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SIMULATION OF WATER CONSUMPTION, GROWTH AND YIELD OF TOMATOES USING THE AQUACROP MODEL

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ABSTRACT

Water for irrigation will undoubtedly be reduced as a result of climate change, disrupted rainfall patterns, and water scarcity, putting crop production in jeopardy. As a result, in order to maintain high agricultural production and meet food demand, new technology must be developed, and the feasibility of cultivating essential vegetable crops without irrigation must be investigated. The goal of this research is to estimate tomato water consumption, growth, and yield using the Aquacrop model. The experiment was put up on carbonate chernozem soil near Stara Pazova (40 kilometers north of Belgrade). There were two treatments: soil treated with organic fertilizer Fertigkompost (OF) and soil treated with no organic fertilizer (K). Both treatments were fed by rain. The obtained results show that the AquaCrop model accurately predicts tomato yields with variations of 7.1 percent and 11.8 percent, respectively, when compared to observed yields on OF and K treatments. For the OF and K treatments, statistical indices of correlation coefficients (r) of 0.97 and 0.95, respectively, root mean square error (RMSE) of 10.1 percent, 9.0 percent, and Willmott index of agreement (d) of 0.98, 0.97, confirm excellent assessment of tomato growth. Water consumption is likewise fairly predicted by the model, with r= 0.72 and 0.63, RMSE = 38.1 and 32.5 mm, and d= 0.83 and 0.76 for the OF and K treatments, respectively. With high confidence, the model may be used to estimate tomato production in a variety of growth circumstances.

Key words: irrigation, water consumption, tomato.

INTRODUCTION

In the last couple of decades, we have witnessed climate changes, which have a negative impact on plant production. The changes are reflected in the erratic precipitation pattern and amount, increased annual temperature, heat waves, frequent occurrence of storms and hail, increased number of dry days increased number of tropical days, etc. (Vuković et al., 2018). Forzieri et al., (2016) points out that the area of Southeast Europe, and especially the area of Serbia, will be much more susceptible to the impact of climate change compared to other European countries. In changed climatic conditions, it is necessary to make strategic plans and implement adaptation measures in agriculture, primarily in crop production, which is the most vulnerable. Given that analyzes have shown that drought has the greatest impact on the success of plant production (Stričević et al., 2020), in the case of water scarsity for irrigation it is necessary to strategically plan which crops to irrigate and which can be grown without irrigation. The application of models for the simulation of plant growth, water needs of crops and water management will be increasingly important in the future for crop growth monitoring, forecasting the yield reduction in drought occurence and to allocate water to ensure profitable crop production.

Many models have been developed to simulate plant growth or water management in agriculture such as DSSAT, Cropsys, EPIC, APEX, WOFOS, SWAP, AquaCrop, etc. (Boogaard et al., 1998; Raes et al., 2009; Hoogenboom et al., 2019, Wang et al., 2011; Kroes et al., 2017). They can all be used in practice, with varying degrees of effectiveness. The models can be categorized into three types: energy-driven, carbon-driven, and water-driven. (Todorović et al., 2009). Studies have shown that this model accurately simulates the yields and water requirements of plants, including both tomatoes and other crops grown worldwide (Stričević et al., 2011; Katerji et al., 2013; Linker et al., 2016, Ćosić et al., 2017; Cheng et al., 2022). Given that water would frequently be a growth-limiting element in the future, the water-driven model AquaCrop 6.1 was selected for this study's simulation of tomato growth, water consumption, and yield under no-irrigation conditions.

MATERIALS AND METHODS

The experiment was put up on carbonate chernozem soil near Stara Pazova (40 kilometers north of Belgrade). Soil characteristic of experimental site is described in details in Djurović et et al., 2016). Climate input data (maximal and minimal air temperature, maximal and minimal relative humidity, net radiation, wind velocity and precipitation) were measured on the field by micrometeorological station on a daily basis, and data are validated with nearest meteorological station of the first order in Surčin on the distance of 20 km. Daily values of minimal and maximal air temperature and precipitation sum during the experiment was shown in Fig. 1.

