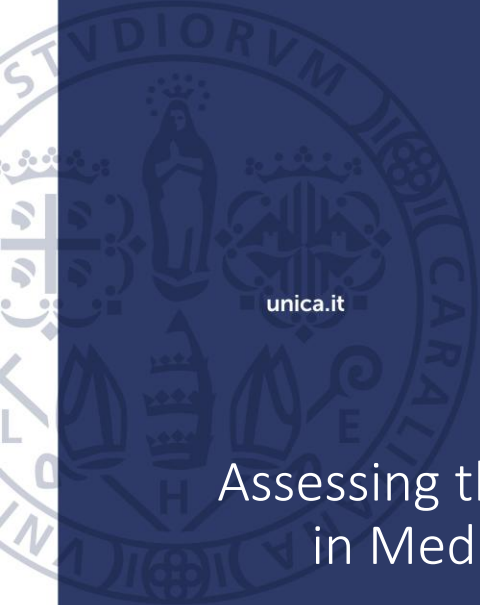




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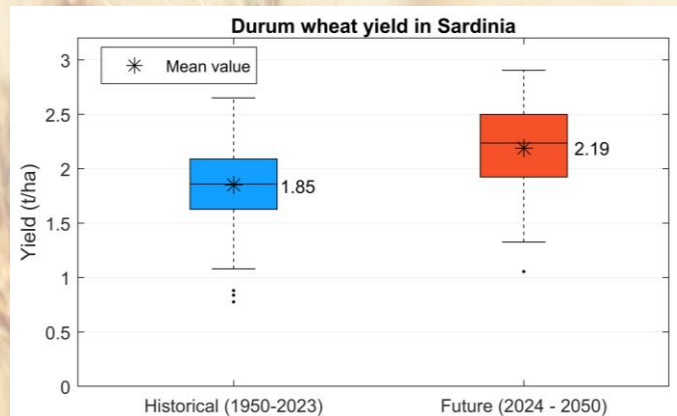
Assessing the Effects of Climate Change on Durum Wheat Yields in Mediterranean Regions: A Water-Food Nexus Perspective

Malin Grosse-Heilmann*, Elena Cristiano, Gabriella Pusceddu, Marino Marrocu, Francesco Viola, Roberto Deidda

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Assessing the Effects of Climate Change on **Durum Wheat** Yields in Mediterranean Regions: A Water-Food Nexus Perspective

Climate
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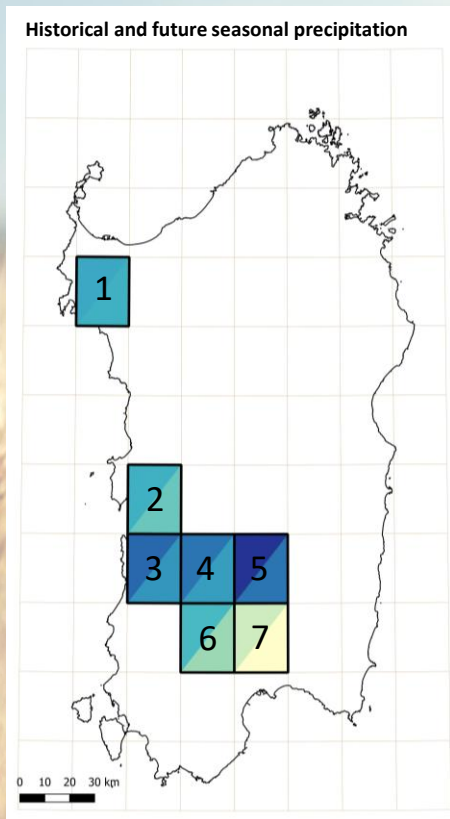
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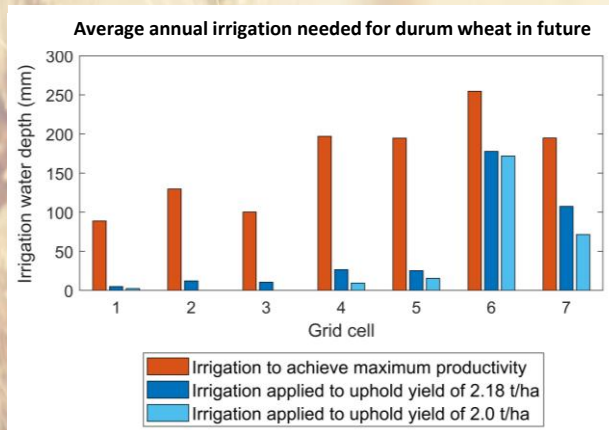
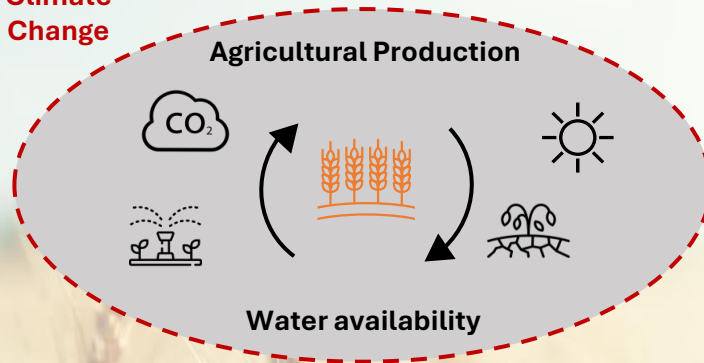
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Assessing the Effects of Climate Change on **Durum Wheat** Yields in Mediterranean Regions: A Water-Food Nexus Perspective



