Arab Universities Journal of Agricultural Sciences
(2022) 30 (2) 195-208
Website: http://ajs.journals.ekb.eg

AquaCrop Model Enhancement Under Soil Mulching Practices Considering Soil Temperature Effect

Sobhy MM Abdelmonem*, Yasser A Ezzat, Ahmed A Abo El-Hassan, Abdel-Ghany E Mohamed
Agricultural Engineering Dept, Fac of Agric, Ain Shams Univ, P.O. Box 68, Hadayek Shoubra 11241, Cairo, Egypt

*Corresponding author: sobhy_mahmoud@agr.asu.edu.eg

https://doi.org/10.21608/AJS.2022.129014.1473

Received 24 March 2022; Accepted 18 July 2022

Keywords:

AquaCrop modification, AquaCrop-OS, Soil temperature, Soil mulching simulation, Crop growth simulation, Irrigation regimes

Abstract: Soil temperature under mulching conditions has a significant impact on crop development, growth rate and other parameters. However, it is not included in the AquaCrop model. Thus, this study aims to improve the AquaCrop model performance for better simulation of soil mulches by considering the heat changing under mulch materials. The proposed modification is conducted through AquaCrop-Open Source software to identify the differences between the temperatures under the mulched soil and air temperatures. It will also help to describe them as additional heat units in specific growth stages. The field data used to evaluate the proposed model has previously been used to calibrate and validate the AquaCrop model in simulating melon growth under different irrigation treatments and soil mulching practices. The results show that the proposed model performs better than the original model in simulating mulched melon under different irrigation regimes. The root mean square error of biomass values was reduced under the modified model by 40%-75% under different irrigation treatments. Additionally, the coefficient of determination (R^2) of the modified model slightly increased from the original one. Thus, the proposed model provides a more reliable and robust model.

1 Introduction

Crop growth models simulate the development and growth of agricultural systems which are usually complex interconnecting the dynamics of the soil-plant-atmosphere continuum with agronomic management practices including water and nutrient inputs and other on-farm interventions. In particular, mulching is essential when the cultivation refers to horticultural crops and occurs in arid and semi-arid regions. Soil mulching has been widely used in the Mediterranean as a water-saving practice along with deficit irrigation (Evans and Sadler 2008, Chartzoulakis and Bertaki 2015). The use of mulches has many benefits, such as the reduction of soil evaporation, shortening of the growing season, an increase in biomass and yield, and protection of plants against frost during the initial growing stages (Shrivastava et al 1994, Ibarra et al 2001, Ramakrishna et al 2006, Chukalla et al 2015). However, there are many types of mulching materials and unusual ways of their use on the ground. Therefore, the modeling of mulching's impact on crop development and growth seems to be a challenging task.

Due to the importance of mulching practices, many crop growth models simulate its impact on soil water balance and plant growth and development. The crop growth model Simulateur mul TIdiciplinaire pour les Cultures Standard (STICS) has an empirical module to simulate the effect of surface residues on soil water balance. The model simulates the mulching effect on radiation interception by modifying the dynamics of soil evaporation, rainfall interception and subsequent surface water runoff reduction. The mulching module has been tested by Scopel et al (2004). The decision support system for agrotechnology transfer (DSSAT) model was modified to simulate the mulch of crop residue application impact on soil water content, nutrients dynamic, crop growth and yield. A maize experiment has been conducted to test the model for residue management practices (Corbeels et al 2016). The mulching effect on soil water balance can be simulated using the DSSAT model and positively reflected on the simulated grains due to evaporation reduction and higher root growth. The plastic film mulching was simulated and assessed using SUCROS-Cotton model as one of the management practices applied for cotton production. The plastic film effect was considered for crop development by calculating the difference in temperature at 5 cm depth soil without and with mulching, their relationship with air temperature, and how they impact the crop growth developments. A cotton experiment was conducted to calibrate and validate the model. The results showed that the growth development was faster under plastic mulching, whereas the physiological stages were shorter. There was very good agreement between the observed and simulated data (Zhang et al 2008). In the same context, Malik et al (2017) tested the growth of sugar beet under straw mulch, black film mulch and non-mulch conditions. They found that the quickest growth in different stages was observed for black film mulch fields due to soil temperature differences under various mulching treatments. In a related context, Guo et al (2018) emphasized in a foxtail millet experiment that the length of different crop growth stages under plastic mulch was shorter than the non-mulch treatments. The AquaCrop model, proposed by the Food and Agriculture Organization (FAO) in 2009 (Raes et al 2009, Steduto et al 2009) considered different mulching management practices (plastic and organic mulching) and their effects on the soil water balance. AquaCrop considered the evaporation reduction depends on mulching material and the percentage of the mulched area (Raes et al 2009). Several studies have reported the results of crop growth simulations using the AquaCrop model under mulching by focusing only on the final biomass and yield (Saad et al 2014, Salunkhe et al 2015). In south Italy, melon growth was simulated using the AquaCrop model under no soil mulching and black plastic mulching conditions. The study reported that the model accurately simulated the mulching effect on soil evaporation and crop transpiration and their reflection on the final biomass. However, the simulation of the mulching impact on growth and development during the season was less satisfactory than the non-mulching treatments (Mahmoud 2016). This is consistent with the experiment conducted by Malik et al (2017), and Guo et al (2018), where they reported that there was an underestimation in AquaCrop performance in simulating canopy cover (CC) of the mulched treatments with a black film under full and deficit irrigation treatments. This was due to the non-consideration of temperature variance under different mulch materials which caused faster growth under plastic mulch. Yang et al (2017) performed a calibration and validation for the AquaCrop model by combining the model with the recalculation of the air temperature of straw-mulched maize. The mean soil temperature under straw mulching at a 5 cm depth was 2.8ºC lower than that without mulching before the maize tasseling stage because of the straw mulching effect. The results of this study emphasize that the calibrated AquaCrop model considering the temperature effect of straw mulch can precisely simulate crop water productivity under the organic mulching conditions in sandy and semi-arid regions.

Therefore, the overall objective is to develop a modification in soil mulching simulation of the AquaCrop model by considering soil temperature under mulch and its impact on biomass growth and development during the season. The AquaCrop model is modified to improve the simulation performance of mulched soil because it is a freely available and open-source crop growth model based on a water-driven engine especially convenient for water-scarce regions where the application of mulching is common.

2 Materials and Methods

2.1 AquaCrop Model Descriptions

The AquaCrop model was proposed by FAO (Raes et al 2009, Steduto et al 2009). The core of the AquaCrop growth engine is the ratio between the above-ground biomass and crop transpiration normalized for reference evapotranspiration, representing the water productivity function. Therefore, above-ground biomass (B) can be expressed as follows:

$$B = WP * \Sigma T_r / ET_o \quad (1)$$

where T_r is the amount of water transpired from the cultivated crop in millimeters, ET_o is the reference evapotranspiration in millimeters, WP is the water productivity parameter (The biomass weight in grams per square meter for the amount of water excreted from the plant during the growth period). The model estimates the final yield (Y) from the biomass (B) and dynamic harvest index function (HI) as follows:

$$Y = HI * B \quad (2)$$

The separation avoids the confounding effect of water stress on (B), (HI), and yield because their responses differ fundamentally different. Thus, we can observe that both equations express a water-driven growth engine in terms of crop model design which is why the AquaCrop model is water-driven.