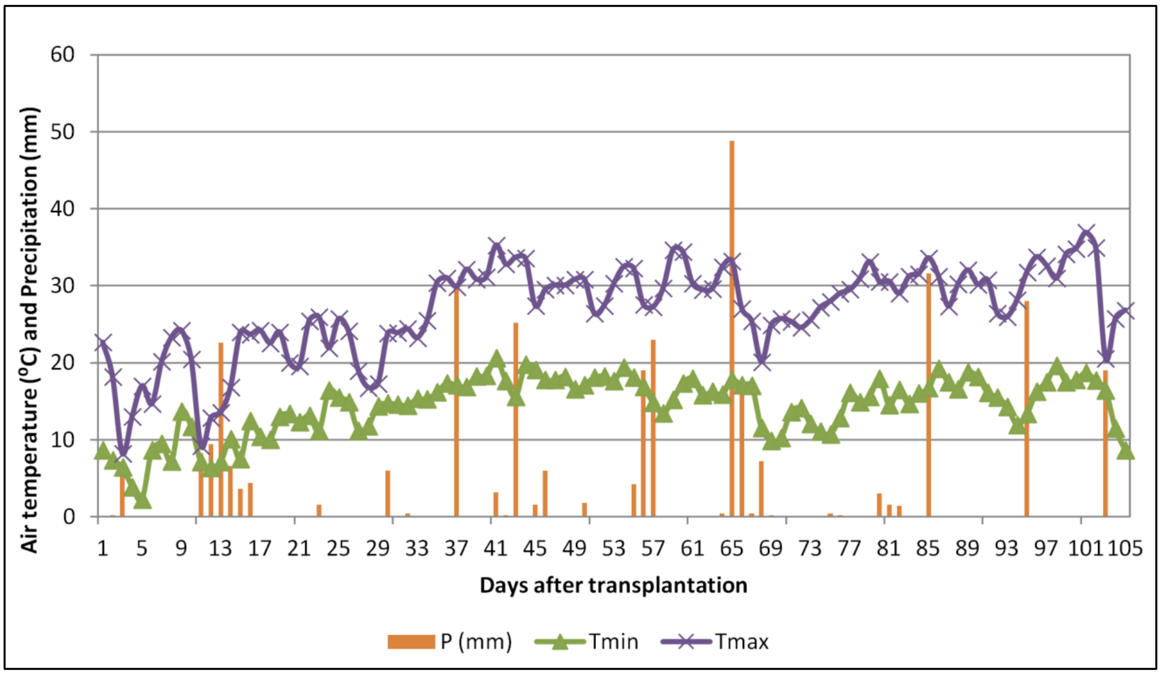

Figure 1. Daily value of minimal and maximal air temperature and precipitation sum

Tomato (*Solanum lycopersicum* L.) variety Chibli (Syngenta) is a mid-early hybrid with determinate growth and lush plant cover. After 70-80 days from planting, the first fruits ripen. Planting was carried out on May 4 and 5, 2019, at a distance of 50 cm between plants and 40 cm between rows, which achieves a density of 30,000 plants per hectare. Soil was fertilized before tomato transplantation with 600 kgha^{-1} of NPK with formulation 15:15:15 based on chemical analysis of soil. Then, two treatments were formed: soil treated with additional 300 kg of organic fertilizer Fertigkompost (OF) and soil treated with no organic fertilizer (K). Chemical composition of Fertigkompost are: 49.7% of dry matter, 1.65 % NH_4NO_3, 1.02 mgl-1 P_2O_5, 2.76 mgl^{-1} K2O, 0.71% MgO, 2.78% CaO, 57.6 % of organic matter content, 32 $mgkg^{-1}$ of Cu and 133 $mgkg^{-1}$ Zn and pH was 6.9. Both treatments were rainfed and grown under plastic mulch.

AquaCrop model v. 6.1 was used in this research. Climate files were formed from above mentioned weather station. Model default crop file for tomato based on calendar date was used. Fertility option was i) non limiting for the OF treatment and ii) for the K was near optimal. Field file with plastic mulch was chosen. Soil input data was formed on measured physical properties. Field file was based on measured data of canopy cover and soil water content. Soil moisture was monitored by the standard gravimetric method, every seven to ten days. The soil was drilled and sampled by layer, at 0-20, 20-40, and 40-60 cm. The canopy cover was measured using a $1m^2$ wooden frame placed around the plants and photos were taken with a digital camera. The photos were later analyzed by software Python in a JupyterLab environment, developed for this particular purpose (available on demand).

