Assessing long-term water footprint of olive growing system under changing climate (Apulia, Italy)

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INTRODUCTION

Olive tree is the most representative tree crop of Apulia and the Mediterranean.

In recent decades there has been a gradual transition from traditional rainfed olive groves to semi-intensive or intensive agriculture.

This transition could have several negative effects on the environment such as:

- increased soil erosion,
- overexploitation and contamination of water,
- loss of biodiversity.

These effects could be exacerbated by **Climate Change (CC)**.

INTRODUCTION

This work aims at analyze the water consumption for olive tree crops under CC and irrigation management scenario through the water footprint (WF) approach.

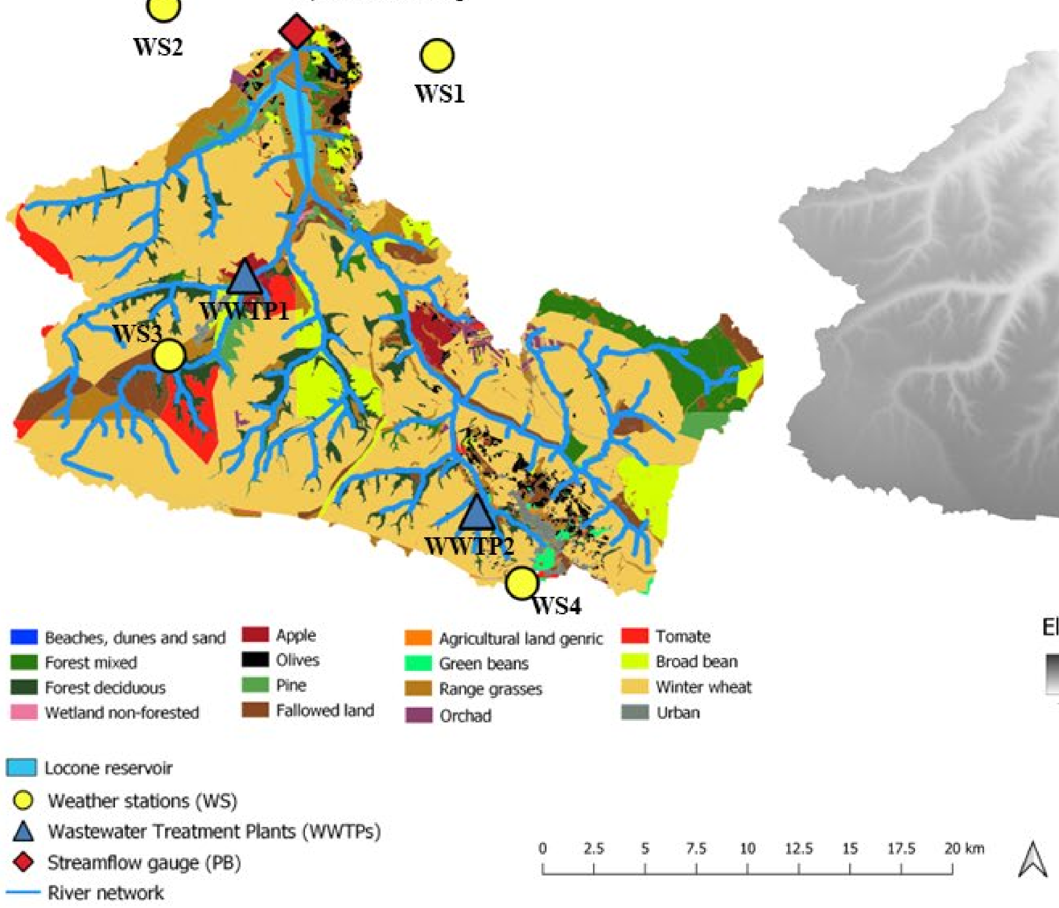
The specific aims were to:

- assess the current WF of the olive tree crop throughout the case study of the Locone River (Apulia, Italy), a data-limited basin with a temporary river;
- develop and analyze some scenarios including different irrigation amount, and diverse levels of CO_2 in the atmosphere.

