temperature has no effect on leaf expansion in temperate environments. However, greenhouse and field experiments indicate that high air temperatures encourage biomass partitioning to above ground organs (Zhou et al., 2023). Therefore, canopy expansion may be hastened under early season high temperature. While it was observed that the canopy stays green until harvest (late February), the simulated LAI suggested senescence started mid-January. These results strongly indicate that WOFOST requires recalibration to simulate potato growth reliably in subtropical regions, particularly for parameters affecting early phenology and canopy dynamics.

Conclusions

This study presents a structured and quantitative approach for adapting WOFOST-Potato to subtropical conditions. By integrating time-dependent global sensitivity analysis, we observed that some adaptations were needed to accommodate the application of the model for subtropical regions. Preliminary results from sensitivity analysis and benchmark simulations provided a foundation for adapting WOFOST-Potato to support irrigation strategy design in subtropical regions. Further refinement through optimisation and extended validation is currently underway. Ultimately, this work aims to enable scenario-based analysis of irrigation strategies to support sustainable intensification under climate change.

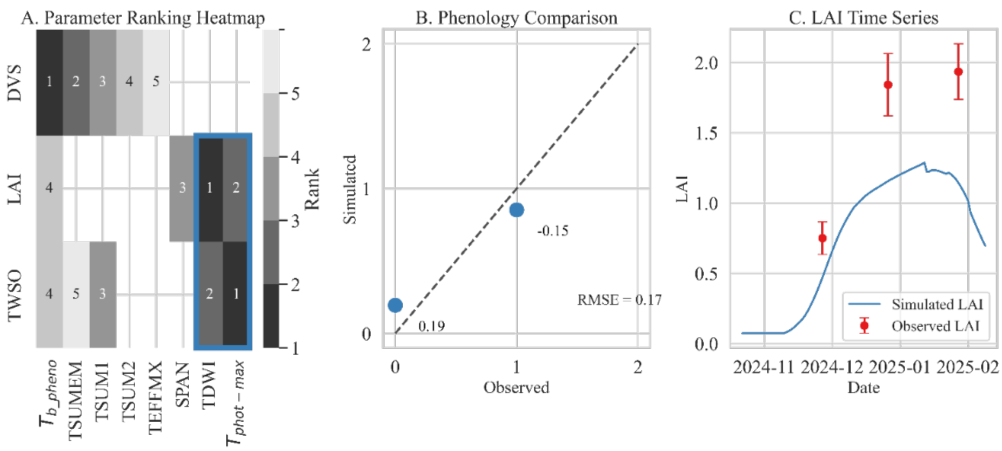

Figure 1. Overview of model sensitivity and validation results for WOFOST-Potato under subtropical conditions. (A) Heatmap showing the relative importance of model parameters across three key outputs: tuber dry weight (TWSO), leaf area index (LAI), and development stage (DVS). Parameters with strong influence on growth and yield are highlighted to guide calibration priorities. (B) Comparison between simulated and observed crop development stages, focusing on emergence and tuber initiation. The root mean square error (RMSE = 0.17) corresponds to a deviation of approximately 86 °C days, indicating approximately 5 days deviation in predicting emergence or tuber initiation. The base temperature was 2 °C as the default value. (C) Time series of simulated versus observed LAI, with error bars representing measurement uncertainty. The model underestimates canopy duration, suggesting that temperature effects on leaf expansion and lifespan may be misrepresented in the current parameterisation.

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Systematic Review of compound climate risks on plant physiology and yield development of winter wheat and soybean

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Keywords: weather extremes, climate change, arable farming, temperate climate

Introduction

Agricultural systems in temperate regions are increasingly exposed to complex climatic stressors that do not occur in isolation but rather as *compound climate risks*—temporally dependent or independent events such as heatwaves, droughts, late frosts, and heavy rainfall (Zscheischler et al., 2020). These multiple stressors often interact in non-linear ways, rather than simply adding up, leading to yield losses that are difficult to predict also due to the absence of long-term data (Jiang et al., 2025). Particularly, non-extreme events tend to be underestimated at first, yet in combination across different growth stages, they can significantly affect crop yields (Hamed et al., 2021). It is unclear to which extent current crop models capture the yield effects of such compounding events; thus, a systematic overview of their impacts is presented here as a basis for integrating these into crop models.

Materials and Methods

This systematic review is based on a literature search conducted via Web of Science, covering the period from 1930 to 2025. A total of approximately 3,200 articles were screened. Included studies focus on winter wheat and soybean in temperate regions and examine observed climatic events in combination of at least two hazards. Management practices, policy influences, adaptation strategies, and future modeling data were excluded from this review.

Results and Discussion

As illustrated in Figure 1, various types of compound climate risks can occur within the growing season of a crop. These events may be simultaneous or temporally staggered, with one occurring earlier and another later in the season. Examples include the combination of heat and drought in June (Statkeviciute et al., 2022), or a mild autumn and winter followed by a wet spring (Noia et al., 2023). The mechanisms leading to yield reductions vary depending on the nature of the compound events and include stomatal closure due to heat stress, reduced solar radiation limiting photosynthesis under persistent cloud cover, increased pest and disease pressure under mild and wet conditions, and soil degradation resulting from heavy rainfall and compaction. A wide range of such combinations has been observed historically, with their impacts differing according to specific regional factors such as soil type and landscape characteristics.

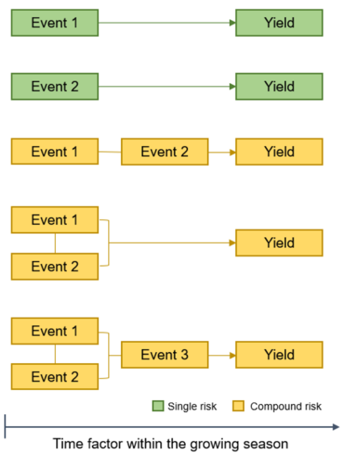

Figure 2 Schematic representation of compound climate event types and their timing

Conclusions

Despite growing attention to individual risks, the understanding of possible occurences, dynamics and cumulative yield effects of compound events on agricultural productivity remains limited. Due to this knowlege gap, the integration of robust representations of such compound events into future yield prediction models appears to be limited and may not yet adequately capture their complexity. Our review aims to support their representation in crop models by providing a comprehensive data basis.

Acknowledgements

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A multi-objective framework for nitrogen management integrating N_2O emissions in malting barley systems

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Keywords: Nitrous oxide, Multi-objective optimization, Site-specific management, Climate variability, Malting barley

Introduction

Nitrogen (N) loss from agricultural systems represents one of the most pressing challenges for sustainable agriculture (Bowles et al., 2018; You et al., 2024), with global N use efficiency remaining critically low at approximately 50% (Zhang et al., 2021). Excess soil N is largely lost to the environment as nitrate (NO_3^-) leaching and nitrous oxide (N_2O) emissions(Wang et al., 2025; Weber et al., 2024), creating cascading impacts on water quality, biodiversity, and global warming(Steffen et al., 2015). Climate change has fundamentally amplified this challenge through accelerating frequency, intensity, and duration of extreme weather events that disrupt agroecosystem N dynamics in unprecedented ways(Liu et al., 2022; Wang et al., 2024; Zhu et al., 2024). In the context of a changing climate, climate-smart N management is essential to maintain crop productivity while minimizing N loss from agricultural soils.

Barley (Hordeum vulgare L.) is the fourth most important cereal globally. It dominates in cooler European climates, such as Scotland, where warm-season crops like rice and maize are less viable. Spring-sown barley serves as the dominant crop for whisky production in Scotland. Optimal N fertilization is essential to meet the distilling industry's grain N requirements while minimizing environmental impact. Here, we applied the calibrated DSSAT model with spatial observation data to simulate N rates from 20-200 kg/ha (20 kg/ha intervals) from 1984-2018. This identified site-specific optimal N rates across four yield stability zones (high, medium, low, and unstable) in a commercial farm, providing spatial and temporal recommendations for precision N management that maintain high yield production while reducing N_2O emissions

Materials and Methods

The Decision Support System for Agrotechnology Transfer model (DDSAT v4.8.2) was utilized for this study. The Barley

crop model (CSM-Barley) was used to run simulations. The DSSAT required input data such as daily weather data (e.g. solar radiation, minimum and maximum temperatures, and rainfall), soil data (e.g. soil texture, organic matter, bulk density), and agronomic management (e.g. sowing date, plants per square meter, fertilizer type, amount and timing). In this study, the initial values of soil water and N contents were recorded several weeks before sowing and one day before sowing, in addition to all the other soil, management and weather data needed. The model was calibrated for the barley cultivar Concerto, in previous studies. The model was tested against observed data, and a series of "what if" scenarios were established. These simulations consisted of ten N fertilization rates run for each sampling point of the four zones identified in the field. The sowing date (mid-April) used in the simulation represents the typical time for drilling spring barley in Scotland. The ten N fertilization application rates were: from 20 kg N ha^{-1} to 200 kg N ha^{-1} with a 20 kg N ha^{-}

[1] increment between each rate. After the simulation, we extract all the variables related to N cycling, and calculate the yield-scaled N use efficiency, grain N concentration, and yield-scale N_2O emissions.

Results and Discussion

Yield-scaled N_2O emissions, yield-scale N use efficiency and grain N concentration showed clear temporal and spatial patterns under different N fertilizer rates.

Conclusions

This study demonstrates the feasibility of integrating N2O emissions into N optimization frameworks for malting spring barley systems in Scotland. Using long-term simulations across spatially variable yield zones, we quantified trade-offs among yield, grain quality, profitability, nitrate leaching, and N2O emissions under a wide range of N rates. Incorporating N2O into N management frameworks shows that environmental and economic objectives cannot be achieved with a single "optimum" rate; reducing emissions and nitrate losses often conflicts with achieving market-driven quality and profitability. Multi-objective optimization offers a pathway to balance these competing goals, identifying a range of N rates that adapts to seasonal variability and mitigates environmental risks without compromising yield. By embedding GHG metrics into N optimization, this work provides a foundation for decision-support tools and sustainability protocols aligned with carbon taxation and climate-neutral production targets.

Acknowledgements Calibri pt 8

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Optimising stocking rates for climate adaptation based on soil type and local weather conditions in Ireland.

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Keywords: climate change, grass growth, modelling, silage, simulations

Introduction

Ireland's dairy industry is predominantly a pasture-based production system and is known globally as one of the major producers of milk and dairy products (O'Brien and Hennessy, 2017). An important determinant for the success of these systems is the effective management of grassland with stocking rate (SR, number of cows ha^{-1}), being a key driver of farm profitability and overall system resilience (McCarthy et al., 2011). When SR is optimal, it contributes to the utilization of grazed grass, reduction on the reliance of expensive feeds, and promotes forage self-sufficiency, which are key objectives for Irish dairy farmers. This study investigates the ideal SR at four locations in Ireland based on soil types and weather conditions and analyses the variability in silage surpluses and deficits, providing a broader contribution to agricultural modelling for climate adaptation.

Materials and Methods.

To find the optimal SR, a modelling exercise was conducted using the Pasture Based Herd Dynamic Milk Model (Ruelle et al., 2015) and Moorepark St Gilles Grass Growth Model (Ruelle et al., 2018) under varying soil and climatic conditions in Ireland. Simulations were carried out for a 13-year (2010-2022) historical weather data at four distinct locations in Ireland: Ballyhaise(B), Johnstown Castle (J), Moorepark (M), and Oak Park (O). For each location, the simulations were run on a 40-ha farm with 2 soil types: free drain soil (FDS) and heavy soil (HS) with a chemical fertilizer application rate of 225 kg N ha^{-1} across soil types. A typical Irish seasonal calving pattern was simulated with an average calving date of 15th February. Concentrate supplementation was fixed at an annual rate of 480 kg DM cow^{-1}. The averge optimal SR was determined using an iterative optimisiation process. An initial simulation was run with the current maximum permitted SR in Ireland (2.75 cows ha^{-1} equivalent to 110 cows for a 40-ha farm). Following the initial run, the number of cows was progressively reduced in subsequent simulations till the average annual silage balance (silage harvested-silage fed) was positive but less than 100 kg DM ha^{-1}.

Results and discussion

The scenario that sustained the highest number of cows was J-HS whereas O-FDS was the lowest (Figure 1). Of all soil types, HS(s) had the highest average grass growth (13.2 t ha^{-1}-B, 14.4 t ha^{-1}-J, 13.9 t ha^{-1}-M, 13.9 t ha^{-1}-O) but the lowest average grass intake (t cow^{-1}) and number of grazing days as cows had to be housed due to paddocks being ungrazable (see black bars in Figure 1). This highlights the importance of weather-soil interactions and the need to adapt SR based on local conditions, taking into account the potentail for grass growth and limitations to grass utilisation.

Although there were high variations across average silage deficits, maximum silage surpluses from good years were sufficient to offset average silage deficits for most location-soil type combinations. This suggests that adapting to climate change will involve investing in storage capacity to allow Irish farmers better utilise silage surpluses from good years.

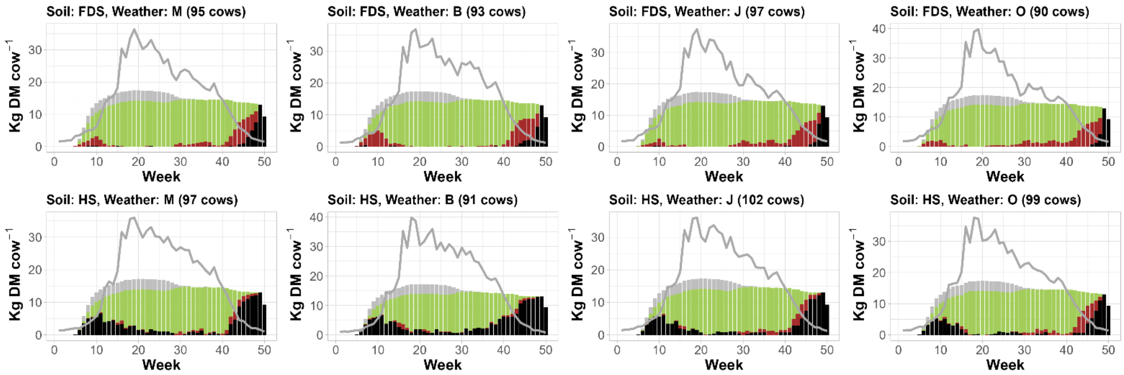

Figure 1: Weekly feed intake per cow of grazed grass (green), indoor silage (black), silage at grazing (brown), concentrate (grey) as well as grass growth (grey line) in kg DM cow^{-1} for different soil types and weather conditions (average of 13 years). FDS = free drain soil type; HS = heavy soil type. M = Moorepark, B = Ballyhaise, J = Johnstown Castle, O = Oak Park.

Conclusions

The variable climatic and soil conditions resulted in the different levels of grass growth, grass intake, number of grazing days, silage surpluses and deficits per location. This implies that a one-size-fits all SR is not ideal for Ireland. To adapt to climate change, SR must be optimised per location due to variability in weather and soil conditions.

