Chapter 7
Climate Change Assessment in Egypt: A Review

Samiha Ouda and Abd El-Hafeez Zohry

Abstract The objective of this chapter was to review all the previous climate change studies done in Egypt on water resources, crops production, evapotranspiration, seasonal crop coefficients, water consumptive use and water requirements of crops, cultivated soils and areas, suitability of growing area to be cultivated with a certain crop and food gaps in Egypt. Literature review was done for 67 research papers found on the internet to cover these items. Thus, adaptation strategies should be applied when possible to reduce the vulnerability associated with climate change.

Keywords Water resources · Crops production · Water requirements of crops · Cultivated soils and area · Suitability of growing area to be cultivated with a certain crop · Food gaps

7.1 Introduction

Egypt is particularly vulnerable to climate change, due to its geographical position and its dependence on climate-sensitive economic sectors, namely agriculture (FAO 2012). Sea level rise is expected to affect the living conditions of millions of people in the coastal zone of Egypt, which could exposed them to economic, social, and/or health risks (Leach et al. 2013). IPCC (2007) indicated that global climate models are probably the only way to investigate the non-linear interactions between the four major components of the climate system: atmosphere, biosphere, oceans and sea-ice. Furthermore, the study of climate variability and climate change has progressed

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over the last decade from the use of relatively simple global models, consisting of atmospheric models coupled to slab ocean models (IPCC 1990a, b), to more realistic global coupled ocean-atmosphere-land-ice models (IPCC 1999).

Uncertainty in future climate change presents a key challenge for water resources adaptation planning. Uncertainty in climate information form limitations in our ability to model the climate system and in our understanding of how future greenhouse gas emissions will change (Moss et al. 2010). Climate projections are based on a variety of scenarios, models and simulations procedures, which contain a number of embedded assumptions. Gagnon-Lebrun and Agrawala (2006) noted that the level of certainty associated with climate change and impact projections is a key in determining the extent to which such information can be used to formulate appropriate adaptation responses.

The objective of this chapter is to review all the previous climate change studies done in Egypt on water resources, crops production, evapotranspiration, seasonal crop coefficients, water consumptive use and water requirements of crops, cultivated soils and areas, suitability of growing area to be cultivated with a certain crop and food gaps in Egypt.

7.2 Climate Change and Water Resources

Egypt is enormously relays on the Nile River as a main source of water resources, which contributes with about 95% of Egypt's water budget. Other sources are precipitation and groundwater, which contribute with about 5% of the available supply. Hulme et al. (1995) indicated that temperature rise by 2 °C coupled with a 20% decrease in precipitation could reduce the flow of Nile by 88%. Whereas, a higher increase in temperature to 4 °C with the same reduction in precipitation could result in 98% decrease in Nile flows. Sayed (2004) indicated that the studies on the effect of climate change on the Nile flow clearly showed that the assessment is strongly dependent on the choice of the climate scenario and the underlying GCM model. For temperature, although the magnitude of the change varies, the direction of change is clear, where all models expected that a rise in the temperature. For rainfall, however, not only the magnitude varies substantially across the models, but even the signal of the change varies. The choice of the emission scenario also leads to different projection. In addition, other studies show that the Nile flow is extremely sensitive to climate, and especially rainfall changes due to the highly non-linear relationship between precipitation and runoff. The uncertainty about the increase or decrease in precipitation near the sources of the Nile, as well as variations in temperature could have a larger than expected effect on Nile flows because these two factors are also interrelated leads to moderate to extreme effects (Elsaeed 2012). In addition, Nour El-Din (2013) reported that there are some uncertainty about that the effect of future climate changes in East Africa, where roughly two-thirds of the general circulation models project an increase in precipitation on the Blue Nile; which contributes more than 75% of the Nile flows. Whereas, one-third expect reduced precipitation. However, it is virtually certain that the Nile Basin has become warmer and the warming is expected to continue.