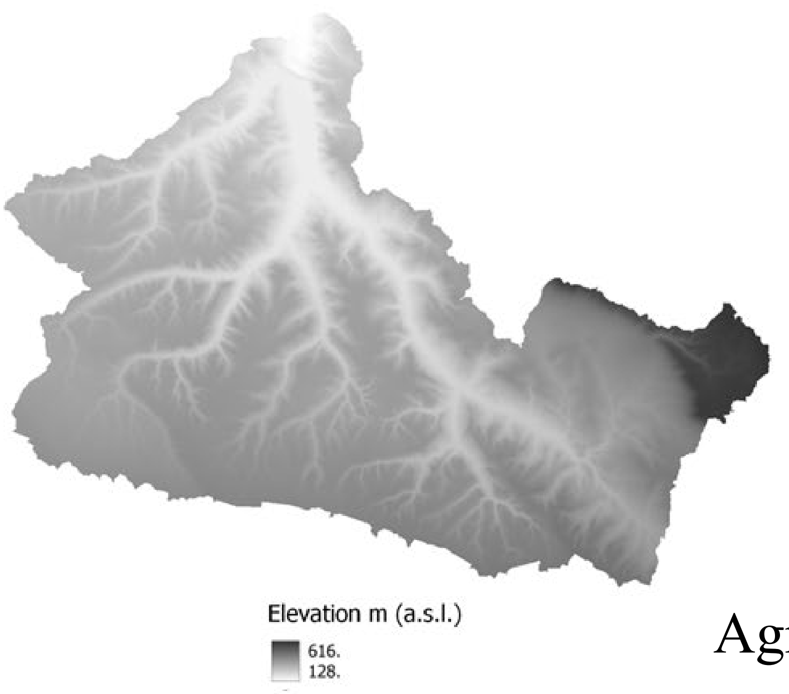
STUDY AREA

A) Locone River Basin (S-E Italy)

A) Land use map



B) DEM



Agricultural watershed

Drainage area: 228 km^2

Mean rainfall: 584 mm

Qm (PB) = 0.45 m^3s^{-1}

METHODOLOGY- hydrological model

SWAT+

Input

DTM (spatial resolution 10m x 10m)
SOIL MAP (spatial resolution 10m x 10m; 12 soil profiles)
LAND USE MAP (spatial resolution 100m; 16 land use type)
RIVER NETWORK

CLIMATE data (1971-2020) Daily scale
Precipitation (WS1, WS2, WS3, WS4),
Temperature (WS1, WS4)
Relative humidity (sim)
Wind speed (sim)
Solar radiation (sim)

Crop management operation

Additional point sources: **Wastewater treatment plants**

Potential evapotranspiration → Hargreaves-Samani formula.
Surface runoff → SCS Curve Number method.

Output

Watershed delineation
739 HRUs
31 sub-basins,
183 LSUs.

Hydrology
Streamflow at daily scale

The simulation runs were performed in parallel on 50 cores using **swatplusR**

Calibration (based on daily streamflows observed in 1971)
Validation (based on daily streamflows observed in 1972)

METHODOLOGY- climate projections

Climate models

- CMCC-CM-COSMO-CLM model (**CMCC**)
- MPI-ESM 1.2 -LR (**MPI**)

Climatic variables at daily scale:

- Precipitation (PCP);
- Temperature (TMP)

Experiment:

- Historical (1971-2005)
- Near future (2040-2049) RCP 4.5 scenario

Bias correction

Precipitation

$$\frac{AVRGmonth(i)Past\_OBS}{AVRGmonth(i)Hist\_SIM} \cdot daily\ PCP\_SIM$$

Temperature

Quantile Mapping method

METHODOLOGY-
Water footprint assessment

The results of SWAT+ model were used to evaluate the WFgreen and WFblue components (WFgreen+ WFblue = “WFg,b”) for olive production.