Climate Change



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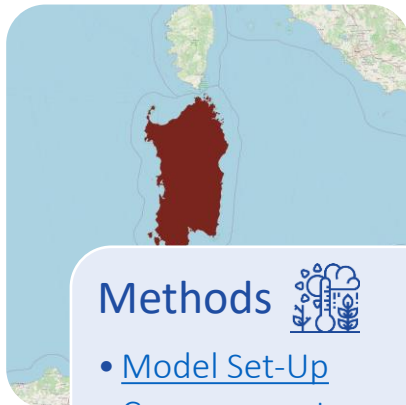
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Methods



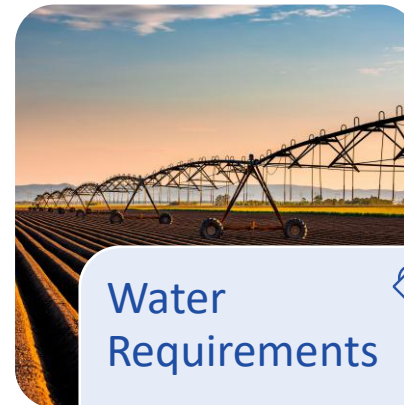
- [Model Set-Up](#)
- [Crop parameters](#)
- [Climatic Input](#)



Durum wheat yields



- [Durum wheat productivity](#)
- [Influencing factors](#)
- [Growing period duration](#)



Water Requirements



- [Future irrigation requirements](#)
- [Annual water requirements](#)
- [Water stress](#)

Durum wheat productivity in Sardinia

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Durum Wheat in Italy

- **Major C3 crops** in the Mediterranean region
- Providing **essential nutrients, proteins, and carbohydrates**
- Used for production of pasta, couscous, and various bakery products
- Durum wheat fields → **agricultural heritage landscape** or system
- Mostly cultivated under **rainfed** condition, with relatively high **tolerance to drought** conditions
- Italy global leader in pasta production
- In Europe Italy is the **largest importer** of durum wheat, mainly from Canada, the United States, France, and Greece





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Model Set-Up Durum Wheat in Sardinia

- AquaCropOS model for durum wheat in Sardinia 
- Input data related to **crop, soil, and climatic conditions** sourced from diverse databases, literature and direct measurements
- Cultivation area in Sardinia from CORINE Land Cover database → seven grid cells as the main DW growing region
- Divided into 0.25 by 0.25 degrees grid cells → seven grid cells were identified as the main durum wheat growing region
- Composition of the top and sub soil came from the European Soil Database (ESDB)
- Soil composition used to identify the soil class according to the FAO soil classification and to derive the corresponding soil hydraulic properties
- Adjustment of [key crop parameters](#) employing Monte Carlo Calibration based on ISTAT yield data