AquaCrop differs between the amount of water that evaporates from soil not covered by plants and water that transpires from the crop according to the size of the green CC (GCC) which was detailed by Raes et al (2009). The approach introduced by Ritchie (1972) is used in AquaCrop for evaporation process simulations from the soil. Soil evaporation simulation in the AquaCrop model considered the soil mulching effect for a mulched soil by decreasing the evaporation through the mulching percentage. Moreover, mulching material types were considered using a factor expressing the evaporation reduction under different materials. The value of this factor ranges from zero under no mulching conditions (evaporation occurring without limitation) to one under plastic mulching (totally preventing the evaporation). The percentage of mulched soil was also considered as presented in the following equation:

$$E_{x,adj} = E_x \left(1 - F_m \frac{Percent\ full\ mulched}{100}\right) \quad (3)$$

where $E_{x,\,adj}$ is the adjusted evaporation rate due to the soil mulching; E_x is evaporation rate; F_m is the adjustment factor for the soil mulching effect on water evaporated from soil, ranging from 0.5 for organic mulch (such as crop residues and straws) to 1.0 for plastic mulch (Allen et al 1998). The heat accumulation under the mulches and its impact on crop growth was not considered in the AquaCrop model.

AquaCrop uses two approaches to crop phenology development. The first is a calendar day which specifies the number of growing season days for any simulation condition even under different pedo-climatic conditions. The second is growing degree day (GDD), which has more flexibility to temperature changes because it uses thermal units to express the development.

2.2 AquaCrop-Open Source (OS)

An open-source version of the AquaCrop model (AquaCrop-OS) was proposed by Foster et al (2017). The code of the AquaCrop-OS model is freely available for versions 5 and 6, which are the most updated version. One of the most important features of AquaCrop-OS is to run and evaluate the model under different scenarios and management practices. The modification was performed on version 6 of the open-source model and coded using MATLAB software.

2.3 AquaCrop-OS Model Modification Under Soil Mulching Condition

The AquaCrop-OS model was updated and modified under the soil mulching practices as shown in **Fig 1** by adding two additional parameters (soil temperature under mulching and without mulching), which were inserted into climatic parameters to calculate the difference between the temperature above the soil under mulches and the air temperature. The temperature increment (ΔT) above the soil underneath mulch materials is calculated according to Zhang et al (2008) as follows:

$$\Delta T = c\left(T_{sf} - T_s\right)\frac{T - T_b}{T_s - T_b} \quad (4)$$

where: T_s indicates the temperature at a soil depth of 5 cm without mulch; T_{sf} indicates temperature at a soil depth of 5 cm with plastic mulch; T_b indicates the crop base temperature of growth and development; C is a parameter indicating the increase in soil temperature caused by an increase in air temperature by 1°C. From emergence stage to recovering stage, C is equal to 0.51 from recovering to the flowering stage, C is equal to 0.22. After the flowering, the mulch has no effect because the crop will cover and shade heavily the mulch material so that C is zero after the flowering stage. T_s and T_{sf} values can be inserted in the modified model as inputs; however, if not measured, they could be calculated from linear regression with air temperature (T) according to Zhang et al (2008) as follows:

$$T_s = 0.89 + 1.017T;\ R^2 = 0.975 \quad (5)$$

$$T_{sf} = 7.5725 + 0.8303T;\ R^2 = 0.805 \quad (6)$$

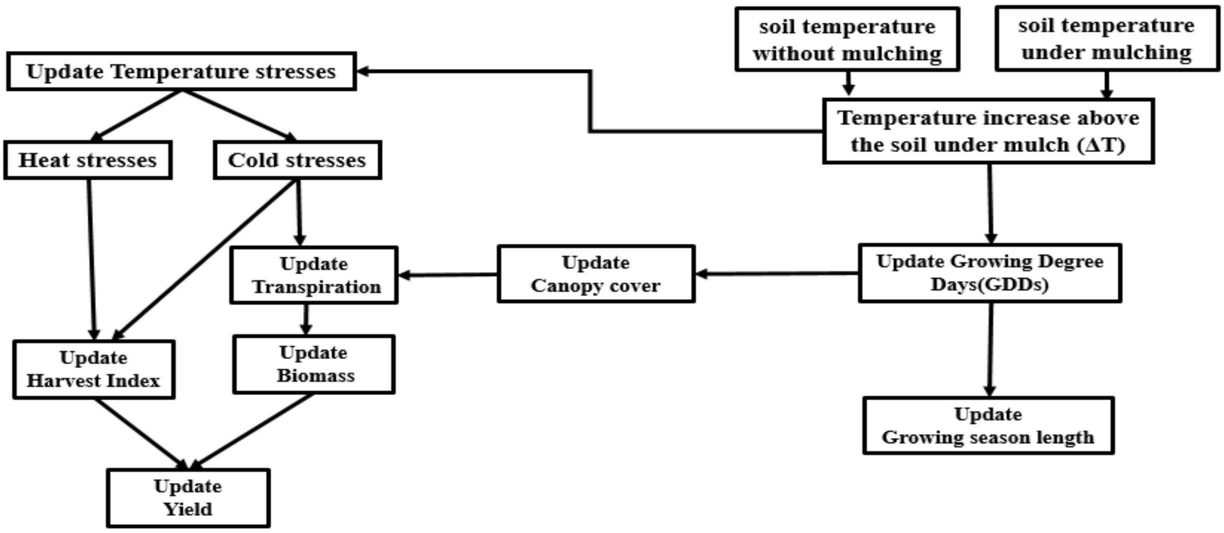

Fig 1. Schematic of the modified AquaCrop for soil temperature under mulching

The model modification makes the plants feel air temperature plus the value of ΔT under soil mulches. Thus, daily GDDs will be updated and reflected on the length of the season.
GDDs are calculated in the original model as follows:

$$GDD = T_{avg} - T_{base} \qquad (7)$$

The base temperature (T_{base}) is the lower temperature limit, which, the plant stops growing if the temperature. T_{avg} is the average temperature of the air. The GDD approach is used to calculate the heat units required for the plant to move from one stage to another and link it with the time taken through the daily temperature data that the plant is exposed which is expressed in GDD (ºCday). Therefore, GDD under the mulching effect is modified and described as follows:

$$GDD = T_{avg} - T_{base} + \Delta T \qquad (8)$$

Crop growth and development rate will also be changed because it is expressed in the model by CC which is a function in the time predicted by GDDs.

The updated GDD under mulching practices reflects on the crop growth and development which is expressed in the AquaCrop model by (CC) development. Thus, modifying the development rate and phenological stage length under soil mulching.

In the AquaCrop model, crop transpiration correlates significantly with GCC. Therefore, transpiration rate and biomass growth differ under soil mulching practices due to the evaporation reduction and temperature change under the mulch material. Thus, the irrigation scheduling generated by the model under the modified mulching simulation differs from the original one.

Furthermore, cold and heat stress simulations were modified under soil mulching practices. The minimum and maximum temperatures that the plants feel in the case of mulch existence are modified and described as follows:

$$T_{max,mulch} = T_{max} + \Delta T \qquad (9)$$

$$T_{min,mulch} = T_{min} + \Delta T \qquad (10)$$

where T_{max} and T_{min} are the maximum and minimum air temperatures, respectively. $T_{max,\ mulch}$ and $T_{min,\ mulch}$ are the maximum and minimum temperatures that the plants feel under the mulch material. Thus, temperature stresses are modified in the case of simulating the soil mulch practices. Transpiration, harvest index, biomass, and yield will be impacted due to the change in temperature stresses.

2.4 Experimental Data Used to Assess the Modified Model

2.4.1 Site

Data used in this work for assessment were collected from an experimental site in Southern Italy located at the Mediterranean Agronomic Institute (IAMB) in Valenzano (Province of Bari) (Mahmoud 2016) with a latitude of 41°03' N, the longitude of 16°51' E, and altitude of 72 m above sea level. At this site, the experiment was conducted during the summer season of 2016 from May 23 to August 17. The site is characterized by a typically Mediterranean climate with hot and dry summers and cold and rainy winters.