The calculation was carried out as an average between the HRU (olive crops) within the basin.

To include interannual climate variability, ten years were analyzed for the **baseline scenario (2000-2009)** and the **near future (2040-2049)**.

METHODOLOGY-
Water footprint green

$$\mathbf{WFgreen} = \frac{\text{CWUgreen}}{Y} \quad [m^3\ t^{-1}]$$

CWU: Crop Water Use
Y: Yield

CWU_{green} was assumed to be equal to the crop evapotranspiration under non-standard conditions (ETc_no_irr) over the complete growing period if the soil does not receive any irrigation (mm $time^{-1}$)

$$CWUgreen = 10 \times ETc\_no\_irr \text{ [volume/area]}$$

After the model calibration (actual conditions), a new simulation was carried out excluding the irrigation.
Y was assumed as the value predicted by the model including the irrigation.
ETc_no_irr and Y were estimated at the HRU level by the SWAT+ model.

METHODOLOGY- Water footprint blue

The WFblue refers to the consumption of water resources used in the crop production (Eta, actual evapotranspiration) and that do not return to the source in the form of return flow.
The “consumption” refers to total loss of freshwater that is incorporated into the crops, evapotranspirated or direct to another basin or to the sea.

$$\mathbf{WFblue} = \frac{\text{CWUblue}}{Y} \qquad [m^3\ t^{-1}]$$

$$\mathbf{CWUblue} = \text{ETa} - \text{CWUgreen} \qquad [m^3\ ha^{-1}\ y^{-1}]$$

The SWAT+ model was run <u>including the irrigation</u> amount to evaluate Eta.

METHODOLOGY- Scenario development

Scenario	Irrigation ($m^3\ ha^{-1}$)		CO_2 (ppm)	Description
	CMCC	MPI		
Baseline			400	Irrigation (1200 $m^3\ ha^{-1}$)
SC1	1200	1200	400	Irrigation amount and CO_2 were assumed as the baseline
SC2	1200	1200	450	No changes in irrigation Increase in CO_2 according to RCP 4.5
SC3	1200	1200	500	No changes in irrigation Increase in CO_2 according to RCP 4.5
SC4	1376	1360	400	Increase in irrigation amount (1376 m3 ha^{-1}; +15% of the baseline). No changes in CO_2
SC5	2822.4	2665.6	470	Increase in irrigation to guarantee the same yield as the baseline Increase in CO_2 by an intermediate value between 450 and 500 ppm

RESULTS- calibration and validation

The calibration was performed including 15 parameters.

Parameter	Description	Range of variability	Type of change	Value
ESCO	Soil evaporation compensation factor	0.15 ÷ 0.35	Absval	0.302
PERCO	Percolation coefficient	-0.3 ÷ 0.3	Abschg	0.195
CN3_SFW	Soil water factor for CNIII	-0.3 ÷ 0.3	Abschg	0.0599
LATQ_CO	Lateral flow coefficient	-0.3 ÷ 0.3	Abschg	-0.12
AWC	Available Water Capacity of the soil layer (mm H2O/mm soil)	-0.5 ÷ 0.5	Relchg	-0.483
BD	Moist Builk Density (Mg/m^3)	-0.5 ÷ 0.5	Relchg	-0.115
K	Saturated hydraulic conductivity (mm/hr)	-0.5 ÷ 2	Relchg	1.91
SURLAG	Surface runoff coefficient	0.01 ÷ 2	Absval	0.0249
CN2	Initial SCS runoff CNII	-0.15 ÷ 0.10	Relchg	20 [A] ÷ 91 [B]
LAT_TTIME	Lateral flow travel time (days)	0.1 ÷ 100	Absval	89.5
LAT_LEN	Slope length for lateral subsurface flow (m)	1 ÷ 100	Absval	17.3
ALPHA	Baseflow alpha factor	0 ÷ 0.2	Abschg	0.163
DEEP_SEEP	Deep aquifer percolation fraction	-0.9 ÷ 1	Relchg	-0.373
SP_YLD	Specific yield of the shallow aquifer (m^3/m^3)	-0.9 ÷ 1	Relchg	0.587
REVAP_CO	Groundwater “revap” coefficient.	0 ÷ 10	Relchg	1.38