Furthermore, Agrawala et al. (2004) indicated that vulnerability of Egypt's water resource and its dependence on the Nile is tied to trends in population growth, land use, and agriculture intensively concentrated along the Nile Valley and Delta. Alkitkat (2017) projected 32% increase in the Egyptian population by the year of 2030, compared to its value in 2014. Thus, it is likely that Nile water availability to be increasingly stressed as demand increases, due to growth in population and increases in temperature leading to greater evaporative losses.

It has also been suggested that Egypt's precipitation may decrease due to climate change, with an annual decline up to 5, 8 and 13% by 2030, 2050, and 2100, respectively (Barbi 2014). On the basis of rain fall deviations from the mean, four categories were developed by Kumar et al. (2009) to monitor and evaluate the rain fall patterns: ±10% deviation consider as normal, −10 to −60% deviation in the rain fall is consider as deficit, less than −60% deviation consider as scanty, and greater than 20% deviation consider as excess. Accordingly, Ouda et al. (2016a) the projected value of annual rainfall in eastern coast of Egypt in 2030 was the lowest than its counterpart values from 1997 to 2014, except for the amount of precipitation fall in 1999, which was lower (Figure 7.1a). Rainfall deviation in 2030 from the average of 18 years was −27%, which considered deficit. Similarly, in the western coast of Egypt, the projected annual rain fall value in 2030 will be the lowest compared to the recorded values from 1997 to 2014 (Figure 7.1b). Rainfall deviation in 2030 from the average of 18 years was −95%, which considered scantly.

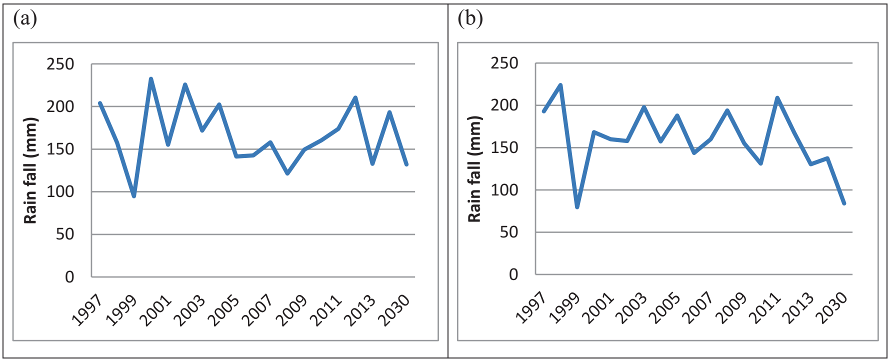

Fig. 7.1 Comparison between annual amounts of rain fall values from 1997 to 2014 and its projected value in 2030 in (**a**) North Sinai and (**b**) Marsa Matrouh. (Source: Ouda et al. 2016a)

7.3 Projection of Climate Change Impacts on Crops Production

7.3.1 Using IPCC Report (1990)

Global models of the climate system of the world are an important tool in climate research. Climate change impact on crops in Egypt started as early as in the 1990c, where the late Prof. Helmy Eid and others assessed its consequences on the production of the crops grown in clay soil under surface irrigation. In his early work, he used MAGICC/SCENGEN model to calculate the annual mean global surface air temperature and global-mean Sea-level implications of emissions scenarios for greenhouse gases. SCENGEN model was run using CSIRO-GCM model and climatic data were extracted using regression model for year 2000 and 2050. The results of this methodology indicated that the increase in annual temperature of Egypt will be 0.9–1.9 °C with an average of 1.4 °C, in addition to sea level rise averaged by 20 cm in the year 2050, compared to the current conditions (Eid et al. 1992).

Furthermore, climate change scenarios created by combining the daily climate data for each site with the output of three equilibrium General Circulation Models (GCMs): the Geophysical Fluid Dynamics Laboratory (GFDL), Goddard Institute for Space Studies (GISS), and United Kingdom Meteorological Office (UKMO) models. Under these scenarios, projected precipitation changes are more uncertain, and solar radiation changes are projected to be small (El-Shaer et al. 1996).