2.4.2 Crop

Melon (Cucumis melo L.) cv. Emerson F1 was grown at the experimental site in Valenzano. The cultivation was on May 23, 2016, with a plant spacing of 2 m between the rows and 0.5 m between the plants on the same row. The harvest date was on August 17, 2016. The base temperature of the melon growth is 10ºC, and its cutoff temperature is 45ºC.

2.4.3 Soil

Soil characteristics were determined before transplant by taking soil samples and analyzing them. The soil textural class was determined using the USDA textural triangle (USDA, Soil Taxonomy), and it was silty loam.at Valenzano field. Soil-water field capacity (FC) and wilting point (WP) were 39% and 23.5%, respectively. The electrical conductivity of the extract of saturated paste of the soil (EC_e) is 0.19 dS/m, and the pH is 8.38.

2.4.4 Weather

Fig 2 shows the main weather variables measured by the agrometeorological station located near the experimental field, which are the maximum and minimum air temperature, maximum and minimum relative humidity, incoming solar radiation, wind speed, and precipitation. The reference evapotranspiration (ET_o) was obtained using the FAO Penman–Monteith approach. The average temperature was 23.4ºC. The total precipitation recorded was 111.3 mm. The average precipitation rate was 1.28 mm/day. The daily variation of ET_o was calculated using the FAO Penman–Monteith approach. The highest daily ET_o was 7.4 mm/day estimated on July 13th (52 days after planting (DAP)), while the cumulative value of ET_o during the whole growing cycle was 465.9 mm. The maximum relative humidity (RH_{max}) was about 100%, whereas the minimum relative humidity (RH_{min}) was 20.5%. Therefore, the average relative humidity (RH_{avg}) was about 60%. The incoming solar radiation oscillates between a maximum of 31.1 MJ/m²/day recorded at 37 DAP and a minimum of 8.6 MJ/m²/day at 9 DAP, with an average value of 25.7 MJ/m²/day. The average wind speed value was 1.4m/s. The highest value was 5.7 m/s on June 16th (24 DAP), while the lowest value was 0.59 m/s on June 1st (10 DAP).

2.4.5 Experiment Treatments and Measurements

The experiment carried out at the Valenzano site foresaw the comparison among three irrigation regimes (full irrigation – 100% of crop evapotranspiration (ET_c) restitution, deficit irrigation - 50% of ET_c restitution, rainfed, two cropping systems (black plastic mulching cover and without mulching arranged as a split-plot design with three replicates (18 plots). Treatments were randomly distributed.

The plastic mulch used in this study was black on its two faces with 80 cm width and 20 Microns thickness. The area covered by the black plastic mulch was only 40% of the cultivated area.

The crop physiological stages were monitored regularly and the mean dates of the duration of each stage of transplanting, flowering, fruit set, maturity, and harvest were assumed that a stage was reached when it occurred for 50% of plants. The two plant samples were collected from each plot from the beginning of the season until the harvesting. Dry-above ground biomass was conducted on the plants. Samples were collected and weighted separately (leaves, stems, and fruits) to estimate the fresh weight and dry weight (after putting them in the oven at 60°C for 48 hours. CC was estimated from the intercepted photosynthetic active radiation (IPAR). IPAR was measured under a cloudless sky using a 1-m long quantum light bar (LI-191, LiCor Inc, Lincoln, NE, USA).

The original AquaCrop model was calibrated and validated for melon growth and yield (Mahmoud 2016) under mulched and non-mulched conditions under different irrigation regimes. The same data were used to test and evaluate the modified model.

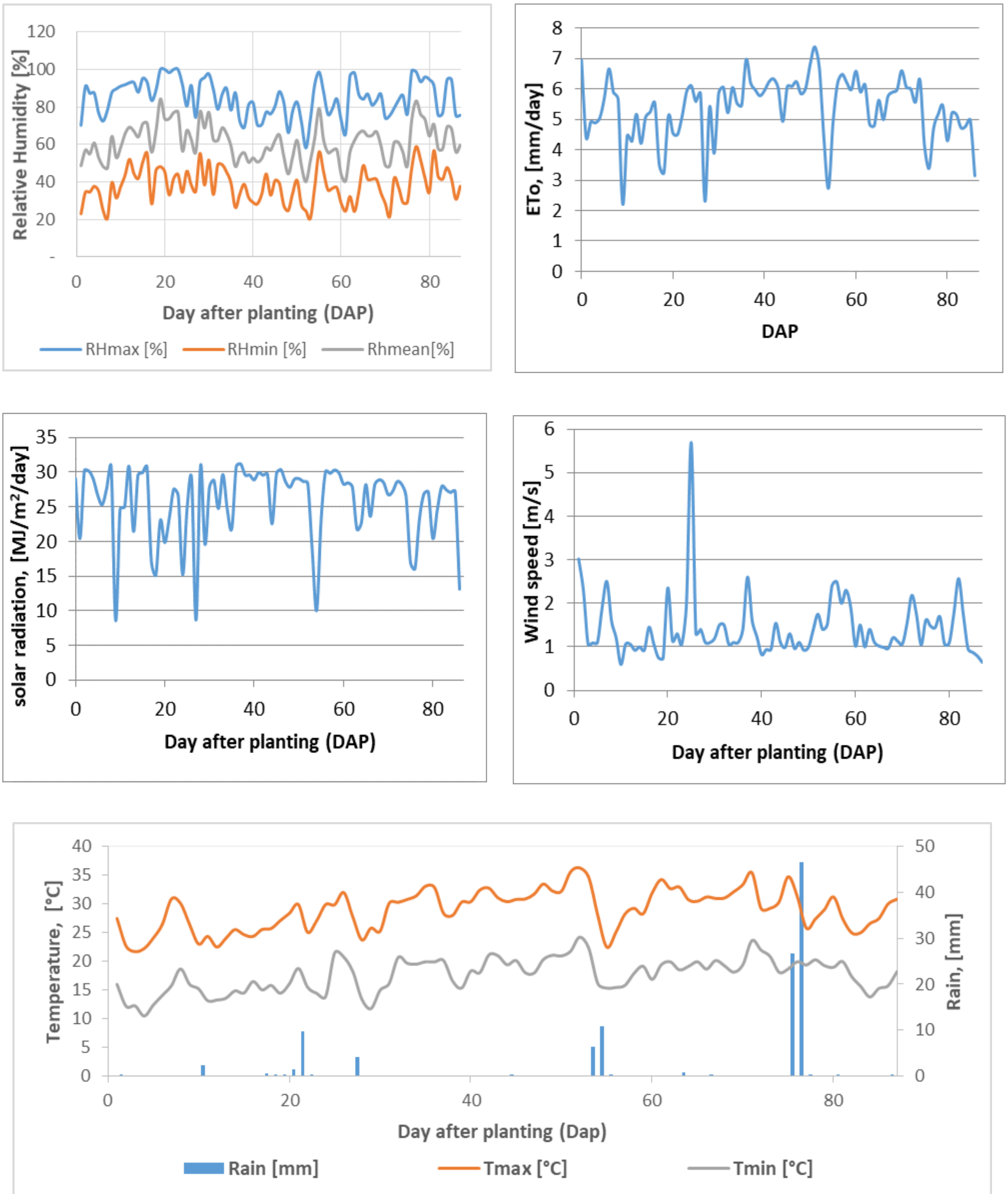

Fig 2. Maximum and minimum air temperatures (Tmax and Tmin), maximum, average, and minimum relative humidity (RHmax, RHmean and RHmin), incoming solar radiation, wind speed, rain, and reference evapotranspiration (ET_o) during growing season

2.5 Model's Performance Evaluation

To compare the model performance before and after the modification, some statistical indexes were used to evaluate the matching between the simulated and observed values. We used the following indicators in this study. Here, O_i and P_i indicate the observed and predicted data, respectively. $\bar{O}$ and $\bar{p}$ indicate the average values of O_i and P_i respectively; n indicates the number of observations.