Previous work: Leone et al., 2023 https://doi.org/10.1016/j.ecohyd.2023.03.005

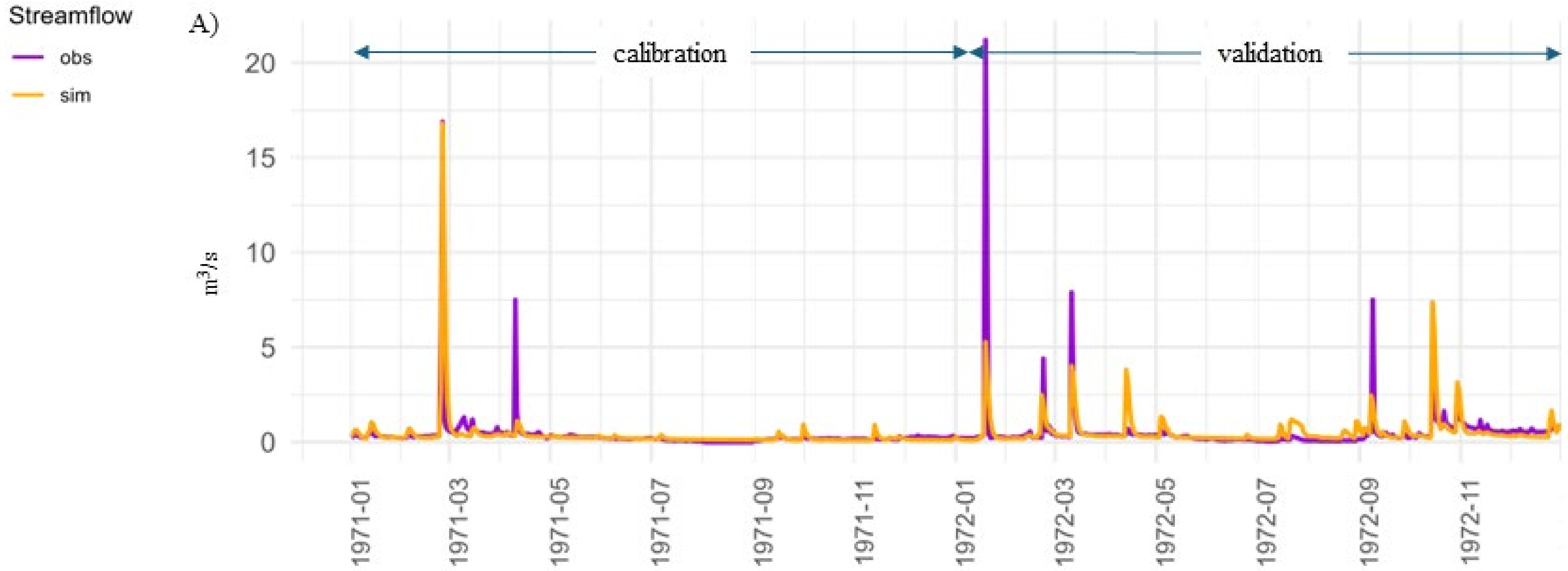
RESULTS- calibration and validation

Sampling of the parameter combinations: Latin Hypercube Sampling.
5000 parameter combinations were included in model simulations.

Simulation selection criterion was:

KGE_cal > 0.75, |pbias_low flow| < 5%, mae_low flow < sd(qobs_low flow)

low flow from 1971-05-01 to 1971-12-31.



