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International Water Resources Association
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XIX WORLD WATER CONGRESS
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Kingdom of Morocco
Ministry of Equipment and Water

Climate change effects on olive tree production and water use efficiency using carbon-water fluxes and remote sensing in a semi-arid orchard in Morocco

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1 Introduction :

The importance of olives trees for morocco :

- 1.2 million hectares of olives, representing 65% of Morocco's fruit tree area.
- Morocco ranks among the world's top six olive producers, with 1.3 million tonnes per year.
- The sector supports hundreds of thousands of rural households and contributes significantly to agricultural GDP.

Fig.1: Main olive-growing regions in Morocco (Sánchez-Lozano et al. 2023).

The Emerging Problem: More Land, Lower Yield

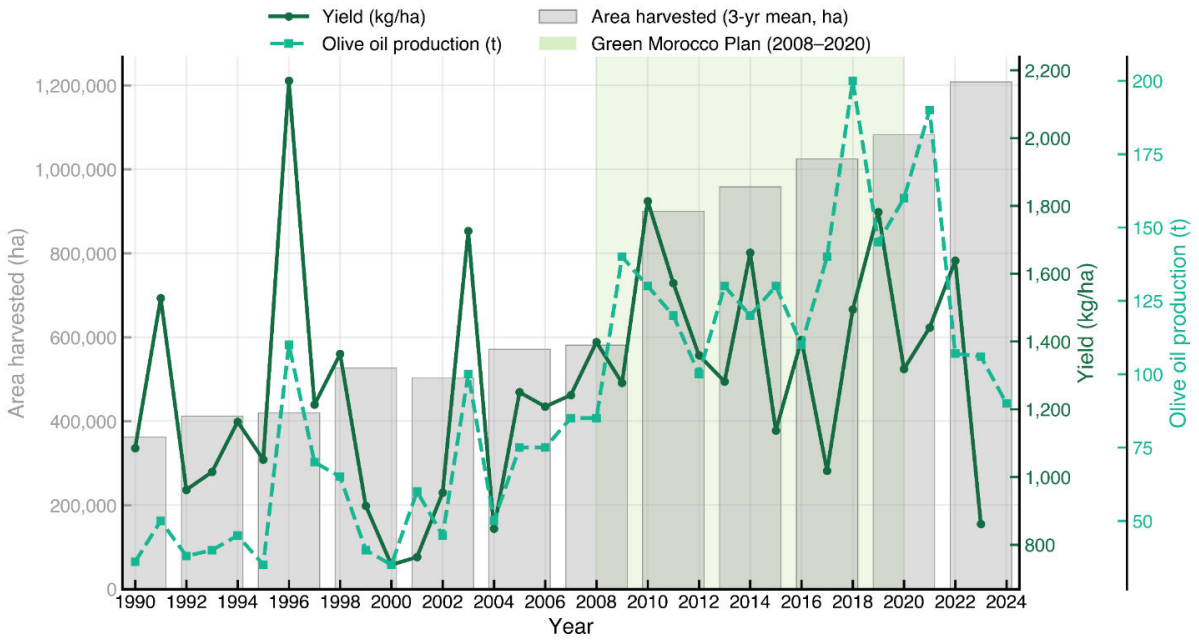


Fig.2: Olive yield, olive oil production, and harvested area in Morocco, 1990-2024. The shaded interval represents the Green Morocco Plan (2008-2020). Olive area and yield are from FAOSTAT (FAO), olive oil production is from the International Olive Council (IOC).

- Olive area has expanded, especially during the Green Morocco (2008-2020) Plan.
- Yields have dropped in recent years, and 2024 is the lowest of the decade.

Shifts in Climate Conditions Across Morocco

- The Mediterranean, including Morocco, is a climate-change hotspot with faster warming and declining rainfall (IPCC, 2023).
- In Tensift Basin, annual rainfall has dropped by about 30% since the late 1970s (Fniguire et al., 2014; Ouassanouan et al., 2022).
- The region is experiencing higher temperatures and more frequent heatwaves, (Masson-Delmotte et al., 2021; Ouassanouan et al., 2022).