2.5.1 Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{\Sigma(O_i - P_i)^2}{n}} \qquad (9)$$

The root mean square error (RMSE) is a common statistical indicator used for measuring the mean size of the difference between O_i and P_i values for a series of n pairs of data. It varies from zero to positive infinite; the values near zero indicate good results and performance and the higher the values expressed the weaker the program's performance. One of the main advantages of the RMSE is that it offers the average difference in the units of the predicted and observed values. However, it does not distinguish between over and underestimation (Jacovides and Kontoyiannis 1995).

2.5.2 Coefficient of Determination(R^2)

The coefficient of determination (R^2) shows the degree of co-linearity between the predicted and observed data. R^2 varies from zero to one. The values near one confirm the better agreement and fewer variations and errors. The values less than 0.5 are not acceptable.

3 Results and Discussion

3.1 Mulching Effect on Crop growth and development

Due to the application of soil plastic mulching, significant differences were found in biomass, growth rate and development, as stated by Mahmoud (2016). The final biomass under mulching conditions increased, especially in the deficit irrigation and rainfed treatments. The biomass increased from 5.6 to 7.4 t/ha under deficit irrigation and from 3.4 to 5.1 t/ha under rainfed. The biomass increase was due to the evaporation reduction and increased transpiration under black plastic mulch. Under the full irrigation, there was no significant difference between the mulched and non-mulched treatments due to the non-existence of any water limitation for greater growth in the mulching and non-mulching treatments. However, the growth rate was higher for all the mulched treatments because of the heat accumulation under plastic mulch. Therefore, the growth season length was shortened from 87 days under non-mulched treatments to 80 days for the mulched treatments.

Additionally, the plastic mulch influences the temperature under plastic mulch which was estimated using the modified model. The soil temperature under the plastic cover was increased above the air temperature by an average of 3.5ºC/day reflecting ΔT above the soil under mulch material. The average of ΔT was 1.1ºC/day. This explains the reason for the higher and faster growth and development and the reduction of season length under plastic mulching. Meanwhile, the soil temperature without soil covering was very close to the average air temperature. The average temperature differences between soil temperatures without covering and air temperatures were 1.2ºC/day as shown in **Fig 3**. The maximum air temperature under the mulch was 36.8ºC, indicating that the temperature increase under the plastic mulch did not exceed the cutoff temperature. Thus, there was no temperature stress due to the temperature increase under mulch.

3.2 Modified Model Assessment under Different Watering Regimes

The modified model testing was conducted using the data collected by Mahmoud (2016). The model performance before and after the modification was evaluated under full irrigation, deficit irrigation (only 50% of evapotranspiration was applied), and rainfed treatment with no irrigation under plastic mulch practice. CC, above-ground biomass, and season length are the variables selected to show the impact of the modified model under each watering regime.

3.2.1 Mulching Effect Simulation without Water Limitation by the Original and Modified AquaCrop

In the original model, there was a gap between the observed and simulated data during the growing season in the simulation of mulched treatments. The main problem is that the model does not consider that the growth rate of the mulched melon is greater than that

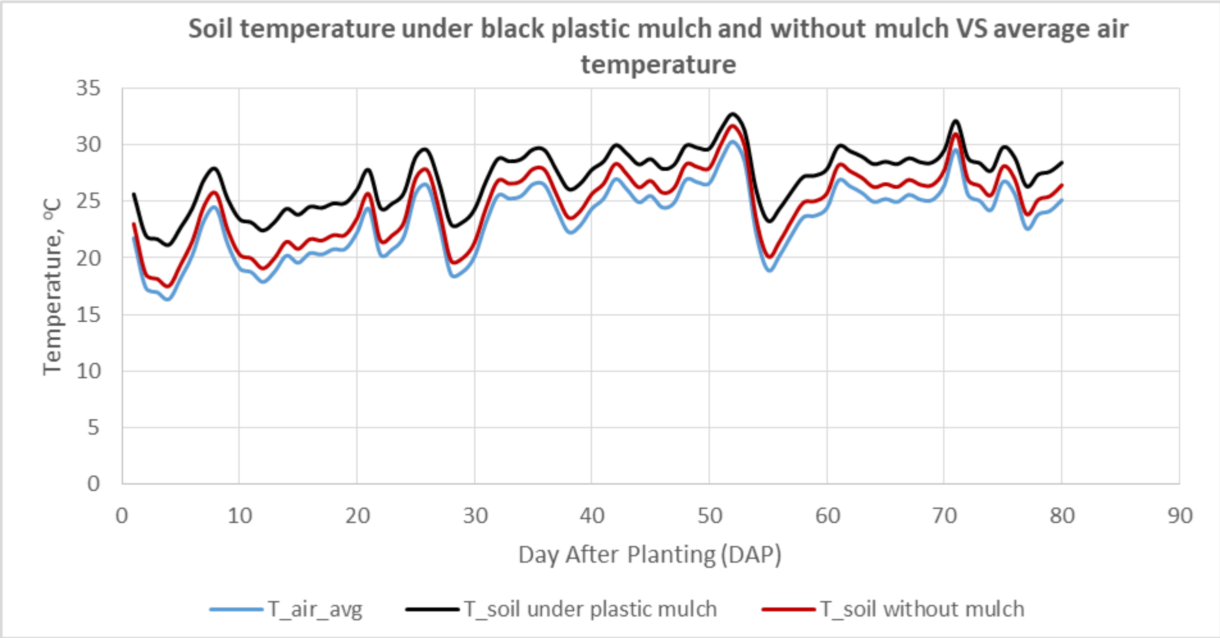

Fig 3. Soil temperature differences with and without plastic mulch from the average air temperature

of the non-mulching conditions. Moreover, the AquaCrop model could not consider the shortening of the growing season under mulching. Otherwise, it could be necessary to recalibrate the model under mulching conditions. As stated in a discussion by Mahmoud (2016), the original model simulated melon growing season length under plastic mulching more than the reality by one week, as shown in **Figs 4 and 5**. Therefore, the model did not well simulate the rapid growth and fast development under plastic mulching which agrees with the previous results (Zhang et al 2008, Malik et al 2017, Guo et al 2018). This could be interpreted due to not taking into account the increase in temperature under plastic mulching which generates more favorable growing conditions and heat accumulation for faster growth and development. Therefore, the season for the mulched treatments ended one week before the season of the non-mulching treatments Additionally, the original simulation did not detect that. the simulation performed using the modified AquaCrop model appeared in excellent agreement for the growing season length which is 80 days as observed in the field. The daily GDDs recorded higher values with 10% more for the mulched treatments simulated using the modified model.

From the statistical indicators of biomass and GCC simulation, we determined that the modified model performed better in simulating the plastic mulch effect than the original model. The coefficient of determination R^2 for the modified model is slightly higher than the original one. Additionally, RMSE decreased from 1.35 t/ha for the original model to 0.33 t/ha for the modified model indicating smaller differences between the observed and predicted biomass for the modified model as shown in **Fig 6**. Thus, greater reliability of the modified program.