To simulate the effect of climate change, DSSAT3 model (Jones et al. 2003) was used to project the yield of several crops on the national level in 2050, namely wheat, barely, maize, sorghum, rice and soybean under increased CO_2 concentration level. Table 7.1 summarized some of the work done in that era.

Table 7.1 Projected percentage of change (%) in the yield of several crops under climate change in 2050 using MAGICC/SCENGEN model

Crop	Change in yield (%)	References
Wheat	−23	Eid et al. (1993a)
	−19	Eid et al. (1994a)
	−19	Eid et al. (1997a)
Maize	−23	Eid et al. (1992)
	−19	Eid et al. (1997b)
Barley	−20	Eid et al. (1995)
Rice	−11	Eid et al. (1995)
	−11	Eid et al. (1996)
Soybean	−18	Eid and El-Sergany (1993)
	−28	Eid et al. (1994b)
	−26	Eid et al. (1996)
Cotton	+17	Eid et al. (1997c)

7.3.2 *Using IPCC Report (2001)*

Other researches depended on the Special Report on Emissions Scenarios (SRES) developed by the IPCC (2001) to generate climate change scenarios, namely A1, A2, B1 and B2. The SRES scenarios combined two sets of divergent tendencies; one set varies between strong economic values and strong environmental values, while the other set varies between increasing globalization and increasing regionalization. Table 7.2 presented some of these investigations.

In 2009, climate change effects on crops grown under different irrigation systems and different soils types in different sites in Egypt were implemented in field experiments to increase our knowledge on its contribution in reducing yield losses. The results of these experiments were used to calibrate CropsSyst model (Stockle et al. 1994) and simulate the effects of A2 and B2 on the yield of wheat, maize, cotton and barley without using CO_2 enrichment was done. Furthermore, early sowing, changing irrigation scheduling and using improved management practices were implemented in field experiments, and then the effect of climate change on these practices was simulated as followed:

In clay soil and surface irrigation, in 2030, Khalil et al. (2009) and Moneir (2012) indicated that wheat cultivar Sakha93 was superior in withstanding the stress of climate change, where its yield losses were the lowest, namely 33–36% and 31–35% for A2 and B2 climate change scenarios, respectively in both investigations. These two climate change scenarios were developed from HadCM3 climate change model. They also indicated that early sowing of wheat in the 1st week of November reduced yield losses by 3 and 4% for A2 and B2, respectively. Using the same climate change model, Ouda et al. (2009) indicated that maize hybrid TWC324 was found to be more tolerant to climate change stress, where its yield losses were 49 and 47% under A2 and B2, respectively. The best adaptation strategy was early sowing in the first week of May and applying irrigation in every 14 days, which reduced yield losses by 4 and 6% under A2 and B2, respectively. Furthermore, application of the second irrigation 21 days after sowing and then every 16 days until the end of the growing season was found to be the best adaptation study (Moneir 2012).

Similar assessment was done for barely, where two climate change scenarios (A2 and B2) resulted from CISRO climate change model were incorporated with

Table 7.2 Projected percentage of change (%) in the yield of several crops under climate change in 2050 using SRES scenarios

Crop	Change in yield (%)	References
Wheat	−18	Hassanein (2010)
Maize	−19	Hassanein (2010)
	−14	Hassanien and Medany (2007)
Rice	−11	Hassanein (2010)
Potato	−2	Medany and Hassanein 2006
	−11	Saleh (2007)
Tomato	−19	Abou-Shleel and Saleh (2011)

CropSyst model to study its effect on barley yield in the year of 2039. The results showed that barely yield will be reduced by 17 and 18% averaged over the six cultivars under A2 and B2 climate change scenarios, respectively. Moreover, changing irrigation schedule to applying irrigation every 23 days improved barley yield by an average of 2%. Giza2000 cv. was less affected by heat stress of climate change scenarios and had the least yield losses, and responded well to changing irrigation schedules. Changing irrigation schedule to barley by applying water every 23 days resulted in reduction of barley yield losses by an average of 2% for both scenarios (Ouda et al. 2010).