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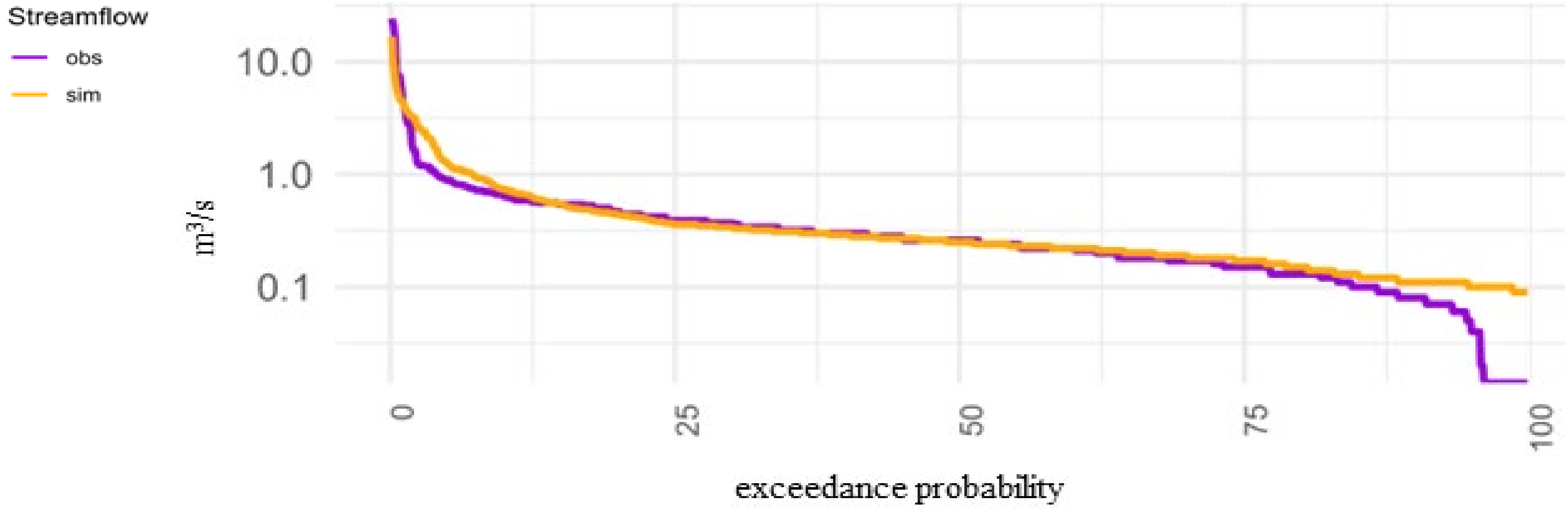
RESULTS- calibration and validation



