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The modelling of tomato crop response to the climate change with different irrigation schemes

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Abstract: The inequality between available water supplies and growing water demand from diverse sectors, as well as the predicted climate changes are putting significant pressures on Egypt's food security. There is a nation-wide demand for new scientifically proven on-farm practices to boost water productivity of major food crops. The objective of this study was to explore the use of various deficit irrigation schemes to improve water productivity (*WP*) of tomato cultivated in Egypt under distinct climate change scenarios, RCP4.5 and RCP8.5, in three time-steps of the reference period (2006–2016), 2030s, and 2050s. The AquaCrop model was used to simulate the influence of climate change on the tomato crop, as well as two deficit irrigation application schemes for the full growing season and the regulated application for the initial and maturity crop stages. With the same irrigation method, the predicted *WP* increased in a general pattern across all climate change scenarios. The combination of irrigation schedule with the 80% deficit irrigation can enhance WP near the optimum level (approximately 2.2 kg·m^{-3}), especially during early and mature stages of the crop, saving up to 16% of water. The results showed that the expected temperature rise by 2050s would reduce the crop growth cycle by 3–11 days for all irrigation treatments, resulting in a 1–6% decrease in crop evapotranspiration (ET_c) and affecting the dry tomato yield with different patterns of increase and decrease due to climate change.

Keywords: AquaCrop model, deficit irrigation, RCP4.5, RCP8.5

INTRODUCTION

The relationship between water and agriculture is one of limitations to food security for many countries, especially those located in arid and semiarid regions. This relationship faces more challenges, due to population growth, global changes in nutrition habits, and the growing threats of climate change. According to the global climate records, the projected increase in temperature under climate change is likely to reduce the productivity of major crops, increase their water requirements, and thus directly reduce crop and water productivity (IPCC, 2014). Climatically, Egypt is considered a hot arid desert region according to the Köppen–Geiger climate classification scheme with limited water resources (Kottek *et al*., 2007). Furthermore, it has a highly diversified distinct agricultural sector, with a complex structure, relying on intensive applications, and has high productivity on the global scale. The amount of irrigation water in the field reached 40.2·10^9 m^3 in 2019 compared to 36.5·10^9 m^3 in 2018, an increase of 10.2% (CAPMAS, 2019). Currently, irrigated agriculture in Egypt is under increasing pressure to adjust water application patterns to narrow the growing gap between water resources and demand.

Climate change puts more pressure on the water and agricultural sectors in Egypt. The expected climate change influences water resources that are uncertain with a high probability of facing water scarcity. Meanwhile, rising temperatures in the future are projected to increase crop-water requirements, which leads to an increase in irrigation demands in the agriculture sector (FAO, 2015b). Therefore, deficit irrigation (*DI*) is considered a water-saving strategy. In this strategy, a crop is exposed to a particular level of water stress, less than the evapotranspiration requirements. The deficit irrigation can be applied during a particular period of the crop cycle or through the whole growing season (Hedley *et al.*, 2014). The main goal of deficit irrigation is to increase crop water productivity (*CWP*) by reducing the amount of water applied. Several field studies mentioned that deficit irrigation saves the applied irrigation water significantly, besides insignificant yield reduction, which varies with respect to the applied deficit level. The overall output of some deficit irrigation levels resulted in a considerable maximisation of *CWP* and farm income (Abuarab, Shahien and Hassan, 2013; Chai *et al.*, 2016). The real challenge of applying deficit irrigation is to identify the deficit levels that maintain a balance between water reduction and yield to a level that increases the quantity and quality of crops and water productivity (*WP*). Crop models help to explore various scenarios for applying deficit irrigation on different crops under current and future climate conditions.

Crop models can help the planning and evaluation of deficit irrigation application. Among crop simulation models used to assess the impact of climate change on agricultural crops, the AquaCrop offers dynamic crop and water management. The model was developed by the Food and Agriculture Organization (FAO). The model is characterised by fewer parameters and a good balance between simplicity, accuracy, and strength (Steduto *et al.*, 2009). AquaCrop accommodates many water management systems, such as rainfed agriculture and supplemental irrigation, deficit irrigation, and full irrigation. Since 2009, the model has been evaluated and calibrated in a large number of studies covering a wide range of crops and strategies for arid and semiarid conditions, and other case studies on water scarcity (Katerji, Campi and Mastrorill, 2013; Bird *et al.*, 2016).

The tomato crop is of commercial importance worldwide, with an annual production of more than 120 Tg, Egypt is one of the most important tomato producers in the world (FAOSTAT, no date), as the tomato crop occupies about 4% of the annual total cultivated area in Egypt and produces about 7.8 Tg annually (Egypt Data Portal, 2018). Climate change is expected to have negative impact on the tomato crop. Ventrella *et al.* (2012) examined these impacts on some current tomato crop cultivars and found that increasing temperature would accelerate tomato phenological stages, leading to a decrease in total dry matter accumulation and yield.

Saadi *et al.* (2015) found that the average length of the growing season for tomato crops in the Mediterranean region is estimated to be shorter in the 2050s from 12 to 15 days. Moreover, crop evapotranspiration is predicted to decrease by 5–6% and the net irrigation requirements under the optimal water level may decrease by 5%. Some validation tests under water stress conditions reported that AquaCrop is acceptable to simulate tomato crop productivity and water requirements under soil water stress conditions, considering the need for accurate calibration (Katerji, Campi and Mastrorill, 2013).

Temperature is one of major climate parameters that have a direct effect on crop growth and production (Tapan and Stoddard, 2018). These features are often overlooked in plant ecology (Darand and Mansouri Daneshvar, 2015). Ventrella *et al.* (2012) studied Italy's agronomic adaptation strategies for several crops under climate change, including tomatoes, and stated that tomato phenology may change by 2050 due to the increase in temperature and may reduce tomato yields. Applying water stress with different levels and schedule has a significant effect on tomato yield and fruit quality (Wang *et al.*, 2011).