3.2.2 Mulching Effect Simulation under Deficit Irrigation Using the Original and Modified AquaCrop

Under deficit irrigation treatments with the application of plastic mulch, the performance of the simulation of the biomass and CC became more robust by simulating with the modified model. The value of R^2 of the biomass simulation is almost the same in the original and modified models with a slight increase in the modified model. For RMSE of the biomass, its value was reduced to about half using the modified model from 0.83 to 0.49 t/ha. The value of R^2 of biomass simulation is almost the same in the original and modified models with a slight increase in the modified model. The CC simulation also has better statistics indicators generated by run the simulation under the modified model. The R^2 value increased by 0.04 and RMSE decreased by 0.3 t/ha using the modified AquaCrop for simulation as shown in **Figs 7, 8 and 9**. The positive changes in the attitudes of RMSE and R^2 are due to the consideration of heat rising under mulching in growth simulation through the growing

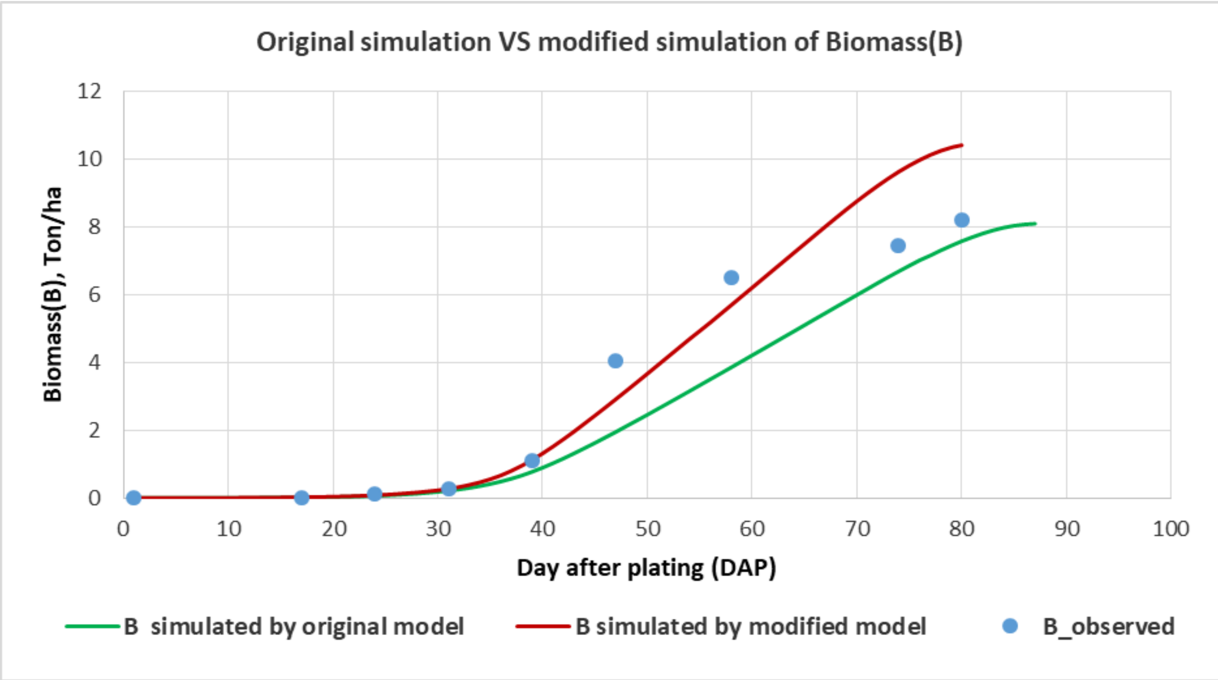

Fig 4. Comparison between the original and modified AquaCrop models for biomass simulation under full irrigation treatment

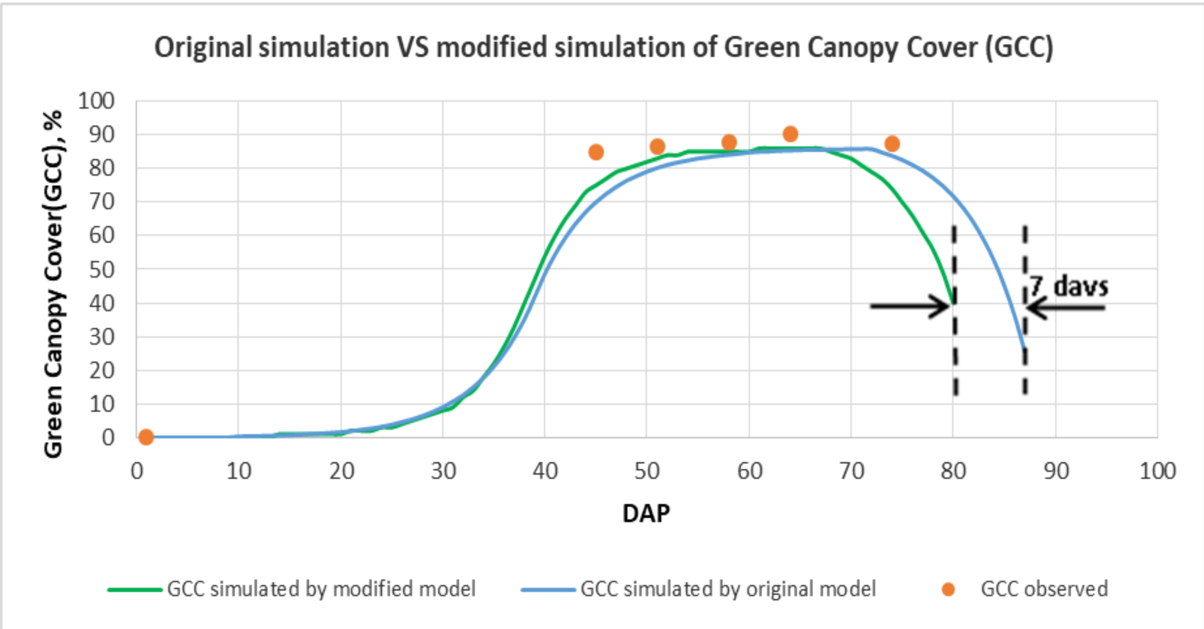

Fig 5. Comparison between the original and modified AquaCrop models for canopy cover simulation under full irrigation treatment canopy cover simulation under full irrigation treatment

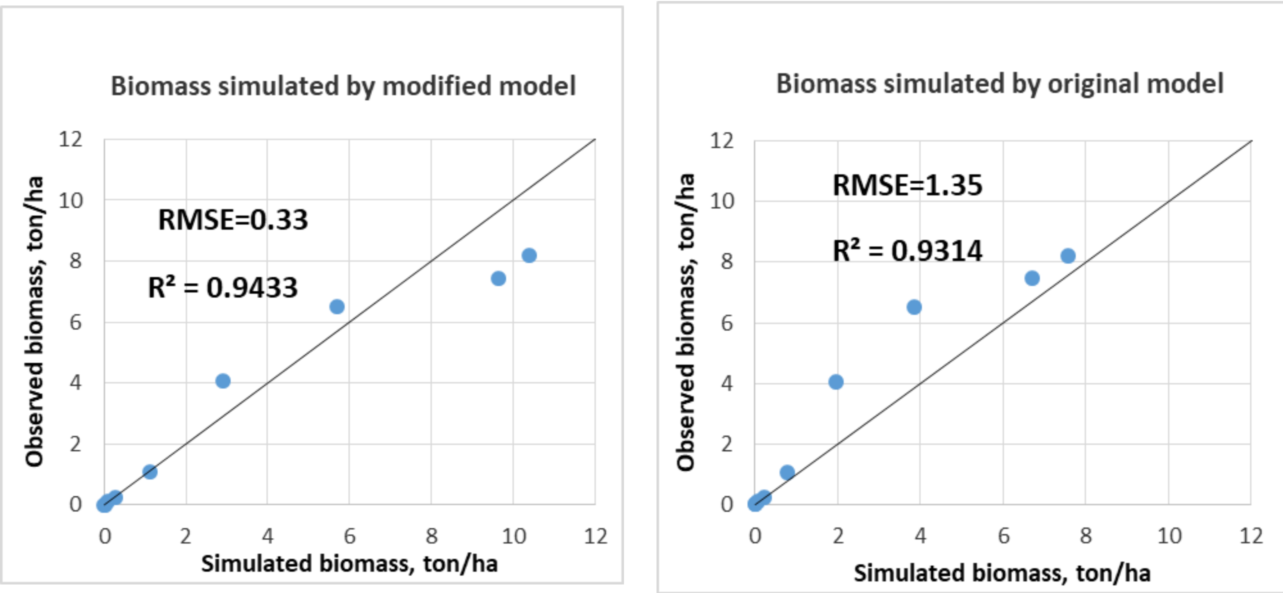

Fig 6. Observed biomass vs simulated biomass in the original and modified models under full irrigation treatment