Statistical results

Calibration

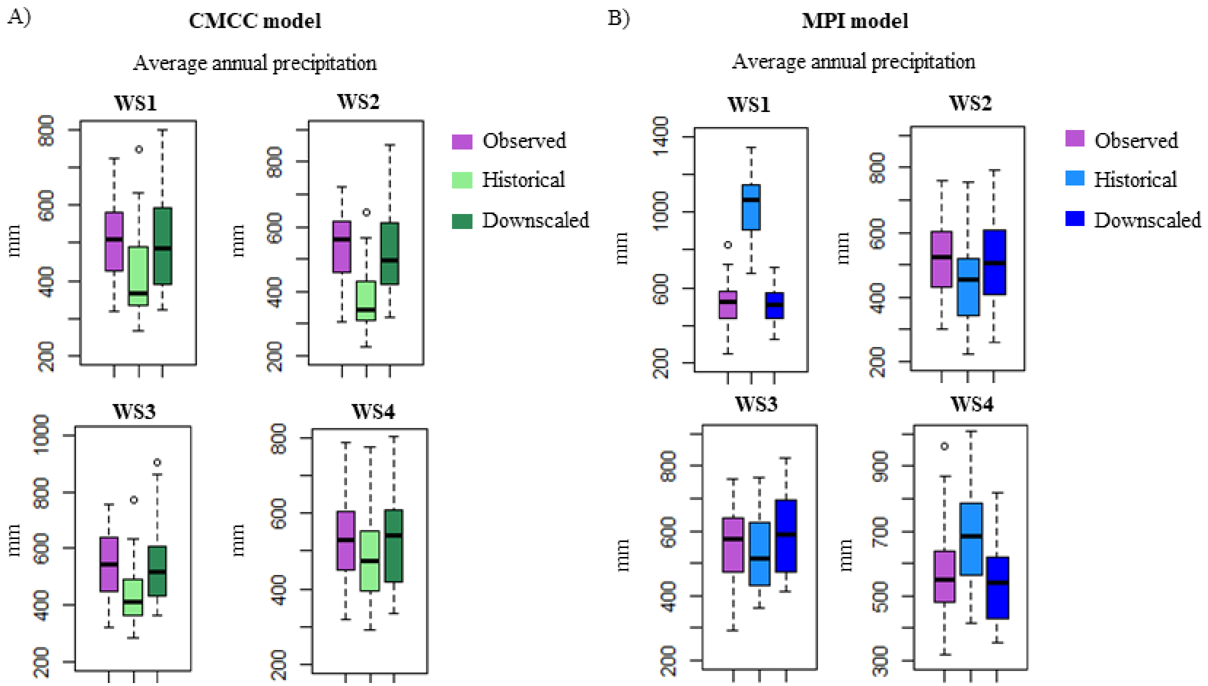
r = 0.80,
MAE= 0.16,
pBias =0.29,
NSE = 0.65,
KGE = 0.75.
Low flow period:
MAE=0.08,
pBias = -4.53