Many studies showed the climate change effect on tomato crop by collecting historical data about the crop and made a prediction about crop production or cultivation areas (Biratu, 2018; Pathak and Stoddard, 2018; Bhandari, Neupane and Adhikari, 2021). Only a few studies have examined the effect of climate change on tomato yield, water productivity, crop growth cycle and water consumption (Attaher, 2012; Giuliani *et al.*, 2019; Abdel-Mawgoud *et al.*, 2021). Therefore, the insufficient number of research into the effect of climate change on tomato crop production is a point of concern and important issue for decision makers. In this context, the present study aims to evaluate the response of tomato crop yield to climate change under full and deficit irrigation scenarios in Egypt. The current work has been accomplished by employing the AquaCrop model and the historical and future climate scenarios generated from the general circulation model (GCM).

MATERIALS AND METHODS

STUDY AREA AND DATA DESCRIPTION

In this study, tomato crop response to climate change was simulated by the AquaCrop model – version 6 (Steduto *et al.*, 2009; FAO, 2015a) to examine the effect of deficit irrigation schemes on tomato crop production to estimate the change in agricultural productivity under future climatic conditions. AquaCrop was chosen because it is a crop water productivity (*CWP*) model that simulates yield response to water and can be used specifically in situations where water is a key limiting factor in crop production (Steduto *et al.*, 2009), also the model requires less number of input data (Hsiao *et al.*, 2009; Raes *et al.*, 2009; Steduto *et al.*, 2009) compared to other models such as DSSAT (Ventrella *et al.*, 2012; Hoogenboom *et al.*, 2014), TOMGRO (Jones *et al.*, 1991; Louski, Linker and Teitel, 2013; Giuliani *et al.*, 2019), and APSIM (Keating *et al.*, 2001; Keating *et al.*, 2003). To simulate the tomato crop response to climate change, the AquaCrop model was calibrated using five irrigation schemes under two seasons then the calibrated crop file was used for climate change simulation.

The tomato crop file was calibrated and evaluated in the AquaCrop model using field data collected from the field experiment conducted in two consecutive winter seasons, in Qalyoubia Governorate, Egypt (30°5'10" N latitude, 31°12'4" E longitude, and 70 m altitude). The soil under study was classified as "clay loam" for soil layer of 0–30 cm depth, whereas the soil layer under 30 cm depth was "clay". Table 1 shows mechanical analysis and soil-water parameters that were determined based on soil samples from the study area.

Tomato of "Elisa F1" (*Lycopersicum esculentum*) was transplanted manually, throughout two winter seasons, on 10th October 2015, and 1st October 2016. The distance between plant rows were 1.2 m, with 0.5 m plant spacing. Drip irrigation system was used with PE laterals of 16 mm built-in drip lines, 4 $dm^3 \cdot h^{-1}$ discharge, and 0.3 m spacing. The cultivation practices of soil preparation, fertilisation, and plant protection continued throughout the experiment according to the recommendations of the Ministry of Agriculture and Land Reclamation in Egypt. The harvesting dates for first and second seasons were on 10th of March 2016 (after 152

Table 1. Mechanical analysis and soil-water parameters of soil samples from the Shoubra El Khima site, Qalyoubia

Soil property	Feature or value in depth (cm)			
	0–15	15–30	30–45	45–60
Texture	clay loam		clay	
Clay (%)	32.8	35.1	41.1	42.2
Silt (%)	41.2	38.8	33.6	33.2
Sand (%)	26.0	26.1	25.3	24.6
FC (v/v)	35.5	36.3	38.6	39.1
WP (v/v)	20.7	21.7	25.0	25.5
Bulk density (g·cm^{-3})	1.37	1.36	1.36	1.35
pH	7.52	7.76	7.73	7.81

Explanations: *FC* = field capacity, WP = wilting point.
Source: own study.

days' season length), and the 27th of February 2017 (after 149 days' season length), respectively. The experiment consisted of five irrigation treatments incorporating three irrigation levels, and two deficit irrigation application schemes – T100 = 100% of crop evapotranspiration (ET_c), TS80 = 80% of ET_c at all crop growing stages, TS80 = 80% of ET_c at initial and maturity crop stages, TC60 = 60% of ET_c at all crop growing stages and TS60 = 60% of ET_c at initial and maturity crop stage.

The five irrigation treatments were randomised and distributed in a complete block design experiment, with three replications, each plot of 21 m^2 (3 × 7 m). Daily weather data (maximum and minimum air temperature (°C) – $T_{\max}$ and $T_{\min}$, respectively, maximum and minimum relative humidity (%) – $RH_{\max}$ and $RH_{\min}$, and average wind speed (m·s^{-1})) were collected from the Central Laboratory for Agricultural Climate (CLAC). The daily distribution of weather parameters during the tomato growing seasons 2015/2016 and 2016/2017 are shown in Figure 1.