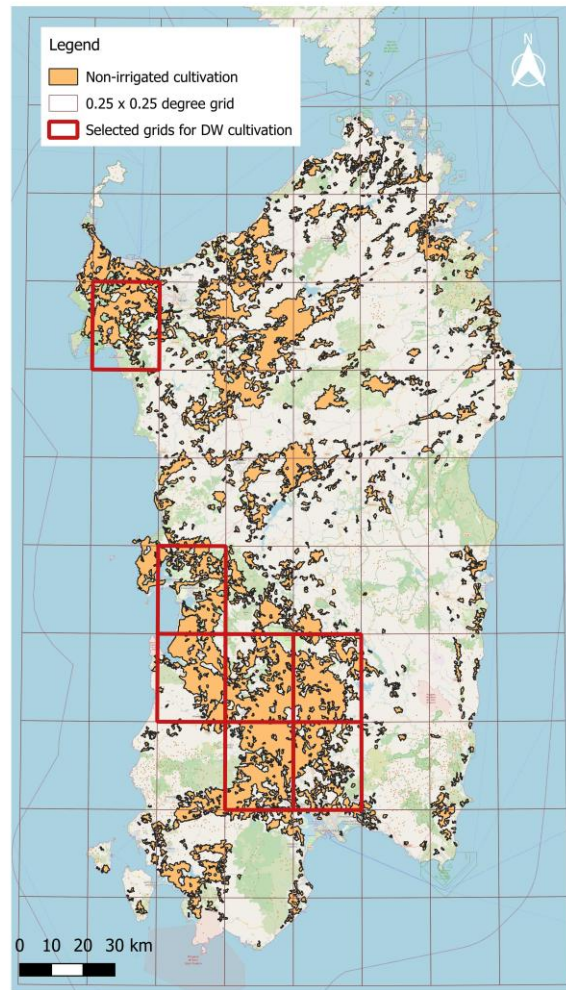


Fig 1: Rainfed durum wheat cultivation area



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Model Set-Up – Crop parameters

Crop data and calibration:

- AquaCrop distinguishes
 - **conservative parameters:** provided by AquaCrop as default values and do not change with geographic location, time or management practices
 - **cultivar-specific:** depend on environmental conditions and must be calibrated by the user
- Sensitivity analysis: reference harvest index (**HI**), crop decline coefficient (**CDC**), crop growth coefficient (**CGC**), the number of **plants per hectare** and the **length** of the different **growing stages**
- Model run in growing degree days
- Adjustment of key crop parameters employing **Monte Carlo Calibration** based on **ISTAT yield data** (2006-2023), for **each grid cell separately**
- Model performance was evaluated based on the root mean square error (**RMSE**): 0.36 t/ha - 0.4 t/ha



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Mean annual precipitation

510 mm 647 mm

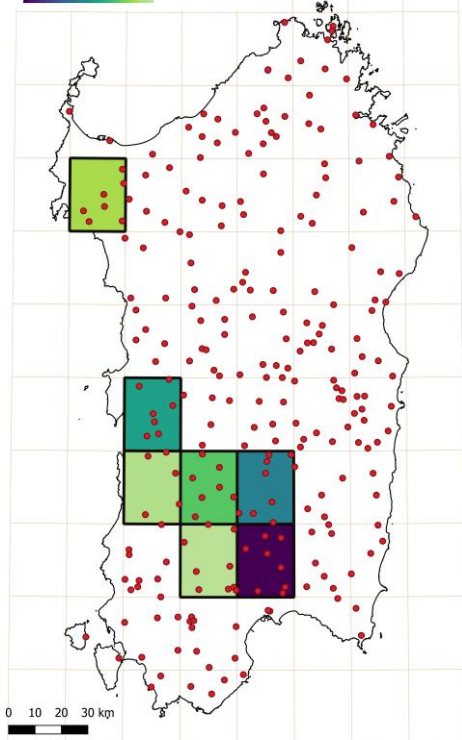


Fig 2: Active rain gauges in Sardinia

Climatic input

Climatic data:

- Required data: **daily values** of **precipitation**, minimum and maximum temperature (**Tmin** and **Tmax**), reference crop evapotranspiration (**ET0**) and carbon dioxide concentration (**CO₂**)
- **7 climate model projections** for period **1950 – 2050** from the High-Resolution Model Intercomparison Project (HighResMIP) group, developed as part of the Coupled Model Intercomparison Project Phase 6 (CMIP6) initiative
- **Bias-adjusted** with linear correction method with long-term rainfall measurements (rain gauge records) and temperature data from ERA5
- CO₂ concentration records of the Mauna Loa Observatory in Hawaii (provided by AquaCropOS)



