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Modeling climate change impact on irrigation water requirement and yield of mango (*Mangifera indica* L.) in Egypt

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ABSTRACT

Assessing the impacts of climate change on irrigation water requirement (IWR) and crop yields is one of important topics with respect to climate change. The purpose of this study was to investigate the impact of climate change on future IWR and yield of mango in three governorates in Egypt (Ismalia, Sharkia, and Bihera) for the 2050s and 2100s.The average climatic data for 2020 period for the three governorates were processed by MAGICC (version 6.0) application and Hadley Centre Coupled Model Version 3 (HadCM3) model, to extract the projection changes in temperatures of the regions under intergovernmental Panel on Climate Change (IPCC) scenarios A1 and B1. The FAO CROPWATE (version 8.0) application was used to estimate the ET_o, and IWR, as well as impact of changes in IWR on mango yield. According to the results, as the end of the century approaches, the irrigation water requirements of mature mango trees will increase. This will result in noticeable reductions in mango yield; the yield of mango will decrease by 92.53% - 85.73% in the future periods under scenarios A1 and B1, respectively. Serious attention has to be paid to the water resources management of Egypt. The use of drought-tolerant cultivars in the region can be a good strategy to deal with the predicted future climatic conditions.

Keywords: Climate change, HadCM3, irrigation water requirements, crop evapotranspiration, temperature, mango

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1 Introduction

Mango (*Mangifera indica* L.) is considered as one of the most important fruit crops in Egypt and all over the world. Mango production in Egypt was significantly increased over the past decades. The total cultivated area in 2019 was 126 ha with an average productivity of 31.56 t ha^{-1} (AEB, 2019). In Egypt, agriculture consumes roughly 80% of available water resources (Swelam and El-Marsafawy, 2019). With a relatively fixed supply of fresh water and an ever-increasing demand, every drop of water should be treated as a drop of life. As a result, efficient on-farm irrigation management is required.

Reference crop evapotranspiration (ET_o) is an important factor in determining and managing crop irrigation schedules. It is critical to determine crop irrigation water requirements for optimal irrigation scheduling (Djaman et al., 2018). The FAO-56 Penman-Monteith method has become the de facto standard for estimating reference evapotranspiration (ET_o), it is a complicated method requiring many inputs that are not commonly available, and alternative methods must be used (Fisher and III, 2013). The CROPWAT application developed by the Food and Agriculture Organization (FAO), it is widely used all around the world to estimate crops water requirements and planning crop irrigation schedules (George et al. 2000). CROPWAT 8.0 includes standard crop and soil data. When local data is unavailable, these data files can be easily modified or new ones created. Similarly, if local climatic data are unavailable, these can be obtained for over 5000 stations worldwide from CLIMWAT, the associated climatic database.

The predicted climate change in Egypt, based on various representative concentration pathways (RCPs), indicated an increase in evapotranspiration (ET_o) due to rising minimum and maximum air temperatures. According to (Abdrabbo and El Afandi, 2015), ET_o would rise by 4.7% to 19.6% in the Middle Egypt region. Moreover, the expected climate changes in Egypt according to the climate change scenarios will cause an increase in crop irrigation requirements (IWR) depending on the climate region. Farag and El-Taweel (2014) found that the IWR increased in the all Egypt climate regions under the A1 scenario from 2050 to 2100. The only study in Egypt that investigated the impact of climate change on IWR of mature mango trees using the FAO56 method was unable to measure the impact of climate change on mango yield (Abdrabbo et al., 2013). Therefore, this study aimed to investigate the impact of climate change on yield variance of mango in three governorates (Ismalia, Sharkia and Bihera) of Egypt, for the periods 2020, 2050s and 2100s.

2 Materials and Methods

2.1 Study sites

The present investigation was conducted during two successive seasons 2019 and 2020 on mango orchards grown in three governorates located in the Delta Egypt region, private orchards located at El-Nobaria region Behira governorate (30.6° N and 30.7° E, and 130 m above sea level), Dir Almalak valley Sharkia governorate (30.7° N and 31.7° E, and 2 m above sea level) and El Tall El Kbeer region Ismailia governorate (30.6° N and 32.2° E, and 82.9 m above sea level). The full irrigation water requirements (IWR) (m^3 $fed.^{-1}$) in the Delta Egypt region are presented in Table 1.

Table 1. The full irrigation water requirements (IWR) in the Delta Egypt region (ARC, 2004)

	IWR (m^3 fed^{-1})
Drip irrigation	4331
Surface irrigation	5724
Winter months	160 -240
Summer months	447-748

IWR = Full irrigation water requirement; Feddan (fed.) = 4200 m^2

2.2 Data collection and preparation

Monthly meteorological parameters for three governorates, including average air temperature (0C), relative humidity (%), wind speed (km d^{-1}), sunshine (h d^{-1}), solar radiation (MJ m^{-2} d^{-1}), reference evapotranspiration (ET_o), and rainfall (mm), were obtained from NASA's website for the 2020 season.