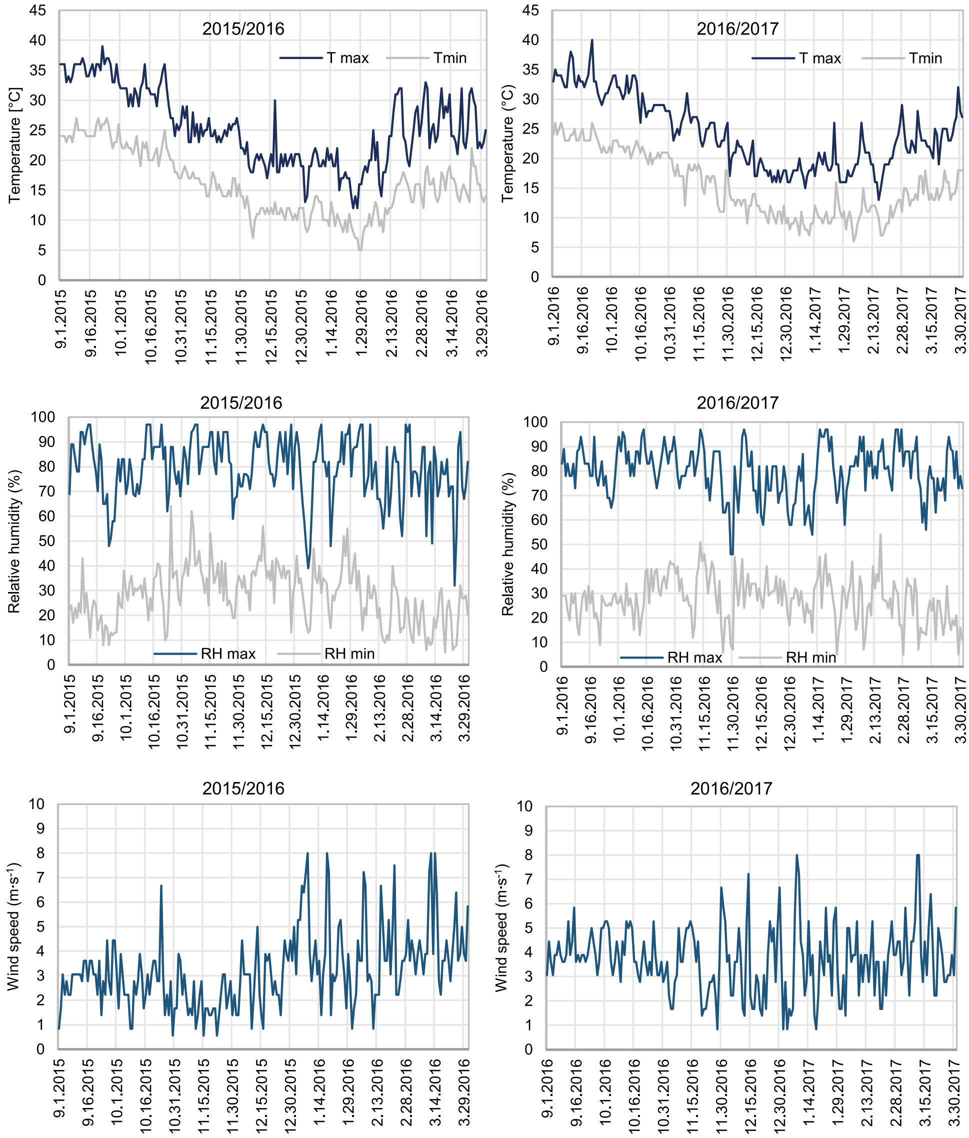


Fig. 1. Daily weather data during tomato growing seasons 2015/2016 and 2016/2017; $T_{\max}$ = maximum temperature, $T_{\min}$ = minimum temperature, $RH_{\max}$ = maximum relative humidity, $RH_{\min}$ = minimum relative humidity; source: own study

The crop evapotranspiration (ET_c, mm) was determined over each season, based on the estimating of the reference evapotranspiration (ET_o, mm) and a crop coefficient factor (K_c) using the following equation for non-water stress treatment:

$$ET_c = ET_o \cdot K_c \tag{1}$$

The daily ET_o was calculated according to daily weather data using "ETo calculator" software (FAO, 2015c), The initial K_c value was 0.6, reached to 1.15 at the "mid-season" stage, and then declined to 0.8 at the "late season" stage according to Allen *et al.* (1998), while, for water stress treatment the following equation have been used:

$$ET_c = ET_o \cdot K_c \cdot K_s \tag{2}$$

where: K_s = water stress coefficient which $K_s < 1$ for soil water limiting conditions the growth stages lengths were modified according to the actual data collected from the experiment.

Daily irrigation schedule was determined based on the soil water content using PMS-714 Lutron soil moisture meter (Lutron Electronic) for each plot at 30 cm depths under the emitter.

MODEL CALIBRATION

The impact of climate change on tomato crops was studied for five irrigation treatments, which consist of three irrigation levels and two deficit irrigation application schemes. For the AquaCrop simulation of climate change impacts, the five irrigation files were created, including the irrigation application method by using drip irrigation, with 30% percentage of soil surface wetted, and 24 applications per season, with an average total of 448 mm per season for T100 treatment. The percentages of water-saving under each deficit irrigation treatment were calculated as 16, 19, 22, and 40% for TS80, TC80, TS60, and TC60, respectively, comparing to full irrigation treatment (T100). Additionally, the plant response to soil fertility was adjusted at the "semi-optimal" soil fertility level, the relative weed cover of 5–10% was considered, and the groundwater level at a depth of 2.5 m from the indicated soil surface was based on historical records of the experimental site.

The AquaCrop calibration process was based on adjusting crop parameters representing the growth cycle of the crop and stressor thresholds. Furthermore, the calibration process considered actual data sets of groundwater, irrigation management, and field management collected from the field experiment. Those data sets were used in the simulations of climate change assessments. The final results of the calibration are shown in Table 2.

Table 2. The crop growth parameters in the calibrated crop file of the AquaCrop model

Crop growth and development parameter	Value
Transplanting date	5 Oct
Row spacing (m)	1.2
Plant spacing (m)	0.5
Maximum canopy cover (%)	70
Days after transplanting to recovery (day)	8
Days after transplanting to maximum canopy (day)	60
Days after transplanting to senescence (day)	100
Days after transplanting to maturity (day)	130
Days after transplanting to flowering (day)	38
Duration of flowering (day)	42
Maximum effective root depth (m)	0.67
Days after transplanting to maximum root depth (day)	70
Harvest Index (*HI*) (%)	65
Base temperature (°C)	9
Upper temperature (°C)	30
The carbon sink strength (%)	0

Source: own study.

CLIMATE CHANGE IMPACT

The climate change impacts were studied by using projected climate data from three "General Circulation Models (GCM)" used in six CMIP5 climate experiments (Taylor, Stouffer and Meehl, 2012). The six experiments consisted of three GCMs, i.e. CSIRO-Mk3, GFDL-ESM2G, and EC-EARTH, running under two CO_2 emission scenarios of RCP4.5 and RCP8.5 these three CMIP5 models was selected for this study according to (McSweeney *et al.*, 2015).

Each experiment provided a dataset that included daily projected data for maximum and minimum air temperature (°C), covering the time series for the years 2006–2050 from the selected location of the study. The reference evapotranspiration was calculated for the six climate data sets using the "ETo calculator" software (Luis *et al.*, 2014).