Validation

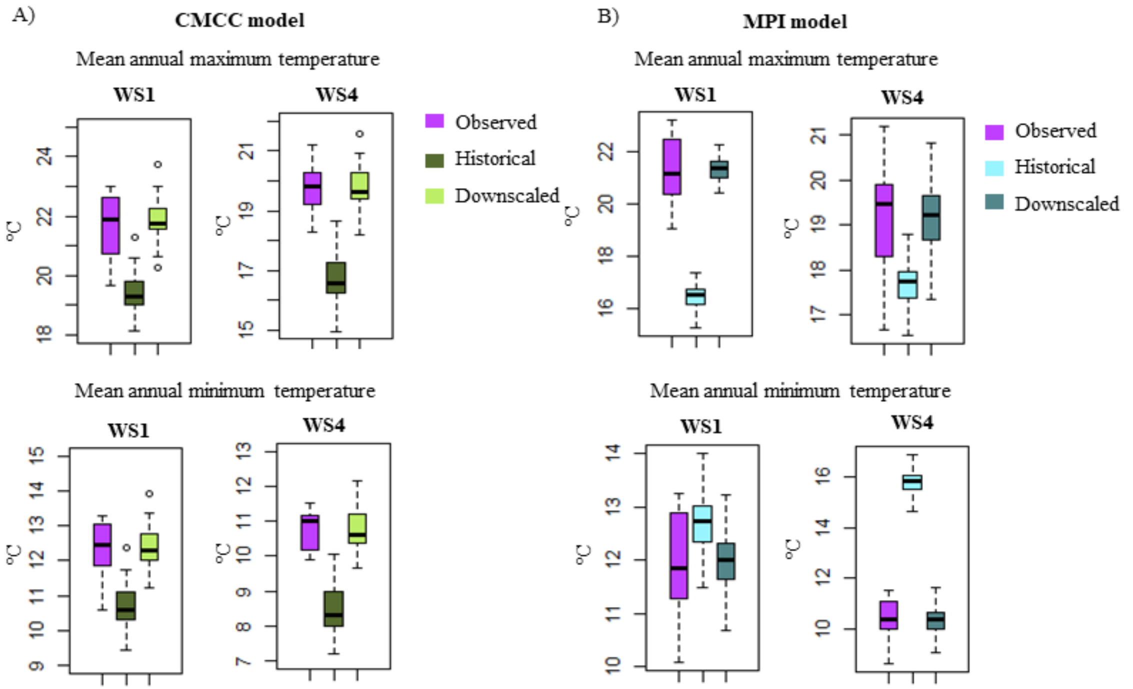
pBias = -1.05,
KGE =0.46,
NSE =0.40

RESULTS- bias corrections

Precipitation



Temperature



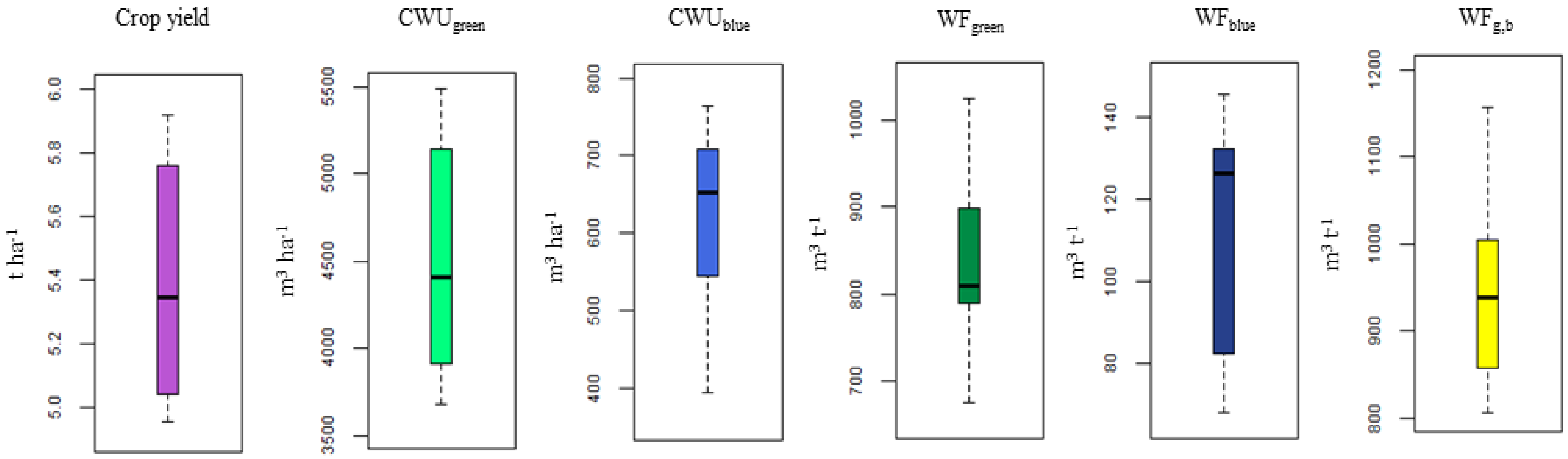
At basin scale..

- …The average annual rainfall was underestimated by about 100 mm by CMCC model,
- The average annual rainfall was overestimated by about 100 mm by MPI model
- ..the mean annual temperature was underestimated by about 3°C by the CMCC model.
- Fairly close to the temperatures observed for the MPI model.

RESULTS- WF baseline (2000-2009)

The Y simulated by the SWAT+ model ranged from 4.9 t ha^{-1} y^{-1} to 5.9 t ha^{-1} y^{-1}

The average annual values of the CWU_{blue} = 617 (±128) m^3 ha^{-1} and CWU_{green} = 4480 (±648) m^3 ha^{-1}.
The WF_{blue} was 116 m^3 ha^{-1} (±29).
The WF_{green} was 830 m^3 t^{-1} (±105).
The $WF_{g,b}$ for olive production was 946 (±101) m^3 ha^{-1} at the basin scale.



RESULTS- WF near future (2040- 2049)

A general increase in $WF_{g,b}$ was simulated for all the scenarios mainly due to the decrease in Y.