Five common statistical methods were used to analyze and compare yield data derived from the field experiments and simulations: correlation coefficient ***r***, root mean square error (RMSE), normalized root mean square error (NRMSE), Nash-Sutcliffe index of efficiency (EF) and Willmott index of agreement (***d***).

RESULTS AND DISCUSSION

Observed and simulated results of dry biomass and tomato yield are shown in Table 1 as well as percent of deviation. Model very closely simulated biomass of fully fertilized tomato with organic fertilizer (deviation is only 2.5%), and slightly lower to control treatment K. Namely, model is calibrated for non limiting fertility, and therefore deviation is less in OF treatment (7,1 %) than in K treatment using option near optimal fertility. In general, model perform excellent estimation of tomato yield and biomass in both treatments. The obtained results were comparable to those obtained in Sought Italy on tomato grown in water stressed and non stressed condition. Namely, Katerji et al., (2013) obtained higher deviation of yield and biomass (from 4.2 % .up to 16.7% in non water stress condition and mild stressed). Battiliani et al., (2014) also stated that AquaCrop model adequately simulated processing tomato yield grown in valley of the river Po as well as Takács et al., (2021) in Hungary. Darko et al., (2016) obtained similar results of simulating yield of processing tomato grown in tropical humid coastal savanna zone of the Central Region of Ghana, Arumugagounde et al., (2022) in Canada.

Table 1. Observed and simulated biomass and yield of tomato

Treatment	Observed	Simulated	Deviation (%)	Treatment	Observed	Simulated	Deviation (%)
	Biomass				Yield		
K	14.06	16.47	13.6	K	9.15	10.34	-11.8
OF	16.69	16.47	-2.5	OF	11.01	10.34	7.1

Observed values of crop cover and simulation results during the growing season of tomato for K and OF treatment are shown in the Fig 2. Even though model was set up for transplantation with initial crop cover of 0.167 % and six recovery days, obtained simulation results show much lower value than it was observed. Lately, during intensive growth and especially during full development stage, model simulates very well crop cover in both K and OF treatment. It is confirmed by high value of ***r, EF*** and ***d*** statistical indices (Tab. 2) almost approaching the value of 1 as well as data shown in Fig 4. Rather high value of NRMSE 16.7% and 21.8 % are the consequences of underestimation during initial period. Slightly better estimation was obtained on OF treatment than on K one (Tab. 2), according to the statistical indices. The obtained data are comparable with those obtained by Katerji et al., (2013), obtaining slightly better results (NRMSE 11%), probably due to better results after transplantation. Some researchers stated that AquaCrop very good perform canopy cover in comparison with satellite canopy cover (Dalla Marta et al., 2019; Corbari et al., 2021;).

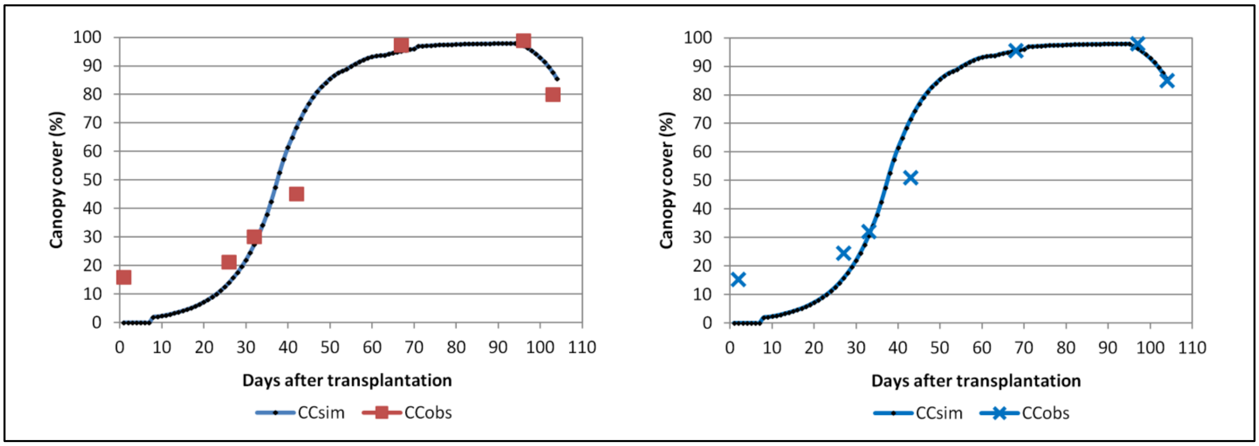

Figure 2. Results of observed and simulation crop cover of K treatment (left) and OF treatment (right)