Then, the six climate change datasets were fed into the AquaCrop model, along with the crop, soil, irrigation, and field management datasets, and the model was run in "growing degree days" mode, in order to simulate the impacts of climate change on tomato production, in terms of the actual crop evapotranspiration (ET_a), crop growth cycle, crop dry yield (DY, in $\text{Mg}\cdot\text{ha}^{-1}$), and water productivity (WP, in $\text{kg}\cdot\text{m}^{-3}$) that was calculated using the following equation:

$$WP = DY/ET_c \tag{3}$$

where: ET_c = crop evapotranspiration (m^3 per season).

In this study, the impact of climate change was investigated as an average impact of the assembly of the three GCMs under the emission scenarios of RCP4.5 and RCP8.5, in three-time steps. The first-time step is the "reference years" (RF), which represent 2006–2016. The second is for the average for 2020–2030, and the third is the average for 2040–2050.

RESULTS AND DISCUSSION

CALIBRATION OF AQUACROP MODEL

Under the local conditions of the current study, the AquaCrop model was calibrated to increase its performance to simulate tomato crop production. The AquaCrop calibration process depended on limited number of key parameters to be adjusted to the other cropping models. The calibration process mainly depended on adjusting some crop parameters at the crop file which represented the crop growth cycle and thresholds of stress factors.

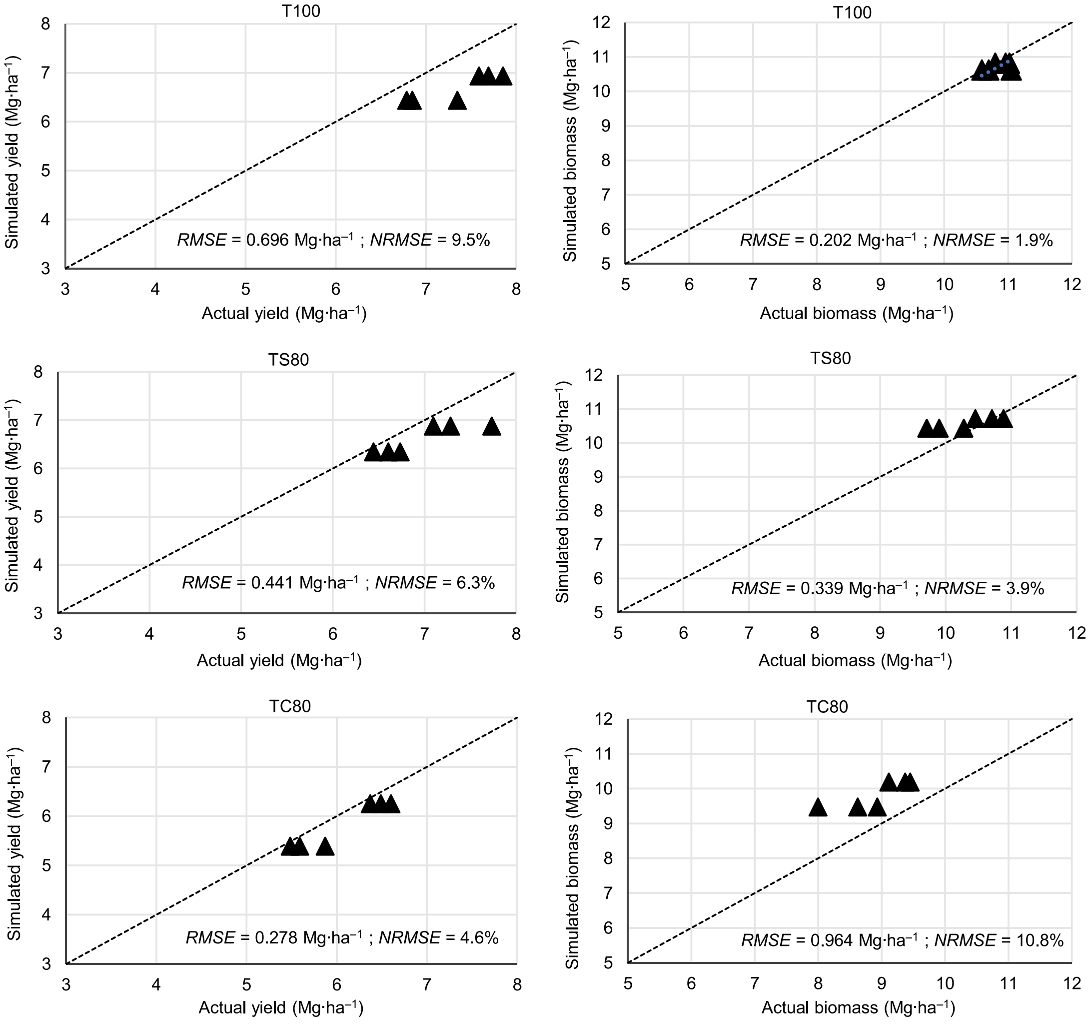
Based on the crop parameters shown previously in Table 2, the comparison between simulated and observed values of tomato biomass indicated a very good calibration of the model, with normalised root mean squared error (*NRMSE*) less than 11% under all irrigation treatments, as shown in Figure 2. The values between actual biomass and simulated biomass showed a perfect fit with the values under full irrigation treatment (T100) with root mean square error (*RMSE*) equal to 0.202 Mg·ha^{-1} and *NRMSE* equal to1.9%. On the other hand, the deficit irrigation treatment (TC80) was the less fitted case, based on which the model overestimated the biomass with *RMSE* equal 0.964 Mg·ha^{-1} and *NRMSE* equal 10.8%.

Similarly, differences between simulated and observed dry-farmed tomato yield were acceptable under all irrigation treatments, as presented in Figure 2. In general, the AquaCrop model performed an excellent to good simulation for all irrigation treatments, with the *NRMSE* ranging from 4.6 to 11.3%, and the *RMSE* ranging from 0.240 to 0.696 Mg·ha^{-1}.

Based on the overall calibration and validation results, it could be concluded that the AquaCrop model had a good ability to simulate the tomato crop biomass and yield under full and deficit irrigation conditions, which agreed with the outcomes by Katerji, Campi and Mastrorill (2013). This encouraged to consider the AquaCrop model as a good tool that could be used with a high degree of reliability in practical management, strategic planning of irrigation, and water limited conditions.

