Climate change effects on processing tomato in southern Italy: a simulation study

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Abstract

In the recent decades, processing tomato (*Solanum lycopersicum* L.) yields have increased due to the introduction of new genotypes with improved morphological, physiological and resistance traits. However, in southern Europe, yield increment was not as high as that attributed to resistance to biotic stresses such as late blight and viruses, that represent the major threats for this fruiting vegetable crop. Such effect is likely due to climate change and future projections for the Mediterranean basin indicating an increase of warm and dry periods. Crop growth and development are very sensitive to climate change and variability. In this study, we aimed to understand the projected impact of climate change on processing tomato grown in the southern Italy. A generic tomato cultivar was calibrated and evaluated using data recorded in open field cropping 'Messapico' hybrid for two consecutive years. Plants were transplanted into twin rows (3.36 plants m^{-2}). Drip irrigation scheduling system was based restoring 100% of Etc when 40% of total available water was depleted. Two nitrogen (N) treatments were investigated (N-150 and N-200 kg ha^{-1}). N-150 treatment of the first trial-year, representing to the typical nitrogen supply in the investigated area, was adopted for the DSSAT v4.7 model calibration (biomass: RMSE = 1584 kg ha^{-1}, D-index = 0.93). This N rate was evaluated on the N-200 (biomass: RMSE = 1648 kg ha^{-1}, D-index = 0.91). Contrasting Global Climate Models were compared respect to the integrated 30-years of historical weather from NASA-AgMERRA data set. The climate change variability affected full flowering and harvest dates. Simulation of the soil water content and air temperature indicates, for some years, negative impacts on the optimal crop growth due to drought and nutrient stresses which negatively impacts on fruit yield. Hence, innovative agronomic and breeding strategies are advisable to overcome the negative effects of climate changes occurring in this production area of the processing tomato.

Keywords: fertilizer, irrigation, sustainability, yield, modelling

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a globally and economically important herbaceous crops and it is widely consumed, both fresh and canned products, for his positive health benefits (FAO-Stat, 2021; WPTC, 2021; Di Cesare et al., 2010). Italy is the is the first producer of processing tomato contributing by 13% of the global production (WPTC, 2021).

Recently, changes in climate patterns affected timing and amount in rainfall, trends of maximum and minimum air temperatures, that associated with extreme events, negatively impact crop sustainability, and reducing yield and quality of several crops (IPCC, 2021). For example, nitrogen and water management in processing tomato production are affected by climate changes as highlighted by recent investigations.

In processing tomato, cultivated in southern Italy, irrigation water requirements accounted to 400-600 mm (Ronga et al., 2019a, b), while 300 kg of nitrogen (N) ha^{-1} represent an optimal supply to achieve remunerative yield (Ronga et al., 2017).

Crop modelling is a useful approach to study soil-plant-atmosphere interactions and has been extensively adopted to investigate the climate change impacts on crop growth as well as

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to study innovative agronomic and genetic basis for possible adaptation strategies (Cammarano et al., 2019). However, to author's knowledge few data are reported in literature on the application of crop growth models to study the impact of climate changes on processing tomato crops grown in southwest of Italy (Ronga et al., 2015).

Therefore, this study was undertaken to increase knowledge about projected impact of climate change on the agronomic management of the processing tomato grown in a relevant area of production.

MATERIALS AND METHODS

Field experiment

The field experiment was carried out at Sele Valley (40°35'03.8"N, 14°58'48"E) (Salerno, southwestern Italy) during a two-year period (2004-2005) in a typical Haploxerepts soil (Soil Survey Staff, 2014).

The soil was well drained, and characterized by the following parameters: sand 26.8%, silt 40.8%, clay 32.4%, limestone 2.4%, pH 7.8, organic matter 1.6%, total nitrogen 1.3‰, P 55 mg kg^{-1}, and K 271 mg kg^{-1}.

The previous crop was durum wheat, and the peeled tomato cultivar 'Messapico' (Nunhems, S'Agata Bolognese (BO), Italy) was transplanted, on 5^{th} of May 2004 and on 9^{th} of May 2005, with a density of 3.36 seedlings m^{-2} into twin rows.