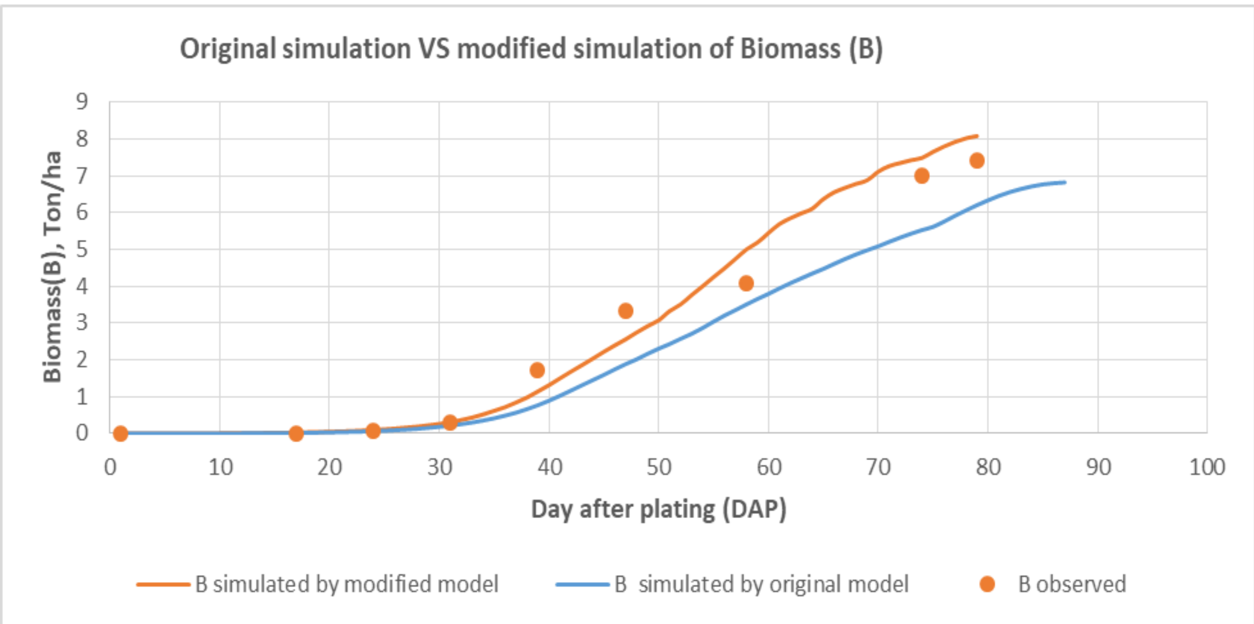

Fig 7. Comparison between the original and modified AquaCrop models for biomass simulation under deficit irrigation treatment

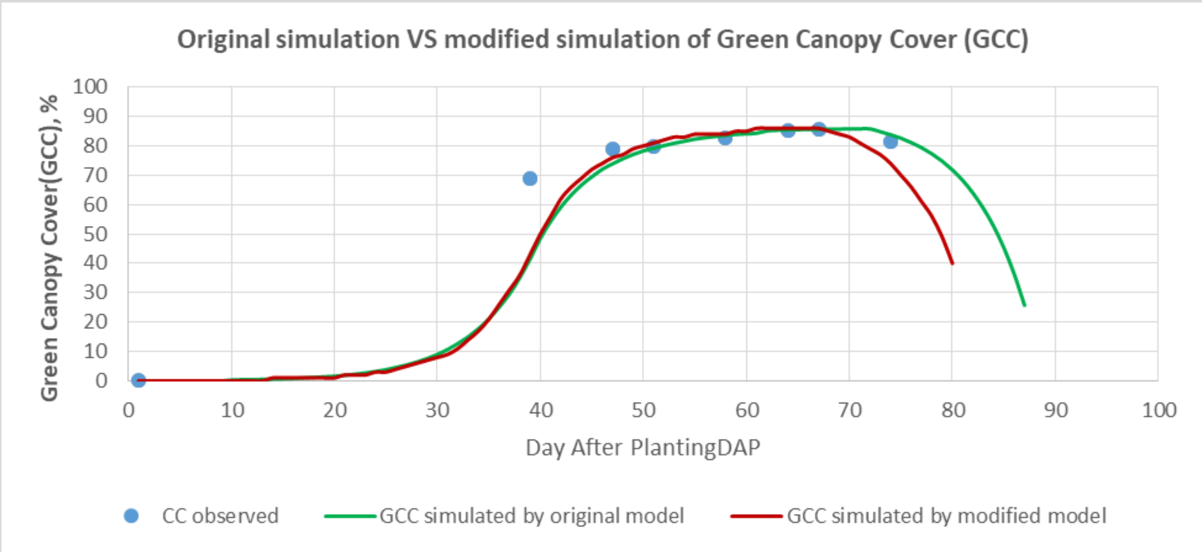

Fig 8. Comparison between the original and modified AquaCrop models for canopy cover simulation under deficit irrigation treatment

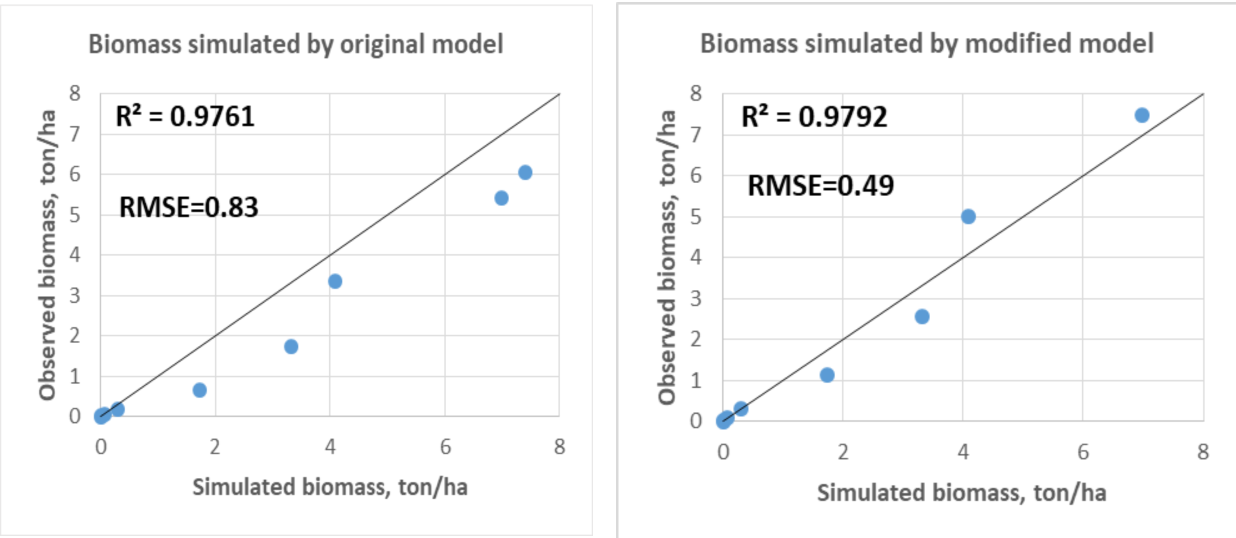

Fig 9. Observed biomass VS simulated biomass in the original and modified models under deficit irrigation treatment

season reflecting on quick development and growth in reality. Thus, the model prediction has less error and variance and better correlation and fit between the simulated and observed data.