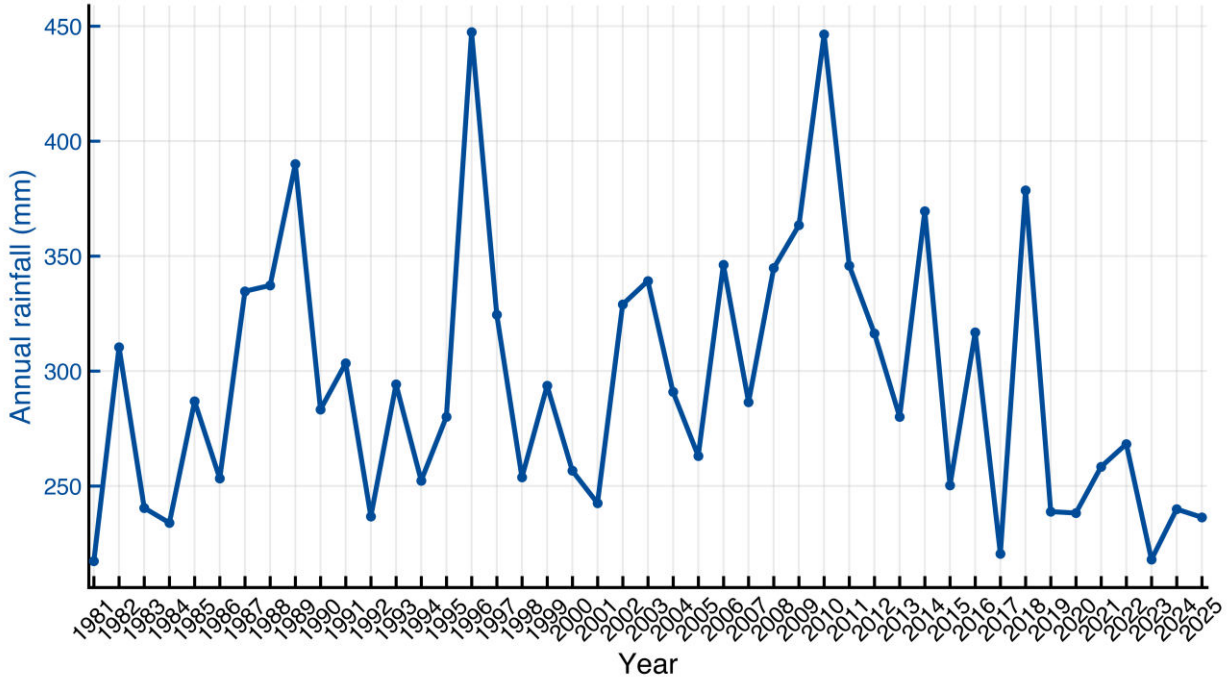


Fig.3: Annual Rainfall Over Morocco (Climate Hazards Center UC Santa Barbara & WFP, CHIRPS).

4 Objectives :

1- Thermal Requirements & Climate Stress Indices

- *Analyze annual CP, GDH, and climate stress indices (hot days, high VPD, low RH) using Mann–Kendall and Sen's slope to detect long-term trends.*

2-Orchard Responses to Climate Stress

- *Relationships between climate stress indices and orchard performance variables at the annual scale.*
- *Identify how warm and dry conditions reduce productivity and increase environmental stress.*

Agdal Olive Orchard

3- Physiological Sensitivity & WUE Analysis

- *Evaluate GPP & ET as physiological proxies.*
- *Detect the most vulnerable phenological stage.*
- *Analyze WUE vs Tair, VPD, and RH to identify WUE thresholds.*

4-Future Projections of Climate Stress Indices

- *Project future climate stress indices under CMIP6 scenarios.*
- *Compare future stress trajectories with historical baselines.*