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Semi-arid regions such as the Mediterranean basin are increasingly exposed to climate pressures threatening agricultural productivity. Rising temperatures, reduced and more variable rainfall, and more frequent extreme events are expected to intensify water scarcity and heat stress during critical crop growth stages, undermining the resilience of food systems. Moreover, Mediterranean agriculture is highly heterogeneous, with diverse pedoclimatic conditions, management practices, and crop choices, making site-specific responses essential. Robust assessment of crop yields under future climates requires process-based models capturing interactions among climate, soil, crop physiology, and management. Ensemble approaches applying multiple models reduce uncertainty, provide more reliable projections than single models, and highlight consistent patterns and divergent outcomes across crops and sites to inform adaptation strategies. To this aim, we applied an ensemble of five agroecosystem models (APSIM, ARMOSA, CropSyst, DSSAT, and EPIC) to simulate the long-term yield dynamics of four major crops (wheat, maize, soybean, and sugar beet) across representative experimental sites in Italy, namely Padova (PD), Piacenza (PC), Perugia (PG), and Foggia (FG). Models were calibrated using a multi-objective evolutionary algorithm with extensive multi-decadal datasets, including crop yields and residues (>9000 observations) and soil organic carbon content (~110 observations). Simulations were harmonized to project crop performance from 2023 to 2100 under three Representative Concentration Pathways, representing low (RCP2.6), medium-high (RCP7.0), and very high (RCP8.5) greenhouse gas emission trajectories. Three downscaled and bias-corrected daily weather data from the EURO-CORDEX ensemble were used to drive the models.

Results highlighted strong crop- and site-specific responses. Wheat slightly benefited from low-emission scenarios, with yield increases up to +37% at PD by 2100 (Fig. 1), particularly under diversified rotations and high nitrogen input. Reductions occurred at FG (–26%) and under RCP7.0 at PG (–41%). At PC, yields exceeded historical values under RCP2.6 but declined under RCP8.5. Maize was most sensitive to water availability: at PC, despite irrigation (~150 mm), yields decreased by –16%, –48%, and –37% under RCP2.6, RCP7.0, and RCP8.5, respectively; severe reductions occurred at PG (up to –73% under RCP7.0) (Fig. 1), whereas PD increased under RCP2.6 (+14%). Soybean dynamics were variable: PC experienced sharp declines (–19% to –59%), while PD recovered under RCP2.6 but declined under RCP7.0 and RCP8.5 (<3 Mg/ha). Sugar beet, simulated only at PD, was least affected, with increases up to +16% under RCP2.6 and moderate declines under RCP7.0 and RCP8.5 (–6% to –9%).

Overall, these findings suggest that mitigation (RCP2.6) may sustain yields in some regions, whereas high-emission scenarios (RCP7.0 and RCP8.5) are projected to reduce yield stability, particularly for summer crops like maize and soybean

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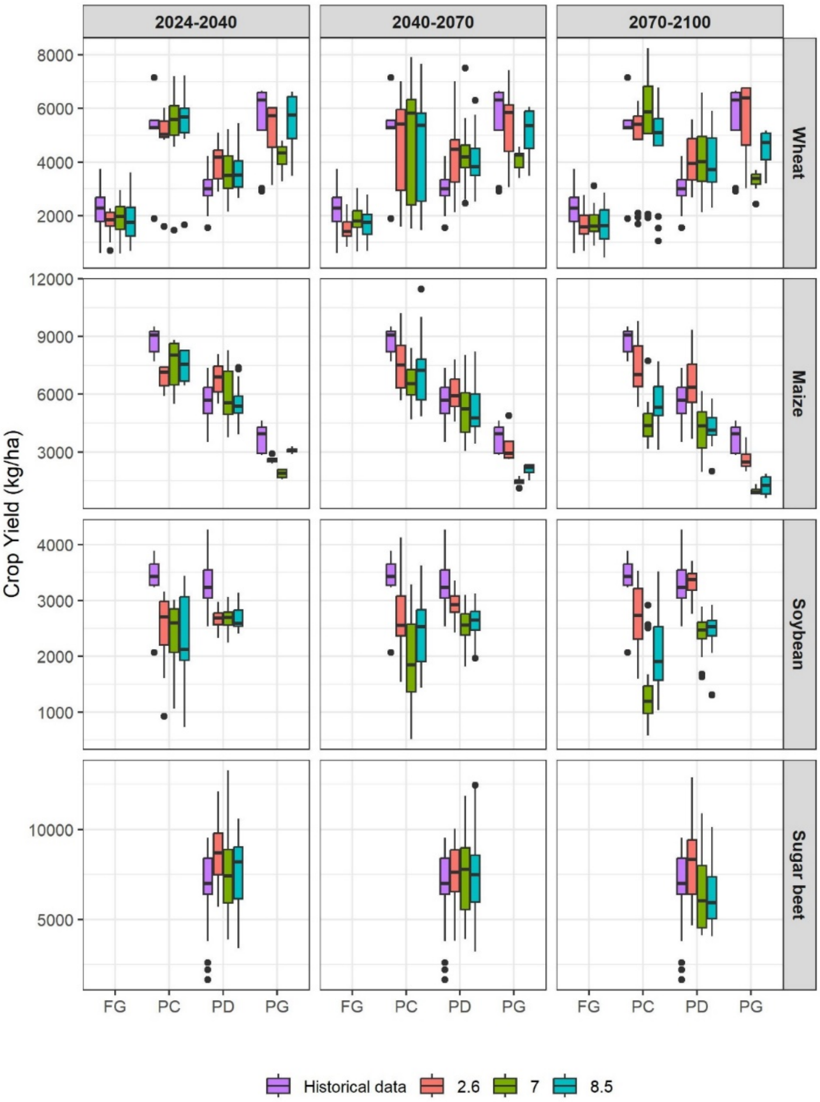

Fig. 1. Historical and simulated crop yields to the end of the century under climate scenario applications at the four sites.

Integrating Field Data and DSSAT Modelling to Assess Climate Impacts on Potato in Southern Ethiopia

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Keywords: Potato, Adaptation, Yield prediction

Introduction

Potato (*Solanum tuberosum L.*) is a high-value crop in Ethiopia's highlands, contributing to food security, income, and dietary diversity. It is sensitive to both heat and moisture stress, and projected climate change threatens to disrupt its productivity (Gervais et al., 2021; Nasir & Tóth, 2022). Crop modelling offers a powerful tool to evaluate potential future impacts and adaptation strategies. This study combines field experiments from the 2020 Belg season in Southern Ethiopia with DSSAT SUBSTOR-Potato modelling to quantify current climate effects. Future yield changes are projected under various climatic scenarios from Regional Climate Models.

Materials and Methods

A factorial experiment with four planting dates and three tuber weight classes was carried out at the Gircha Highland Fruits and Vegetables Research Center in Southern Ethiopia. The early planting dates were 8 February and 23 February. The late planting dates were 6 March and 21 March. Tubers weighting less than 35 g were classified as small, those between 37g – 75g as medium and those heavier than 75g large. Canopy cover was measured using a wood-and-rope grid mesh and plant height as the distance from the soil surface to the top of the shoot apex of the main stem biweekly. Climate data including rainfall, temperature and solar radiation were measured from an on-site automatic weather station. Soil characteristics were taken from a previous study in the same experimental field (Shara et al., 2019).

DSSAT SUBSTOR was calibrated using early season planting data (R1, R2) and evaluated with the march dates (R3, R4). The calibrated model will then be driven by bias-corrected daily climate projections from four CMIP6 models under three Shared Socio-Economic Pathways (SSPs) scenarios to assess the impact of future climate on potatoes yield. The simulations will focus on the midcentury (2041–2070) and end century periods (2071–2100); future yield will be compared to the historical one, obtained by driving DSSAT with historical CMIP6 data (2000-2015).

Results and Discussion

Calibration achieved $R^2 = 0.86$, RMSE = 5.1 t·ha^{-1}, and MBE = +4.2 t·ha^{-1}; validation on independent plantings achieved $R^2 = 0.89$, RMSE = 8.3 t·ha^{-1}, and MBE = +7.6 t·ha^{-1}. R^2 reflects the strength of the relationship between observed and simulated yields, RMSE captures the average prediction error, and MBE indicates the model's bias. These results closely aligned with findings from other tropical environments For example that of Nand et al. (2016) in Fiji that reported R^2 values between 0.66 and 0.92 following calibration of SUBSTOR-Potato.

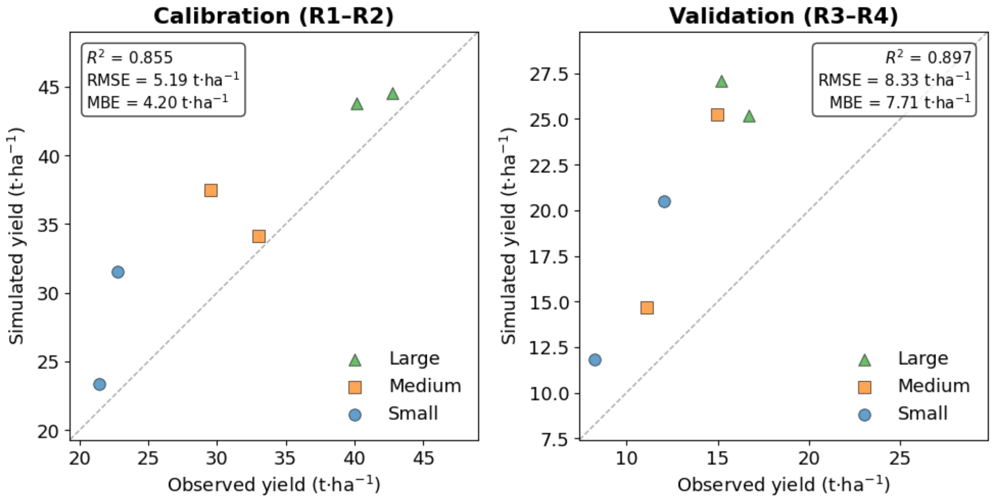

Figure 1. Observed versus simulated potato yields (t·ha^{-1}) from DSSAT SUBSTOR-Potato after calibration and validation. Calibration with early-season field trials (R1–R2); Validation with later-season trials (R3–R4).

Conclusion

We anticipate that low emissions scenarios may allow stable potato yields with high emissions scenarios leading to significant losses.

Acknowledgements

The analysis was carried out on the High-Performance Computing DataCenter at IUSS, co-funded by Regione

Lombardia through the funding program established by Regional Decree No. 3776 of November 3, 2020.

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Assessing Climate Change Impacts on Italian Viticulture at Regional Scale with STICS soil-crop model: Yield, Water Stress, and Phenology Projections via Dynamic Crop Modelling

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Keywords: grape; vine; phenology; projection; Sardinia

Introduction

In Mediterranean viticulture, rising temperatures may reduce yields and accelerate phenology, altering grape composition (Fraga et al., 2012). In Sardinia, Cannonau (Grenache) accounts for ~29% of vineyards; it is vigorous, drought-resistant, and produces deeply colored, high-alcohol wines. This study assesses climate change impacts on Cannonau using the STICS soil-crop model.

Materials and Methods

Study Area

The study was conducted with reference to the Sardinia region, an island located in the centre of the Western Mediterranean Sea, between latitude 38° 51′ N, 41° 15′ N and longitude 8° 8′ E a 9° 50′ E, with a significant cultivation of Grenache.

STICS Model

STICS (Brisson et al., 2009) was validated with field data (phenology, yield, management) from a vineyard in Jerzu (2020–2023). Inputs included meteorological series from a local station and soil data from field analysis (2014) and pedotransfer functions.

Climate, Soil and Terrain Dataset

Climate projections (Highlander project) were derived by downscaling CMCC-CM under RCP4.5/8.5 (2.2 km resolution) (Raffa et al., 2023). Soil (ESDAC, HWSD) and terrain (TINITALY DEM, 10 m) data were used. Plant density was 4000 plants ha^{-1}; no irrigation or fertilization was assumed. Harvest was set at 76% berry water content (~24 BRIX).

Model Spatial Simulation

Plant density was set at 4000 plant*ha^{-1}, a common value across the Sardinia region. Irrigation and fertilization were not applied, and harvest decision was set when the water content in the grape berries reached 76% (~24 BRIX and ~13.4 alcohol content) (De Cortazar-Atauri et al., 2009). Outputs collected: yield, water stress, phenology.

Results and Discussion

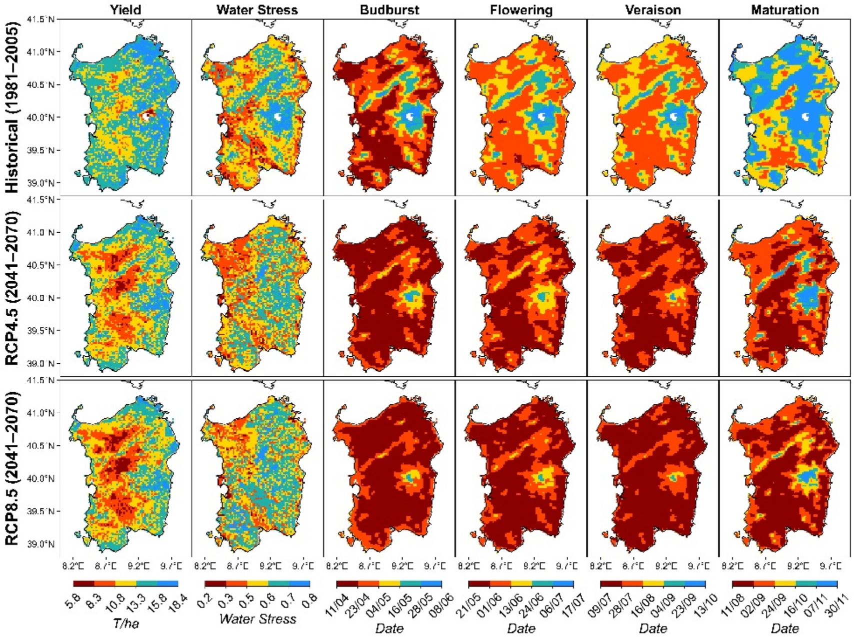
Model Validation

STICS showed excellent performance: yield deviations ranged from -4.91% (2021) to -1.20% (2022). Yield trends were correctly reproduced (increase in 2022, decrease in 2023). Phenological differences were minimal (0–3 days), confirming model accuracy.

Impacts of climate change

Projections (2041–2070) indicate widespread yield losses (−1/−2 t ha^{-1} in coastal zones; −4/−6 t ha^{-1} inland), with gains restricted to high elevations previously unsuitable for viticulture. These trends align with higher water stress indices. Phenology advances markedly: flowering occurs up to 10 days earlier in lowlands and 15–30 days earlier at higher elevations compared to 1981–2005.

Figure 1. Maps of STICS projections for yield. Water stress, and phonological timing across historical (1981-2005) and future (2041-2070) scenarios



under RCP 4.5 and RCP 8.5.

Conclusions

Preliminary results confirm that climate change will intensify water stress, reduce yields, and advance phenology in Sardinia, with only high-altitude zones benefiting. Despite numerous studies, high-resolution regional analyses with process-based models remain essential. Further investigation will refine these results.

Acknowledgements

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Climate change impacts on Sub-Saharan Africa cropping systems: knowledge gaps and research needs

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Keywords: low-input cropping systems, crop models, drought, elevated CO_2 response, multiple stressors

Introduction

Crop yields in sub-Saharan Africa (SSA) must improve to ensure food security and support farmers' livelihoods (Wollburg et al., 2024). However, efforts toward sustainable intensification are often hindered by high inter- and intra-annual weather variability, which is expected to intensify under climate change and with more intensive cropping systems. Future agricultural systems in SSA will need to be not only more productive and sustainable but adapted to, e.g., elevated CO_2 concentrations, rising mean temperatures, and more frequent extreme events (Kotir, 2011). Field experiments and modeling studies have been conducted in SSA to assess climate change impacts on crops and explore potential adaptation strategies, yet the evidence base remains fragmented. In this review, we evaluate the extent of the evidence base on climate change impacts on key annual arable cropping systems of SSA, accounting for main climate change drivers, key indicators of cropping systems performance and under different levels of nutrient limitation. A second aim is to assess the strengths and limitations of existing models and identify opportunities to improve the representation of SSA cropping systems in both regional and global climate impact assessments in future.