2.3 Prediction of the climatic variables

To simulate future monthly temperatures, the Hadley Centre Coupled Model version 3 (HadCM3) model was utilized. The HadCM3 and the processes used to create the climate projections are described in depth in (Gordon et al., 2000; Johns et al., 2001). The University of East Anglia's (UK) MAGICC 6.0 software was used to extract the projection changes under the two IPCC special report emissions scenarios (SRES) A1 and B1 that are presented in Table 2. MAGICC 6.0 works on the premise of allowing the user to investigate the impacts of a medium range of future emission scenarios (Meinshausen et al., 2011).

Table 2. Characteristics of A1 and B1 scenarios IPCC (2007)

Scenario	Characteristics
A1	Rapid economic growth, low population growth, rapid adoption of new technologies, convergence of regions, capacity building, increased social interaction, reduced region differences in per capita income temperature increased 1.4 - 6.4 °C
A2	Convergent world with low population growth, transition to service and info economy, resource productivity improvements, clean technology towards global solutions temperature increased 1.1 - 2.9 °C

2.4 Evaluation of (HadCM3) model and scenarios

To evaluate and compare the accuracy of the scenarios and to select the most efficient predictive scenario, statistical indices coefficient of determination (R^2) and root mean square error (RMSE) were used (Paredes et al., 2014). The coefficient of determination is an indicator of degree of closeness between simulated and measured data. It is unit less and may assume values ranging from $-\infty$ to $+1$, with values close to 1 indicating a better model simulation efficiency, and typically values greater than 0.50 are considered acceptable in simulations (Moriasi et al., 2007).

The coefficient of determination (R^2) was calculated using the following equation:

$$R^2 = \left[\frac{\sum_{i=1}^{n} (M_i - \bar{M})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n} (M_i - \bar{M})^2 \sum_{i=1}^{n} (S_i - \bar{S})^2}} \right]^2 \quad (1)$$

where S, M, and n are the simulated, measured, and the number of measurements, respectively.

Table 3. Mango crop parameters

Stage	Initial	Developing	Mid	Late	Total
Length (days)	90	90	90	95	365
Crop coefficient values (Kc)	0.9	0.9	1.1	0.9	-
Rooting depth (m)	2	2	2	2	-
Critical depletion	0.6	0.6	0.6	0.6	-
Yield response factor	0.8	0.8	0.8	0.8	0.8
Crop height (m)	6	6	6	6	6

Table 4. Soil parameters of Bihera, Sharkia and Ismalia governorates

Governorate	Bihera, Sharkia and Ismalia
Total available soil moisture (FC - WP) (mm m^{-1})	100
Maximum rain infiltration rate (mm d^{-1})	30
Maximum rooting depth (cm)	900
Initial soil moisture depletion (as %TA)	0
Initial available soil moisture (mm m^{-1})	100

The root mean square error (RMSE) is a measure to calculate the total or mean deviation between the measured and simulated values. The closer the value is to zero, the better the model simulation performance. The root mean square error (RMSE) was estimated by the following equation (Loague and Green, 1991):

$$RMSE = \left[\frac{\sum_{i=1}^{n} (S_i - M_i)^2}{n} \right]^{0.5} \quad (2)$$

where S, M, and n are the simulated, measured, and the number of measurements, respectively. The index of agreement (d) is a measure of the relative error in the model estimates. It is a dimensionless number that ranges between 0 and 1, with 0 indicating no agreement and 1 indicating a perfect agreement between the simulated and measured data (Krause et al., 2005).

2.5 Estimation of ET_o and IWR

The FAO CROPWAT (Ver. 8.0) model was used to calculate crop evapotranspiration (ET_o), irrigation requirements (IWR), and the effect of changes in irrigation water requirements on mango yield (FAO, 1992). For simulation, the CROPWAT model requires three input archives: climate archive, crop archive, and soil archive. Monthly averages of air temperature (°C), relative humidity (%), wind speed (km d^{-1}), sunlight (h d^{-1}), solar radiation (MJ m^{-2} d^{-1}), reference evapotranspiration (ET_o), and rainfall (mm) are all included in the climate archive. Tables 3 and 4 provide more extensive information about crop and soil properties utilized in simulations, respectively.

