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Impacts of climate change on irrigation requirements and water productivity of citrus and olive crops in Egypt

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Abstract

Climate change could affect the meteorological parameters and which directly lead to changes in irrigation requirements (IR) and water productivity (WP) of fruit crops. The objective of the current study was to investigate the impacts of potential climate change on irrigation requirements and water productivity of citrus and olive in four governorates of Egypt (El-Bihera, Al-Dakahlia, Matruh and North of Sinai) using a CROPWAT 8.0 model in conjunction with the climate change scenarios A1FI and B1.The irrigation requirements of two crops in all future periods (2020s, 2050s and 2100s) were increased as compared to current period (1990-2019). While, the water productivity values for citrus and olive crops in all future periods (2020s, 2050s and 2100s) were decreased as compared to current period 1990-2019. The IR for citrus and olive were increased by 21.80% and 27.51% respectively. The WP values for citrus and olive were decreased by 43.21% and 17.99%, respectively. The results of this study are helpful in formulating adaptation measures to address water stress and increase yield of citrus and olive crops under climate change scenarios in Egypt.

Keywords: Climate change, CROPWAT, irrigation requirements, water productivity, citrus, olive

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1 Introduction

Egypt tops the world countries in production of olive table (*Olea europaea* L.) and citrus (*Citrus* spp.), with total production 981.50 thousand tons and 4.23 million tons, respectively (AEB, 2019). The annual irrigation requirements for olive and citrus mature trees ranged from 180 m^3 ha^{-1} to 2.600 m^3 ha^{-1} (Gucci and Tattini, 2010) and 9 to 11 m^3 ha^{-1} (Abobatta, 2018), respectively. According to the reports of intergovernmental panel on climate change (IPCC, 2013; IPCC) which mentioned that the potential climate changes in Egypt are likely to reduce the productivity of crops, and increase its water requirements. Abobatta (2019), who investigated the potential impacts of global climate change on citrus cultivation. The climate change affects growth and productivity citrus varieties, different environmental factors like high temperature, heatwaves, drought, cool temperature and frost has an impressive effect on growth and productivity of citrus. Climate change is likely to increase the water scarcity. Rising temperatures, a probable increase in the amount of evaporation, combined with more rainfall uncertainty have a significant influence on the irrigation water requirement, and climate change could affect future water availability worldwide (Boonwichai et al., 2018). The potential climate change impacts on crop water requirements, under Egyptian conditions and different climate change scenarios, have been studied in scattered and limited studies. Recent studies have investigated the relationships between potential climate changes and crop irrigation requirements under different Egyptian climatic regions. Farag et al. (2015) investigated the impact of climatic changes on crop irrigation requirements based on air temperature changes according to different scenarios and reported that the expected climate changes in Egypt will cause an increase in crop irrigation requirements depending on the climatic region. The increase in the Delta region is projected to be between 2.4% to 16.2%, while Middle Egypt use increased by 5.9% to 21.1% and Upper Egypt region by 5.8% to 22.5%. Farag and El-Taweel (2014) and Abdrabbo et al. (2013) reported that the projected future climate changes are likely to increase irrigation requirements of olive (from 10.8% to 29.1%) and mango (from 11.0% to 27.0%), respectively. Therefore, knowledge on future changes in irrigation demand in the context of climate change is very important for long-term planning and management of water resources of Egypt. The current study was carried out to investigate the impacts of potential climate change on irrigation requirements and water productivity of citrus and olive in El-Bihera, Al-Dakahlia, Matruh and North of Sinai governorates using a CROPWAT 8.0 model in conjunction with the climate change scenarios A1FI and B1.

2 Materials and Methods

2.1 Study site

This study was conducted during 2019 and 2020 on citrus and olive orchards grown in four governorates located in the north of Egypt (Fig. 1), El-Bihera (30.47 N, 30.09 E; 94.5 m above sea level), Al-Dakahlia (31.05 N, 31.38 E; 2.89 m above sea level), Matruh (29.25 N, 25.51 E; 82.91 m above sea level) and North of Sinai (30.35 N, 33.20 E; 414.15 m above sea level) (https://power.larc.nasa.gov/data-access-viewer/).