Materials and Methods

First, we will conduct a systematic review to assess the extent of the experimental evidence and model suitability for SSA cropping systems, screening literature by keywords, abstracts, and then full texts to extract key information. Second, building on this evidence, we will identify knowledge gaps and propose paths forward for climate impact assessments in SSA. Since the work is still ongoing, preliminary results will be available and presented at the conference following the structure of Figure 1.

The review focuses on annual arable food crop-based systems (e.g., highland temperate mixed, root crop based, and cereal root crop based), which cover around 40% of the SSA population and 25% of arable area (Dixon et al., 2001). We will examine climatic drivers (e.g., drought, temperature extremes, heat stress, elevated CO_2, heavy rainfall, and their combinations) and multiple performance indicators (e.g., yields, quality, soil organic matter, biodiversity, water use, nutrient losses, GHG emissions, erosion). Where possible, we will account for management practices (e.g., nitrogen and phosphorus limiation, tillage, residue management, pest and weed control). For modeling studies, we will also evaluate calibration and prior validation, and the model strengths and limitations.

Expected Results and Discussion

We propose that addressing these gaps requires more systematic methodology approaches that combine experimental data with advanced modeling techniques in future. Novel, cost-effective experiments and non-replicated, co-developed experimental designs are needed to capture multiple stressors and better support model development. On-farm monitoring with validated low-cost sensors, integrated with machine learning, can expand data collection across diverse agroecological conditions. For low-input systems where the data is constrained for required complex model development, combining process-based models with machine learning may offer a pathway to both constrain out-of-sample projections and refine process representation and advance the data-driven climate-smart agriculture in SSA region.

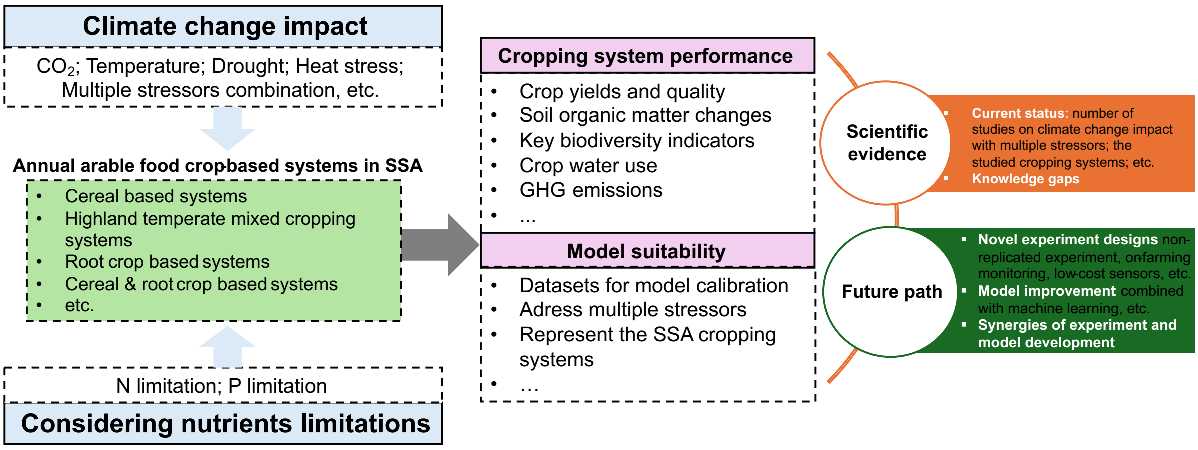

Figure 1. Conceptualization and overview of this review.

Acknowledgements

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Impact of Climate Variability on Rainfed Maize under Multiple Fertilization Strategies: DSSAT Simulations in Sub-Saharan Africa

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Keywords : Crop Phenology, Yield Variation, Integrated Nutrient Management, Crop Modeling.

Introduction Calibri pt 10

Climate change and variability threaten rainfed agriculture in Sub-Saharan Africa (SSA), where maize production is especially vulnerable to rainfall and temperature fluctuations, leading to yield gaps and food insecurity (Mnukwa et al., 2025). Smallholder farmers often cultivate nutrient-depleted soils with minimal inputs, underscoring the need for adaptive agronomic strategies. Crop simulation models, which capture soil–plant–weather–management interactions, provide a valuable tool for assessing climate impacts and testing management options (Jones et al., 2016). This study aims (i) to quantify long-term effects of climate variability on maize yields across agro-ecological zones, and (ii) to evaluate the effectiveness of alternative nutrient management strategies.

Materials and Methods Calibri pt 10

This study used the DSSAT CERES-Maize model to simulate maize yields in Sub-Saharan Africa over 40 years (1984–2023) under four fertilizer strategies: no input, inorganic only, organic only, and combined organic–inorganic. Daily weather data from NASA POWER were validated against ground stations, and model calibration focused on six crop parameters: P1, P2, P5, and PHINT regulating phenological timing, and G2 and G3 defining yield potential. Simulations captured inter-annual climate variability, and outputs on grain yield and growth were analyzed using RStudio for statistical and graphical evaluation.

Results and Discussion Calibri pt 10

Calibration and evaluation were performed for phenology (anthesis and maturity)(figure 1) and yield. Simulations aligned well with observations during calibration (Anthesis RMSE: 3.42, D-index: 0.941; Maturity RMSE: 7.58, D-index: 0.978; Yield RMSE: 820, D-index: 0.92), with accurate performance in Kenya and Tanzania and minor deviations in Ghana, Burkina Faso, and Sierra Leone. Evaluation confirmed reliability, though accuracy declined slightly (Anthesis RMSE: 5.90, D-index: 0.725; Maturity RMSE: 6.34, D-index: 0.985; Yield RMSE: 1118, D-index: 0.81), consistent with DSSAT results across SSA (Kipkulei et al., 2022; Chisanga et al., 2021).

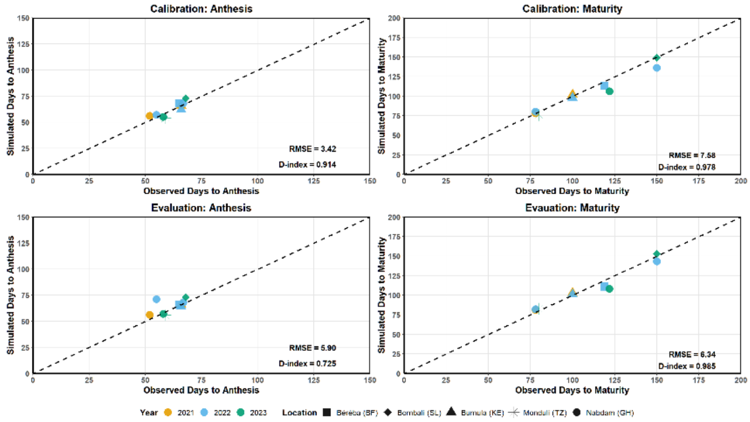

Figure 1. Calibration (top rows) and Evaluation (bottom rows) of Simulated Days to Anthesis and Maturity Using DSSAT Model for the 2021 (yellow dots), 2022 (sky blue dots) and 2023 (green dots)

Regarding temperature-Driven Dynamics of Maize Phenology , The simulations results show a clear shortening of maize development with increasing temperature across the five African sites. Anthesis date (flowering) consistently occurs earlier as average temperature rises . In quantitative terms, the model indicates that each 1°C increase in seasonal mean temperature shortens the time to anthesis by about 3–7% (relative to the baseline duration which is 56 to 76 Days depending on the location . Maturity date (physiological maturity or harvest readiness) also tended to occur earlier with increasing temperature at most sites, but the temperature sensitivity was less steep than for anthesis (table 1).

Table 1. Site-Specific Thermal Response of Maize: Change in Anthesis and Maturity Dates per °C

Site	Stage	Mean days	Reduction_Days _per_^{0}C	Reduction_Percent _per_^{0}C
Béréba (BF)	Anthesis	65.2	−3.06	−4.71 %
Bombali (SL)	Anthesis	57.5	−3.31	−5.75 %
Nabdam (GH)	Anthesis	55.9	−2.24	−4.01 %
Bumula (KE)	Anthesis	67.5	−4.56	−6.76 %
Monduli (TZ)	Anthesis	74.2	−2.43	−3.27 %
Béréba (BF)	Maturity	80.5	−1.70	−2.11 %
Bombali (SL)	Maturity	112.5	−5.25	−4.68 %
Nabdam (GH)	Maturity	81.0	−3.00	−3.69 %
Bumula (KE)	Maturity	106.0	−6.80	−6.42 %
Monduli (TZ)	Maturity	158.0	+1.35	+0.86 %

Fertilizer-based treatments did not consistently improve yields in all location, with gains observed in Ghana (+20%) but little or no benefit in Burkina Faso and slight decreases in Sierra Leone and Tanzania. However, organic–inorganic inputs reduced interannual yield variability, with yield benefits strongest in high-rainfall areas and constrained under semi-arid conditions.

Conclusions Calibri pt 10

This study demonstrates that climate variability, particularly temperature and rainfall fluctuations, has played a decisive role in shaping maize yield dynamics across Sub-Saharan Africa over the past four decades. Simulations with the DSSAT CERES-Maize model revealed that nutrient management substantially improves yields, yet the magnitude of the benefit depends strongly on climatic conditions. While fertilization consistently enhanced productivity in favorable environments, elevated temperatures and drought stress in semi-arid zones often suppressed yield gains, underscoring the dual vulnerability of maize to both soil fertility constraints and climate extremes. Benefits are site-specific and should be paired with water-conserving practices in drought-prone zones. Building resilient maize-based systems in SSA will therefore require a combination of improved soil fertility management, adoption of heat- and drought-tolerant cultivars, and complementary water-conserving practices.

Acknowledgements

This research was carried out within the framework of the EWABELT Project, and I gratefully acknowledge the support and collaboration of all project partners who contributed to its successful implementation. I also extend my sincere thanks to Aarhus University for its academic guidance, where this work was conducted under the supervision of Prof. Davide Cammarano during my Erasmus exchange period.

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Global attainable maize yield shifts under climate change and varying fertilization strategies

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Keywords: maize yield, climate change, nitrogen fertilizer

Introduction

Climate change is projected to reduce global maize yields by the end of century, with the emergence of climate impact to occur before 2024 (Jägermeyr et al., 2021). Maize production is likely to rise further to satisfy a growing demand for animal protein in Africa and Asia (Erenstein et al., 2022), risking substantial environmental impacts (Kozicka et al., 2023). Increased production must therefore be with decreasing environmental impacts and avoiding conversion of natural ecosystems (Cassman and Grassini, 2020). This study aims to develop a modelling approach to predict: 1) maize yields across maize growing areas from 1980 until 2024 for a more reliable estimation of attainable yield and, 2) the relative changes in maize yield for mid-century under two climate change scenarios (SSP2-4.5 and SSP5-8.5) and three nitrogen (N) fertilizer applications scenarios.

Materials and Methods

We compiled 271,357 maize yield observations from different open-access databases from 1980 to 2023 in 44,441 sites across 74 countries. We predict maize yields using a suite of climatic, soil, socioeconomic, and fertilizer input covariates, applying two modelling approaches: a Bayesian regression model using Integrated Nested Laplace Approximations (INLA) with Stochastic Partial Differential Equation (SPDE) for modelling the spatial correlation, which captures generalizable yield–environment relationships with quantified uncertainty, and a Random Forest model, which accommodates complex, non-linear interactions across diverse environments. Using these models, we generate global maps of attainable yield under present-day conditions and simulate yield responses under future climate scenarios and varying nitrogen fertilization levels. Together, these outputs provide an empirically grounded benchmark for assessing yield gaps and evaluating the resilience of maize systems to climate and nutrient constraints.

Results and Discussion

Our models explain up to 97% of yield variance (R^2) and provide robust spatiotemporal predictions. Our timeseries prediction aligns with maize production estimates from FAOSTAT, MapSPAM, FAO GAEZ, and AgMIP Phase 3 multi-model means for most countries. Our findings show that without fertilizer inputs adaptation, maize yields may decline by up to 34% in the most vulnerable regions, especially in major producing regions such as central Africa, South and West Asia, and South America, while Europe and North America are predicted to be less affected. Yield losses are concentrated between 40°N and 30°S, where most maize is grown, whereas high-latitude regions (> 40° or <– 30°) show slight gains. However, low N input countries can benefit from applying optimum N rate (150 kg/ha) to mitigate the detrimental impact of climate change. Future studies on adaptation to climate change should focus on other methods for enhancing N in the soil such as crop residue, manure application, minimum tillage and including legume crops in the rotation.

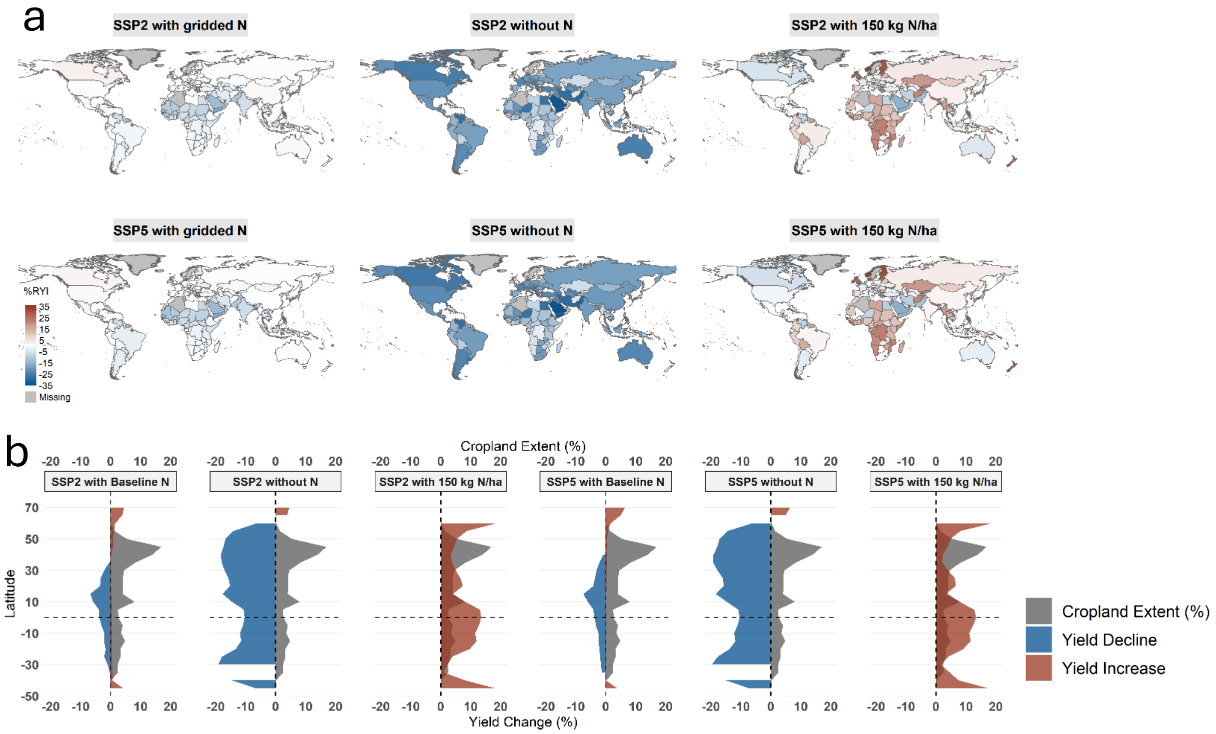

Figure. Relative yield impact for mid-century 2050 for two Shared Socio-economic Pathways (SSP2 and SSP5) under three Nitrogen application rates (baseline N fertilizer rates, without N fertilizer and 150 kg N/ha) summarized by a) country level maps and b) the latitudinal profile of yield change (%) and cropland fraction (%) simulated for grid cells of current maize harvested area from CROPGRIDS for all climate and N application rates scenarios.