AquaCrop model simulate soil water content under mulch fairly, sometimes overestimating but more often underestimating the observed values (fig. 3), but follow the clear trend of drying and wetting cycle due to transpiration and precipitation pattern. Model better perform soil water content on OF than on control K treatment, according to the statistical indices, though, the difference is not significant. For example NRMSE are 12.6% and 15.5 % for OF and K treatment, respectively. Similar differences were obtained for other statistical indices as well (Tab. 2). Model clearly predicts wetting and drying cycle as confirmed by Katerji et al., (2013), Corbari et al., (2021). That AquaCrop model overestimated SWC was also obtained on cherry tomato grown in greenhouse under plastic mulch (Cheng et al., 2022). NRMSE was higher in the treatments when applied less amount of nitrogen (from 6.4% up to 27.8%). which is consistent with our findings, the more organic fertilizers the better results of simulation.

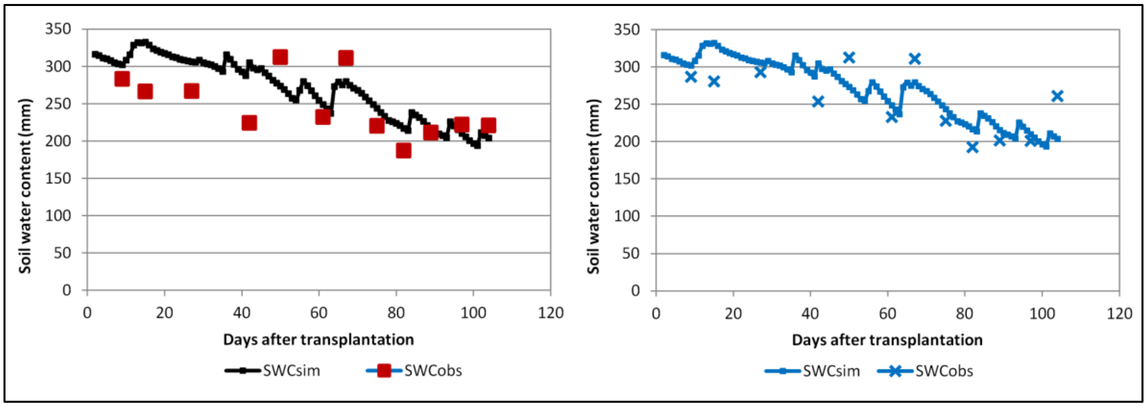

Figure 3. Observed and simulation results of soil water content of K treatment (left) and OF treatment (right)

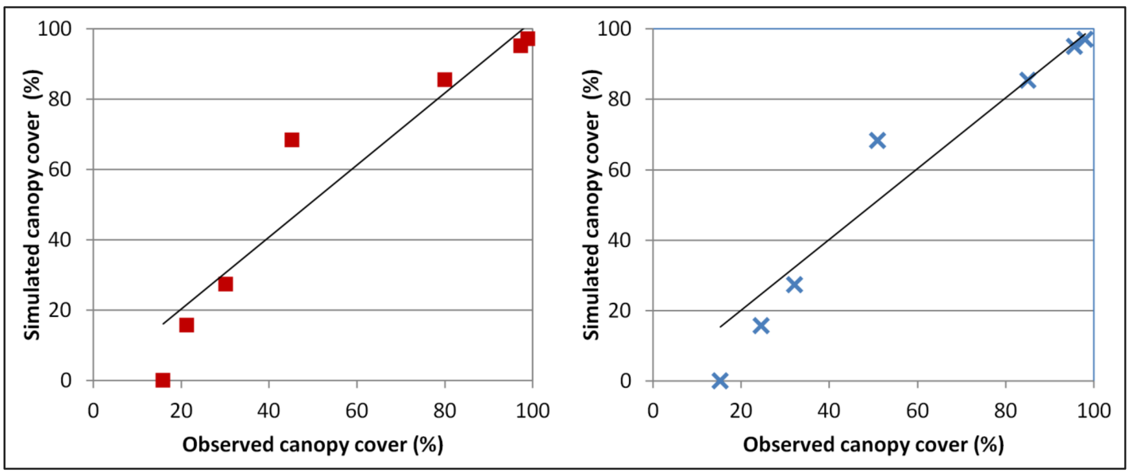

Figure 4. Relationship between observed and simulated canopy cover K treatment (left) and OF treatment (right)