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Climatic input

ID	Model Name	Resolution	Main components	Modelling consortium and reference
M1	CMCC-CM2-VHR4	25 km	aerosol, atmosphere, land, ocean, and sea ice	Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) in Lecce, Italy (Scoccimarro, 2017)
M2	EC-Earth3P-HR	50 km for atmosphere and land, 25 km for ocean and sea ice	atmosphere, land, ocean and sea ice	international consortium of research institutions and universities from several countries, coordinated by the EC-Earth consortium based at the Swedish Meteorological and Hydrological Institute (SMHI) (EC-Earth Consortium, 2018)
M3	FGOALS-f3-H	25 km for atmosphere and land, 10 km for ocean and sea ice	atmosphere, land, ocean and sea ice	Chinese Academy of Sciences (CAS) in Beijing, China (Bao, 2019)
M4	HiRAM-SIT-HR	25 km	atmosphere, land, ocean	Research Center for Environmental Changes, Academia Sinica (AS-RCEC) in Taipei, Taiwan (Tu, 2020)
M5	MPI-ESM1-2-XR	50 km	aerosol, atmosphere, land, land ice, ocean, ocean biogeochemistry, and sea ice	Max Planck Institute for Meteorology (MPI-M) in Hamburg, Germany (von Storch, 2017)
M6	MRI-AGCM3-2-S	250 km for aerosol, 25 km for atmosphere and land	aerosol, atmosphere and land	Meteorological Research Institute (MRI) in Tsukuba, Japan (Mizuta, 2019)
M7	NICAM16-8S	25 km for aerosol and land, and 50 km for atmosphere and sea ice	aerosol, atmosphere, land and sea ice	International consortium, including Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Atmosphere and Ocean Research Institute, University of Tokyo (AORI), National Institute for Environmental Studies (NIES), and RIKEN Center for Computational Science (R-CCS), coordinated under MIROC (Kodama, 2019)



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Climatic input

Precipitation:

- Predictions vary strongly between models, differences of 20 mm in monthly means
- In some months (such as February and March) precipitation is projected to be lower than measured conditions in almost every model
- For other months (in particular the rainy months November and December) rises and decreases are predicted depending on the model

Temperature:

- Rising temperatures (Tmax and Tmin) for each month in every model
- highest increases in summer months, especially in August with an average of 2.1°C in maximum temperature and 2°C in minimum temperature
- During winter period the increase is lower ~ 1°C on average

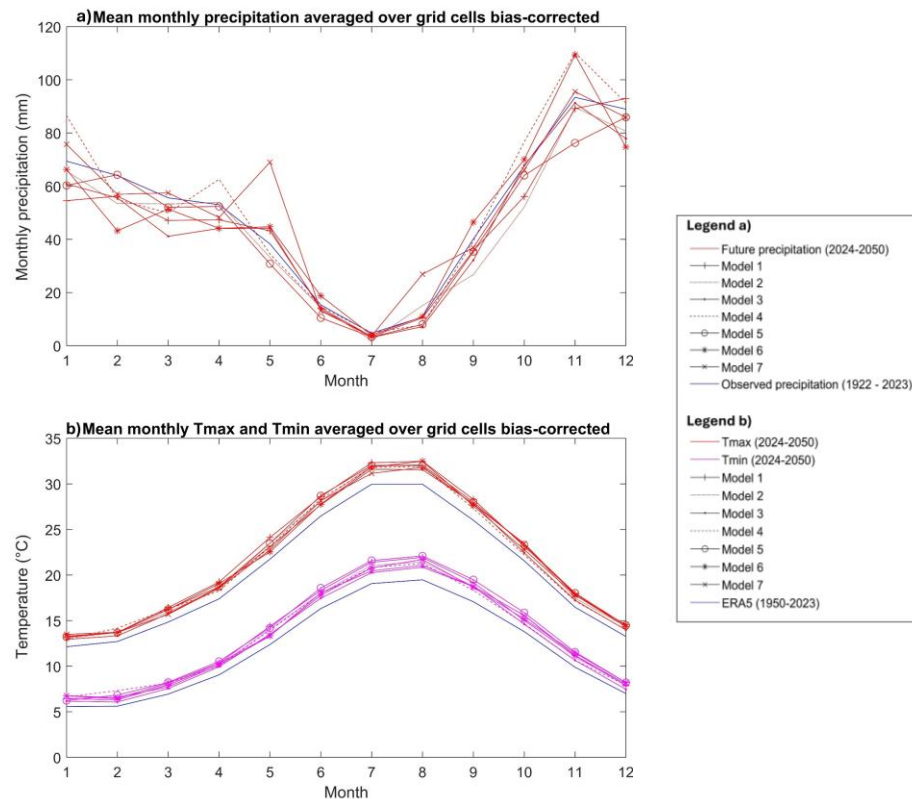


Fig 3: Climatic projections for the future period (2024 – 2050) over the seven grid cells



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Precipitation predictions– Variations across grid cells