Conclusions

Climate change is projected to reduce global maize yields by 2050, with regional variation influenced by nitrogen fertilizer application rates and Shared Socioeconomic Pathways (SSP2-4.5 and SSP5-8.5). Without adaptation, maize yields may decline by up to 34% in most vulnerable regions. Increasing nitrogen application to optimal levels can partially mitigate yield losses in low-input regions.

Acknowledgements

This work was supported by the Bill & Melinda Gates Foundation and the Foreign, Commonwealth & Development Office (FCDO). We thank the International Maize and Wheat Improvement Center (CIMMYT) for providing data.

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Climate change impact on Arabica coffee plantations: Future trends in traditional and non-traditional coffee growing regions of India

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Keywords: Arabica coffee, SSP2-4.5, CMIP6 projections, sensitivity analysis, suitability mapping

Introduction

Globally, coffee is one of the most valuable plantation crops ranking as the world's second-most consumed beverage. It is considered premium, but it is more sensitive to climatic variations and pests compared to the more resilient Robusta variety (Hebbar et al., 2019) (Coste, 1992). Variations in temperature and rainfall can significantly alter flowering cycles, bean quality, and ultimately the yield of the crop (amargo,1985). In India, Arabica coffee is predominantly cultivated in the southern states, where both traditional and emerging non-traditional regions contribute to production. Among all these, Karnataka is the largest producer, contributing over 70% of the nation's total coffee output. Kerala (21%), while Tamil Nadu accounts for about 5% of overall production (Gokavi and Kishor,2020). The present study investigates the impact of climate variability on Arabica coffee yield across five South Indian states- Karnataka, Kerala, and Tamil Nadu (traditional coffee-growing regions) along with Andhra Pradesh and Odisha (non-traditional coffee-growing regions) with district-level analysis focusing on coffee yield sensitivity to key bioclimatic variables.

Materials and Methods

This study assessed the impact of climate change on Arabica coffee yield in both traditional and non-traditional coffee-growing regions of southern India under the CMIP6 emission scenario SSP2–4.5 ("middle of the road" socio-economic development pathway). Historical climate datasets (2007–2023) and projected data for 2021–2080 were retrieved using Google Earth Engine (GEE) through both JavaScript and Python APIs. Annual yield data (2006–2023) were obtained from the Market Research & Intelligence Unit, Coffee Board of India. To explore the long-term climatic trend, Mann–Kendall trend analysis, Sen's slope estimator and for relationship between climate variables and productivity linear regression models were applied. Statistical analyses were conducted in Python (Jupyter Notebook environment). Suitability mapping for Arabica coffee was developed for four-time intervals i.e. 2000-2020, 2021-2040, 2041-2060 and 2061-2080 using temperature, rainfall and elevation data from GEE, to identify potential spatial shifts in cultivation zones.

Results and Discussion

The results indicate a statistically significant increasing warming trend i.e., around 0.033 °C/year (~0.33 °C per decade), and the coffee planted area has been decreasing significantly by around 147.5 ha/year, pointing to a steady loss in cultivation area across all major coffee regions, accompanied by erratic rainfall patterns. Regression analysis revealed that Arabica yield shows stronger sensitivity to rising temperature than to rainfall, with notable declines projected under future scenarios. Suitability maps suggest a contraction of optimal coffee zones in parts of Karnataka and Kerala, while some higher-elevation districts may remain relatively stable or even become more suitable. In non-traditional regions such as Andhra Pradesh and Odisha, the spatial extent of suitability remains limited, with future projections showing mixed outcomes depending on local climatic conditions.

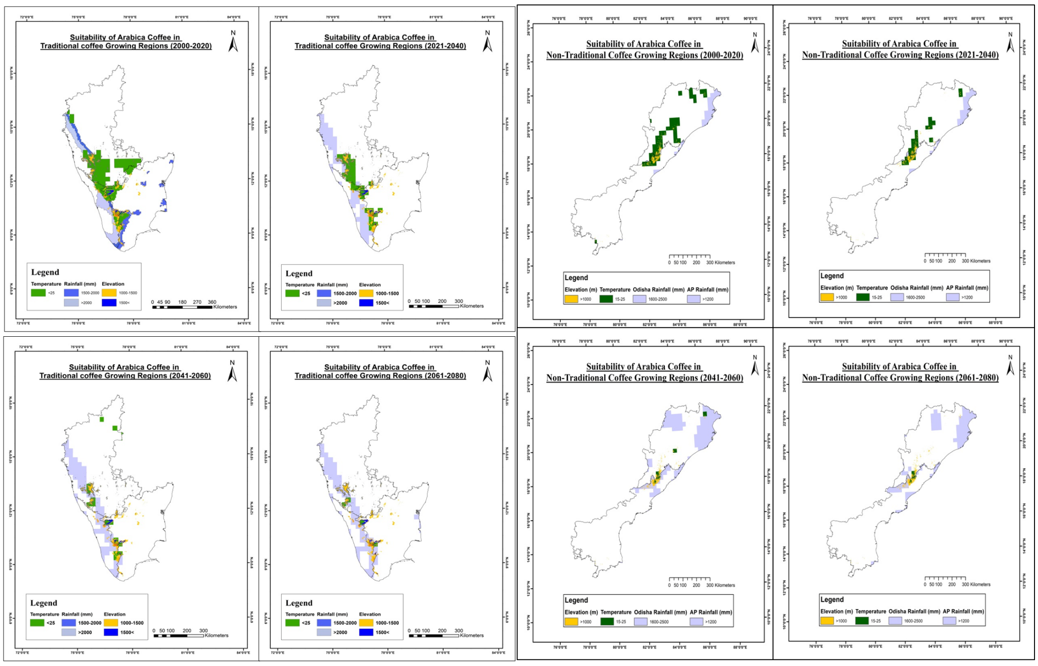

Figure 1. Suitability maps of traditional and non-traditional coffee growing regions of India (2000-2080)

Figure 1, showing the spatial suitability maps clearly illustrate a declining trend in suitable areas for Arabica cultivation across all five states between the years 2000 and 2080. Traditional regions such as Karnataka and Kerala show the most pronounced contraction, while non-traditional areas like Andhra Pradesh and Odisha remain marginally suitable. This visual evidence reinforces the projected vulnerability of Arabica coffee under future climate scenarios.

Conclusions

The findings underscore the vulnerability of Arabica coffee to ongoing climatic shifts in South India. While rainfall fluctuations partly explain yield variability, incremental warming poses the greatest long-term risk. These insights can support adaptive strategies, including agroforestry-based microclimate buffering, improved irrigation scheduling, and climate-resilient varietal development. The results emphasize the urgency of region-specific adaptation measures to sustain Arabica coffee cultivation under changing climate regimes.

Acknowledgements

The authors would like to express their sincere gratitude to the Director, NRSC, Hyderabad, and the Chief General Manager, Regional Centres, NRSC, New Delhi, for their guidance and encouragement. They also gratefully acknowledge TERI School of Advanced Studies for its academic support and encouragement throughout this work.

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Shifting Calendars? Spatial Patterns of Arabica Coffee Anthesis and Maturation under Climate Change in Brazil

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Keywords: *Coffea arabica*, Coffee Farming, Phenology, Future Climate Scenarios, Global Warming.

Introduction

Climatic variability, particularly temperature and rainfall, directly modulates the timing of anthesis and fruit maturation in *Coffea arabica*, with consequences for yield formation and beverage quality (Freitas et al., 2025). Although flowering is visually striking, it is driven by a complex physiological process that is highly sensitive to hydrothermal triggers and management practices. Coffee maturation, in turn, is typically accelerated in regions with higher rainfall and air temperatures, leading to an earlier cropping cycle. These dynamics are especially consequential in Brazil, the world's largest coffee producer and exporter, where edaphoclimatic gradients, management practices, and cultivar genetics jointly shape phenological timing (Freitas et al., 2024). Accordingly, this study evaluates how CMIP6 climate projections under two emissions pathways (SSP2-4.5 and SSP5-8.5) and three future horizons (near: 2041–2060; intermediate: 2061–2080; far: 2081–2100) may shift the dates of anthesis and physiological maturation of Arabica coffee across Brazil's main production regions.

Materials and Methods

Thirty-six (36) sites representative of traditional Coffea arabica–growing regions in Brazil were selected. These regions typically exhibit favorable climatic conditions for Arabica coffee, with mean temperatures between 20.5–21.2 °C, annual precipitation exceeding 1,400 mm, and elevations above 700 m. Historical daily weather data (1990–2020) was obtained from the Brazilian Daily Weather Gridded Data (BR-DWGD) (Xavier et al., 2022). Future climate projections for 2041–2060 (near future), 2061–2080 (intermediate future), and 2081–2100 (far future) were derived from CLIMBra (Ballarin et al., 2023), which applies statistical downscaling and bias correction to CMIP6 global climate models under SSP2-4.5 and SSP5-8.5, consistent with the IPCC AR6 synthesis. Anthesis onset was defined as the first 10-day period after early April in which cumulative thermal time reached 1,980 °C·day (base temperature, Tb = 8.5 °C) following a rainfall event ≥ 16 mm. Physiological maturation was defined as the point at which post-anthesis accumulation attained 3,000 °C·day (Tb = 10 °C) (Freitas et al., 2025). For each site, scenario, and time horizon, shifts were computed relative to the historical mean 10-day period.

Results and Discussion

Figure 1 summarizes projected shifts in anthesis and maturation dates. Historically, flowering in *Coffea arabica* occurs predominantly from September to October, and maturation between April to July. Under future scenarios, results indicate spatially responses consistent with hydrothermal controls. In northern, warmer production zones, anthesis tends to occur later than in the historical period, by more than 25 days in some locations, reflecting stronger dependence on rainfall events to trigger bloom in non-irrigated systems. Conversely, in southern and/or cooler, higher-elevation zones, anthesis is advanced, in some cases by up to ~50 days relative to 1990–2020. The magnitude of these shifts generally increases from SSP2-4.5 to SSP5-8.5 and temporal distance (from near to far future), with particularly strong signals in low-latitude regions, consistent with progressive warming and altered rainfall timing. Earlier flowering in cooler regions may compress pre-flowering management windows and heighten sensitivity to heat or water deficits, potentially diminishing the realized benefits of fertilization if phenophase–management alignment is lost. Regarding maturation, projections indicate advances across nearly all regions and climates, implying substantial cycle shortening under warming conditions. In the warmer northern zones, advances are typically ~20–50 days while in cooler regions, particularly at higher elevations in the south, advances are pronounced, in some cases exceeding 150 days, especially under SSP5-8.5 by 2081–2100. A shortened filling period risks incomplete synthesis of key quality-related compounds (e.g., chlorogenic acids, amino-acid precursors), with potential degradation of cup attributes (e.g., increased bitterness), alongside logistical challenges for harvest scheduling. These phenological shifts necessitate re-scheduling of management operations, including irrigation for bloom induction, nutrient applications, pest/disease scouting, and harvest logistics. Regions exhibiting later anthesis but earlier maturation may face increased floral asynchrony, raising costs and variability in bean quality. Targeted adaptation pathways include: (i) revising fertilization and harvest calendars; (ii) stabilizing bloom triggers via supplemental irrigation where feasible; (iii) matching cultivar and altitude to emerging thermal regimes; and (iv) monitoring and buffering heat and water-stress risk windows during sensitive stages.

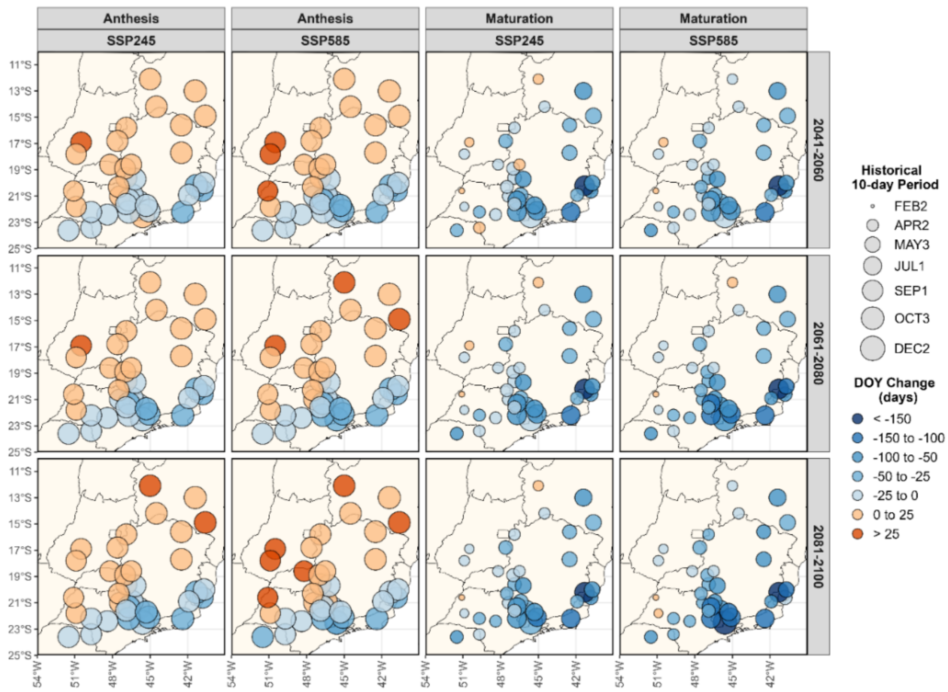

Figure 1. Projected changes of Arabica coffee anthesis and maturation for the near (NF: 2041–2060), intermediate (IF: 2061–2080), and far (FF: 2081–2100) futures, compared to the historical baseline (1990-2020), under SSP2-4.5 and SSP5-8.5 emission scenarios across 36 Brazilian coffee-producing localitions. Circles represent historical mean (10-day periods), and fill indicates projected changes.

Conclusions

Climate change is projected to alter the phenological calendar of *Coffea arabica* across Brazil's growing regions.In general, anthesis will likely advance in cooler, high-altitude zones and be delayed in warmer, low-latitude areas, while maturation is projected to advance broadly, particularly under SSP5-8.5, leading to shortened developmental cycles across all climates. These shifts necessitate adaptive management to sustain yields and beverage quality, with particular attention to aligning nutrient and irrigation strategies with revised phenological calendars, mitigating floral asynchrony to reduce harvest complexity and quality variability, and, strategically matching cultivars and sites to buffer risks associated with warming and altered rainfall timing.

Acknowledgements

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Navigating the trade-off among biomass production and GHG emissions for smart management of grasslands

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Keywords: Crop model, Eddy covariance, Mowing, Fertilization intensity, N_2O emission

Introduction

The concentration of greenhouse gases (GHGs) has been rising in the atmosphere, with long lasting effects on the global climate system. Grasslands are a vital element of terrestrial ecosystems for regulating climate change. They can store ~34% of the global terrestrial carbon stocks (Bai et al. 2022). However, recent heat waves and droughts particularly in Europe have threatened the functioning of these ecosystems. The future increase in magnitude and frequency of these extemes can clearly alter the ecosystem GHG exchange (Reichstein et al. 2013). However, the resilience of grasslands to these extremes and their role as carbon sinks/sources under these extremes strongly depends on soil, climatic conditions, and management intensity. For example, frequent mowing often reduces drought resistance, while fertilization effects remain inconsistent at moderate drought (Qu et al. 2020). It is unclear if and to what extent grassland farmers adjusted their management practices to these extremes, and if so, what is the trade-off among biomass, Net Ecosystem Exchange (NEE), and nitrous oxide (N_2O) emissions towards sustainable grassland management. Process-based models constitute a robust approach to answer these questions by simulating the interactions of soil, weather conditions, and management practices. These models are used to facilitate *ex ante* assessment of ecosystem productivity, environmental footprints, and development of management strategies (Kamali et al. 2022). In this study, we combined a processed-based model with comprehensive eddy covariance measurements from an intensively managed grassland site in Switzerland to simulate biomass production, NEE, and N_2O fluxes under various management practices (Fig. A1).