SC1_Y < BASELINE_Y (17% and 12% for CMCC and MPI, respectively)

SC2_Y < BASELINE_ Y; SC3_Y < BASELINE_Y (up to 14%, CMCC).

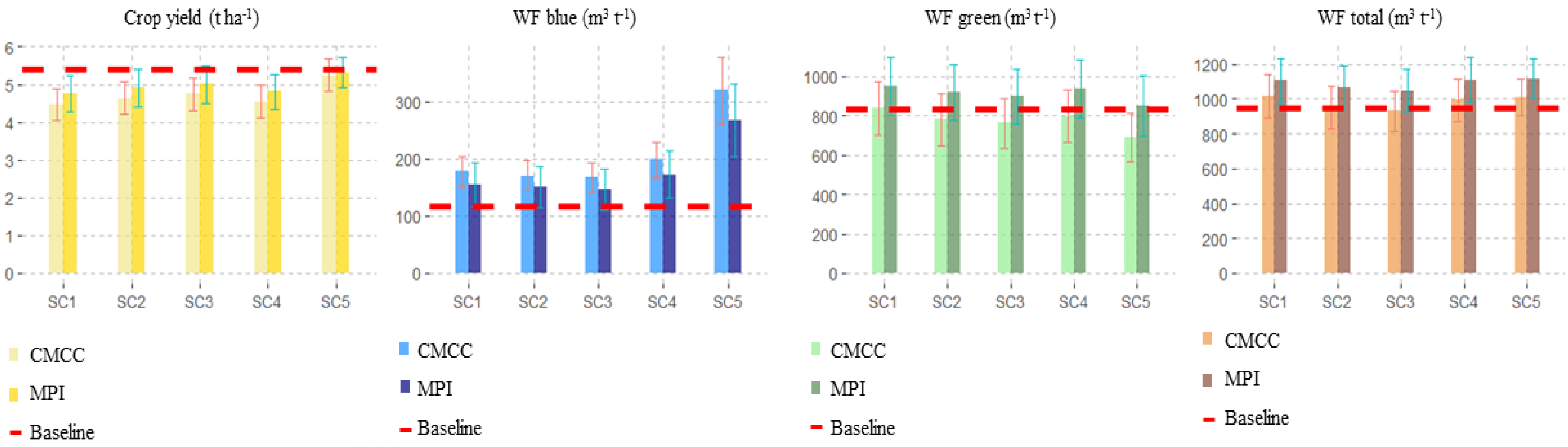
SC3_Y > SC2_ Y> SC1_Y < BASELINE_Y

SC4_Y > SC1_Y but SC4_Y < BASELINE_Y

SC5_Y ≈ BASELINE_Y with a large increase in irrigation (from 1200 to 2822 m^3ha^{-1} (CMCC) to 2666 m^3ha^{-1} (MPI).

These results indicated that CO_2 fertilization improved crop production, but it was not enough to recover the loss of production due to CC.

Large increase in irrigation implies a greater CWUblue which results into an increase in WFg,b up to 18%.



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CONCLUSIONS

- SWATplusR package proved to be very useful for calibrating the SWAT+ model in Mediterranean rivers where extremely low flows are very common.
- Bias correction operations proved to be fundamental to provide as much adherence as possible between measured data and modelled climatic data.
- CC could reduce yields by up to 17% in the next 20–30 years and the positive effect of CO_2 fertilization on the crop yield is not sufficient to maintain the baseline productivity.
- An increase in the WF_{green} and WF_{blue} in the future compared to the baseline (6% and 15%, for CMCC and MPI, respectively) is expected. To maintain the actual crop yield production, an important increase in irrigation amount will be necessary for the next decades.

This study presents some limitations such as the number of models used for climate projections.
This work did not investigate the effects of CC on important aspects such as extreme events and changes in pests and diseases that could negatively affect crop production, therefore the $WF_{g,b}$ could be underestimated.

Despite the limitations, this study provides useful information for decision-making on future planning and management directions.

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