3 Results and Discussion

3.1 Evaluation of model and scenarios

The average monthly temperatures values had a relatively high fit to the observed values, according to all statistical measures (Table 5). Scenarios A1 and B1, on the other hand, provided a better fit to the observed data. Therefore, scenarios A1 and B1, the least optimistic ones and most optimistic, respectively, were used to estimate the crop evapotranspiration, irrigation water requirement, and yield of the crops. The HadCM3 model seems to be appropriate for the prediction of the temperature of the Ismalia, Sharkia and Bihera governorates. The scenarios A1 and B1 were shown to be the most efficient for the prediction of the air temperatures. In a study of the three governorates using the HadCM3 model, B1 was found to be the best scenario among the others (Farag and El-Taweel, 2014), which is in agreement with the findings of this study. Evaluating the results of the present study and the other studies presents the usefulness of the HadCM3 model for the prediction of the future temperature. However, performing more studies with different climatic models will help us in selecting the most appropriate model for the future research. Furthermore, the model and methods used in the present study can be applied for studies in other regions throughout the world to check whether compatible results are derived. It is also necessary to note that the present model and methods are easy to use and inexpensive. This means that they can be exploited by researchers in regions with less accessibility to scientific facilities. Nonetheless, such models and methods demand a huge data set for being ran efficiently, which might be difficult to attain.

Table 5. Performance of the model in the current period (2020) using the statistical error criteria

Future periods	RMSE	R^2
A1 (2050s)	0.921	0.085
A1 (2100s)	0.984	0.078
B1 (2050s)	0.92	0.079
B1 (2100s)	0.851	0.082

RMSE = Root Mean Square Error; R^2 = Coefficient of determination

3.2 Prediction of air temperature

The simulation results showed that the average monthly temperature would rise in summer months and decrease in winter months for all periods and under all scenarios (Table 6), in comparison with the current period. The highest increase in the average monthly temperature was attributed to the period 2100s and the A1 scenario, in which the average temperature increased by 4.8 °C. The lowest increase in the average monthly temperature belonged to the period 2050s of the B1 scenario, with an increase of 2.1 °C. The average monthly temperature was projected to increase in all months of the periods but to decrease in December, January and February under all scenarios in all periods. Such predicted increasing trends in the future temperature have been also reported by other studies (Farag and El-Taweel, 2014; Attaher et al., 2006; Malkia and Etsouri, 2018). Shifts in the seasons would, however, be the reason for the prospective temperature increase in June, July, and August. Since the Ismalia, Sharkia and Bihera governorates are severely impacted by Khamsin winds, it is possible that the winds will lead to shifts in the seasons of the area. Furthermore, the highest average monthly temperature will relate to the scenario A1 and period 2100s. The results of the present study are in agreement with the results attained by (Abdrabbo et al., 2013; Farag and El-Taweel, 2014). The highest temperature was predicted by scenario A1. This seems acceptable due to the governing physical rules to simulate the continuing increase in the radiative forcing and CO_2 accumulations until the end of the century.

3.3 Prediction of ET_o

All scenarios projected that the monthly crop evapotranspiration (ET_o) will increase in all months of all periods, except in winter months, compared to the current period (Table 7). The highest increase in the monthly ET_o was related to the scenario A1 in the period 2100s in comparison with the scenario B1. The lowest increase in monthly ET_o belonged to the scenario B1 in the period 2050s compared to the current period. Investigating the month by month indicated that the ET_o will increase in June, July and August under all scenarios and periods, with July in 2100s having the highest amount. Except for these months, the ET_o will decrease in all months of all scenarios and periods, with January in 2050s having the greatest decrease. The scenario-based projected increases in the ET_o compared to the current values can overall be explained by the prospective elevation of the temperature by the end of the century. Khalil (2013), Farag and El-Taweel (2014) and Farag et al. (2015) predicted that the ET_o would increase in Egypt by the end of the century. The Egypt is severely affected by the warming. Thus, the highest ET_o projections for the period 2100s might be describable.

3.4 Estimation of irrigation water requirement (IWR)

The results demonstrated that the irrigation water requirement (IWR) of mature mango trees will increase in all periods under both scenarios (Table 8). Meanwhile, the IWR will further increase as the end of the century approaches. The monthly and total change percentage of the IWR is also shown in Table 8. An IWR change between 10.03% and 25.18% was observed under both scenarios in all periods compared to the current periods. Our calculated irrigation water requirement (IWR) was a function of actual evapotranspiration. The crop evapotranspiration in this study was partly derived from the temperatures. Therefore, the higher IWR for mature mango trees by the approach of the end of the century was reasonable, since the temperatures of the attributed months were predicted to increase by approaching the end of the century. Crop evapotranspiration in Egypt regions is expected to increase, which can increase the requirement for agricultural irrigation (Farag and El-Taweel, 2014; Farag et al., 2015). The IWR was shown to be enhanced by an increase in temperature and crop evapotranspiration (Attaher et al., 2006; Moratiel et al., 2011; Irmak et al., 2012; Nour El-Din, 2013).