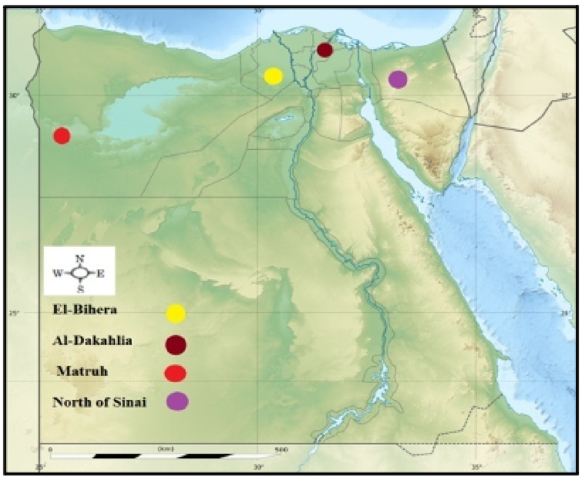

Figure 1. Geographical location of the study site

2.2 Climate data and models used

Current climate conditions for four governorates are considered using mean monthly climate data (minimum and maximum air temperature (°C), relative humidity (%), wind speed (km d^{-1}), sunshine (h d^{-1}), solar radiation (MJ m^2 d^{-1}), rainfall in mm), measured during the 1990-2019 period on main climatological stations of Hydrometeorological Service of Egypt. Assessment study was carried out using projections of the future climate taken from the HadCM3 global climate model with the A1FI and B1 scenarios for greenhouse gas (GHG) emissions for the 2020s, 2050s and 2100s integration period. To synthesize monthly climate data series from MAGICC 6.0 (Model for the Assessment of Greenhouse Gas Induced Climate Change) (Meinshausen et al., 2011) was used as a tool for statistical downscaling in 5° × 5° coordination grid. Weather generator is trained using 1990-2019 period as reference climatology. Monthly data of present and future climate are used as input data for CROPWAT 8.0 model (FAO, 1992). This computer program is developed by FAO Land and Water Management Division to predict the irrigation requirements (IR) based on climate, crop and soil data (Fig. 2).

All calculations in CROPWAT 8.0 are based on the two FAO publications, "Crop Evapotranspiration - Guidelines for computing crop water requirements" and 'Yield response to water'. Besides climate data, important input data for CROPWAT model are crop and soil data. Having in mind economic and strategic impact, citrus and olive are chosen as a crops of interest. Crop characteristics used in simulations are presented in Table 1.

According to United States department of agriculture (USDA) soil classification dominant soil types on selected governorates are: Clay loam in major part of Al-Dakahlia as well as sand in El-Bihera, Matruh and North of Sinai. More detailed information's about soil characteristics, used in simulations, are presented in Table 2.

Reference evapotranspiration is calculated using Penman - Monteith equation while effective precipitation is calculated using FAO/AGLW formula (Vozhehova et al., 2018). The relative change of reference evapotranspiration and actual irrigation requirements in for the 2020s, 2050s and 2100s is calculated in respect to 1990-2019 as a reference period.

Estimation of the ET_o using the Penman Montieth equation as follows:

$$ET_o = \frac{0.408\Delta\left(R_n - G\right) + \gamma \frac{900}{T+273} u_2 \left(e_s - e_a\right)}{\Delta + \gamma\left(1_0.34 u_2\right)} \quad (1)$$

where ET_o = reference evapotranspiration (mm d^{-1}), R_n = net radiation at the crop surface (MJ m^{-2} d^{-1}), G =soil heat flux density (MJ m^{-2} d^{-1}), T = air temperature at 2 m height (°C), u_2 = wind speed at 2 m height (m sec^{-1}), e_s =saturation vapour pressure (kPa), e_a =actual vapour pressure (kPa), $e_s - e_a$ =saturation vapour pressure deficit (kPa), Δ = slope vapour pressure curve (kPa °C^{-1}), and γ = psychrometric constant (kPa °C^{-1}).