5 Study Area and Eddy Covariance Measurement Sites

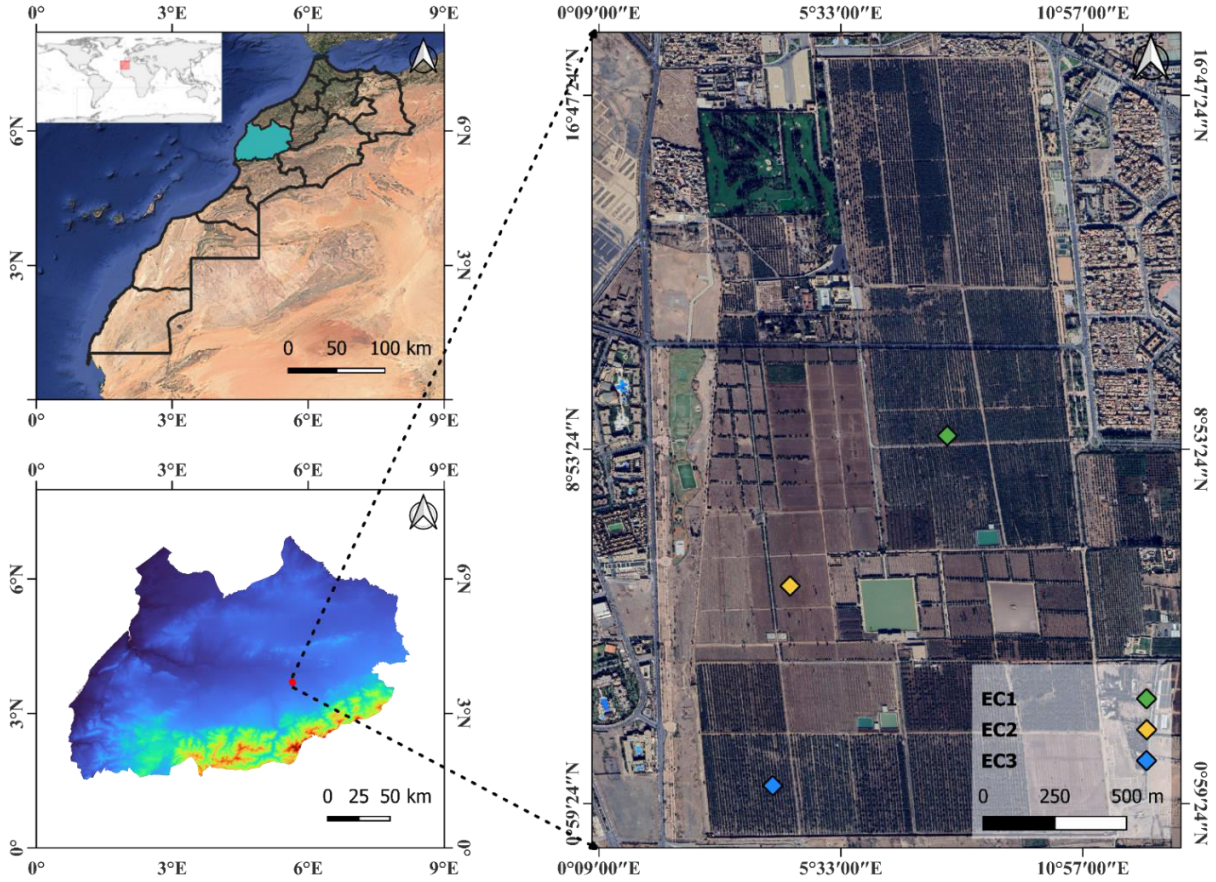


Fig.4: Location of Eddy Covariance Stations in the Agdal Olive Orchard, Morocco.

- **Location:**
  - drip-irrigated olive orchard in a semi-arid region (Agdal, Marrakech).
- **Eddy covariance towers:**
  - EC1 – over olive canopy with subsurface drip irrigation.
  - EC2: over bare soil.
  - EC3: over olive canopy with surface drip irrigation
- **Olive variety** : Picholine Marocaine.

6 Methodology

Key Climate Drivers Affecting Olive Performance

Winter chill

Winter cold needed for olive flowering

Insufficient chill causes poor flowering and low yield.

Heat stress

Number of Hot Days (Tair>35 °C)

Temperatures above 35°C limit photosynthesis and carbon assimilation.

Atmospheric water demand

Number of Low RH Days (RH<30%)

Dry air increases water loss and lowering water-use efficiency

Carbon uptake (GPP) and water loss (ET) as proxies of olive tree physiological performance