3.5 Estimation of yield

The mango yield in all periods under both scenarios were decreased (Table 9). Moreover, the yield reduction became more severe as the end of the century approached. Overall, the projected reduction in the mango yield can be linked to the predicted increase in the temperatures, as well as the increase in the ET_o. High and abnormal crop evapotranspiration rates derived from climate warming can impose serious water stress on a crop, which might lead to a significant reduction in the yield. It was forecasted that the high temperature will decrease the yield of mango in world as the end of the century approaches (Normand et al., 2015).

Table 6. Comparison of average monthly temperature (°C) of periods 2050s and 2100s under scenarios A1 and B1 with the current period 2020

Month	Current	A1 (2050s)	A1 (2100s)	B1 (2050s)	B1 (2100s)
Jan	13.9	15.7	17.1	15.4	16.2
Feb	14.6	16.6	18.8	16.3	17.1
Mar	18.03	19.6	21	19.4	20.1
Apr	21.8	23.4	24.7	23	23.7
May	26.3	28.8	31.2	28.5	29.8
Jun	28.5	31.5	34.4	31.2	32.7
Jul	28.6	32.3	35.5	31.6	33.2
Aug	27.6	30.4	32.8	29.9	31
Sep	26.9	30.6	33.3	29.9	31.3
Oct	24.1	27.2	30.2	26.9	28.4
Nov	19.5	21.8	24.2	21.3	22.6
Dec	15.1	17.4	19.3	16.8	17.8
Average	22.1	24.6	26.9	24.2	25.3
Change (°C)		2.5	4.8	2.1	3.2

Values are means of of three governorates.

Table 7. Comparison of average *ETo* (mm/day) of periods 2050s and 2100s under scenarios A1 and B1 with the current period 2020

Month	Current	A1 (2050s)	A1 (2100s)	B1 (2050s)	B1 (2100s)
Jan	2.5	2.7	2.8	2.6	2.8
Feb	3.2	3.5	3.8	3.5	3.6
Mar	4.3	4.6	4.9	4.6	4.7
Apr	5.6	5.9	6.2	5.8	6
May	6.9	7.6	8.4	7.6	7.9
Jun	8.1	9	9.8	8.9	9.2
Jul	8.5	9.8	10.9	9.6	10.2
Aug	7.7	8.6	9.5	8.5	9
Sep	6.5	7.4	8.2	7.3	7.6
Oct	5	5.7	6.3	5.6	5.9
Nov	3.7	4.4	4.7	4.3	4.5
Dec	2.5	2.8	3	2.8	2.8
Average	5.4	6	6.5	5.9	6.2
Change (%)		11.6	21.7	10.2	15

Values are means of of three governorates.

Table 8. Comparison of average IWR of mature mango trees (m^3 fed.$^{-1}$) of periods 2050s and 2100s under scenarios A1 and B1 with the current period 2020

Month	Current	A1 (2050s)	A1 (2100s)	B1 (2050s)	B1 (2100s)
Jan	248.5	280.6	311.2	273.5	289.2
Feb	314.5	355.2	394	346.2	366
Mar	445	502.2	556.7	489.5	517.3
Apr	652.9	737.3	817.6	718.6	759.7
May	825.3	931.8	1033.1	908.1	960.1
Jun	924	1042.8	1156	1016.3	1074.1
Jul	949.7	1072	1188.4	1044.7	1104.2
Aug	889.8	1004.6	1113.8	979	1034.9
Sep	732.9	827.6	917.7	806.5	852.7
Oct	583.3	658.8	730.6	642	678.8
Nov	328.1	370.3	410.5	360.9	381.4
Dec	250.6	282.8	313.6	275.7	291.4
Average	7145	8066.6	8943.8	7861.5	8310.2
Change (%)		12.9	25.1	10	16.3

Values are means of three governorates;
Feddan (fed.) = 4200 m^2

Table 9. Results of the change percentage of the mango yield under scenarios A1 and B1 in periods 2025s and 2100s versus the current period (2020) in three governorates

Scenario	A1 (2050s)	A1 (2100s)	B1 (2050s)	B1 (2100s)
Change (%)	-89.5	-92.5	-70.6	-90.6

Values are means of of three governorates.

4 Conclusion

The coupling of a modern climatic model with the classical irrigation water requirement and yield models was shown to be successful and efficient. The HadCM3 climatic model was appropriate for the prediction of the temperature of the Ismalia, Sharkia and Bihera governorates. Moreover, scenarios A1 and B1 were the most efficient ones for the prediction of the temperature of the three governorates. The models of the present research can be used to study climate change impacts on agroecosystems of other regions of the world. In general, the irrigation water requirement of mature mango trees will increase as the end of the century approaches. This will lead to noticeable reductions in the yield of mango and can endanger the export values of mango in Egypt. Therefore, significant attention has to be paid to the water resources management of the Ismalia, Sharkia and Bihera governorates. In addition, the use of drought-tolerant cultivars can be a good strategy to deal with the predicted future climatic conditions.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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