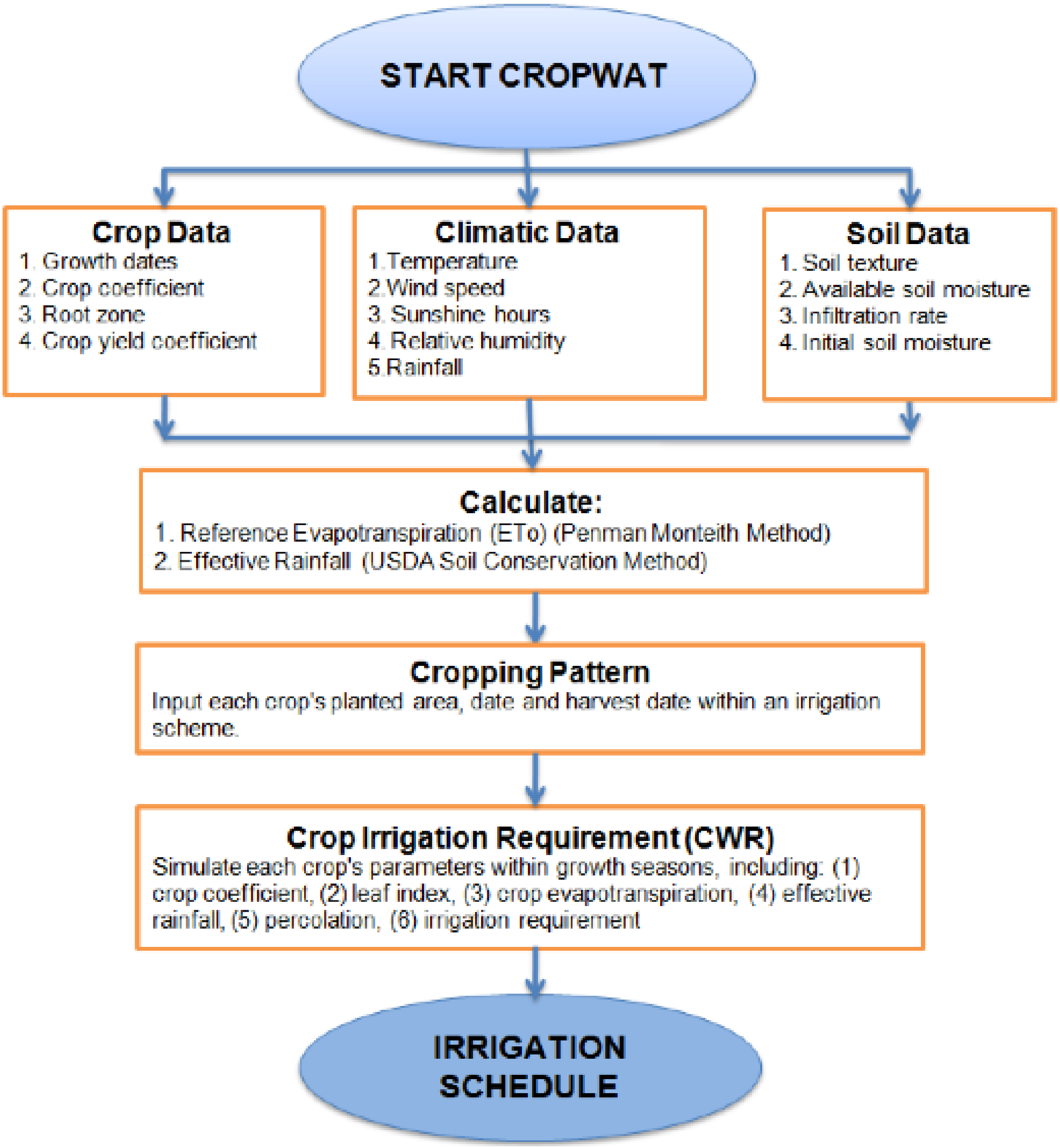

Figure 2. Conceptual platform of CROPWAT8.0 model

Table 1. Citrus and olive crop parameters

Crop	Stage	Initial	Develop	Mid	Late	Total
	Length (days)	60	90	120	95	365
	Crop coefficient values	0.7	0.7	0.65	0.7	-
	Rooting depth (m)	1.4	1.4	1.4	1.4	-
Citrus	Critical depletion	0.5	0.5	0.5	0.5	-
	Yield response factor	1	1	1	1	1
	Crop height (m)	4	4	4	4	4
	Length (days)	60	90	120	95	365
	Kc values	0.65	0.7	0.7	0.7	-
Olive	Rooting depth (m)	1.7	1.7	1.7	1.7	1.7
	Critical depletion	0.65	0.65	0.65	0.65	-
	Yield response f.	0.2	0.2	0.2	0.2	0.2
	Crop height (m)	4	4	4	4	4

Table 2. Soil parameters of Al-Dakahlia, El-Bihera, Matruh and North of Sinai governorates

Governorate	TSM (mm m^{-1})	RIR (mm d^{-1})	MRD (cm)	IMD	ISM (mm m^{-1})
Al-Dakahlia	200	30	900	50	100
El-Bihera, Matruh, and North of Sinai	100	30	900	0	100

TSM = Total available soil moisture (FC - WP); RIR = Maximum rain infiltration rate; MRD = Maximum rooting depth; IMD = Initial soil moisture depletion (as % of TSM); ISM = Initial available soil moisture.

2.3 Water productivity (WP) calculation

The WP was calculated according to FAO (1992) as follows:

$$WP = \frac{Y}{IR} \quad (2)$$

where WP = water productivity (kg m^{-3}), Y = yield (kg), and IR = total amount of irrigation water used in the field during the growth season.

2.4 Statistical analysis

Statistical analysis was carried out using SAS software program. The paired t-test was used to establish whether there exist significant differences in current reference evapotranspiration (ET_o), irrigation requirements (IR) and water productivity (WP) in 1990 to 2019 and estimated ET_o, IR and WP under different climate change scenarios (A1FI and B1) in 2020s, 2050s and 2100s, under significant level 0.05 (SAS, 2000). The data were tested for differences in calculated ET_o and IR in the four governorates (El-Bihera, Al-Dakahlia, Matruh and North of Sinai).

3 Results and Discussion

This study was divided into two parts, forecasting the future air temperatures and then assessing the impacts of the predicted air temperatures on the ET_o and irrigation requirements (IR) of olive and citrus crops. The use of MAGICC 6.0 to downscale climatic change parameters such as minimum and maximum air temperature for the current climate was good agreement with the observed data, thus the future climate simulation statistical downscaling data was input into the CROPWATE 8.0 model to estimate future irrigation requirements.

3.1 Air temperature under current and future climate conditions

The annual minimum temperature increased significantly under climate change scenarios A1FI and B1 at 2020s, 2050s and 2100s compared to 1990 - 2019 in all governorates ($p<0.05$). The highest annual minimum air temperature values arise under A1FI, while the lowest arise under B1. The average annual minimum air temperature increased under 2020s, 2050s and 2100s A1FI scenario 1.20 °C, 1.60 °C and 3.10 °C on El-Bihera, 0.6 °C, 0.90 °C and 1.90 °C on Al-Dakahlia, 2.21 °C, 3.63 °C and 4.26 °C on Matruh and 0.92 °C, 1.25 °C and 2.45 °C on North of Sinai than 1990-2019 year, respectively. In other site B1 scenario increased temperature in 2020s, 2050s and 2100s about 0.80 °C, 2.00 °C and 2.67 °C on El-Bihera, 0.60 °C, 1.20 °C and 1.40 °C on Al-Dakahlia, 1.14 °C, 2.75 °C and 3.75 °C on Matruh and 0.65 °C, 1.54 °C and 1.95 °C on North of Sinai than 2000-2009 year , respectively (Fig. 3).