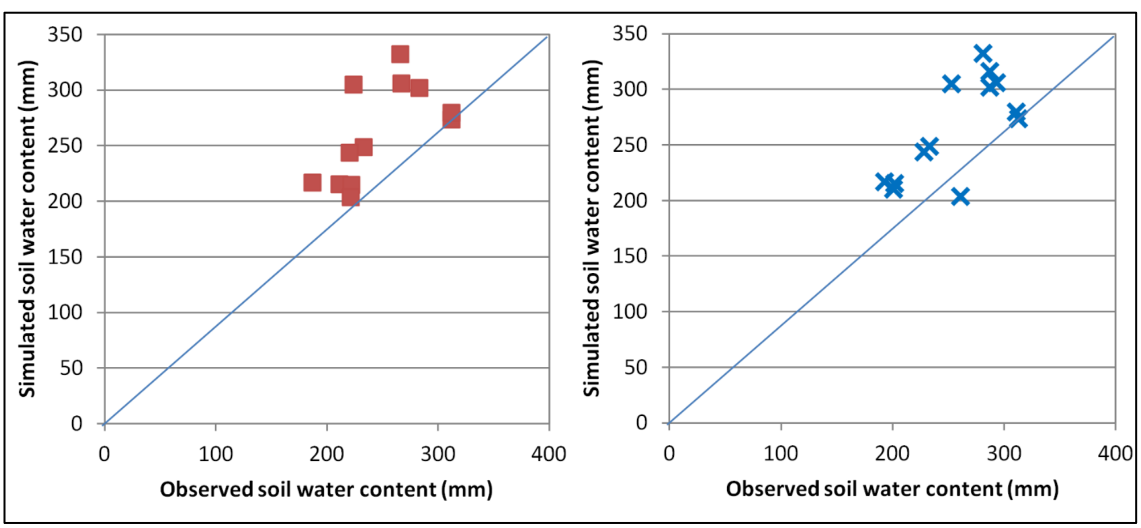

Fig 5. Relationship between observed and simulated soil water content K treatment (left) and OF treatment (right)

Statistical indices shown in Table 2 indicate that model accurately predict canopy cover according to the r, EF and d indices and good estimate SWC according to the NRMSE and d indices. Further correction and calibration could improve model performance for SWC simulation (Corbari et al., 2021).

Table 2. Statistical indices of crop cover (CC) and soil water content (SWC)

	CC (%)	SWC (mm)	CC (%)	SWC (mm)
Sstatistical indices	K		OF	
r	0.95	0.63	0.97	0.72
RMSE	12	38.1	9.5	32.5
NRMSE	21.8	15.5	16.7	12.6
EF	0.87	0.04	0.91	0.36
d	0.97	0.76	0.98	0.83

Tomato had enough water to achieve high yield. On both treatments transpiration rate was 94 % or 333 mm, 74 mm was spent on evaporation. Total water consumption was 407 mm, and water productivity was 2.51 kgm^{-3}. Favorable rainfall distribution and amount (342 mm) together with water stored in the soil enable achievement of high yield.

CONCLUSION

The aim of this research was to test whether model could be used for the simulation of plant growth, water needs of tomato in rainfed condition, because it will be increasingly important in the future in the case of water scarcity for irrigation it is necessary to strategically plan which crops to irrigate and which can be grown without irrigation. This research find out that the AquaCrop model may be used to estimate tomato growth, yield production in a variety of growth circumstances with high confidence. Model is not very sensitive to subtle changes in the soil fertility, and fine tuning calibration is needed. Water consumption reflected via soil moisture is likewise fairly predicted by the model. Further correction and calibration could improve model performance for SWC prediction when crop is grown under plastic mulch.

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