In silty clay soil and under sprinkler system, four wheat cultivars, i.e. Sakha94, Sakha93, Giza168 and Gemmiza9 were planted in three sowing dates: 9th of November, 24th of November and 8th of December under four irrigation treatments, i.e. irrigation with 0.6, 0.8, 1.0 and 1.2 ETc. The results indicated that Sakha93 planted in 24th of November under 1.2 ETc had the lowest yield losses, namely 39 and 34% under A2 and B2 climate change scenarios, respectively (Noreldin et al. 2012). In the above soil type and under drip system, four maize hybrids, i.e. SC10, SC128, TWC310 and TWC323 were sown under three sowing dates: on the 2nd of May, on the 13th of May and on 1st of June with 4 irrigation treatments, i.e. irrigation amount with 0.6, 0.8, 1.0 and 1.2 ETc in a field experiment. The effect of climate change was simulated using A2 and B2 climate change scenarios. The lowest yield losses were found for hybrid SC128 planted on 2nd week of May using 1.2 ETc, namely 28 and 25% under A2 and B2 climate change scenarios, respectively (Ouda et al. 2012a).

In salt affected soil and under surface irrigation, the effect of climate change on two crops was studied: wheat and cotton. In both experiments, three irrigation treatments were studied, i.e. farmer irrigation practice (characterized by large applied irrigation amount), required irrigation amount and irrigation amount applied for raised bed cultivation. With respect to cotton, yield losses under farmer practice were 28% under A2 climate change, and between 22% under B2 climate change scenario. Cotton yield losses were lower under required irrigation amount by 25 and 21% and under the irrigation amount applied for raised bed cultivation by 22 and 18% under A2 and B2 climate change scenarios (Ouda et al. 2013). Wheat yield losses under farmer irrigation practice were also high namely 47 and 44% under A2 and B2 climate change scenarios, respectively. Wheat yield losses were reduced by 5% when required irrigation amounts was applied, whereas the losses in wheat yield were further reduced by 7 and 9% under A2 and B2 climate change scenarios, respectively (Ouda et al. 2012b).

In sandy soil and under sprinkler irrigation, wheat was grown under two treatments: farmer traditional practice in applying chemicals through broadcasting fertilizers and use the sprayers to add herbicides to the plants, and chemigation, where chemicals are applied via the sprinkler system. Wheat yield losses under farmer practice were 32 and 27% under A2 and B2 climate change scenarios, respectively. Whereas, wheat yield losses under chemigation were 26 and 20% under A2 and B2 climate change scenarios, respectively (Ouda et al. 2010). In another experiments, the effect of using improved agricultural management practices on wheat yield was studied. Eight fertigation treatments (interaction between irrigation with 0.6, 0.8, 1.0 and 1.2 ETc and fertigation application in 60 and 80% of irrigation time), in addition to farmer irrigation were tested. The results showed that the highest yield reduction, i.e. 39 and 37% was obtained under A2 and B2 climate change scenarios, respectively for farmer irrigation. The lowest yield reduction was obtained under irrigation with 1.0 ETc and fertigation application in 80% of irrigation time, i.e. 27 and 24% under A2 and B2 climate change scenarios, respectively (Taha 2012). Similar experiment was applied for maize with the same treatments. The results showed that the highest yield reduction, i.e. 43 and 41% was obtained under A2 and B2 climate change scenarios, respectively for farmer irrigation. The lowest yield reduction was obtained under irrigation with 1.2 ETc and fertigation application in 80% of irrigation time, i.e. 38 and 35% under A2 and B2 climate change scenarios, respectively (Taha 2012).