Materials and Methods

The data from Chamau have been collected within the Swiss FluxNet since 2005, in which NEE and N_2O (from 2012 onwards) fluxes have been measured using the eddy-covariance technique at ecosystem scale (Feigenwinter et al. 2023). The data was integrated into the MONICA agroecosystem model (Model for Nitrogen and Carbon dynamics in Agro-ecosystems) (Kamali et al. 2022). The model was then calibrated and validated against LAI, biomass, soil water content, NEE, and N_2O using a multi-objective calibration approach (Kamali et al. 2022). To find the trade-off among three variables of biomass, NEE, and N_2O, the calibrated MONICA was applied to simulate these variables (during 2005-present) under various management scenarios: 1) earlier/later cutting dates compared with dates implemented in the past; 2) less/more frequent cutting events compared to the past; 3) higher/lower amounts of fertilization applied compared to the past (Fig. B1). The contribution of management practices to the variability of these variables were then determined and the Pareto optimality was used to determine trade-offs among three variables.

Results and Discussion

The error values indicated acceptable model performance across all variables (Fig. A2). Model calibration showed the lowest error for biomass (≈ 0.29), with slightly higher values for LAI (≈ 0.39), soil moisture (≈ 0.41), NEE (≈ 0.36), and N_2O

(≈ 0.49). The relative contributions of cutting date, cutting frequency, and fertilization amount to three variables showed that biomass was explained only by a smaller portion of three types of management practices (Fig. B2). N_2O were mainly influenced by fertilization amount, while for NEE, the contributions of cutting date and frequency were determining. Overall, climate-smart grassland management could be achieved by identifying trade-offs among biomass, NEE, and N_2O. Using Pareto optimality, management practices that optimize all three variables were identified, suggesting the important role of cutting dates during drought periods.

Conclusions

Our proposed approach supports evidence-based, climate-smart management decisions for farmers and offers a transferable framework applicable to diverse case studies and environments

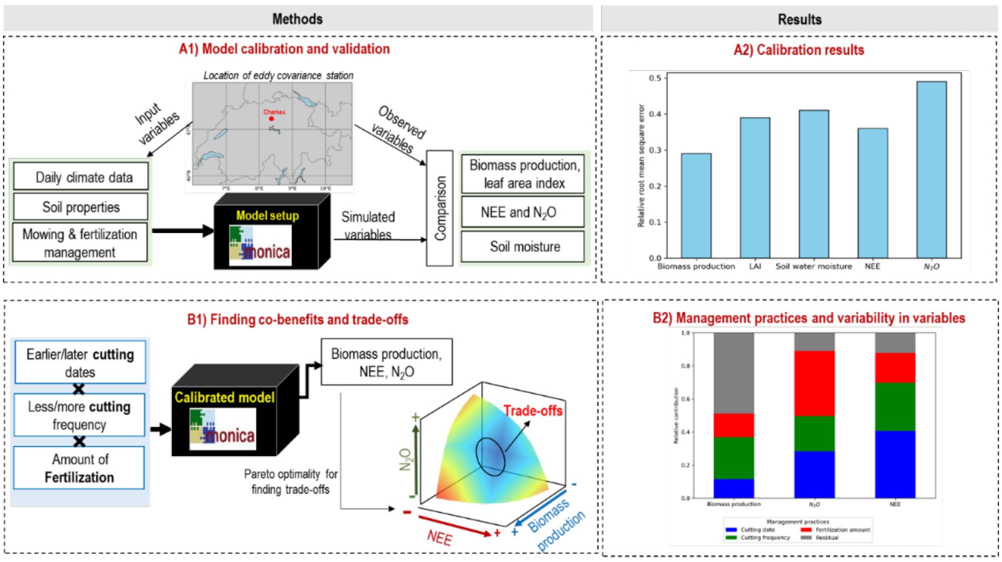

Fig. 1. **A1)** Workflow of model setup, calibration and validation; **A2)** calibration performance**; B1)** workflow for finding trade-offs among biomass, NEE, and N_2O; **B2)** variability explained by management practices

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Bitter or Better? The climate future of cocoa cultivation.

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Keywords: Climate Change Impacts, CropSuite, Cocoa

Introduction

Specialty crops such as cocoa are often understudied, despite their high economic value and their crucial role in supporting the livelihoods of many smallholder farmers. These crops not only contribute significantly to rural incomes but also support global value chains. However, compared to major staple crops, they have received relatively little scientific attention, leaving critical knowledge gaps in their production, sustainability, and resilience to climate change.

Materials and Methods

Contrary to mechanistic crop models, crop suitability models require less input and are less computationally intensive. Therefore, they allow for the consideration of more crops at higher spatial resolution. Crop suitability models can be used for climate impact assessments, adaptation and land-use planning at global, regional or local scale.

Here, we present global results from the open-source model CropSuite (Zabel et al. 2025), which provides a GUI and a wide range of options that allows users to apply the model and analyze the results. It includes a spatial downscaling approach for climate data, which enables crop suitability analysis at very high spatial resolution. CropSuite uses a fuzzy logic approach and is based on the assumption of Liebig's law of the minimum. An expandable number of environmental and socio-economic factors that impact on crop suitability can flexibly be integrated into CropSuite by determining membership functions. CropSuite allows for the consideration of irrigated and rainfed agricultural systems, vernalization requirements for winter crops, lethal temperature thresholds, photoperiodic sensitivity, the inter-annual climate variability and several other limitations for crop growth. The model endogenously calculates and outputs climate-, soil- and climate-edaphic suitability, the optimal sowing- and harvest dates, the potential for multiple cropping, the (most) limiting factor(s), as well as the recurrence rate of potential crop failures according to the inter-annual climate variability. It allows for the consideration of crop rotation systems. In addition, several management options, such as irrigation and liming are included in the model.

Results and Discussion

We applied CropSuite for cocoa globally at a spatial resolution of 30 arc seconds (1 km at the equator) and present first results (Fig. 1) and discuss possible implications. Cocoa is a tropical crop with very specific climate requirements. In the tropics, current climate is already close to existing plant-physiological thresholds. Therefore, cocoa is strongly impacted by climate change under higher emission scenarios, such as SSP585. Most of the current growing areas will become less suitable or even unsuitable under future climates. Western Africa, where 2/3 of current global cocoa production takes place, shows large decrease in suitability, while other regions in Africa, such as Cameroon remains relatively stable and even shows some areas with increasing suitability. Other regions, such as southern parts of Brazil will become suitable where cocoa is currently not cultivated.

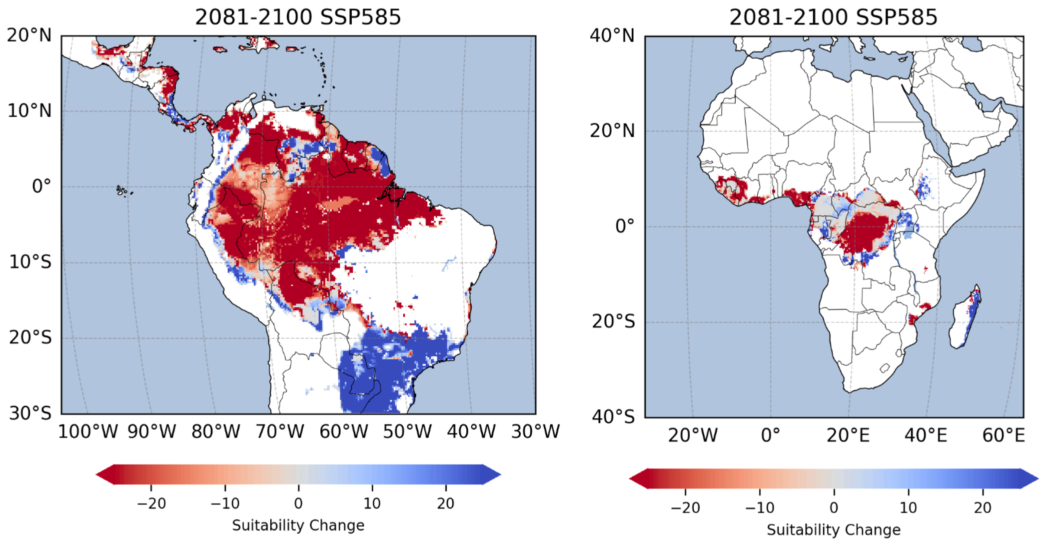

Figure 3: Change in suitability for cocoa under SSP585 for 2081-2100 compared to 1991-2010 for South America (left) and Africa (right).

Conclusions

CropSuite is a powerful tool to investigate and assess agro-climatic risks under future climates. This is important for strategic land-use planning and the development of effective adaptation strategies.

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The resilience of barley to drought in a changing climate is determined by its lateral root diameter

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Keywords: barley, lateral root diameter, climate change, functional-structural plant modeling

Introduction

Climate change is intensifying droughts and threatening food security. Roots are the plants' main organ for water uptake and are crucial for their adaptation, with their structure being a decisive factor. In barley (*Hordeum vulgare*), lateral roots form ~60% of the total root length and are important for water uptake (Schneider et al., 2017). Hydraulic conductance scales strongly with root diameter: thicker laterals conduct more water per unit length but demand higher carbon for construction and maintenance (Strock and Lynch, 2020; Lynch et al., 2014). During soil drying, this creates a potential carbon-water trade-off. We tested whether such a trade-off exists and whether it affects drought resilience across environments by comparing the diameter that optimizes the carbon-water trade-off with that maximizing shoot dry mass (SDM).

Materials and Methods

We simulated spring barley at six representative global sites (one per continent). Growing-season climate (2000–2049 projections) came from Open-Meteo; soils from SoilGrids2.0. Root growth was modeled with OpenSimRoot, a crop model equipped with a root architectural model (Postma et al., 2017), over 50 years per site. Lateral root diameter spanned five levels (0.01–0.05 cm). Outputs included SDM, carbon allocation to roots as a normalized index CCI, and root hydraulic conductance, also normalized as accumulated conductivity investment (ACI). We assessed drought performance and the carbon-water trade-off using fixed thresholds to define four quadrants and compared trade-off-based optima to SDM optima.

Results and Discussion

Globally, SDM depended strongly on diameter with a peak near 0.02 cm (Fig. 1a). This peak is close to the average diameter commonly reported. However, Fig 1A masks large site-to-site variation, indicating no universal optimum and the need for root plasticity. A scatterplot of root carbon costs vs hydraulic conductance illustrates the trade-off in two-quadrants: high-cost/low-capacity (upper left) versus low-cost/high-capacity (lower right) strategies (Fig. 1b). Diameter clusters in the quadrants according to the trade-off (Fig. 1c).

At the global level, SDM and trade-off analyses converged to the same diameter, reflecting a general trend. Site-specific analyses diverged, however, because SDM emphasizes short-term biomass gains whereas the trade-off emphasizes efficiency and resilience. These differences were most evident under variable climate and soil conditions. In some environments, incomplete expression of all quadrants further displaced local optima from the global result.

These findings challenge a "cheap-root" hypothesis: finer roots did not consistently maximize both conductance and yield (Lynch, 2013). Under several regional climate scenarios, thin laterals failed to deliver simultaneous hydraulic and biomass advantages, implying that climate change can shift the relative benefits of "cheap-root" strategies across environments. Variation in climate, soil, and the evaluation objective (yield related to conductance) likely accounts for the mixed and sometimes contradictory reports of 'optimal' diameter under drought and other resource-limited conditions (Jeong et al., 2013; Lozano et al., 2020).

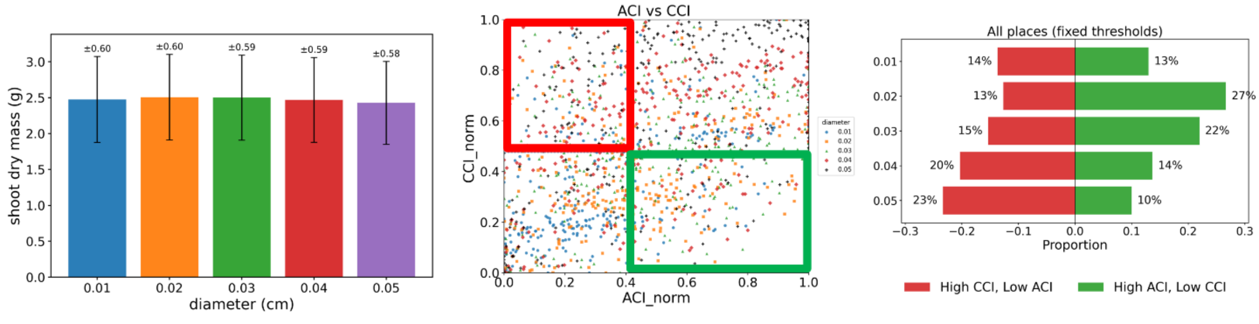

Figure 1. Shoot dry weight by diameter and carbon-water trade-offs.

(a) Bar chart pooled across all places: x-axis, root diameter; y-axis, shoot dry mass (g, mean ± SEM). The y-axis starts at 1.5 for readability.

(b) Root carbon cost (CCI_norm) and root hydraulic conductance (ACI_norm) were scaled to 0–1 within each location using the 5th and 95th percentiles as lower and upper bounds. Scatterplots were then divided into four quadrants (high-cost/low-capacity in the upper left; low-cost/high-capacity in the lower right) using pooled medians as fixed thresholds to allow direct comparisons across locations and treatments.

(c) Within-diameter proportions in the opposing quadrants (left bar = upper-left; right bar = lower-right). The shares shift inversely across diameter classes. Colors are kept consistent across panels.

Conclusions

The effect of lateral root diameter on drought-resilience is driven by the trade-off between carbon allocation and water uptake. The diameter that performs best depends on the environment (climate and soil) and the objective (e.g., maximizing SDM versus efficiency/resilience). When data are pooled across all sites, SDM- and trade-off-based optima coincide, but site-level results differ. Therefore, breeding for drought resilience should target site- and objective-specific trait values rather than a single fixed optimum.

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Linking climatic suitability and productivity of dryland crops during the Holocene using EcoCrop and LPJmL models

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Keywords: Holocene, crop modeling, dryland agriculture, climate resilience, paleoclimate

Introduction

Dryland crops such as sorghum, millet, and wheat have sustained societies for millennia, especially in Africa and the Mediterranean Basin, where agriculture has been highly sensitive to long-term climate variability (Marshall & Hildebrand, 2002; Dearing et al., 2015). Most crop modeling studies address present or future scenarios (Asseng et al., 2013; Alimagham et al., 2024). In contrast, dynamic global vegetation models (DGVMs) are widely used in paleoecology to reconstruct vegetation and carbon dynamics (Prentice et al., 2007). Few studies, however, apply process-based models to hindcast crop productivity. We introduce such an approach, combining EcoCrop niche modeling with LPJmL productivity simulations to study Holocene agricultural resilience.

Methodology

We applied EcoCrop (Ramirez-Villegas et al., 2013) with CHELSA-TraCE21k paleoclimate data (Karger et al., 2023) to estimate sorghum suitability across Africa from 10,000 BP (years before present) to the present. EcoCrop evaluates climatic thresholds for temperature and precipitation to identify potential growing zones, allowing us to trace temporal changes in suitable areas at continental and subregional scales. Next, we will use LPJmL model (von Bloh et al., 2018) to simulate crop productivity and water use in these zones, testing whether climatically suitable regions also supported sustainable yields.

Results and Discussion

Our exploratory EcoCrop curves (*Fig 2.*) and climate data (*Fig 1.*) show that total sorghum-suitable area grew from 5 million km² at 10,000 BP to nearly 9 million km² at present. Northern Africa lost suitability after mid-Holocene aridification, while eastern, middle, and southern Africa gained suitable areas.