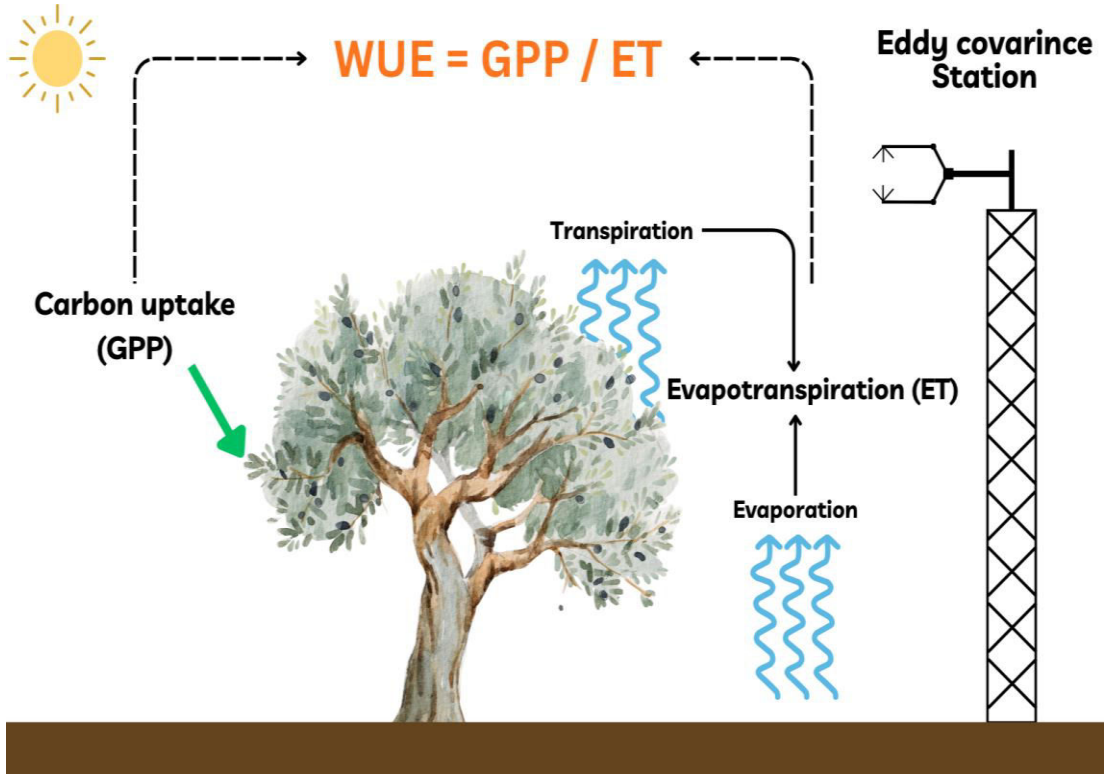


Fig.5: Illustration of Carbon Uptake (GPP), Water Loss (ET), and WUE in Olive Trees Monitored by an Eddy Covariance Station.

- **GPP:** the tree carbon gain and Biomass production.
- **ET:** how much water the tree loses through transpiration and evaporation.
- **Both GPP and ET:** react immediately to climate conditions through stomatal regulation.
- **WUE:** identify whether the tree is performing efficiently or simply surviving under stressful conditions.

Thermal requirement shifts under climate change

- **Winter chill** dropped sharply since **2016**, falling below the level needed for normal flowering.
- **2024** had the lowest chill (3 CP), making it the weakest flowering and lowest-yield year.
- Spring heat stayed adequate, but low chill created a thermal imbalance that disrupted flowering.
- Low chill years showed **lower yields**, confirming chill loss as a key driver of production decline.