3.2.3 Mulching Effect Simulation under Rain-Fed Treatment using the Original and Modified AquaCrop

The fit between the simulated and observed data for biomass and CC became better when simulating with the proposed model as shown in **Figs 10, 11 and 12**. The RMSE value showed a positive difference for the modified model in mulched biomass simulation with 1.47 t/ha while the difference in CC simulation by the modified AquaCrop was only 0.06%. Additionally, R^2 for biomass and CC did not show a big difference between the original and the modified AquaCrop model. These values are almost the same.

3.2.4 Simulated Transpiration using the Modified Model under Different Watering Regimes

Transpiration rate simulation by the modified model has increased slightly at the beginning of the season due to the increased growth rate under plastic mulch. However, the cumulative transpiration under mulch

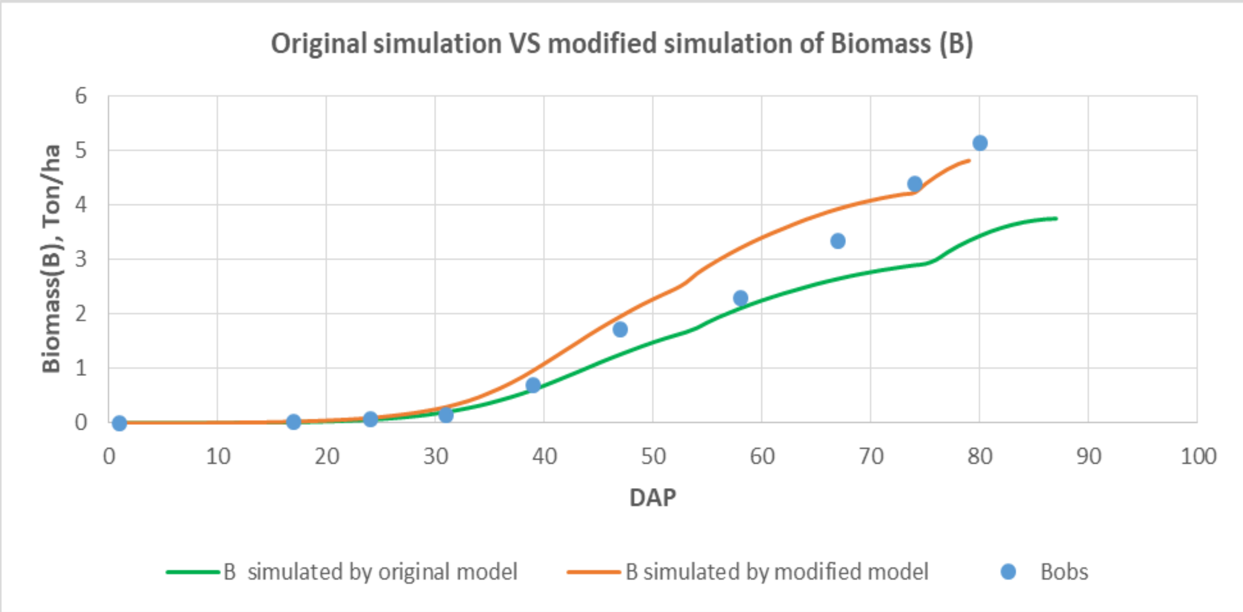

Fig 10. Comparison between the original and modified AquaCrop models for biomass simulation under no irrigation(rainfed) treatment

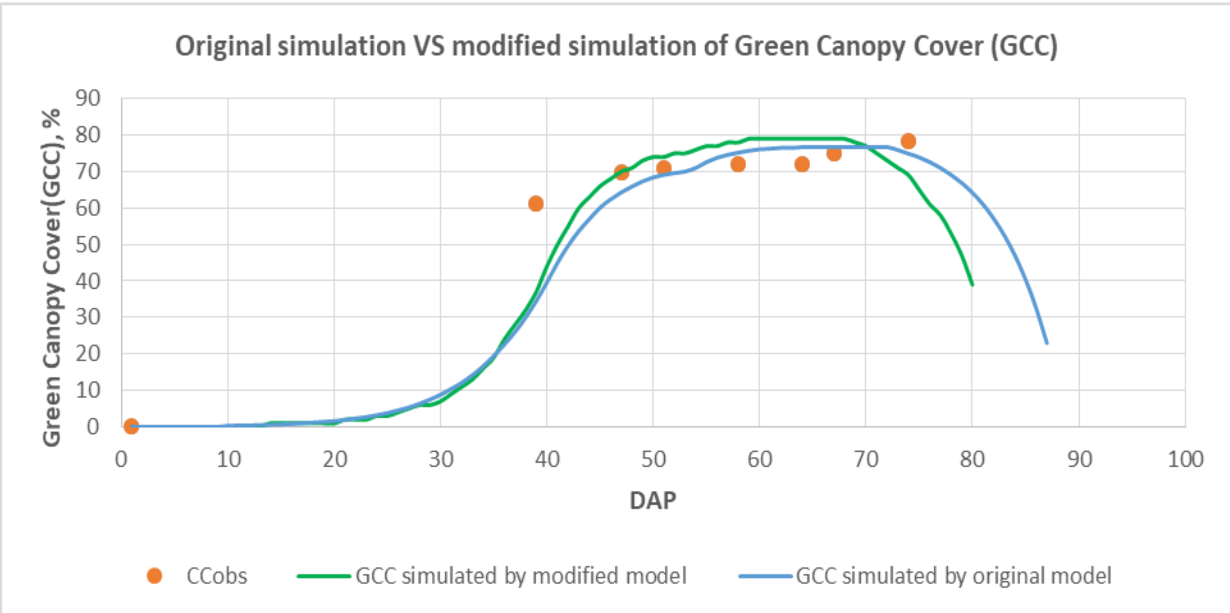

Fig 11. Comparison between the original and modified AquaCrop models for canopy cover simulation under no irrigation (rainfed) treatment