THE IMPACT OF CLIMATE CHANGE ON THE TOMATO CROP GROWTH CYCLE

The ambient environmental conditions of the winter tomato season are presented in Table 3 for the two climate scenarios (RCP4.5 and RCP8.5). Those changes in temperature and CO_2 reduced the tomato crop growth cycle as presented in Figure 3. As an average of irrigation treatments, and by 2050s, the crop growth cycle is expected to decrease by a range of 3–11 days corresponding to a temperature increase of about 0.4–0.8°C for RCP4.5 and RCP8.5, respectively. The maturity rate was relatively faster with the high emission scenario (RCP8.5) compared to the low emission scenario (RCP4.5). For instance, the average growing season length on planting date October 5th, varied between 131 and 135 days for the low emission scenario (RCP4.5) and 129 to 133 days under the high emission scenario (RCP8.5), compared to 134 to142 days for historical records under full and deficit



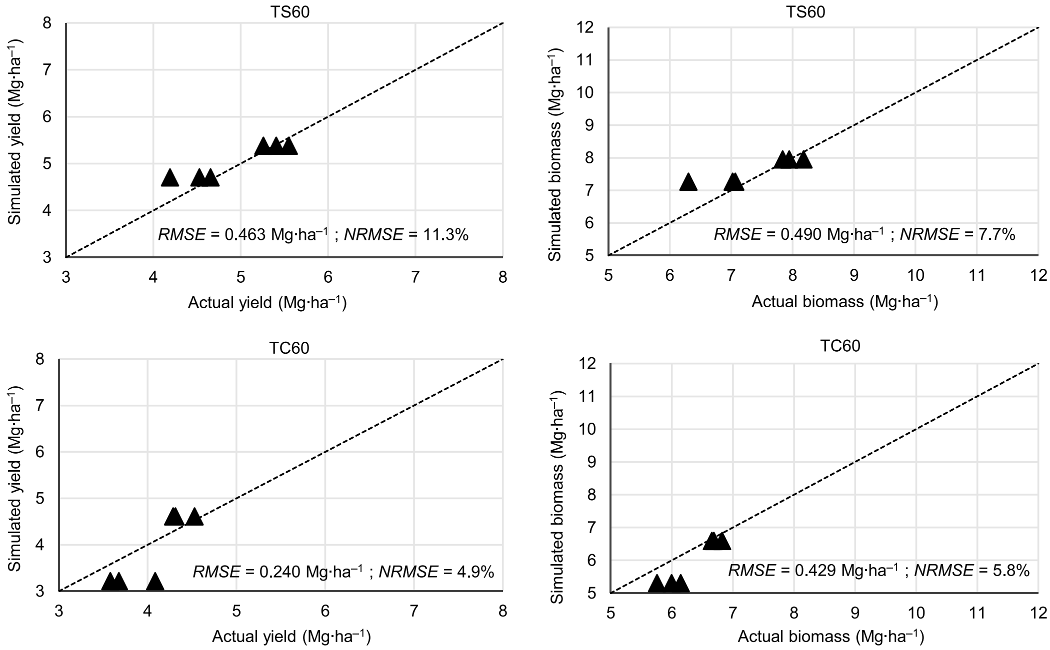


Fig. 2. The actual yield and biomass vs. the simulated yield and biomass with the calibrated AquaCrop to simulate the tomato crop; *RMSE* = root mean squared error, *NRMSE* = normalised root mean squared error; source: own study

Table 3. The average ambient environmental conditions of the tomato winter season resulted from the assembly of the three General Circulation Models, under RCP4.5 and RCP8.5 scenarios, of the three time-steps of the investigation

Parameter	Value for					
	RCP4.5			RCP8.5		
	RF	2030s	2050s	RF	2030s	2050s
The average mean temperature (°C)	16.5	16.4	16.9	16.3	16.5	17.1
CO_2 (ppm)	393	423	461	393	423	461
Growing degree days (°C per season)	1199	1199	1198	1200	1199	1199

Explanation: RCP = representative concentration pathway, RF = reference years (2006–2016).

irrigation treatments. These results of the impact of temperature on the acceleration of tomato growth stages are in agreement with Ventrella *et al.* (2012) and Tapan and Stoddard (2018).

THE IMPACT OF CLIMATE CHANGE ON THE TOMATO ET_c

The impact of climate change on the tomato ET_c is presented in Figure 4. The simulations gave an average ET_c of the full irrigation treatment (T100) at the reference period as 297 mm per season. The irrigation treatments negatively affected ET_c values, and showed a general reduction pattern under all deficit irrigation treatments, and the TC60% had the lowest ET_c values of less than the T100 by about 20% and 15% for RCP4.5 and RCP8.5, respectively.

By 2050s, the ET_c of the irrigation treatments was in the range of 234–289 mm per season for low emission scenario (RCP4.5) and 238–282 mm per season under high emission

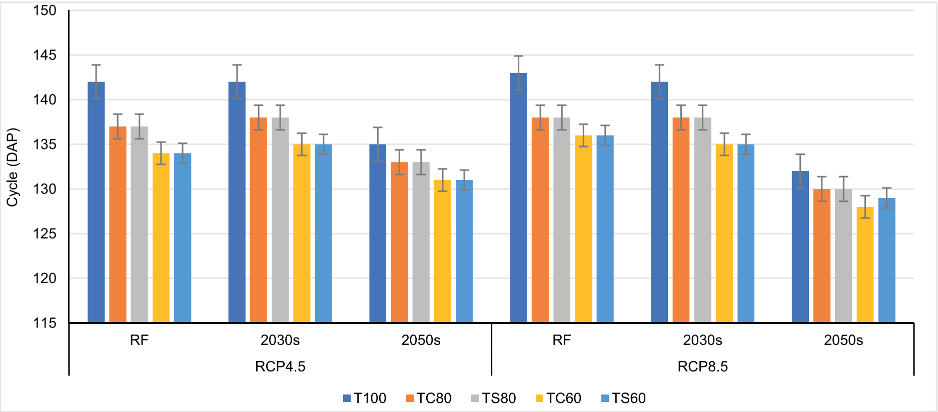


Fig. 3. The impact of climate change on the tomato growth cycle (DAP: days after planting), under the climate scenarios RCP4.5 and RCP8.5, for the three time-steps of the investigation; RCP = representative concentration pathway, T100 = 100% of crop evapotranspiration (ET_c), TC80 = 80% of ET_c at all crop growing stages, TS80 = 80% of ET_c at initial and maturity crop stages, TC60 = 60% of ET_c at all crop growing stages, TS60 = 60% of ET_c at initial and maturity crop stage; source: own study