The average annual maximum air temperature

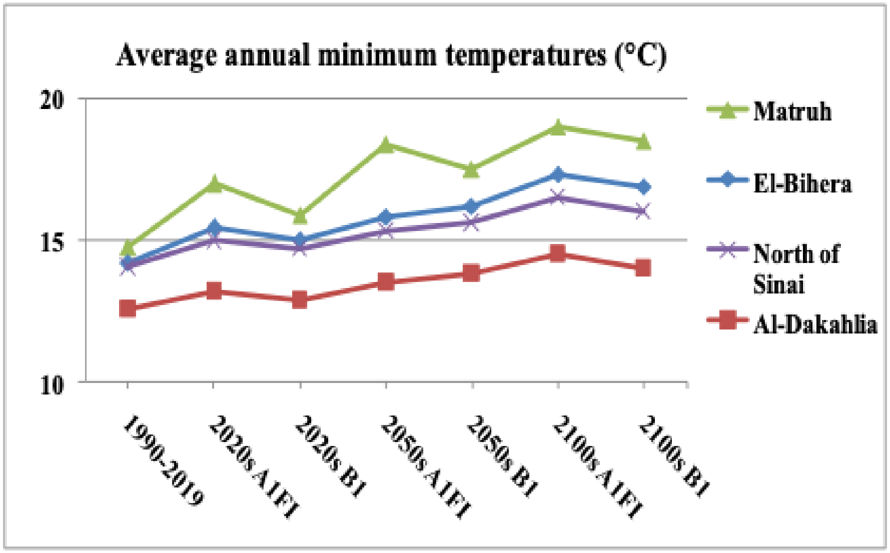

Figure 3. Average annual minimum air temperatures (°C) in Matruh, El-Bihera, Al-Dakahlia and North of Sinai governorates under A1FI and B1 scenarios, for the time periods 1990-2019, 2020s, 2050s and 2100s.

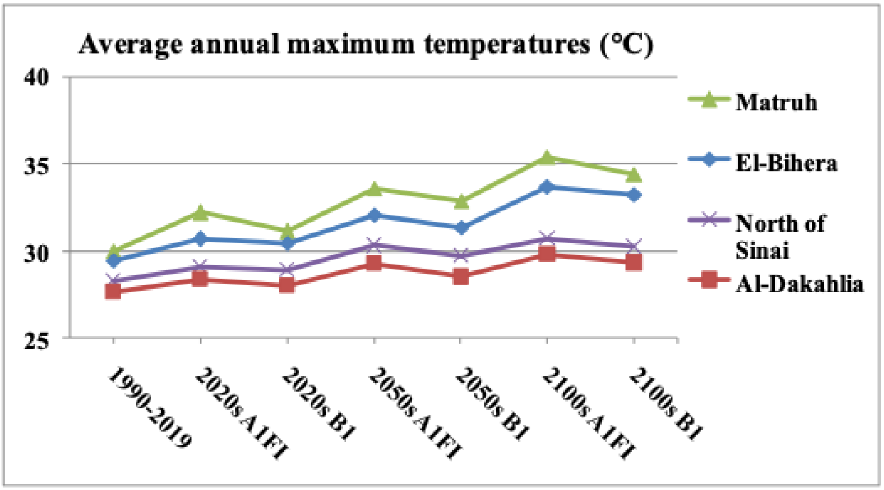

Figure 4. Average annual maximum air temperatures (°C) in Matruh, El-Bihera, Al-Dakahlia and North of Sinai governorates under A1FI and B1 scenarios, for the time periods 1990-2019, 2020s, 2050s and 2100s.

also increased significantly for all climate change scenarios A1FI and B1 at 2020s, 2050s and 2100s compared to 1990-2019 ($p<0.05$) (Fig. 4), climate change scenario A1FI having the highest average annual maximum air temperature, while the B1 scenario had the lowest annual maximum air temperature. The average annual maximum air temperature increased under 2020s, 2050s and 2100s A1FI scenario 1.21 °C, 2.63 °C and 4.20 °C on El-Bihera, 0.73 °C, 1.63 °C and 2.18 °C on Al-Dakahlia, 2.22 °C, 3.64 °C and 5.42 °C on Matruh and 0.85 °C, 2.05 °C and 2.42 °C on North of Sinai than 1990-2019 year, respectively. In other site B1 scenario increased temperature in 2020s, 2050s and 2100s about 0.98 °C, 1.88 °C and 3.75 °C on El-Bihera, 0.38 °C, 0.88 °C and 1.68 °C on Al-Dakahlia, 1.14 °C, 2.89 °C and 4.45 °C on Matruh and 0.65 °C, 1.44 °C and 1.95 °C on North of Sinai than 2000-2009 year, respectively. These results agreed with Farag and El-Taweel (2014) who carried out a case study of Egypt to investigate the impact of climatic changes on irrigation requirements based on air temperature changes according to A1 and B1 scenarios. Reported that, the air temperature will increase by 5.20 °C and 3.8 °C in different climatic regions of Egypt under A1 and B1 scenarios, respectively. The air temperature all over Egypt could be increased by range of 1.0 -1.3 °C, 1.9 - 2.6 °C and 2.2 - 4.9 °C under climate change scenarios (A1, A2, B1 and B2), respectively (Attaher et al., 2006). Air temperature will increase by uneven values in different climatic regions of Egypt under climate change conditions, the best estimate for the low scenario (B1) is 1.8 °C (likely range is 1.1 °C to 2.9 °C), and the best estimate for the high scenario (A1FI) is 4.0 °C (likely range is 2.4 °C to 6.4 °C) (IPCC, 2007). Betts et al. (2011) reported that under the six climate change scenarios (A1FI, A2, A1B, B2, B1 and A1T) global mean temperatures are likely to increase by between 1.1 °C and 6.4 °C by the end of the 21st century.