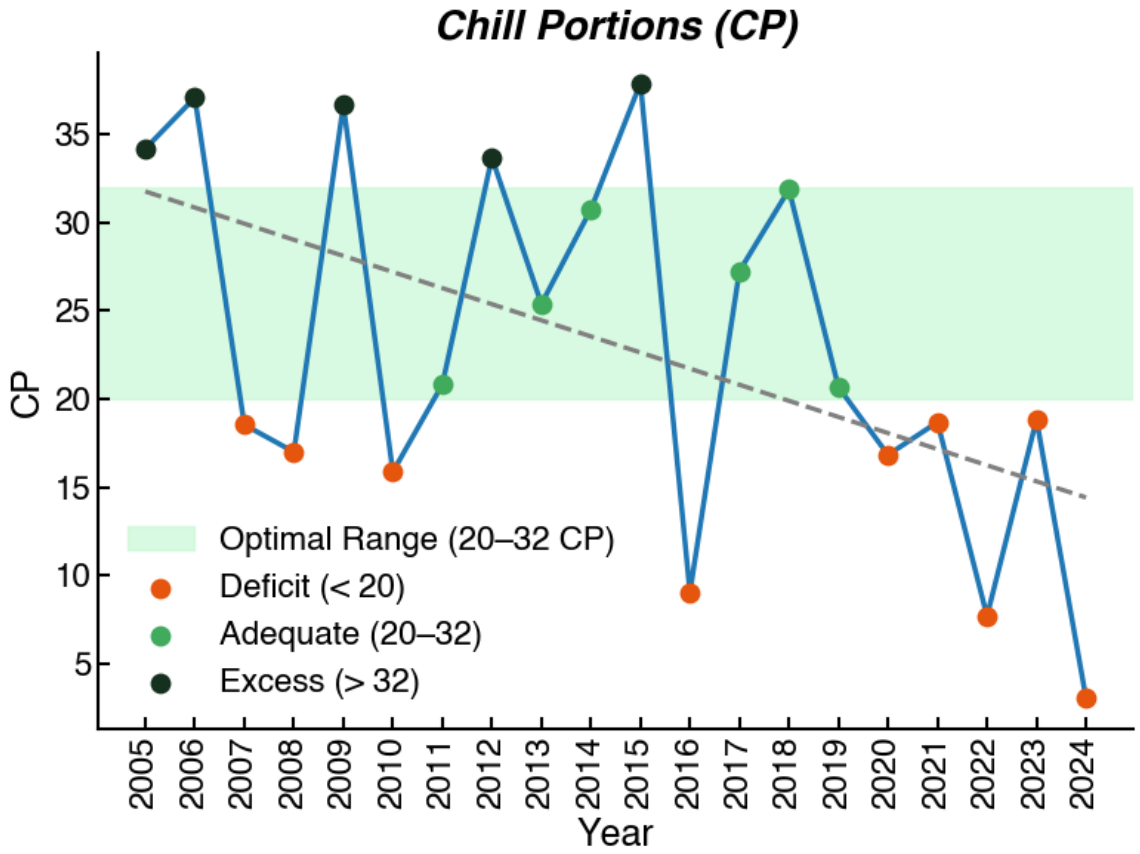


Fig.6: Winter Chill (2005–2024) for 'Picholine Marocaine' in the Agdal Orchard.