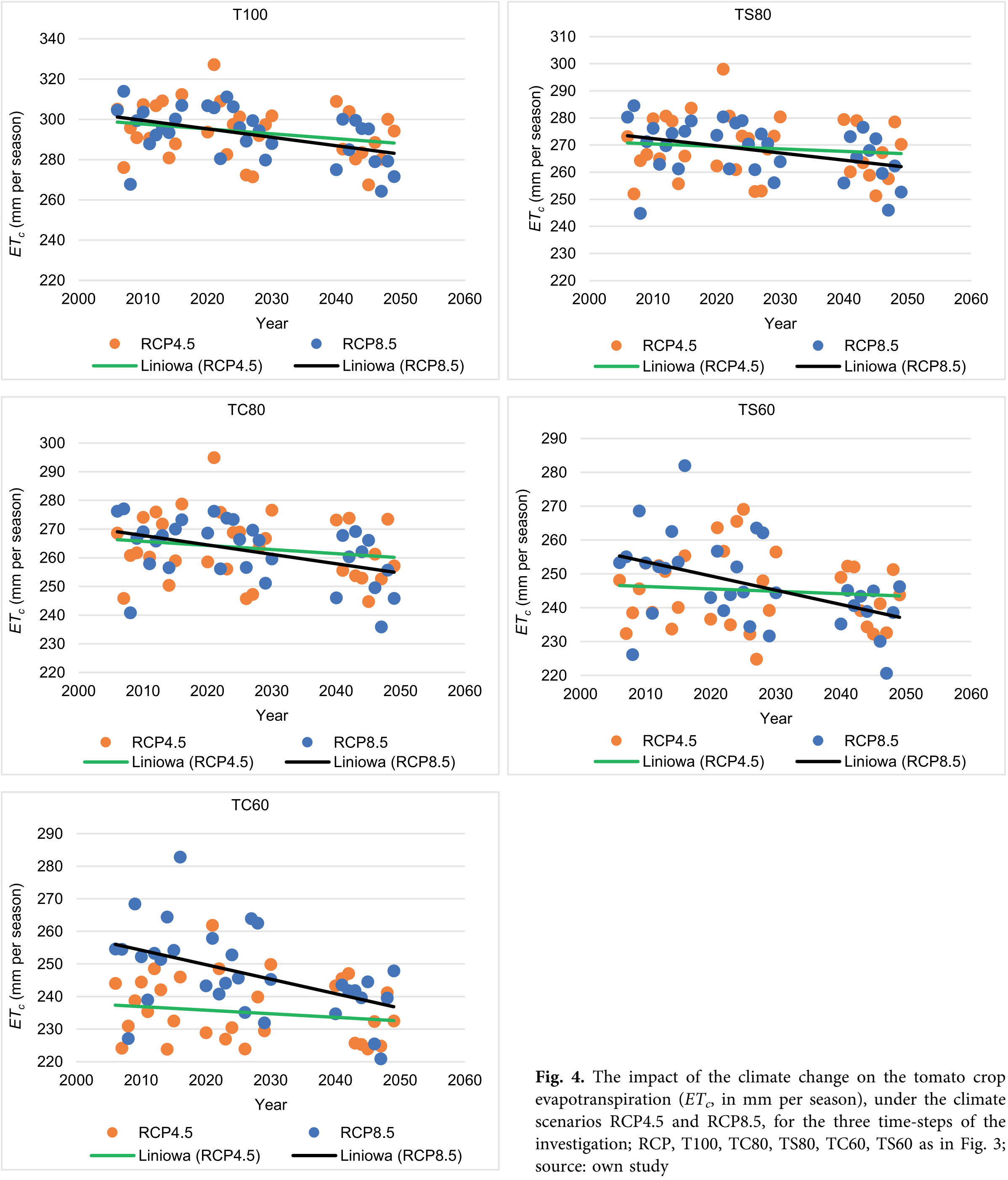


Fig. 4. The impact of the climate change on the tomato crop evapotranspiration (ET_c, in mm per season), under the climate scenarios RCP4.5 and RCP8.5, for the three time-steps of the investigation; RCP, T100, TC80, TS80, TC60, TS60 as in Fig. 3; source: own study

scenario (RCP8.5), compared to 238–295 mm per season for the reference period. The rate of ET_c decrease is relatively high under high emission scenario (RCP8.5) compared to low emission scenario (RCP4.5). That by the end of 2050s, the ET_c values under RCP8.5 scenario are expected to decrease by a range of 2–6% compared to the reference period.

The reduction in ET_c values under deficit irrigation treatments and temperature increase could be explained as a result of the addressed shortening on the crop growth cycle, and the stomatal closure as a physiological defiance mechanism against water and heat stress (Zhou *et al.*, 2017). The reductions are in agreement with the results introduced by Saadi *et al.* (2015) and Incoom *et al.* (2022) for the south Mediterranean region.

THE IMPACT OF CLIMATE CHANGE ON TOMATO DRY YIELD

Figure 5 shows a noticeable change in the tomato crop dry yield under climate change conditions. Regardless the effect of the irrigation treatments, under RCP4.5 scenario, the tomato dry yield values range was 4.6–6.7 Mg·ha^{-1}, compared to 4.4–6.4 Mg·ha^{-1} for the reference period, whereas, the dry yield values range was 4.6–5.8 Mg·ha^{-1} for RCP8.5 scenario, compared to 4.6–5.9 Mg·ha^{-1} for the reference period.