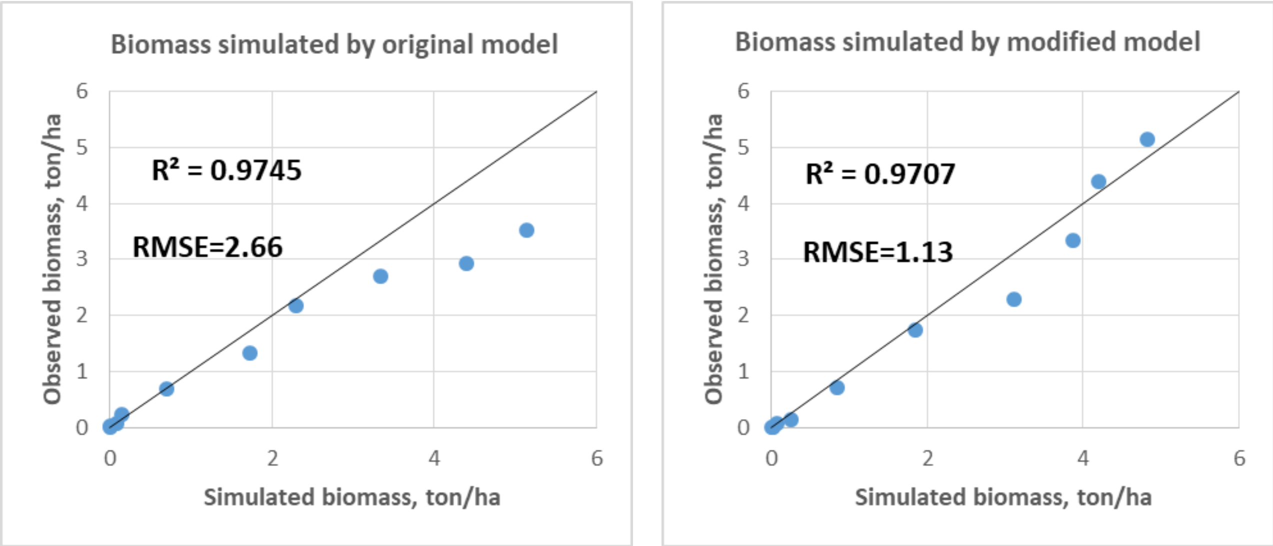

Fig 12. Observed biomass vs simulated biomass in the original and modified models under no irrigation (rainfed) treatment

throughout the entire season was less than the simulation using the modified model due to the season shortening. The total transpiration of mulched melon under no water limitations simulated by the modified model decreased by 9 % from 235 mm under the original model to 212 mm under the modified model. The cumulative water transpired by melon simulated using the modified model under deficit irrigation and rainfed treatment throughout the entire season declined by 15% and 9%, respectively. Consequently, the modified model simulates less total transpiration and higher biomass because of the temperature increase as observed in reality. Thus, higher water productivity.

4 Conclusion

Soil mulching simulation using the AquaCrop model considering the increase in temperature under plastic mulching that causes heat increment is considered more suitable conditions for fast growth when the temperature does not exceed the cutoff temperature of the simulated crop. The proposed model for soil mulching simulation in the original AquaCrop model version 6 showed a more convincing performance for simulating melon growth under different watering regimes than the original model. The season length under plastic mulching was simulated very well in all mulched treatments. The modified model simulated less cumulative transpiration under different irrigation treatments because of a shorter growth season with a higher growth rate. Hence, simulates higher water productivity and biomass, as observed in reality. The overall results of statistical indicators of biomass and CC used to assess the model performance in the original and modified simulation have a better agreement between the observed and predicted values for the modified model. The differences in R^2 values were not big between the original and modified simulations. However, for RMSE, there was a clear positive impact of the simulation performed using the modified AquaCrop which provided a more robust and dependable model.

References

Allen RG, Pereira LS, Raes D, et al (1998) Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Food and Agriculture Organization, Rome 300, D05109. https://www.fao.org/3/x0490e/x0490e00.htm

Chartzoulakis K, Bertaki M (2015) Sustainable water management in agriculture under climate change. *Agriculture and Agricultural Science Procedia* 4, 88-98. https://doi.org/10.1016/j.aaspro.2015.03.011

Chukalla AD, Krol MS, Hoekstra AY (2015) Green and blue water footprint reduction in irrigated agriculture: effect of irrigation techniques, irrigation strategies and mulching. *Hydrology and Earth System Sciences* 19, 4877-4891. https://doi.org/10.5194/hess-19-4877-2015

Corbeels M, Chirat G, Messad S, et al (2016) Performance and sensitivity of the DSSAT crop growth model in simulating maize yield under conservation agriculture. *European Journal of Agronomy* 76, 41-53. https://doi.org/10.1016/j.eja.2016.02.001

Evans RG, Sadler EJ (2008) Methods and technologies to improve efficiency of water use. *Water Resources Research* 44, W00E04 https://doi.org/10.1029/2007WR006200

Foster T, Brozović N, Butler AP, et al (2017) AquaCrop-OS: An open source version of FAO's crop water productivity model. *Agricultural Water Management* 181, 18-22. https://doi.org/10.1016/j.agwat.2016.11.015

Guo DX, Chen CF, Guo PY, et al (2018) Evaluation of AquaCrop model for Foxtail Millet (*Setaria italica*) growth and water use with plastic film mulching and no mulching under different weather conditions. *Water* 10, 836. https://doi.org/10.3390/w10070836

Ibarra L, Flores J, Díaz-Pérez JC (2001) Growth and yield of muskmelon in response to plastic mulch and row covers. *Scientia Horticulturae* 87, 139-145. https://doi.org/10.1016/S0304-4238(00)00172-2

Jacovides CP, Kontoyiannis H (1995) Statistical procedures for the evaluation of evapotranspiration computing models. *Agricultural Water Management* 27, 365-371. https://doi.org/10.1016/0378-3774(95)01152-9

Mahmoud S (2016) Simulation of melon growth and yield under different water regimes and mulching practices. M.Sc. Thesis in Land and Water Resources Management, Irrigated Agriculture, Land and Water Resources Management Department, Mediterranean Agronomic Institute of Bari (IAMB), Bari, Italy.

Malik A, Shakir AS, Ajmal M, et al (2017) Assessment of AquaCrop model in simulating sugar beet canopy cover, biomass and root yield under different irrigation and field management practices in semi-arid regions of Pakistan. *Water Resources Management* 31, 4275-4292. https://doi.org/10.1007/s11269-017-1745-z

Raes D, Steduto P, Hsiao TC, et al (2009) AquaCrop-The FAO crop model to simulate yield response to water: II. Main algorithms and software description. *Agronomy Journal* 101, 438-447. https://doi.org/10.2134/agronj2008.0140s

Ramakrishna A, Tam HM, Wani SP, et al (2006) Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. *Field Crops Research* 95, 115-125. https://doi.org/10.1016/j.fcr.2005.01.030

Ritchie JT (1972) Model for predicting evaporation from a row crop with incomplete cover. *Water Resources Research* 8, 1204-1213. https://doi.org/10.1029/WR008i005p01204

Saad AM, Mohamed MG, El-Sanat GA (2014) Evaluating AquaCrop model to improve crop water productivity at North Delta soils, Egypt. *Advances in Applied Science Research* 5, 293-304. https://rb.gy/37pi1l

Salunkhe R, Kale MU, Wadatkar SB, et al (2015) Validation of aqua crop model for drip irrigated capsicum under polyethylene mulch. *International Journal of Tropical Agriculture* 33, 359-364.

Scopel E, da Silva FAM, Corbeels M, et al (2004) Modelling crop residue mulching effects on water use and production of maize under semi-arid and humid tropical conditions. *Agronomie* 24, 383-395. https://hal.archives-ouvertes.fr/hal-00886027

Shrivastava PK, Parikh MM, Sawani NG, et al (1994) Effect of drip irrigation and mulching on tomato yield. *Agricultural Water Management* 25, 179-184. https://doi.org/10.1016/0378-3774(94)90044-2

Steduto P, Hsiao TC, Raes D, et al (2009) AquaCrop—The FAO crop model to simulate yield response to water: I. Concepts and underlying principles. *Agronomy Journal* 101, 426-437. https://doi.org/10.2134/agronj2008.0139s

Yang N, Sun Z, Zheng M, et al (2017) Performance assessment of combining AquaCrop model with recalculating air temperature of straw-mulching maize for estimating evapo-transpiration and yield. *International Journal of Agriculture and Biology* 19, 1156-1164. https://doi.org/10.17957/IJAB/15.0413

Zhang L, Van Der Werf W, Cao W, et al (2008) Development and validation of SUCROS-Cotton: a potential crop growth simulation model for cotton. *NJAS: Wageningen Journal of Life Sciences* 56, 59-83. https://doi.org/10.1016/S1573-5214(08)80017-6