- Growing season: December to June
- Decrease in rainfall depth for all seven grid cells , more pronounced towards the south
- Grid cell 5 and 7, both located in the south and sharing a boarder, show the highest and lowest seasonal rainfall depth
- Future monthly rainfall: November and December highest rainfall months and June to August as the low-rainfall season

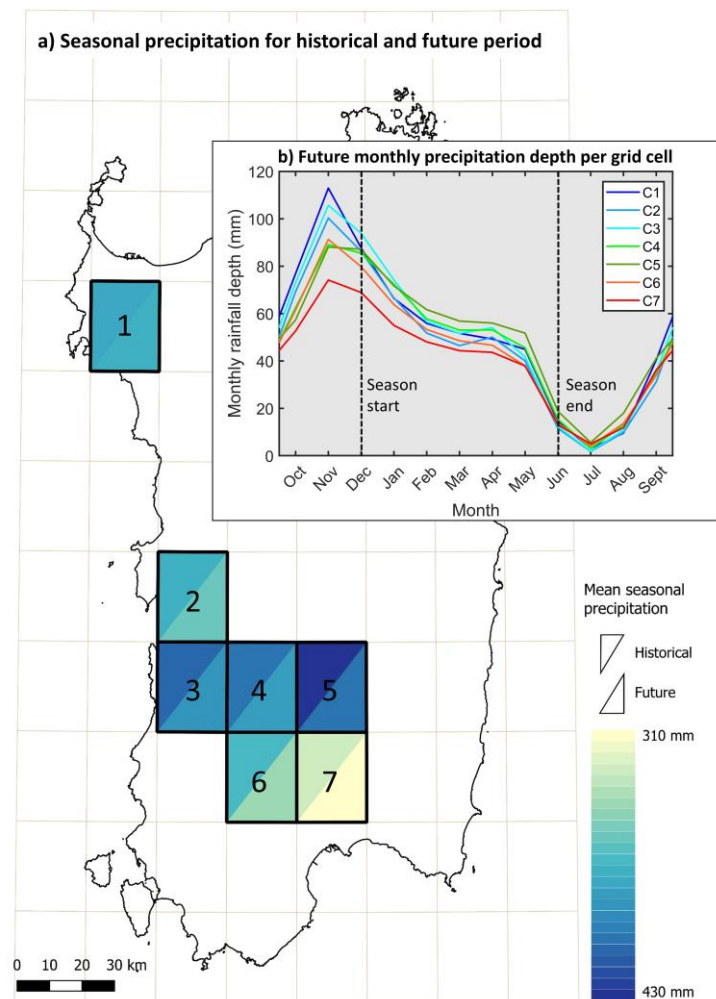


Fig 4: Precipitation patterns of in the main cultivation areas

Durum wheat productivity in Sardinia

Simulation of present and future yields

- Simulations based on different climatic timeseries: ground and reanalysis data (GR), historical climate model (HCM) and future climate model (FCM)
- **Increase in average yield** in the future to 2.19 t/ha from 1.85 t/ha
- Further research findings :
 - **Increase in crop failure** in future