Long-Term Increase in Climatic Stress Conditions

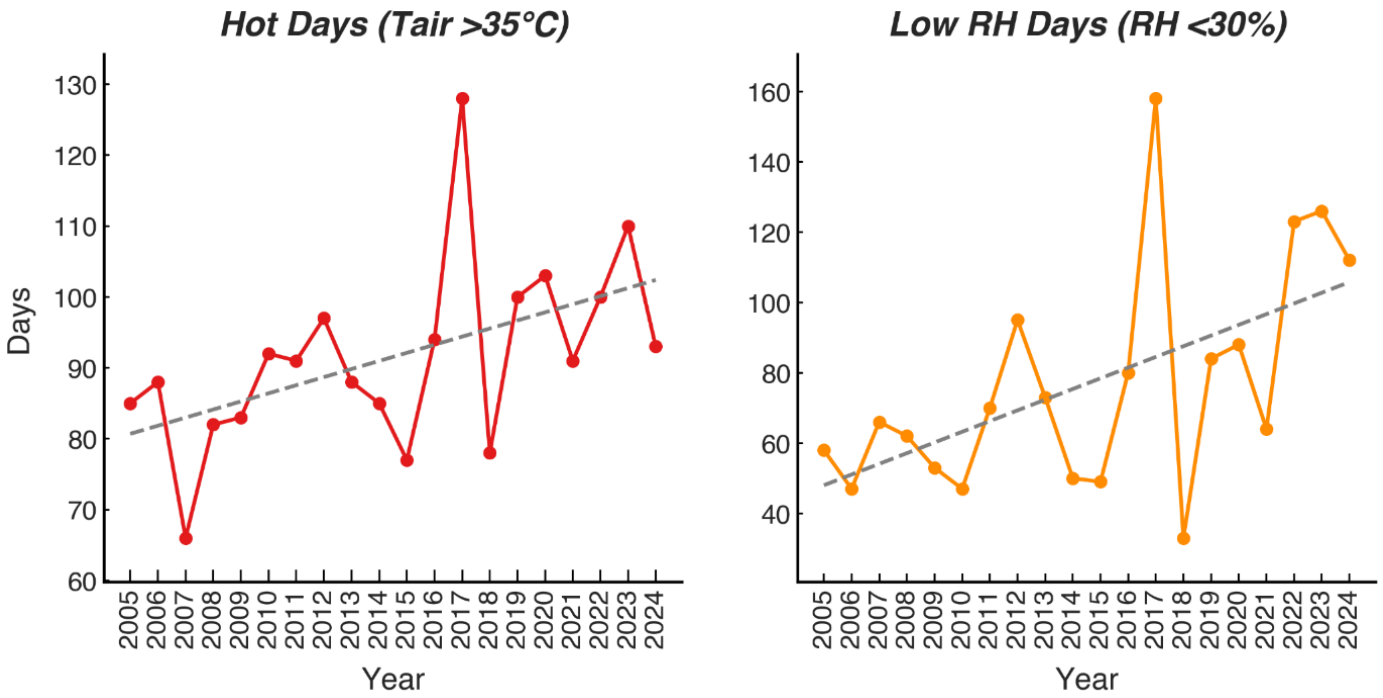


Fig.7: Annual trends in climate stress indices from 2005 to 2024.

- **Hot days** grew from 85 (2005) to 93 (2024), with extreme peaks in **2017** and **2022**.
- **Low RH days** doubled from 58 (2005) to 112 (2024).
- These show that the orchard's growing conditions have shifted toward a **warmer** and more **stressful climate**.

Olive yield response to climate stress

- Higher heat and dryness reduce yield: More hot days and low-RH days are strongly linked to lower olive production.
- Yield drops with each stress day: About ***-0.17*** t/ha per extra hot day and ***-0.08*** t/ha per extra low-RH day.

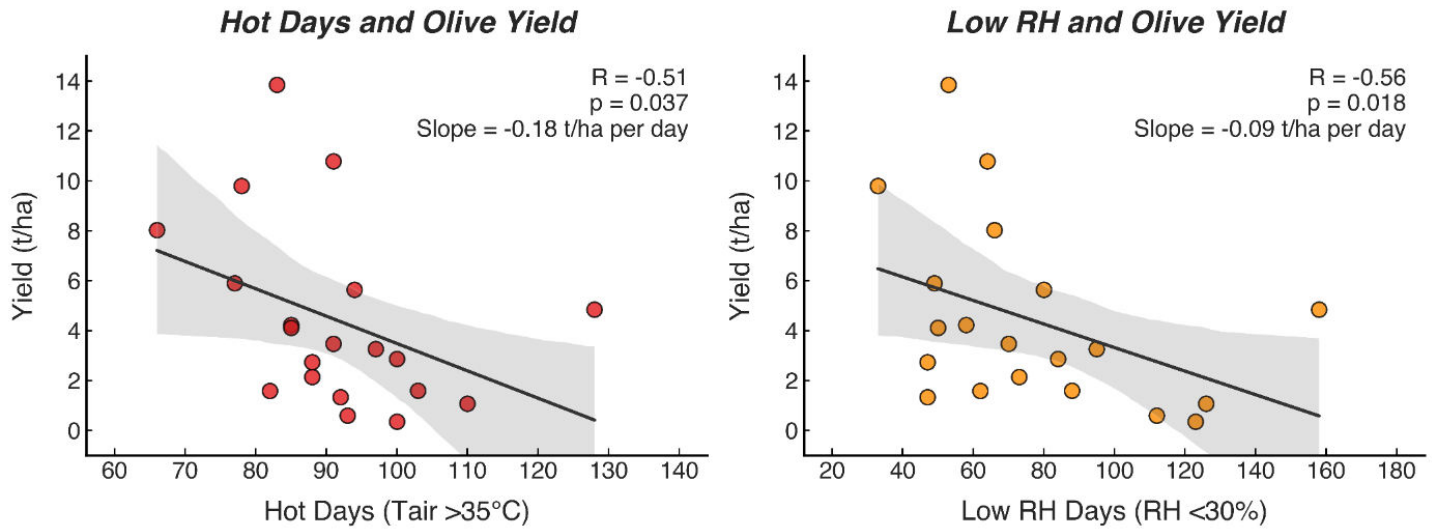


Fig.8: Relationships between olive yield and climate stress indices (2005-2023).