Under T100 treatment, and by 2050s, the temperature increases of about 0.4°C under RCP4.5 scenario lead to tomato crop yield increase by 3.8% compared to the reference period value (6.4 Mg·ha^{-1}). This pattern of crop increase was observed under deficit irrigation treatments for the same climate scenario

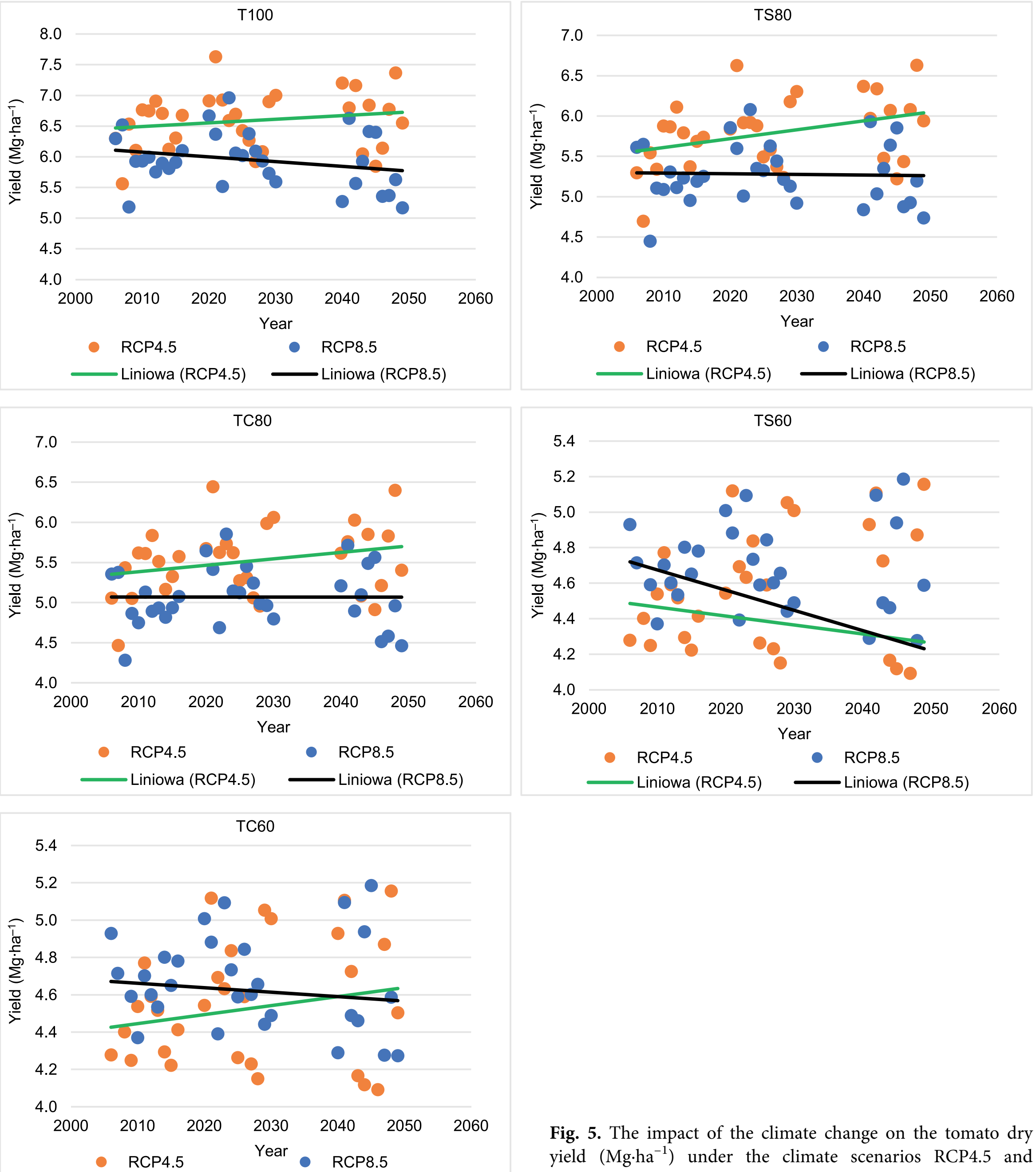


Fig. 5. The impact of the climate change on the tomato dry yield (Mg·ha^{-1}) under the climate scenarios RCP4.5 and RCP8.5, for the three time-steps of the investigation; RCP, T100, TC80, TS80, TC60, TS60 as in Fig. 3; source: own study

and projection time-step. The highest increase in tomato dry yield was observed under TS80 treatment, with an increase of 6.8% above the reference period value (5.6 Mg·ha^{-1}).

Under the RCP8.5 scenario, the impact of the temperature increase showed different pattern of tomato dry yield. The values increase by 2.2% to 5.3% by 2030s above the reference period, and dry yield values decreased by a range of 0.4% to 2.8% by 2050s below the values of the reference period. The treatments TC80 and TS80 showed the highest increase under the RCP8.5 scenario, with values for 2030s of 5.3% and 4.6% above the reference period values, for the two irrigation treatments respectively. Moreover, under the same scenario and by 2050s, the tomato crop yield of the same irrigation treatments is expected to increase by 0.5% and 1.2% above the reference period values.

The observed increase patterns in tomato crop yield under some climate change scenarios and time-steps could be attributed to the physiological behaviour of the tomato plant as one of the C3 group plants, which is limited by carbon dioxide concentration; and it can benefit from the increased carbon dioxide concentrations with increased growth and yields (Ainsworth and Rogers, 2007). Lipiec *et al.* (2013) emphasised that the increase in crop yield corresponding to the increase in CO_2 could be limited by temperature and water stress conditions. Under certain limits of temperature and/or water stress increase, the CO_2 fertilisation effect may fade. Based on the simulation results, the pattern of yield increase is more obvious under the RCP4.5 scenario. The magnitude of the temperature increase is relatively small and does not exceed the temperature stress thresholds for the tomato plant and the investigated cultivar. Moreover, the projection of the RCP8.5 scenario for 2050s showed changes in the growth cycles up to 11 days shorter than the reference period. This may cause small reduction on the crop dry yield.

THE IMPACT OF CLIMATE CHANGE ON TOMATO WATER PRODUCTIVITY

The crop water productivity (*CWP*) patterns are an outcome of changes in the crop yield and the ET_c. Figure 6 shows the impacts of climate scenarios RCP4.5 and RCP8.5 on the *WP* of the tomato crop produced using the investigated irrigation treatments.