3.2 Average annual ET_o under current and future climate conditions

Fig. 5 illustrated the averages of annual ET_o at 1990 - 2019 and two climate change scenarios A1FI and B1 at 2020s, 2050s and 2100s under El-Bihera, Al-Dakahlia, Matruh and North of Sinai governorates. Under current climate conditions (1990-2019), the highest annual ET_o was recorded in El-Bihera governorate and Matruh, respectively. But the lowest annual ET_o was recorded in Al-Dakahlia governorate and North of Sinai, respectively. Matruh has the highest annual ET_o (4.77 mm d^{-1}); while Al-Dakahlia has the lowest annual ET_o (2.9 mm d^{-1}). The ET_o increased significantly under climate change scenarios A1FI and B1 at 2020s, 2050s and 2100s compared to 1990 - 2019 in all governorates ($p<0.05$). The highest ET_o value 6.68 mm d^{-1} was found at 2100s under A1FI scenario at Matruh; while the lowest ET_o value 2.96 mm d^{-1} was found at Al-Dakahlia under B1 scenario in 2020s (Fig. 5). These results agreed with Farag and El-Taweel (2014) who reported that, the ET_o increased significantly under climate change scenarios A1 and B1 at 2050s and 2100s compared to 2000-2009 in all climate regions (Ismailia, Assuit, Fayoum, North Sinai and Matrouh).

Fig. 6 showed the annual ET_o change rate under current and future climate conditions. The annual average ET_o increased from 0.46 to 1.40 mm d^{-1} for El-Bihera; in Al-Dakahlia ET_o increased from 0.08 to 0.48 mm d^{-1}; in Matruh ET_o increased from 0.56 to 1.91 mm d^{-1}; while in North Sinai ET_o increased from 0.16 to 0.87 mm d^{-1} under A1FI scenario. The B1 scenario increased ET_o under different climate region as the following, El-Bihera from 0.32 to 1.2 mm d^{-1}; Al-Dakahlia from 0.06 to 0.28 mm d^{-1}; Matruh from 0.43 to 1.78 mm d^{-1} and North Sinai from 0.13 to 0.83 mm d^{-1}, These results agree with Farag and El-Taweel (2014) who reported that, projected ET_o of Egypt will increase from 0.6 to 1.4 mm d^{-1} under A1 scenario. Ouda et al. (2015) reported that climate change condition (A1B scenario) in 2040 is expected to increase ET_o values for all governorates in Egypt, by 8% in the Nile Delta governorates (Alexandria, El-Bihera, Kafr El-Sheik, Al-Dakahlia and Demiatt), 11% in Middle Egypt governorates and 18% in Upper Egypt governorates.

Fig. 7 provided the annual irrigation requirements values for mature citrus and olive trees at El-Bihera, Al-Dakahlia, Matruh and North of Sinai governorates under current and climate change scenarios A1FI and B1. Annual average irrigation requirements for mature citrus and olive trees resulted from multiplying the average annual ET_o for each governorate by crop coefficient (kc) of mature citrus and olive trees. According to current climate conditions (1990-2019), the highest annual irrigation requirements for citrus and olive trees were recorded in El-Bihera governorate and Matruh, respectively. But the lowest annual irrigation requirements for citrus and olive trees were recorded in Al-Dakahlia governorate and North of Sinai, respectively. One feddan of citrus irrigation requirements about 2608.64 m^3 yr^{-1} and 3245.82 m^3 yr^{-1} for Al-Dakahlia and El-Bihera, respectively. In other site, one feddan of olive irrigation requirements about 3048.22 m^3 yr^{-1}, 3227.26 m^3 yr^{-1} and 2917.1 m^3 yr^{-1} for El-Bihera, Matruh and North of Sinai, respectively. The irrigation requirements for citrus and olive trees under climate change increased significantly in both scenarios A1FI and B1 at 2020s, 2050s and 2100s compared to the current situation 1990-2019 ($p<0.05$). Furthermore, the B1 scenario was lower than A1FI scenario in irrigation need under 2020s, 2050s and 2100s years. While 2020s and 2050s was lower than 2100s under both tested scenarios.