Regarding fertilization, the total P_2O_5 and K_2O rates were calculated according to the soil analysis and applied at ploughing time (Ronga et al., 2019a). For N fertilization, two rates were investigated (150 and 200 kg of N ha^{-1}).

Drip irrigation scheduling was based on restoring 100% of Etc when 40% of total available water was depleted (255 and 294 mm in 2004 and 2005, respectively). Weed and pest controls were done according to the cultivation protocols of the Campania Region (Italy). A single harvest was done on 9^{th} of August 2004 and on 5^{th} of August 2005 when the ripe fruits accounted for approximately 85% of the total.

A randomized complete block design was used using four replicates, each of 4.0×5.1 m.

Parameters recorded, climate data and crop simulation model

Physiological, morphological and destructive parameters were biweekly assessed on two plants per plot. Leaf, fruit (ripe and un-ripe), and total biomass dry weights were recorded, and leaf area index (LAI) was measured through an LI-3000A leaf area meter (LI–COR, Lincoln, NE, USA) on subsample of fresh leaves.

The climate data was obtained from the weather station installed in the next to the field and included daily weather data from 1984 to 2018. Solar radiation (MJ d^{-1} m^{-2}), maximum and minimum air temperatures (°C), and rainfall (mm) were recorded and used for the subsequent simulation.

The climate projections to near-future (2010-2040) were obtained by perturbing the baseline weather data and using the CMIP5 projections (Taylor et al., 2012) from 40 Global Climate Models (GCMs). To narrow down the number of GCMs the approach of Ruane and McDermid (2017) was used and four contrasting GCMs projecting different changes of rain-temperature patterns were selected. For this study, RCP 4.5 was used, where the RCPs are a greenhouse gas concentration trajectory which are consistent with the ranges of possible changes of greenhouse gas emissions. For example, the RCP 4.5 assumed that the greenhouse gas emission peaks around 2040 and then decline.

DSSAT (Decision Support System of Agrotechnology Transfer) crop model version 4.7 was used in this study.

The input data consisted in the daily weather data, soil data and agronomic management (soil water and mineral N amounts before transplanting, and inputs and timing of N fertilization and water irrigation). The model was calibrated using the treatment N-150 of the first year and evaluated on the other treatment and year.

The crop model was setup to simulate the current irrigation amount and a projected amount that was given anytime the crop was stressed based on the criteria defined above.

Data analysis

The simulated and observed values were evaluated using the root mean square error. In addition, a second index [Willmott index of agreement (D-index)] was used to evaluate the crop model respect to the observation, with values ranging between 0 (poor fit) and 1 (indicating a good fit). Finally, the relative change of yield, water and nitrogen respect to the baseline was done. The analysis and the indexes were calculated as reported by Cammarano et al. (2020). The box and whiskers plots were used to plot the relative changes and the horizontal line in the box represented the median, the box was the 25th and the 75th percentiles, the whiskers the 10th and 90th percentiles. All the figures were made using GGPLOT2 (Wickham, 2016).

RESULTS AND DISCUSSION

Our study reports a reduction of rainfall and an increase of the air temperatures, during the growing season of the processing tomato, highlighting remarkable increasing in irrigation water and N fertilization crop demand, which reducing sustainability of the cultivations.

Climate impact

The different GCMs had distinct patterns of mean air temperature and rainfall through the growing season in respect to the baseline weather data (Figure 1). The projections for the mean air temperature were between 0.8 and 2.4°C, while the total rainfalls indicated a variability of response among GCMs ranging between 4.6 and -42.6% (Figure 1). For this study 4 GCMs corresponding to contrasting temperature-rainfall interactions were selected: i) GFDL-ESM2M (GCM1); ii) INMCM4 (GCM2); iii) MIROC4H (GCM3); and iv) MRI-CGCM3 (GCM4).