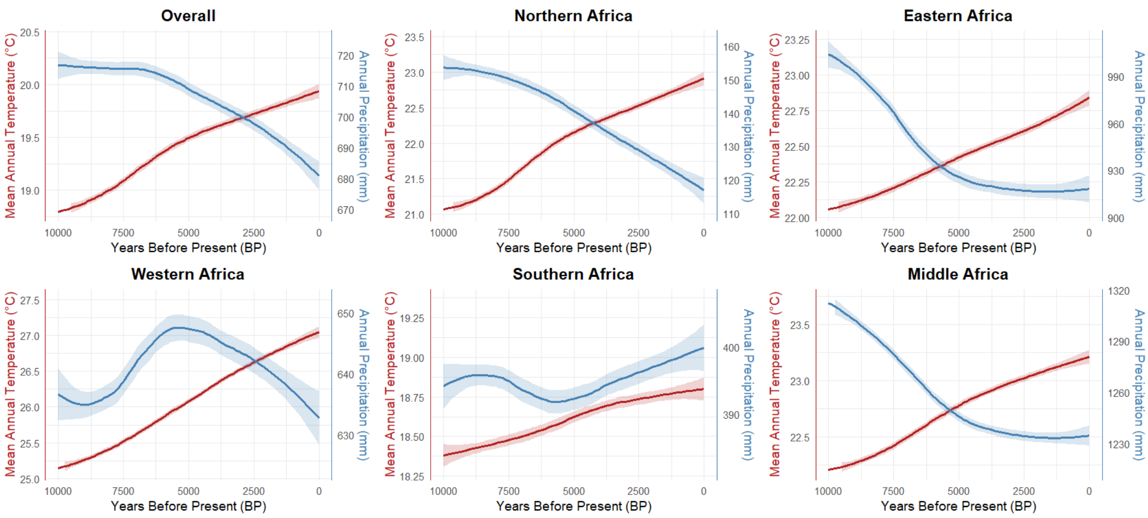

Figure 1. Holocene temperature and precipitation trends across Africa and subregions (CHELSA-TraCE21k).

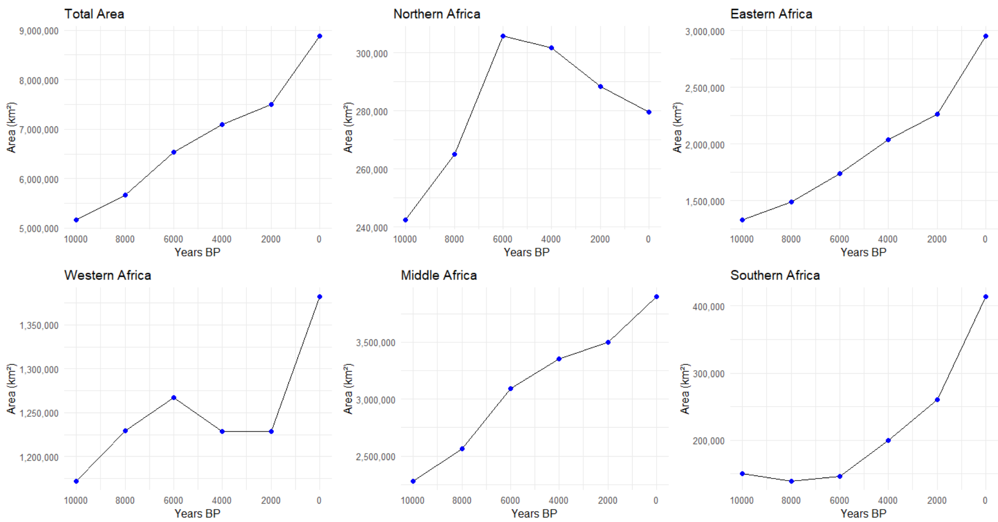

Figure 2. Holocene sorghum-suitable area in Africa and subregions (EcoCrop model).

These shifts raise central questions:

- Did all climatically suitable zones sustain productivity?
- Which thresholds of aridity or temperature limited yields despite suitability?
- Do modeled productivity hotspots align with known archaeological centers?

Conclusions

This study is ongoing and represents one of the few attempts to apply process-based crop and vegetation models to paleo-agriculture. By combining EcoCrop suitability with LPJmL productivity simulations, it seeks to answer how past climate shaped both the extent and performance of dryland crops. Situating crop modeling in the Holocene allows us to identify long-term thresholds and resilience pathways, providing historical analogues that remain highly relevant for present food security and preparing agriculture for future climate change.

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Crop climate impacts and drivers across the CMIP6 ensemble and sub-ensembles

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Keywords: growing season weather; emulator; machine learning; global gridded crop model; EPIC

Introduction

Global crop climate impact studies, including state-of-the-art crop model ensembles, are typically forced with a selection of global climate model (GCM) simulations for high and low concentration pathways (Jägermeyr et al., 2021). These GCM sets are selected based on global changes in temperature and precipitation expected to bracket the whole ensemble, and in part opportunistic based on timely data availability. The practice of GCM selection per se is owed to computational constraints in impact models such as global gridded crop models (GGCMs). Impact model emulators have been developed to deal with such constraints (Müller et al., 2021). However, early generations of GGCM emulators have been based on long-term annual climate shifters that neglect changes in growing season-specific climate. Here, we present a study using a novel GGCM emulator that combines growing season-specific climate feature engineering with a machine-learning algorithm to derive highly accurate yield predictions and simultaneously provides insights into growing-season climate change as a functional climate impact-driver (Ruane et al., 2022). This emulator is trained on the GGCM EPIC-IIASA and applied to bias-corrected projections for 29 GCMs from the CMIP6 ensemble to evaluate potential bias introduced in impact studies by GCM selection and eventually the role of growing season climate-informed GCM characteristics.

Materials and Methods

Global gridded crop yield estimates were produced using the CRop Model Emulator Suite (CROMES) v1 (Folberth et al., 2025). Using state-of-the-art crop-specific growing season information (Jägermeyr et al., 2021), CROMES first estimates climate features for each annual crop growing season and cardinal crop growth phases based on GDD accumulation. These features and additional soil information are then used for training a CatBoost algorithm to predict crop yield estimates from EPIC-IIASA GGCM simulations that were forced with five selected GCM projections from the Intersectoral Impact Model Intercomparison Project (ISIMIP). Predictions for GCM projections not seen in the algorithm training have been shown to have very high agreement with simulation outputs from the process-based crop model with typically R2>0.95 and RMSE<0.7 t ha^{-1} (Folberth et al., 2025). We then apply the emulator to the whole set of 29 GCMs for which bias-corrected data are provided by Thrasher et al. (2022). Rainfed maize is used as a model crop.

Results and Discussion

We find that the five GCMs presently considered in state-of-the-art global crop climate impact assessments follow roughly a pattern of proportional increases in annual precipitation and temperature (Figure 1). I.e., the point pairs for these two key climate variables are roughly located along a transect from low increases in both temperature and precipitation to large increases in both temperature and precipitation. While this GCM selection brackets the range of precipitation and temperature changes among models at large, it misses out on GCMs deviating from the above temperature-precipitation coupling, essentially "hot-dry" and "cool-wet" models.

Changes in global average rainfed maize yields are strongly dominated by changes in temperatures with the highest losses in the hottest GCM (UKESM1-0-LL) despite a moderate increase in precipitation. Only relatively large increases in precipitation can in part mitigate yield losses due to temperature increases in this exemplary C4 crop. Accordingly, the lowest losses occur for GCMs that have large increases in precipitation and low to moderate increases in temperature, located in the upper left quadrants of Figure 1a, b. The selection of GCMs consequently also affects ensemble averages and ranges for yields. While the ensemble maximum loss is hardly affected for both SSPs when contrasting the five priority GCMs with the whole ensemble, the median yield loss for five priority GCMs for SSP2-4.5 is 26% smaller (the most optimistic projection is 40% higher) than that of the extended ensemble. A very similar pattern occurs for SSP5-8.5, where the median is 22% smaller (the most optimistic projection is 46% higher). In short, the priority GCM selection neglects that there is a larger number of GCM simulations that result in large losses and a few that are comparably optimistic. Regionally, yield impact estimates are far more detrimental for the whole GCM ensemble in North America and Southern Europe (not shown), highlighting also the importance of ensemble construction for regional impact projections or interpretations of global impact patterns.

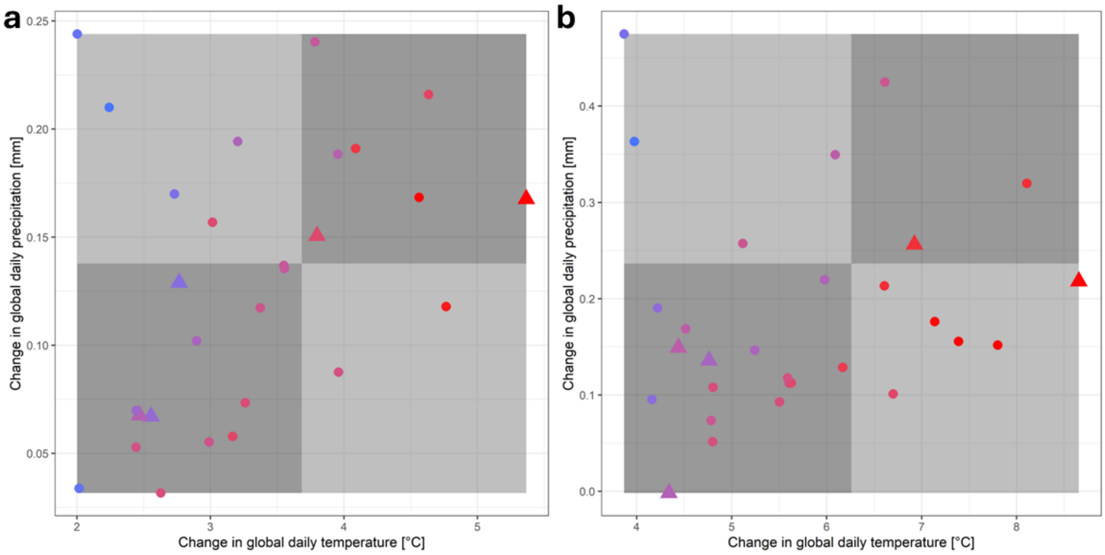

Figure 1. Change in average global daily temperature and precipitation over cropland for 29 members of the CMIP6 ensemble for (a) SSP2-4.5 and (b) SSP5-8.5 yb the end of century. Colors indicate changes in rainfed maize yields with blue=low losses and red=large losses. Symbols indicate triangles=five ISIMIP priority GCMs, points=all other GCMs. Background shading solely serves for visual orientation indicating the axes mid-points.

Conclusions

Our initial findings show that the presently widely used selection of GCMs provides in part more optimistic crop yield impacts than the wider CMIP6 ensemble and has a narrower range of outcomes. While the GCM sub-selection brackets the global ranges of temperature and precipitation changes individually, it does not cover their combinations. Whether all of these climate projections are in the range of physically plausible outcomes will need to be informed by atmospheric sciences to identify most useful GCM selections for impact ensembles. Meanwhile, high accuracy emulators as applied herein can provide insights across climate ensembles complementary to process-based simulations on the one hand or to inform impact pattern-based GCM selections on the other.

Acknowledgements

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Climate change has a significant impact on agricultural production globally. Countries in sub-Saharan Africa are especially vulnerable to these changes, as they are already facing a range of non-climatic stressors on food security and the majority of rural populations depend on agriculture for their livelihoods. The same is true of Madagascar, an island state where most farms are small-scale subsistence farms and around 80% of households depend at least partially on agricultural activities. The four major crops in Madagascar in terms of growing area are rice, cassava, sweet potato and maize, all of which are primarily grown for self-consumption. Frequently occuring extreme weather events such as cyclones, severe drought and flooding are already challenging food production throughout the country, and recent droughts in the arid south have led to a severe food insecurity crisis (Harvey et al., 2014).

Future climate change is expected to exacerbate the situation through more frequent extreme weather events as well as shifts in growing areas and growing seasons. In contrast, increased atmospheric CO2 concentrations are likely to benefit crop growth and may help mitigate or even compensate for losses induced by climate change (Tomalka et al., 2020). However, the combined effects of these factors, and the consequent adaptation strategies, will be crop- and region-specific. This study therefore aims to assess the impact of future climate change on the yields of rice, maize and cassava in Madagascar. Particular attention is given to the combined effects of water and nutrient stress and elevated CO_2.

The impact assessment is conducted using the DSSAT crop modelling system (Hoogenboom et al., 2019) and climate data from ten CMIP6 climate models for three future climate scenarios. Information on crop management and reported yields is obtained from Madagascar's Ministry of Agriculture. Prior to spatial application, the model is evaluated against reported field experiments in Madagascar, as well as free air CO_2 enrichment experiments, for the three crops. The simulation accounts for farmers' autonomous adaptation to climate change through shifts in cultivars and growing seasons.

The simulation results suggest a shift in the suitability of the different crops. Maize is the crop most strongly affected by climate change, with the highest yield decreases predicted for the hot western part of the country. On the other hand, yields of irrigated lowland rice are simulated to increase due to the CO_2 fertilisation effect. Upland rice and cassava yields are also predicted to increase, but their stability is threatened by increased drought stress. In conclusion, the results suggest that rice and cassava will be more advantageous than maize in the future. However, the simulated yield gains through elevated CO_2 should be considered a potential upper limit as not all yield-limiting factors are adequately represented in the model.

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Consequences of extended spring drought for winter wheat production outlooks in Germany

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Keywords: Climate change, MONICA model, winter wheat, spring drought

Introduction

Crop model simulation studies provide optimistic end-of-century outlooks on crop yields including winter wheat, mainly due to CO_2 fertilization effects under climate change (Jägermeyr et al., 2021). In addition to elevated CO_2 levels, climate projection data predict above-average precipitation in upcoming years compared to the 30-year moving average. In contrast to that, observed spring precipitation decreased by more than 50% during the last 15 years in Germany. This suggests a potential discrepancy between future wheat production outlooks and recent developments in drought conditions during spring.

Therefore, we evaluated the consequences of spring drought, as observed in the recent past, on winter wheat production in Germany.

Materials and Methods

We created a climate projection data set with dry springs (March-May) over Germany, using quantile delta mapping (QDM), a bias correction method that is frequently deployed to adjust statistical deviations between climate models and observational data. QDM reduces systematic differences between model simulations and observations while preserving the climate change signal by transferring the probability density function (PDF).

We first determined the PDF of the model simulations and observations for a specified training period. We selected daily weather data from the German observation grid (HYDRAS) from the ten driest springs since 1950 as the observation data and training period, respectively. The model simulations refer to climate projection data from the regional German core ensemble under CMIP5, consisting of 17 members (5 members for RCP 2.6 and 6 members for RCP 4.5 and 8.5, respectively). Delta factors were calculated as deviations between the quantiles of the model and observation PDF and added to the corresponding quantiles of the PDF of the entire model time series. This allowed us to compensate for overly wet springs compared to the training data. QDM not only preserves the distributions of each individual variable (precipitation, temperature, relative humidity) but also the physical relationships between the variables, such as the correlation between precipitation and temperature.

We used the process-based crop model MONICA (Nendel et al., 2011) to simulate winter wheat development, growth, and yield formation at the 1 km grid from 1970 until 2100 over Germany, based on soil data from the German soil map (BÜK200). We ran simulations using both the newly generated climate data including spring drought and projections from the German core ensemble as a reference. We used fixed sowing on September 22 of each year and automatic harvest as soon as maturity was reached. To meet nitrogen (N) demands, we applied 40, 80, and 40 kg of mineral N at 60, 120, and 150 days after sowing, respectively. Prior to the simulations, MONICA was calibrated to capture the response to drought conditions, using experimental data from 2020 until 2023 from six experimental locations across Germany. Simulation results from individual climate models were averaged per RCP.