The highest irrigation requirement values for cit-

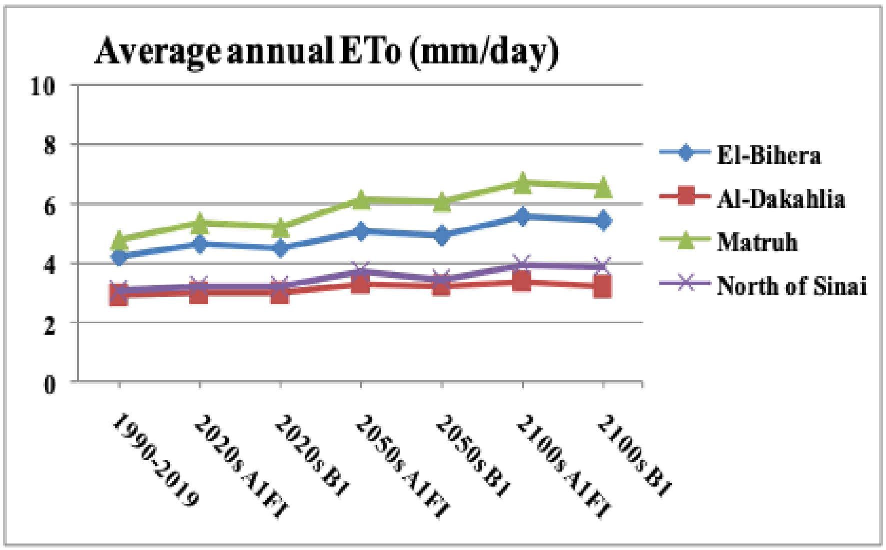

Figure 5. Average of annual ET_o (mm d^{-1}) in Matruh, El-Bihera, Al-Dakahlia and North of Sinai governorates under A1FI and B1 scenarios, for the time periods 1990-2019, 2020s, 2050s and 2100s.

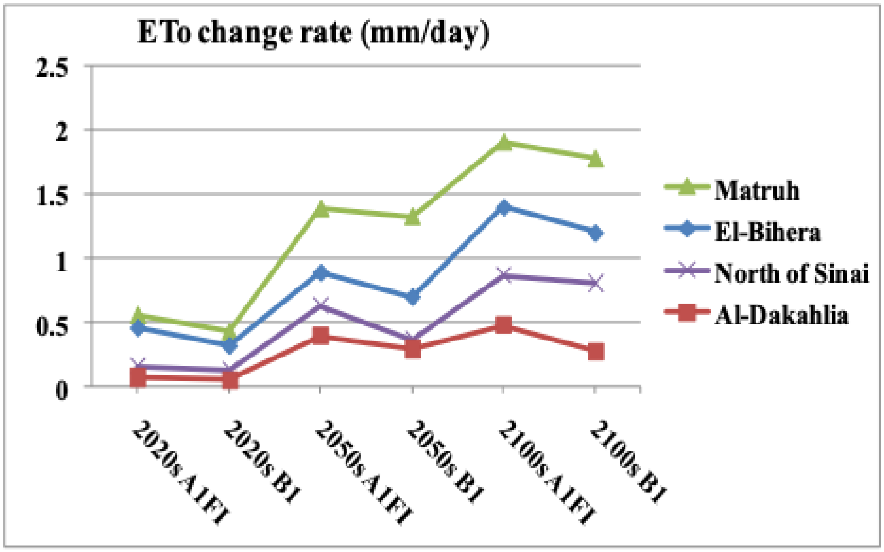

Figure 6. Annual ET_o change rate (%) in Matruh, El-Bihera, Al-Dakahlia and North of Sinai governorates under A1FI and B1 scenarios, for the future periods 1990-2019, 2020s, 2050s and 2100s.

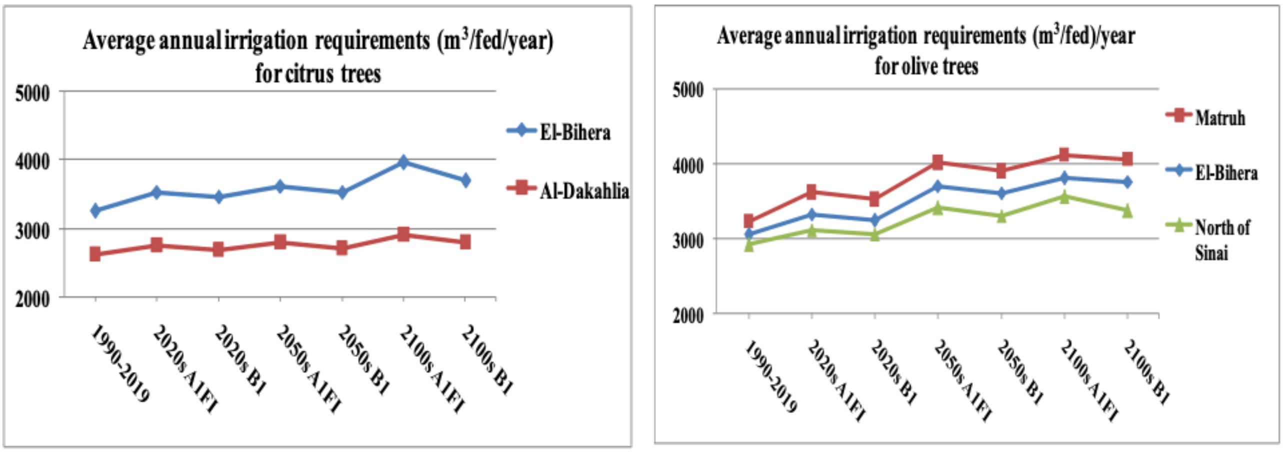

Figure 7. Average of annual irrigation requirements (m^3 fed^{-1}) for mature citrus and olive trees in Matruh, El-Bihera, Al-Dakahlia and North of Sinai governorates under A1FI and B1 scenarios, for the time periods 1990-2019, 2020s, 2050s and 2100s