Phenological stages most sensitive to climate shifts

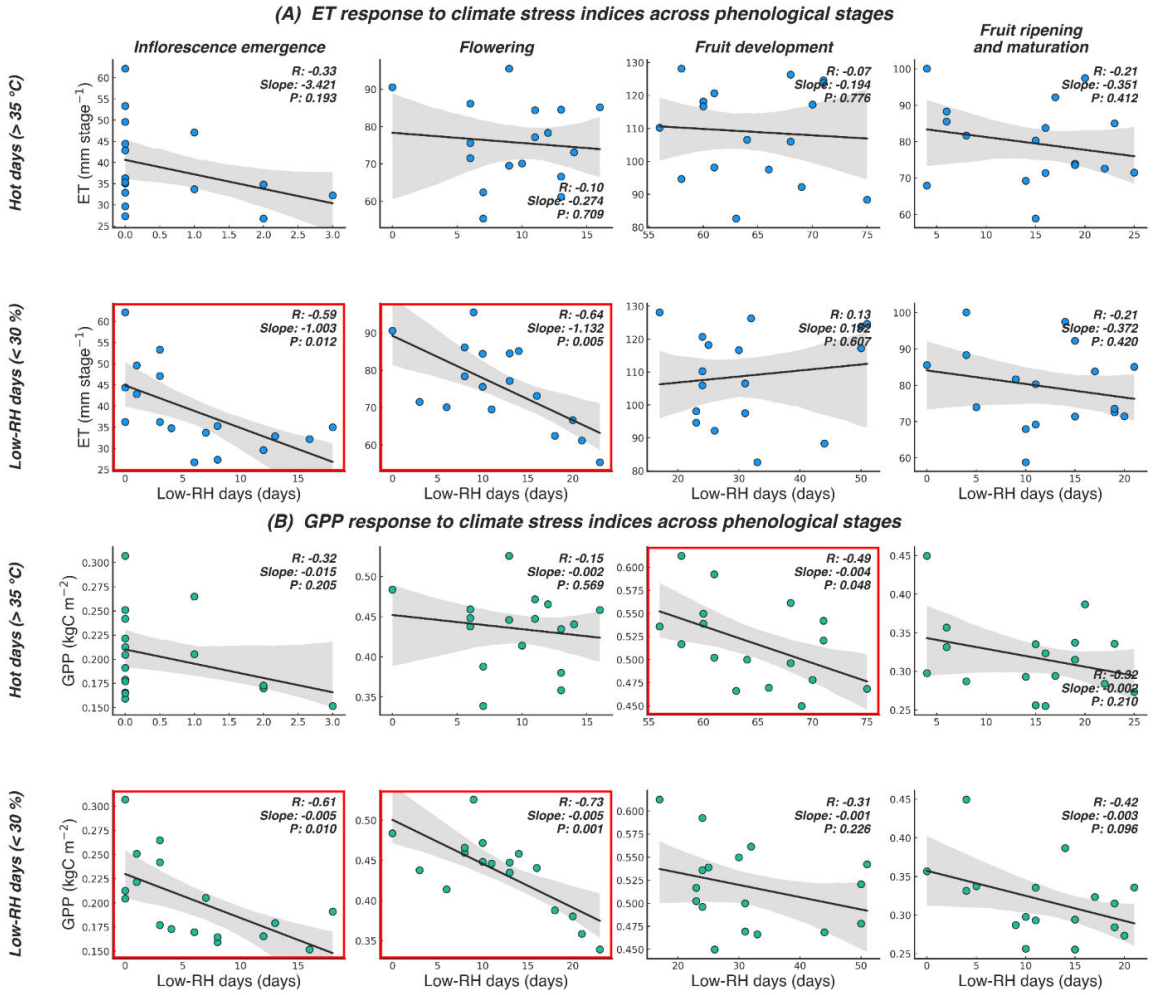


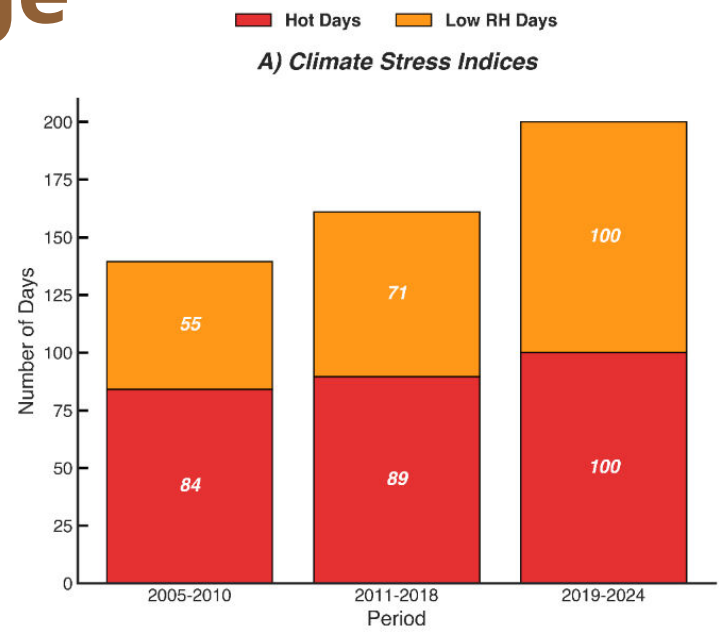
Fig.9: Impact of climate stress indices on GPP and ET across phenological stages.