Results and Discussion

Figure 1 shows relative winter wheat yield differences between simulations under spring drought compared precipitation conditions as projected by the German core ensemble for a randomly selected year (2062) of the projection period.

While spring drought would substantially affect projected yields under RCP 2.6 (mean difference -13.16 %), especially in the low-rainfall regions of central Germany, the effect diminished under rising CO_2 levels (-6.13 % and -4.38 % under RCP 4.5 and 8.5, respectively). North-eastern Germany, where soils are sandy with low water holding capacities, was consistently negatively affected by spring drought, even under RCP 8.5. In contrast, high soil quality regions in central and southern Germany showed even slight yield increases under spring drought. This can be attributed to shifts in phenology and higher N mineralization due to increased temperatures in the newly generated data set, together with the benefit of high water holding capacities and only minor precipitation differences during the winter months.

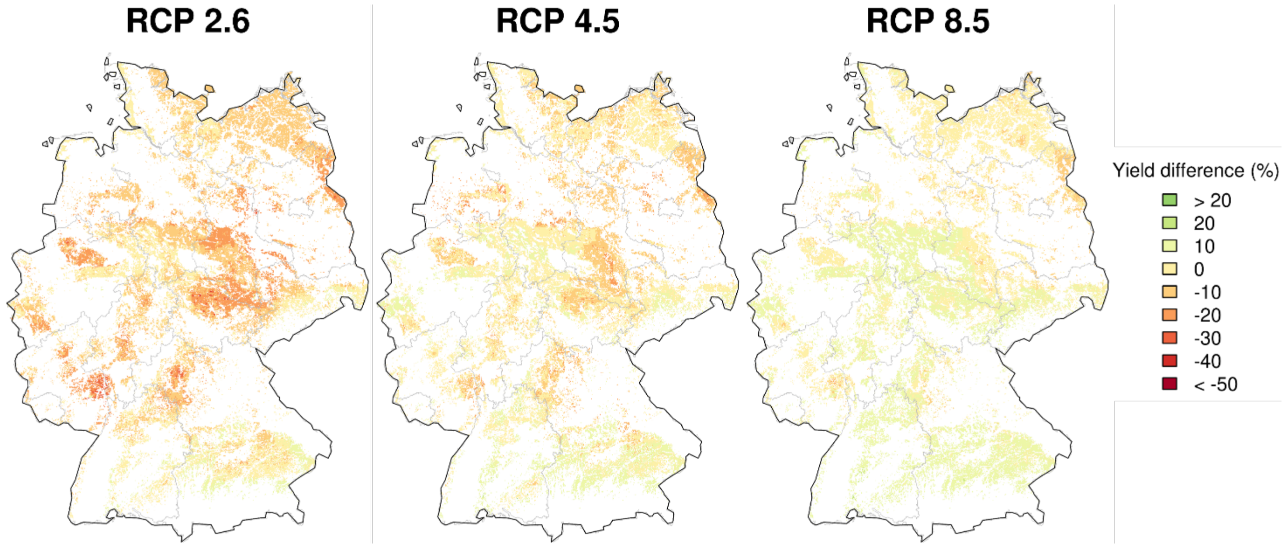

Figure 1. Relative yield differences [%] between simulations under spring drought and precipitation conditions as projected by the German core ensemble in 2062. Reds indicate lower yields while greens indicate a yield increase.

Table 1 gives an overview of the relative deviation between meteorological variables under spring drought conditions compared to the German core ensemble. During the corrected months (March-May) precipitation decreased by 35 to 38 %. Average daily temperatures increased by more than 11 %, and relative humidity decreased by around 5.5 %. Over the entire growing season, precipitation decreased by around 10 %, average daily temperatures increased by up to over 3 % and relative humidity decreased by around 1.5 %.

Table 1. Relative deviation [%] of meteorological variables under spring drought compared to climate projections from the German core ensemble.

Period	Variable	RCP 2.6	RCP 4.5	RCP 8.5
	Precipitation sum	-37.86	-38.93	-35.41
Spring	Average temperature	11.15	8.66	5.59
	Relative humidity	-5.45	-5.52	-5.36

Season	Precipitation sum	-10.73	-10.99	-10.20
	Average temperature	3.75	2.96	1.89
	Relative humidity	-1.55	-1.59	-1.56

Conclusions

Our present results show the complex interactions between meteorological variables and their impact on winter wheat development, growth, and yield formation. Preserving the physical relationships between meteorological variables under spring drought did not affect precipitation alone, but also relative humidity and – importantly – temperature. Together with rising CO_2 levels under climate change, these might even overrule reduced water availability, given our present process understanding.

Acknowledgements

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Climate-smart agriculture in action: EPIC simulations for the Po valley, Northern Italy

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Keywords: Conservation agriculture, Agroecosystem modelling, ClimaxPo

Introduction

In the Po River Basin, climate change is intensifying pressures on water and soil management through rising temperatures, reduced summer flows, and more frequent extreme events (Montanari et al., 2023; Mombrini et al., 2025). Within the LIFE CLIMAX PO project, conservation agriculture practices such as reduced tillage and cover crops are being tested for their potential to limit soil degradation, enhance water retention, and sequester carbon (Tadiello et al., 2023). Process-based crop models are applied to assess impacts on soil organic carbon, soil moisture, and yields under changing climate conditions, providing early insights into their role as adaptation strategies for sustainable resource management.

Materials and Methods

The Environmental Policy Integrated Climate (EPIC) model is being applied to evaluate the impacts of conservation agriculture on soil and crop dynamics in two commercial farms located in Lombardy, Northern Italy (Figure 1). Site-specific data, available from 2019, includes a complete soil profile, annual measurements of soil organic carbon and bulk density in the topsoil, crop rotations (with maize and wheat as the main crops), and a range of management information such as sowing and harvest dates, irrigation, fertilization, tillage operations, and yields. As a first step, simulations are run with the default EPIC parameter set in order to assess the model's baseline performance. In a second step, a sensitivity analysis on selected model parameters is being conducted to test their influence on yield and relevant soil properties. This will be followed by parameterization and calibration, aimed at adapting the model for application at a larger scale across the Po River Basin.

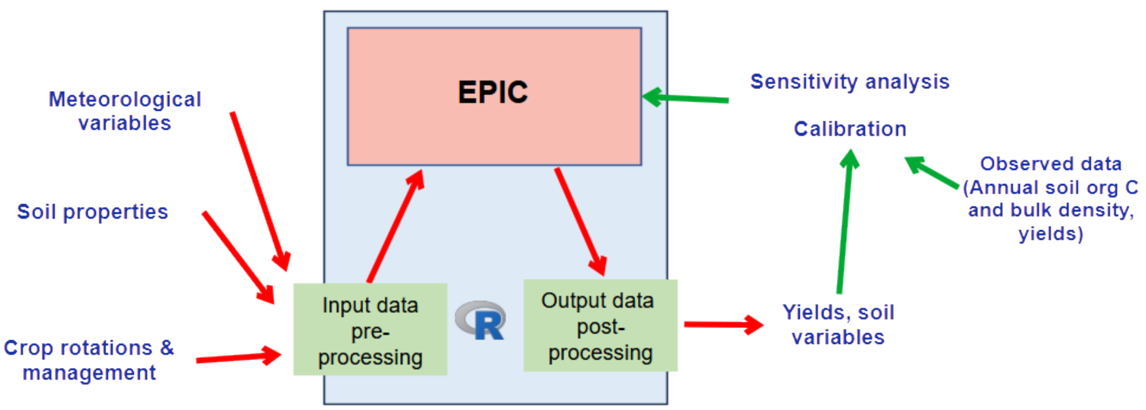

Figure 1. Schematic workflow of the study.

Results and Discussion

Preliminary results indicate that the default EPIC configuration is able to reproduce soil responses with reasonable accuracy. However, the observation period is relatively short for capturing long-term soil responses, so trends and uncertainties in both observed and simulated data must be carefully assessed to confirm the model's performance. In contrast, crop yields tend to be underestimated compared to farmer-based estimates, a discrepancy that may reflect the uncertainty of yield data—which are not directly measured—as well as limitations in the default parameterization. We expect the sensitivity analysis to identify the most critical parameters, thereby indicating potential directions for model adjustment and calibration.

Conclusions

This ongoing study within the LIFE CLIMAX PO project provides preliminary insights into the potential of conservation agriculture as an adaptation strategy in the Po River Basin. Initial EPIC simulations reproduce soil indicators with reasonable accuracy but underestimate crop yields compared with farmer-based estimates. Given the uncertainty of observed yield data, a sensitivity analysis on selected model parameters is essential to identify key drivers of yield variability and guide model adjustment. These early results highlight both the promise of conservation practices for improving soil quality and the methodological challenges of calibrating process-based models under heterogeneous farm data. Future steps will include targeted parameterization, full calibration and validation, and scenario analyses to strengthen the evidence base for climate-smart agricultural management in the region.

Acknowledgements

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APSIM modelling for climate change and irrigation management: Evaluating crops resilience under UAE arid agriculture.

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Keywords: APSIM-model, heat-water stress, irrigation strategies, crop development, crop yield. **.**

Introduction

United Arab Emirates (UAE) faces severe environmental challenges, characterized by arid climatic conditions and high soil salinity, which significantly hinder water resource management and compromise agricultural resilience. Moreover, the country has a historical reliance on imported agricultural commodities to ensure food supply for its population, with a food self-sufficiency ratio below 10% throughout the 2010–2020 decade (FAO, 2021). Climate change has intensified those challenges to food security, compelling the UAE government to allocate significant logistical-financial resources toward the application of advanced technologies for assessing cropping systems across country. Crop modeling has emerged as cutting-edge tools for accurately analyzing crop management, assessing water resource usage and soil health (Keating and Thorburn, 2018; Webber et al., 2014). This study aimed to evaluate performances of three annual crops—wheat, maize, and potato— under integrated climate change projections and irrigation management strategies within the arid agroecosystems of UAE.

Materials and Methods

We employed APSIM-model to simulate crops eco-physiological responses, and compare their vulnerability–adaptability patterns under combined climate-water stressors. Model calibration-validation processes were conducted using dataset encompassing measured and observed crop phenological and productivity state variables. Time-series simulations were then performed under baseline historical and future projected period (1988–2100) defined by four Shared-Socioeconomic-Pathways (SSPs: 2.6–4.5–7.0–8.5).

Results and Discussion

We found that APSIM-model was successfully calibrated, and model validation further confirmed its robust accuracy in simulating crops development and yield prediction under the UAE's agro-environmental conditions. Also, increasing temperatures and water-stress have emerged as critical abiotic stressors, significantly reducing yield across three crops (e.g., wheat-yields up to half and maize-yields up to 75%), acting as well as primary driver of wheat and potato premature crop failure, particularly during the last two decades of the century. Leveraging APSIM-model for irrigation recommendations proved effective in ensuring maize efficient water-use, whereas it helps supporting appropriate potato scheduling across high-emissions scenarios.

Conclusions

Findings highlighted the importance of investing in crop breeding paradigms and resilient crop species (adapted cultivars - C4 crops), while simultaneously promoting the implementation of UAE's adapted soil-water management and climate-smart agricultural strategies.

Acknowledgements

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Assessing Coffee Suitability in Brazil with the CropSuite Model under SSP Pathways

Abstract

Climate change poses a growing threat to coffee production in Brazil, but the relative importance of climatic limiting factors under different future scenarios remains underexplored. We used the CropSuite model together with high-resolution climate forcing data from GSWP3-W5E5 and multiple Shared Socioeconomic Pathways (SSPs: ssp126, ssp245, ssp370, ssp585) to assess changes in suitability and limiting factors for coffee across Brazil. Climate data were obtained via the ISIMIP / GSWP3-W5E5 framework, which provides bias-adjusted daily variables at ~0.5° spatial resolution. This dataset combines the W5E5 reanalysis over land and ocean with GSWP3 to provide long-term homogeneous climate series.

Our results indicate a shift in the dominant climatic limiting factor: whereas under current baseline and the ssp126 scenario, climatic variability remains the primary constraint, under more intense warming (ssp245, ssp370, ssp585), precipitation becomes the limiting factor in all major coffee-growing regions in Brazil. Under these higher emission scenarios, CropSuite projects an overall suitability decrease of ~50 % between the historical period (2000) and 2030, with strongest losses under ssp585.

These findings suggest that adaptation strategies in Brazil must increasingly address water availability either via improved water management, drought-tolerant cultivars, or shifting of cultivation zones to maintain coffee production under climate change.

Keywords: Coffee production, Climate Change, Crop Suitability, Climate risk

Land-based mitigation measures in global agro-ecosystems: A systematic review of multiple impacts on ecosystem services

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Key words: land-based mitigation, climate change, soil and water conservation, air quality biodiversity, food security

Climate change increasingly threatens the resilience and functioning of soil and water systems, particularly in agricultural landscapes that are essential for food production and ecosystem services. In response, land-based mitigation measures (LMMs), have been widely promoted as key strategies to reduce greenhouse gas emissions and enhance carbon sequestration in agricultural contexts. These measures involve changes in land management practices aimed at climate mitigation and include cover crops, organic amendments, crop residue retention, biochar, agroforestry, crop rotations and reduced tillage. However, their effects often extend beyond their primary purpose (greenhouse gas emissions and carbon sequestration), potentially influencing other environmental and agronomic dimensions such as soil health, water resources, air quality, biodiversity, and food security. Assessing whether LMMs generate co-benefits or lead to trade-offs across these dimensions is crucial for guiding their effective and sustainable deployment.

We conducted a systematic review of peer-reviewed studies (2000–2024) in Web of Science and Scopus following PRISMA guidelines. From 3613 records, 200 studies met strict inclusion criteria: evaluation of at least two domains beyond greenhouse gas balance and carbon sequestration. We classified LMM into eight categories and their impacts into five domains (food security, soil quality, water resources, biodiversity, air quality). Indicators, methods and impact type (positive, negative, unclear, non-significant) were coded. Quantitative evidence was summarised and cross-domain relationships were analysed.

Food security and soil quality are the categories of impacts dominating the analysed literature, with ~70 % of studies assessing yield and soil fertility, mainly through field experiments, while only a minority explicitly report the use of process-based or hybrid crop models (e.g. DSSAT, APSIM, STICS). Combined methodological approaches (field + model or lab) represent about one third of the corpus. Water quality indicators are also frequent (15 %), whereas biodiversity and air quality remain underrepresented (7 and 2 % respectively) and often rely on heterogeneous monitoring protocols. Most impacts are positive, particularly for cover crops, residue retention, organic fertilisation and biochar. Agroforestry and combined LMMs reveal strong synergies but also context-dependent trade-offs (e.g., yield penalties under reduced tillage, nitrogen losses after organic fertilisation). Evidence on compound stresses and socio-economic drivers is still scarce, and the systematic integration of crop or ecosystem models into multi-domain assessments remains limited. Co-occurrence analysis, derived from binary matrices of impact domains, highlights an uneven research focus: synergies between food security and soil quality are widely explored, whereas biodiversity–air quality linkages and model-based evaluations remain rare.

LMMs can substantially contribute to climate change mitigation and adaptation while improving soil, water and crop productivity. However, evidence is uneven across regions, indicators and stressors, limiting their integration into process-based models and decision-support tools. Strengthening multi-domain research, long-term monitoring and harmonising indicators are crucial for designing effective, climate-resilient agroecosystem strategies.