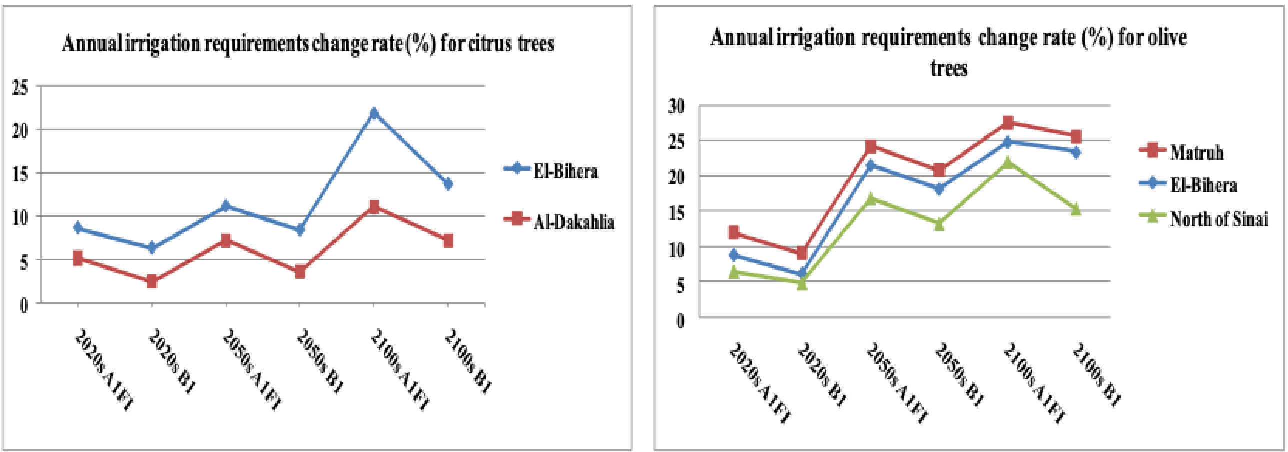

Figure 8. Annual irrigation requirements change rate (%) for mature citrus and olive trees in Matruh, El-Bihera, Al-Dakahlia and North of Sinai governorates under A1FI and B1 scenarios, for the future periods 1990-2019, 2020s, 2050s and 2100s.

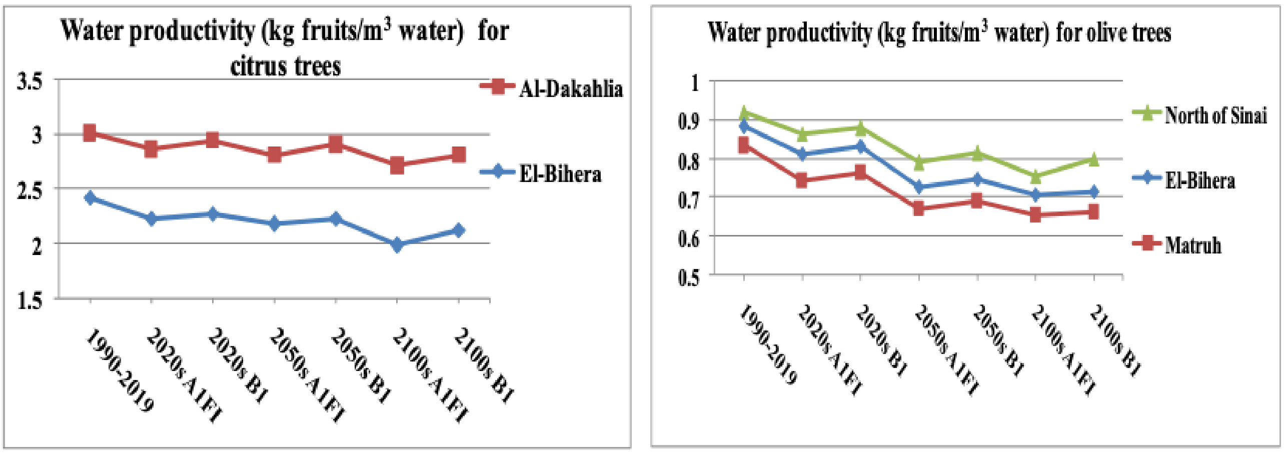

Figure 9. Average annual water productivity (kg fruits m^{-3} water) for mature citrus and olive trees in Matruh, El-Bihera, Al-Dakahlia and North of Sinai governorates under A1FI and B1 scenarios, for the time periods 1990-2019, 2020s, 2050s and 2100s.