Under full and deficit irrigation treatments, the *WP* ranged 1.96–2.34 kg·m^{-3} for RCP4.5, compared to 1.83–2.12 kg·m^{-3} for reference period, whereas, it was 1.92–2.09 kg·m^{-3}, compared to the reference period under the same irrigation treatments.

Taking the average of the irrigation treatments, *WP* values increased above the reference period values by 1.0–4.0% and 6.5–8.0% for 2030s and 2050s under RCP4.5, respectively. Moreover, under RCP8.5, *WP* values increased above the reference period values by 4.0–6.2% and 3.8–7.0% for 2030s and 2050s, respectively. This pattern could be attributed to the slight increase in the tomato yield coupled with the decrease in ET_c.

The combination between irrigation scheduling and deficit irrigation level of 80% could improve the *WP* near to the optimal level (about 2.2 kg·m^{-3}), especially with deficit level of 80 applied at initial and maturity crop stages (TS80), which provide water saving of up to 16%.

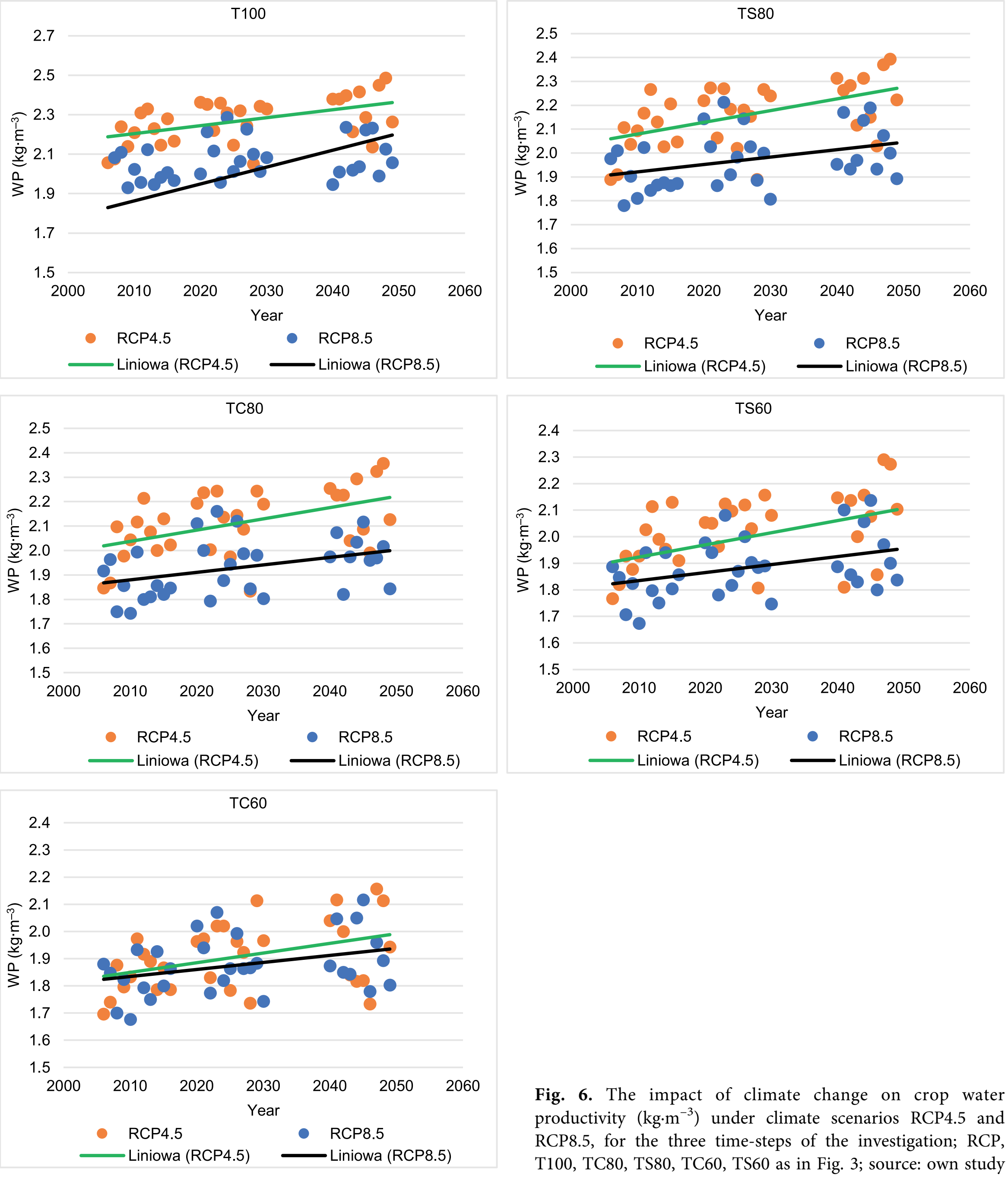


Fig. 6. The impact of climate change on crop water productivity (kg·m^{-3}) under climate scenarios RCP4.5 and RCP8.5, for the three time-steps of the investigation; RCP, T100, TC80, TS80, TC60, TS60 as in Fig. 3; source: own study

CONCLUSIONS

The present work evaluates the impacts of future climate on tomato crop. The results of this work can be used as evidence to identify the most appropriate water application practices to reduce climate risks. Moreover, these results could assist decision-making for water allocation and water policies in the agriculture sector. Irrigation treatments TC80 and TS80 showed the highest patterns of tomato yield increase under climate change scenarios. The predicted *WP* values showed a general increasing pattern under all climate change scenarios for the same irrigation treatment. The combination of irrigation scheduling and deficit irrigation level of 80% shows a good potential to improve *WP* under the investigated climate change scenarios, especially when the solution is applied at the initial and maturity crop stages.

In conclusion, evaluated deficit irrigation practices and schemes could present some good possibilities for tomato crop production under water scarcity and climate change, ensuring valuable water saving and improving *WP*. AquaCrop, as a crop model, can help to efficiently evaluate different deficit irrigation practices, considering that the quality of the simulation performance is highly related to the quality of the data used in the local calibration process, and the assumptions and inputs of the simulations. Further studies are recommended to investigate several managements of on-farm options to improve *WP* of important crops, using the AquaCrop model with high-quality field data.

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