Supplemental irrigation in rainfed potato: long-term costs, benefits, and insights from Prince Edward Island, Canada

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Keywords: drought, climate change adaptation, yield gain, economic feasibility, nitrous oxide emissions

Introduction

In the humid climate of Eastern Canada, most crops are rainfed. Prince Edward Island (PEI) is Canada's smallest province but contributes 20% of the country's potato production. Potato is sensitive to water stress due to its shallow root system and requires the most water during tuber formation (July to August) when drought is most extreme (Stark et al. 2020). In 2025, the island experienced its third driest summer, 5 years after the last record in 2020, making rainfed yields and the province's economy vulnerable without supplemental irrigation (SI). In a region that has always relied on precipitation, only 10% of farms use SI. The long-term economic benefits are still unclear, and farmers are hesitant to take the financial risk. Using the process-based crop model STICS, we calculate the potential yield gain from applying SI and evaluate the long-term cost-benefit of SI systems to support rainfed potato across PEI.

Materials and Methods

The STICS crop model (Brisson et al. 2003) was previously calibrated and evaluated for cultivars Russet Burbank in Sainte-Foy, Quebec and Fredericton, New Brunswick and Shepody in Charlottetown, PEI (Morissette et al. 2016). First, historical climate data (2001–2024) was obtained from four weather stations across the island. Russet Burbank yields under the three most common soil series in PEI were simulated with and without water stress to calculate total potential yield gain and water requirements. The second stage will use the latest CMIP6 climate scenarios to evaluate the near future (2021 – 2050) cost-benefit of SI and address environmental impacts (e.g. soil N_2O emissions).

Results and Discussion

Four common irrigation systems were considered (Jiang et al. 2022; Jiang et al. 2024). A payback period was calculated for a system lifespan of 24 years. Over 2001-2024, SI was the least beneficial for the ARY soil (highest WHC), particularly in the eastern part of the island (EP) which has the lowest mean cumulative GDD and daily solar radiation and highest daily windspeed. SI was mostly beneficial for CTW soil (most common on the island) with 75% of low market yield scenario payback periods < system lifespan. SI was highly beneficial for CLO soil (lowest WHC) with a payback period as short as 3 years (Figure 1).

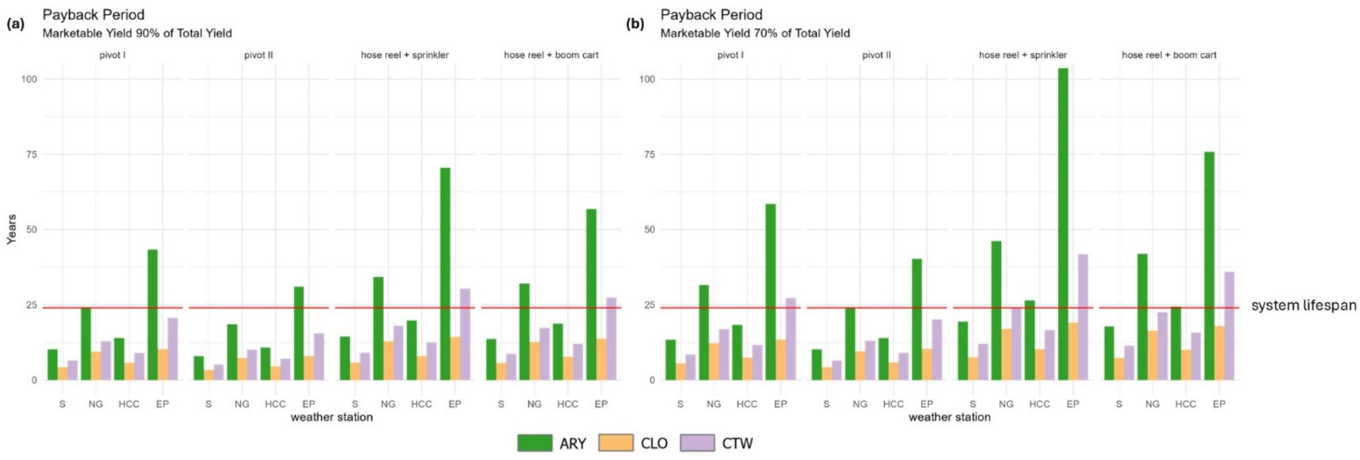

Figure 1. Payback period by soil type and weather station for four common irrigation systems assuming marketable yield is (a) 90% and (b) 70% of the total yield at harvest.

The province mandates a 3-year rotation of potato-barley-red clover. Here we assume irrigation could be applied each year with one field or part of a field always in potato. The analysis will be expanded to include scenarios exclusively following the rotation (i.e. potato only every third year).

Conclusions

More frequent droughts and the uncertainty of future climate change have many farmers in PEI contemplating SI. The possible benefits are unique to each farm, depending on soil type, weather and irrigation system. Previously, a cost-benefit of SI across all these variables had not yet been explored for PEI. Initial results show SI is beneficial for soil with lower WHC and less favourable climates for plant cooling. This work provides a complementary decision-support resource for farmers deliberating the suitability of SI for their operation.

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Climate change adaptation practices for sustainable maize production in central Ethiopia

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Keywords: DSSAT, CERES-Maize, Sustainable Production, Ethiopia

Introduction

Now a days, climate change poses greatest challenges for the global food production, particularly the impact in developing countries, like Ethiopia, is severe where agriculture is the backbone of the economy and source of food production *(World Bank, 2011* and CSA, 2018). However, this sector is highly rainfed, smallholder dominated. In addition, poor adaptive capability, imited access of climate information for farm level decision and poor integration of adaptation practices exacerbate the vulnerability of agriculture for climate change and variability (FAO, 2019). Thus, identifying and promoting optimal climate-smart practices for crop production, particularly for widely cultivated cereals, is critical to offset the adverse impacts of cli mate change and sustaina production. With this, this study targets to assess the impact of climate change on maize production and evaluation of potential adaptation practices for sustainable maize production using integrated crop climate modeling approach. In this study, Decision Support System for Agro-Technology Transfer (DSSAT v4.8.5) (Hoogenboom etal, 2019) is employed to investigate the impacts of climate change and to evaluate potential adaptation practices for sustainable maize production in dryland growing areas of Ethiopia. Four widely cultivated maize genotypes (Melkassa-2, Melkassa-4, Melkassa-6Q, and BH140) were parameterized and assessed for their performance under changing and variable climatic conditions.

Materials and Methods

For this study, Decision Support System for Agrotechnology Transfer **(DSSAT4.8.5)** is used to evaluate the possible climate change adaptation practices (Hoogenboom et al., 2019). DSSAT simulates growth and development of crops in response to weather, soil and crop management practices (Jones & Singels, 2008). Field experiment were conducted to collect crop growth and development data for model parametrization and evaluation. Climate and soil profile data were also obtained from Ethiopian Institute of Agriculture Research and GLUE was applied to estimate GSPs. Climate chaange scenario data were developed from GCMs using empirical quantile mapping downscaling approach for mid (2040–2069) and end (2070–2099) century, under moderate (SSP2-4.5) and extreme (SSP5-8.5) emission scenarios assumptions. To identify optimal adaptation strategies, various nitrogen fertilizer application rates and alternative planting windows were evaluated under both current and projected climate conditions.

Results and Discussion

Results revealed that maize yield responses to projected climate change varied across locations, climate models, and time periods considered. Production in dry lowland areas was found to be more vulnerable compared to mid- and high-altitude regions. Melkassa-2 and Melkassa-4 responds better for dry lowland areas and short rainy season whereas Melkassa6Q and BH-140 performs good in intermediate altitude region and during good rainy season. However, adaptation strategies such as the use of drought-tolerant and early maturing maize genotypes, adjustment of planting dates (mid-June planting), and improved soil fertility management significantly enhanced maize productivity and compensate yield loss because of climate variability and change.

Conclusions

In conclusion, climate change is expected to accelerate the existing food security challenges in many developing and least developed countries, including Ethiopia, unless proactive and location-specific adaptation practices are developed and implemented. In this regard, advanced tools such as Decision Support System for Agro-Technology Transfer (DSSAT) serve as an important tool to support farm-level decisions as well as seasonal and strategic planning. The findings of this study are therefore impactful to show strong insights for policymakers, researchers, and agricultural experts to design and promote sustainable adaptation pathways that enhance maize production and resilience in the face of future climate uncertainties.

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Climate Change Threats and Adaptation Strategies for Open-field Vegetable Production in China: A National-Scale Assessment of Chinese cabbage and Chili Pepper

China, the world's most populous country, accounts for 50% of global vegetable consumption. With rapid dietary shifts (e.g., increased higher demand for vegetables than meat, eggs, dairy and cereals) and climate change threats, ensuring vegetable self-sufficiency in China presents a critical challenge with global implications.

This study focuses on two representative and most popular vegetables—Chinese cabbage (leafy) and chili pepper (fruit)—to analyse their historical (1990–2019), near-term future (2020-2050), and far-term future (2050–2080) production under climate change. Using newly developed WOFOST-vegetable models upscaled with soil, site, crop, management, and climate input data, we simulate potential and water-limited yields to identify spatiotemporal patterns and key climatic drivers of yield variability.

We first simulated historical yield patterns (1990-2019) using the WFDE5 dataset, then projected future yield changes for both near-term (2020-2050) and far-term (2050-2080) periods under elevated CO_2 conditions. Our multi-model ensemble approach incorporated five CMIP6 models (GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, UKESM1-0-LL) across three SSP scenarios (SSP126, SSP370, SSP585). This framework enabled us to: (1) identify vulnerable hotspot regions experiencing significant yield reductions, (2) quantify the contribution of key climatic drivers (including extreme events) to yield variability, and (3) evaluate adaptation strategies through scenario analysis - including optimized sowing dates, improved cultivars, irrigation/fertilization management, and strategic cultivation area reallocation.

Our findings provide the first national-scale assessment of climate change impacts on open-field vegetable production, offering actionable insights for maintaining self-sufficiency and informing global adaptation strategies in high-value crops.

Expanding Climate Risk Assessment: Integrating UNSEEN and APSIM to Evaluate Maize Vulnerability in Ames, Iowa

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Keywords: Extremes, Climate Change, Crop Yield, UNSEEN, APSIM Modelling

Introduction

Historically, it has been accepted practice to assess the risk of future extreme weather based on the frequency of past weather events. In the context of today's rapidly shifting climate, it is insufficient to predict extreme weather risks based on patterns in our relatively short 30-year historical weather record. Recent advances in the climate sciences allow us to increase the sample size of plausible extreme weather events beyond the data available in the relatively short historical record using the UNSEEN (UNprecedented Simulated Extremes using ENsembles) methodology. This study integrates UNSEEN with a process-based crop model (APSIM) to evaluate agricultural vulnerability to unprecedented but plausible extremes. By coupling large-ensemble climate simulations with mechanistic crop modeling, we provide a novel case study demonstrating how unprecedented climate shocks, absent from the historical record, could impact maize yields in Ames, Iowa. Iowa State University's maize research program provides extensive public climate, soil, and yield data, making it an ideal location to demonstrate the UNSEEN + APSIM approach. By offering new insight into agricultural risk assessment under a changing climate, our work highlights the importance of moving beyond historical baselines when designing agricultural adaptation strategies.

Materials and Methods

Increasing the sample size of plausible extreme weather events beyond the data available in the relatively short historical record using the UNSEEN methodology will provide an improved understanding of present-day extreme weather risk and an assessment of how the frequency and intensity of events in a given region have changed between 1981 (hindcast ensemble start date) and the present (Thompson et al., 2017; Coughlan de Perez et al., 2023; Kent, 2017). Predominant methodologies for extreme weather risk assessment are limited to scenarios within the 30-year historical record. UNSEEN generates thousands of additional plausible event scenarios using climate model ensembles initialized with observed climate forcing data (Peterson et al., 2013; Thompson et al., 2017). Our ensemble is derived from archived SEAS5 ensemble temperature and precipitation data (Johnson et al., 2019).

Bias corrections will be applied where appropriate, and the UNSEEN ensemble will be evaluated using a protocol developed by Kelder et al. (2022) to assess ensemble member independence, model stability, and fidelity against historical observational datasets (Chan et al., 2023). A non-stationary Generalized Extreme Value (GEV) distribution will then be fitted to the simulated ensemble to calculate return periods for given hazards. The same distribution will be fitted to observational temperature and precipitation data to calculate observed return periods (Coughlan de Perez et al., 2023). Historical Weather station data from the Iowa Environmental Mesonet, will provide the observational precipitation and temperature data. UNSEEN results have been validated against the historical record (Example Fig. 1A) and predict an increasing frequency of extreme temperature events in regions throughout the United States (Example Fig. 1B) (Coughlan de Perez et al., 2023).

Selected UNSEEN events will then be fed into APSIM-Maize once the model is evaluated and validated using historical yield and weather data. Inputs to APSIM-Maize include management assumptions from Archontoulis et al. (2014), soil profile data from Archontoulis et al. (2014) and the APSoil Database, weather data from the Iowa Environmental Mesonet, and observed county-level yields from the USDA Risk Management Agency (RMA).Once an unprecedented extreme weather event (likely a heatwave) is modeled in Ames, Iowa using current best-practice management and cultivars, the model will be re-run with alternative management scenarios (planting date, harvest date, fertilization, cultivar selection, etc.) to identify how maize farmers might adapt to an extreme heat event that has yet to occur in their lifetime.

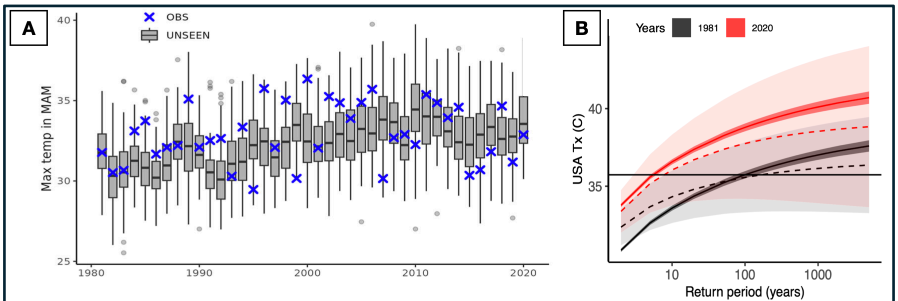

Figure 1. Example plots of UNSEEN events. (A) Historical observations of temperature overlaid on boxplots (gray) of UNSEEN ensembles. (B) Seasonal maximum temperature return period in 1981 and 2020, based on GEV fits of the UNSEEN ensemble (dark lines and shading) and based on observations alone (dotted lines and light shading).[11]

Results and Discussion

Based on prior studies, we anticipate finding that damaging extremes in Iowa are more frequent than the observational record suggests. Kent et al. (2017) estimate the annual probability of severe water stress in Iowa at around 12% using model ensembles, nearly double the 6–9% suggested by observations. Similarly, Weiss & Coughlan de Perez (2025) show that events historically considered “1-in-100 year” heatwaves now occur ten times as often in U.S. cropping regions. When selected UNSEEN events are fed into APSIM, these conditions are expected to result in sharp changes in yield, particularly when extreme heat or water stress coincide with important physiological periods such as flowering and grain filling. Adaptation experiments (e.g., shifting planting dates, adopting heat-tolerant cultivars) are anticipated to provide partial resilience but not fully offset losses.

Conclusions

Our anticipated findings suggest that the historical record underestimates the climate risks facing Iowa maize production. Prior UNSEEN analyses already indicate a higher likelihood of extreme heat and water stress than farmers have experienced to date, and these unprecedented but plausible extreme weather events coupled with APSIM simulations are expected to show substantial changes to yield. While management strategies like adjusting planting dates or adopting heat-tolerant cultivars may help, they are unlikely to fully offset unprecedented extremes. By combining UNSEEN with APSIM, this study highlights the importance of testing agricultural systems against a wider range of plausible futures that are not just based on historical weather. This integration represents a methodological advance by linking large-ensemble climate simulations with process-based crop modeling. Together, these tools allow for a more robust assessment of agricultural vulnerability to extremes beyond the observed record.

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