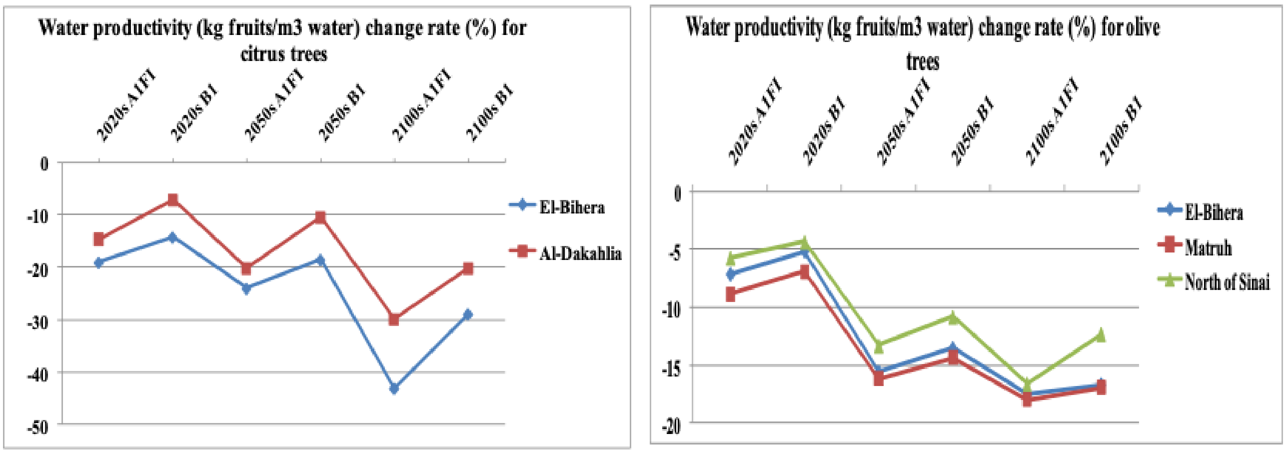

Figure 10. Annual water productivity (kg fruits m^{-3} water) change rate (%) for mature citrus and olive trees in Matruh, El-Bihera, Al-Dakahlia and North of Sinai governorates under A1FI and B1 scenarios, for the time periods 1990-2019, 2020s, 2050s and 2100s.

rus and olive trees were recorded at 2100s under A1FI scenario 3953.52 m^3 fed^{-1} and 4115.18 m^3 fed^{-1}, respectively. While the lowest irrigation requirement values for citrus and olive trees were recorded at 2020s under B1 scenario 2672.30 m^3 fed^{-1} and 2917.1 m^3 fed^{-1}, respectively (Fig. 7).

The highest increasing percentage of the estimated irrigation requirements for citrus and olive trees was found in El-Bihera governorate 21.80% and Matruh 27.51% at 2100s under A1FI scenario, respectively. While the lowest increasing percentage of the irrigation requirements for citrus and olive trees was found in Al-Dakahlia governorate 2.44% and in North of Sinai 4.91 % at 2020s under B1 scenario, respectively (Fig. 8). These results are in line with Ouda et al. (2015) who reported that, the values of IR increased by 8% in the Nile Delta governorates, 9% in Middle Egypt governorates and 12% in Upper Egypt governorates under climate change conditions (A1B scenario). Several studies indicated that the irrigation requirements of the important strategic crops in Egypt would increase under all IPCC SRES scenarios of climate change by a range of 5 to 13% (Irmak et al., 2012; Moratiel et al., 2011; Nour El-Din, 2013), by a range of 16.8 to 29.1% (Farag et al. 2014) and by a range of 6 to 16% (Attaher et al. 2006) during the 2100s. Malkia and Etsouri (2018) also reported that the irrigation requirements of the Bounamoussa perimeter, North-East of Algeria will increase from 3 to 5 times the current requirements. The increase in these requirements will be mainly due to the increase in air temperature and the decrease in rainfall.

3.3 Water productivity under current and future conditions

Fig. 9 showed the annual water productivity values for mature citrus and olive trees at El-Bihera, Al-Dakahlia, Matruh and North of Sinai governorates under current and future (A1FI and B1 scenarios) conditions. Results indicated that water productivity decreased significantly under climate change scenarios (A1FI and B1) in all governorates at 2020s, 2050s and 2100s compared to the current situation 1990-2019 ($p<0.05$).

The highest water productivity for citrus and olive trees obtained in Al-Dakahlia and North of Sinai governorates under current climate condition, respectively. The lowest water productivity for citrus and olive trees was obtained in El-Bihera and Matruh governorates, respectively. On the other hand, under climate change scenarios the highest water productivity for citrus and olive trees was obtained in Al-Dakahlia (2.93 kg^{-1} water) and North of Sinai (0.87 kg^{-1} water) at 2020s B1, respectively. The lowest water productivity for citrus and olive trees was obtained in El-Bihera (1.7 kg^{-1} water) and Matruh (0.73 kg^{-1} water) at 2100s A1FI, respectively (Fig. 9). Similar results were reported by Farag and El-Taweel (2014) and Farag et al. (2015).

The highest decreasing percentage of annual water productivity for citrus and olive trees was found in El-Bihera governorate 43.21% and Matruh 17.99% at 2100s under A1FI scenario, respectively. While the lowest decreasing percentage of the annual water productivity needs for citrus and olive trees was found in Al-Dakahlia governorate 7.15% and in North of Sinai 4.32% at 2020s under B1 scenario, respectively (Fig. 10). Finally, our results indicated that the water productivity to increase depending on irrigation requirements. The high irrigation requirements under climate change scenarios (A1FI and B1) makes water productivity of citrus and olive trees for all governorates becoming the lowest compared with water productivity under current conditions (1990-2019).

4 Conclusion

The results concluded that, the climate change conditions (A1FI and B1 scenarios) in 2020s, 2050s and 2100s is expected to increase maximum and minimum air temperatures values and ET_0 values for Egyptian governorates (El-Bihera, Al-Dakahlia, Matruh and North of Sinai) compared to the current situation 1990-2019. As a consequence, irrigation requirements (IR) for citrus and olive crops are also increased by 21.80% and 27.51%, respectively. But the water productivity (WP) values for citrus and olive crops were decreased by 43.21% and 17.99%, respectively, as compared to the current situation 1990-2019. Our results revealed a significant negative impact of climate change on irrigation requirements and water productivity of citrus and olive crops in Egypt. This emphasizes the need for new strategies for sustainable water resources management for the mitigation of the implications of climate change in Egypt.

Conflict of Interest

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

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