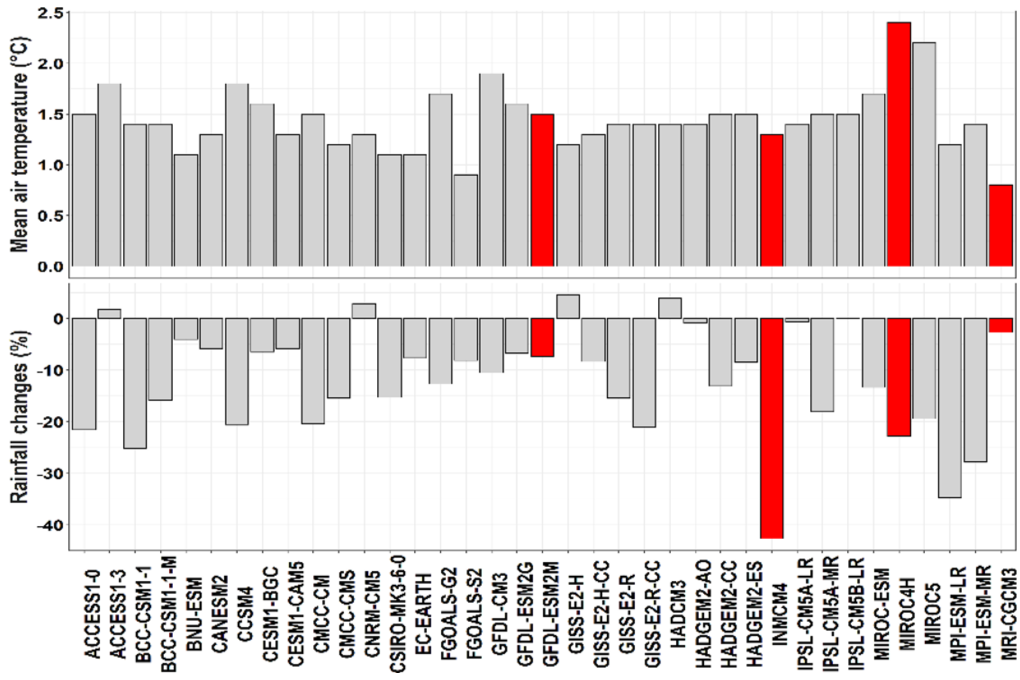

Figure 1. Relative change for the mean air temperature and growing season rainfall respect to the baseline weather for the 40 Global Climate Models from the CMIP5. The red bars indicate the four climate projections in terms of rain and temperature changes that were used in this study.

The calibration and evaluation of the DSSAT tomato was satisfactory giving low RMSE and higher agreement between simulation and observations (D-index > 0.6). Thus, the model was applied to simulate the impact of projected climate on different physiological and agronomic aspects of the tomato crop (Table 1).

Table 1. Statistics of the calibration and evaluation in terms of root mean square error (RMSE) and index of agreement (D-index). A good agreement between simulations and observation is when the D-index is >0.6.

Variable	Type	Unit	RMSE[b]	D-index
LAI[a]	Calibration	-	0.95	0.69
Leaf weight	Calibration	kg DM ha^{-1}	449	0.67
Aboveground biomass	Calibration	kg DM ha^{-1}	1584	0.93
Yield	Calibration	kg DM ha^{-1}	1039	0.95
LAI	Evaluation	-	0.68	0.85
Leaf weight	Evaluation	kg DM ha^{-1}	415	0.72
Aboveground biomass	Evaluation	kg DM ha^{-1}	1648	0.91
Yield	Evaluation	kg DM ha^{-1}	1008	0.94

[a]Leaf area index; [b]Root mean square error; DM = dry matter.

The DSSAT tomato was then run for each of the GCM to predict the impact of yield changes respect to the baseline (Figure 2). Overall, only one GCM predict decreasing in yield (GCM2, which projected a higher temperature increase), suggesting that the reduction in fruit production, provided water resources are available, is negatively impacted by the increase in air temperature. Increasing in air temperature will affect the tomato production by accelerating developmental rates, thus reducing the useful time for plant photosynthesis and thus decreasing biomass accumulation and the yield process. These results are in accordance with finding reported by Ventrella et al. (2012).