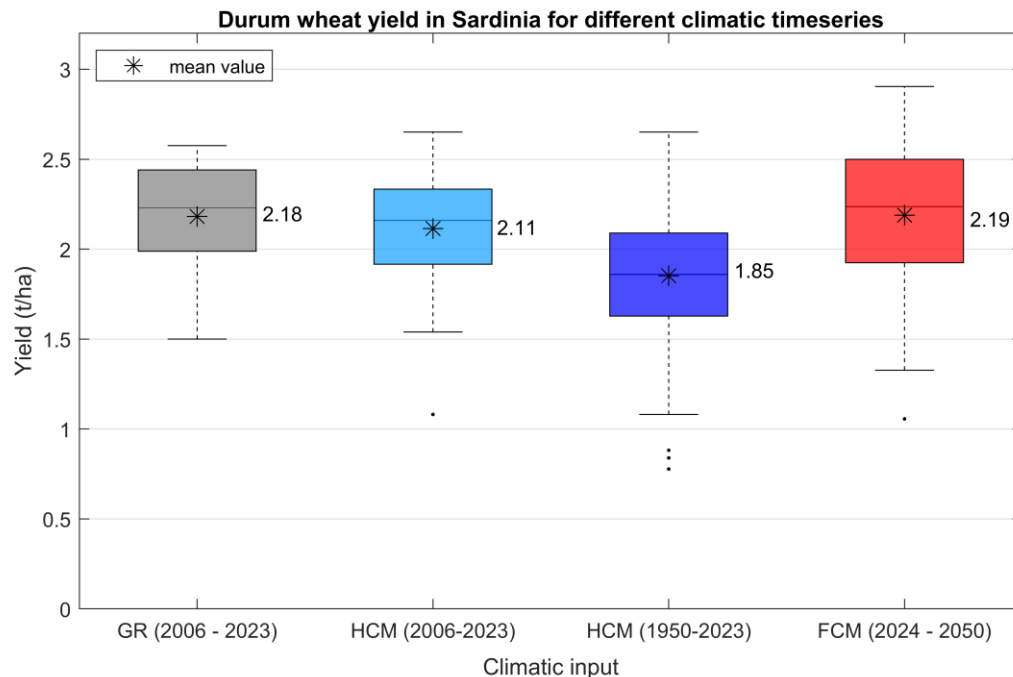


Fig 5: Durum wheat productivity averaged over the main cultivation area in Sardinia for four climatic timeseries

Influence of changes in Temperature, Rainfall and CO₂

- **Model re-run** with future climatic data where:
 - **Scenario A:** FCM with temperature scaled to HCM monthly climatology
 - **Scenario B:** FCM with precipitation scaled to HCM monthly climatology
 - **Scenario C:** FCM with CO₂ constant at 398.55 ppm (last measurement from Mauna Loa dataset)
- Decrease in yields for scenarios A and C → **future temperature and CO₂ conditions** might be **beneficial** for durum wheat yields
- Higher productivity with a lower internal variability in Scenario B → **future changes in precipitation** pattern **main constraint** for durum wheat productivity

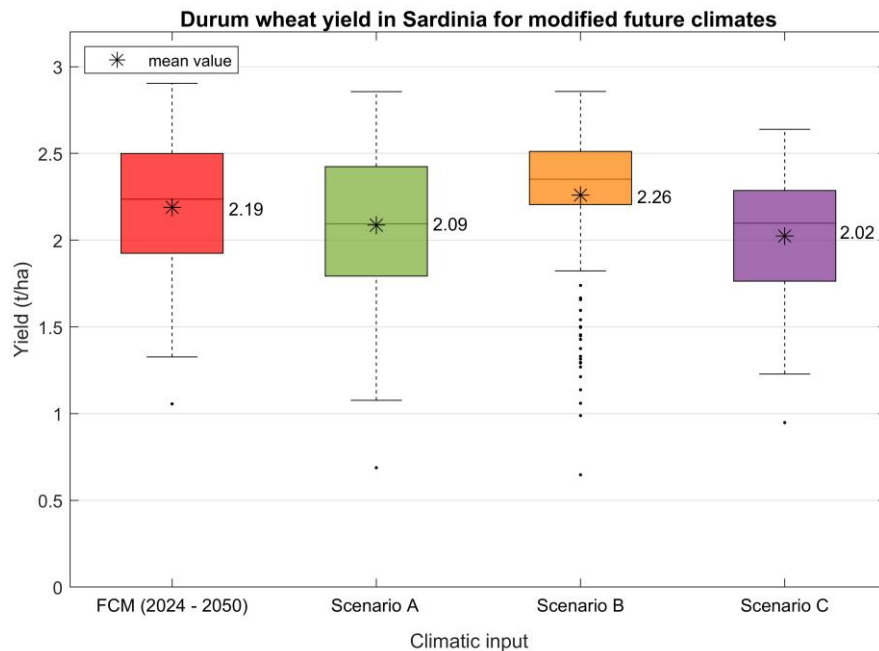


Fig 6: Productivity of durum wheat for modified and unmodified future climate model (FCM (2024-2050)) forcing