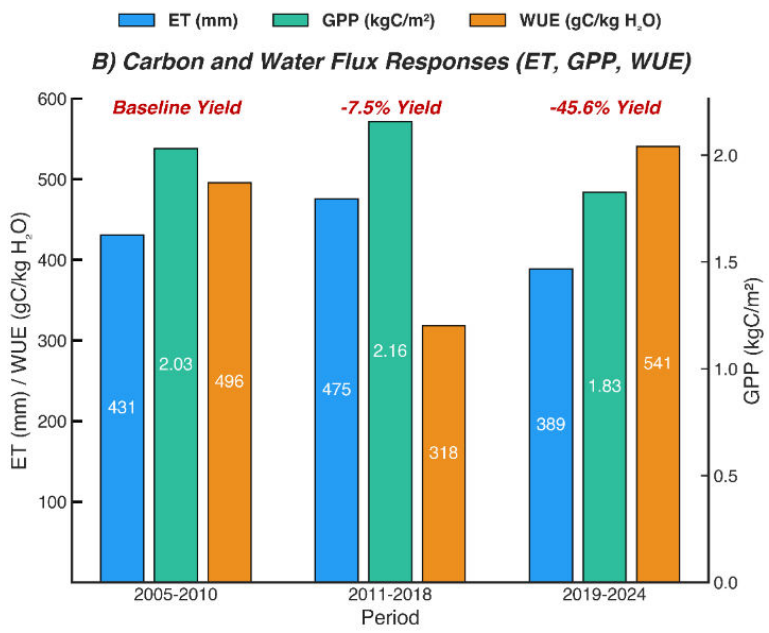
- Inflorescence emergence **(IE)** and flowering **(FLO)** are the most climate-sensitive stages, showing the strongest declines in **GPP** and **ET** under dry-air conditions.
- **Low RH days** is the dominant stressor, with strong negative effects on both **GPP** and **ET** during **IE**.
- **IE** and **FLO** coincide with spring warming (March–May), when rises in **low RH and high VPD** directly disrupt flower development, pollination, and carbon assimilation.

WUE response to the climate change

- **2005-2010** : Low stress and sufficient winter chill, resulting in high **WUE** and the highest yields.
- **2011-2018**: Climate stress increased, **higher irrigation** kept trees functioning. **WUE** dropped because trees needed more water per unit of carbon gained.
- **2019-2024:** Extreme Climate stress, and **reduced irrigation.** WUE increased to its highest-level but not improved productivity.

High WUE reflects resilience, not productivity.





Adaptation strategies

Pathway 1: Cultivar Adaptation

Introduce low-chill cultivars

Introduce low-chill varieties (10-13 CP): Arbequina, Coratina, Farga, Chalikidikis (Abou-Saaid et al., 2022).

Pathway 2: Orchard Management (existed trees)

Protect sensitive stages (IE, FLO)

- **Phenology aligned irrigation.**
- **Nutrition support.**
- **Kaolin sprays to reduce canopy heat.**

Water-Saving Practices outside sensitive stages

Deficit irrigation outside critical stages

Concluding Remarks

- **Winter chill declined below cultivar variaty needs, creating irregular flowering and reducing the yield.**
- **The warmer and drier conditions reduce photosynthesis rate, water exchange, and overall productivity.**
- **Low winter chill was the main reason 2024 became the worst yield year.**
- **Flowering stages (IE & FLO) are the most sensitive, and stress during these periods reduces flower formation and fruit set, resulting in lower yields.**
- **WUE increased under stress because trees reduced water loss, but this also limited carbon uptake, weakened growth, and ultimately led to lower yields.**
- **Adaptation is essential: introduce low-chill cultivars, use phenology-aligned irrigation and apply kaolin for cooling.**

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Thank you!

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