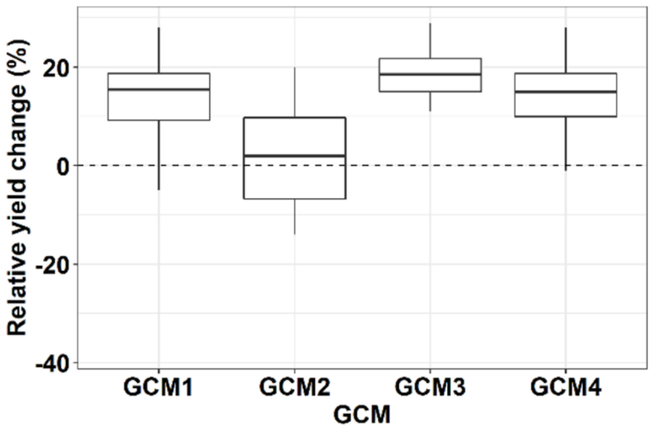

Figure 2. Simulated relative yield change (respect to the baseline) for the 4 different GCMs using the optimized agronomic management for each of the projected climate patterns.

In the context of climate changes, the positive impacts of CO_2 on fruit yield (as shown for some GCMs in Figure 2) can be offset by increasing in air temperature (Figure 3).

The projected yield changes vary, on average, between -5 to +17% for the simulations with the baseline irrigation, and between +1 and +20% adopting the optimized irrigation scheduling (Figure 2). This suggest that it might be possible to keep acceptable levels of yield.

The baseline irrigation accounts to 425 mm and the baseline fertilization is 290 kg N ha^{-1}. Based on the projected changes from the 4 GCMs, to keep up an optimal fruit yield additional inputs of water (90- 110 mm) and N (20-30 kg N ha^{-1}) are request. Findings of the simulation study show that for the GCM2 climate patterns the highest amount of water and N are required, while GCM4 has the lowest requirements.

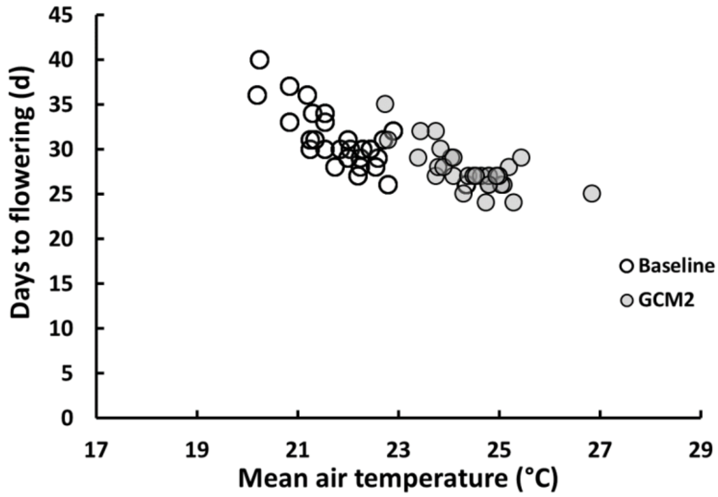

Figure 3. Relationship between mean air temperature and days to flowering for the baseline simulations and the ones from GCM2.

Negative impacts of increased temperature and reduced rainfalls, as predicted by the majority of the GCMs here investigated, could be mitigate adopting innovative practices or products. Among the latter, biostimulants deserve to be mentioned, since they are able to help the plants to overcome the thermal and drought tresses, thus ensuring the optimal physiological processes under adverse grown conditions (Goñi et al., 2018; Hernández et al., 2018).

CONCLUSIONS

Our findings highlight in perspective how processing tomato yields might be affected by the projected changes in climate patterns. In particular, a shortening of growing cycle and a decreasing in fruit production are expected due to rainfall reductions and increasing in air temperature occurring in the growing season. Based on projected climate changes higher supplies of irrigation water and nitrogen will be necessary to preserve satisfactory tomato yields. This scenario might be not sustainable; hence, researchers are called to investigate innovative agronomic approaches, as well as innovative genotypes able to overcome drouth and warm stresses, to ensuring profitable production under southern Europe growing conditions.

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