Duration of growing period

Future vs. historical yield per duration

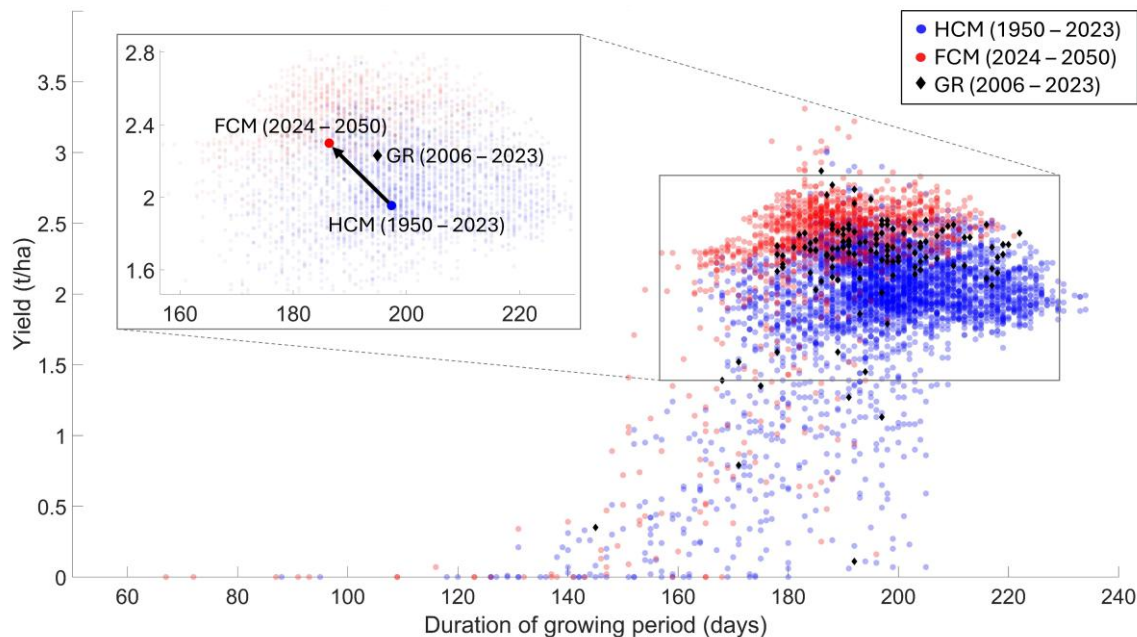


Fig 7: Yield per growing period duration for HCM (1950-2023), FCM (2024-2050) and GR (2006-2023) data

- Growing period predicted to **decrease** in future, concurrently with an **increase in crop yields**
- for measured climatic input: within an intermediate range
- Instances of **crop failure** appear **earlier** in future compared to historical period
- **Primarily** attributable to **rising temperatures**, which predominantly shorten the vegetative development phase → early flowering



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Future irrigation requirements for durum wheat

- Durum wheat in Sardinia **currently** almost exclusively **rainfed**
- Investigation of three irrigation scenarios under FCM conditions
- Irrigation requirements vary strongly between grid cells and between irrigation scenarios
- **Grid cells 1-3 lower irrigation** requirements to uphold productivity → more convenient for future cultivation?
- Irrigation requirements not corresponding with distribution of seasonal rainfall (highest value in C5, lowest in C7)
- C1 – C3 different soil composition (loam instead of clay loam)

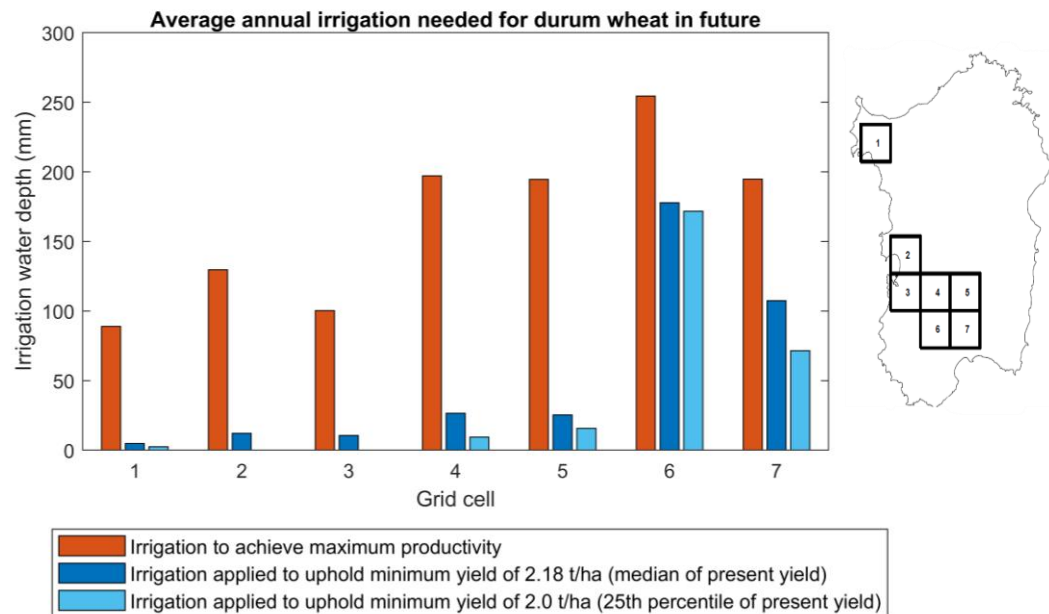


Fig 8: Average annual irrigation water depth in the future per grid cell



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Future water requirements

- **Annual water volume for irrigation** calculated based on **irrigation requirements per grid** and **cultivation area** based on ISTAT area (averaged over time) distributed over grid cells according to land used for durum wheat cultivation
- Potential competition over irrigation water resources with other irrigated crops in future
- Climate change projected to affect other water-using sectors such as industry, energy and civil

	Irrigation to achieve maximum productivity	Irrigation applied to uphold minimum yield of 2.24 t/ha	Irrigation applied to uphold minimum yield of 2.12 t/ha
Annual water volume	69.872.314 m ³	27.305.446 m ³	22.739.897 m ³
Share of water volume used for agriculture	42,1 %	16,5 %	13,7 %
Share of total water available	5,4 %	2,1 %	1,8 %



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Future water stress for durum wheat

- AquaCrop considers effects of water stress (WS) in form of four stress coefficients,
 - WS coefficient for leaf expansion
 - WS coefficient for early senescence
 - WS coefficient for stomatal closure
 - WS for pollination failure
- A coefficient of zero equals total stress while a coefficient of one translates into no stress
- Slight increase in water stress can be observed for the future (mean and distribution)

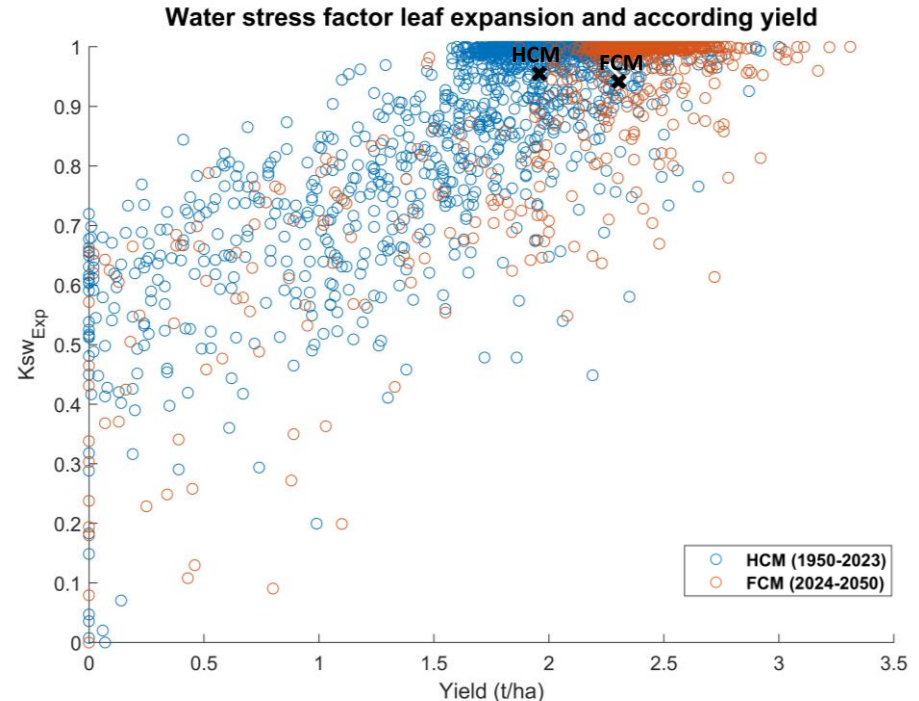


Fig 9: : Water stress factors for leaf expansion and corresponding yield



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Conclusion – Take Home Messages

- General **enhancement** in **durum wheat productivity** in the future, with a simultaneous **increase in crop failures** → highlighting the necessity of emergency irrigation measurements
- Reduction in growing period length, mainly attributable to rising temperatures
- **Increasing CO₂ concentrations and temperatures** are likely to have a **positive effect** on future yields, while **decreasing rainfall** throughout the cultivation season is expected **to constrain productivity** due to increased water stressed
- Three irrigation scenarios were investigated, results demonstrated significant **variability in irrigation water demands across different grid cells**, with lower demands in the northern regions and higher demands in the southern regions of Sardinia.
- Aggregated for the whole island, the volume of **water required for irrigation** to guarantee maximum yields would **increase** the seasonal **irrigation water volume allocation** by **more than 40 %**, raising concerns about **competition for water resources** in the future.
- Recognizing the role of durum wheat cultivation in Sardinia as **agricultural landscape heritage** reflecting traditional farming practices while supporting biodiversity and sustainable land use.

Thank you for your attention!

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