7.3.3 Using IPCC Report (2013)

IPCC (2013) developed new global climate change models for new projection, mitigation and adaptation scenarios involving policy decisions and options for targeted climate change stabilization at different levels during the IPCC Fifth Assessment Report (AR5). Its findings were based on a new set of scenarios that replace SRES (Wayne 2013). The climate projections in the IPCC fifth assessment report were based on Coupled Model Inter-comparison Project Phase 5 (CMIP5). This presents an unprecedented level of information on which to base projections including the latest versions of climate models. It includes more complete representation of forcings to produce a new four Representative Concentration Pathways scenarios (RCPs) and more output available for analysis.

Sayad et al. (2015) compared between measured weather data and projected data (2006–2014) from four global climate models (BCC-CSM1-1, CCSM4, GFDL-ESM 2G and MIROC5), with four Representative Concentration Pathways scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) developed for four Egyptian governorates (Kafr El-Sheikh, El-Gharbia, El-Minya and Sohag) to determine the suitable RCPs climate change scenarios in 2030 at each governorate. Their results indicated that the RCP6.0 developed by CCSM4 model and RCP8.5 developed by BCC-CSM1-1 and MIROC5 models were acceptable for Kafr El-Sheikh governorate. Whereas, the suitable scenarios for El-Gharbia governorate was RCP6.0 developed by CCSM4 model and RCP8.5 developed by MIROC5 model. Nevertheless, in El-Minia governorate, the highest agreement between measured and projected values was found for RCP8.5 and RCP6.0 scenarios developed by CCSM4 model. With respect to Sohag, the most suitable scenario was RCP6.0 which is developed by CCSM4 model. Consequently, they recommended the use the RCP6.0 scenario developed by CCSM4 model as a suitable scenario for all selected governorates.

Using the results of the above investigation, Ouda (2017) calculated the increase in weather elements in 2030, compared to its values in 2040. Table 7.3 shows the

Table 7.3 The increase in the values of weather elements in 2030, compared with its values in 2014

	Solar radiation (MJ/m/day)	Temperature (°C)	Wind speed (m/s)
Alexandria	0.5	0.5	1.5
Behira	0.4	1.0	0.9
Gharbia	0.8	1.9	0.2
Kafr El Sheikh	0.9	1.2	0.6
Dakahlia	0.5	1.9	0.9
Damietta	0.7	1.1	0.8
Sharkia	0.9	0.7	0.7
Menoufia	0.9	2.0	0.8
Qalyubia	0.9	2.1	0.8
Giza	0.8	2.6	0.5
Bani Sweif	0.9	2.1	0.6
Fayoum	0.7	1.3	0.7
Minya	1.0	1.1	0.8
Assiut	1.0	1.7	1.3
Sohag	1.2	1.9	1.4
Qena	2.3	2.1	1.7
Aswan	3.3	2.2	1.3
New Valley	2.1	2.0	1.5
Average	1.1	1.6	0.9

Source: Ouda (2017)

increase in the values of weather elements in 2030 using RCP6.0 scenario developed by CCSM4 model, compared with its values in 2014. The table showed that it is expected that solar radiation will increase by 1.1 MJ/m/day, temperature will increase by 1.1 °C and wind Speed will increase by 0.9 m/s in 2030.

Furthermore, Morsy (2015) simulated the effect of climate change on wheat and maize yield using under climate change using RCP6.0 scenario developed by CCSM4 model in 2030 and he projected 10–12% wheat yield losses and 13–15% maize yield losses.

7.4 Climate Change and Evapotranspiration

Climate change is likely to have significant impacts on the hydrological cycle, and it will be intensified with more evaporation and variable precipitation will be unequally distributed around the globe (IPCC 2001).

The IPCC Forth Assessment Report (IPCC 2007) synthesized current scientific understanding of global warming and projected future climate change using the most comprehensive set of well-established global climate models. The report identified three climate change scenarios: B1, A2 and A1B, where the global tempera-

Table 7.4 Percentage of increase in ETo under A1b climate change scenario in 2020, 2030 and 2040

Governorate	ETo in 2020	ETo in 2030	ETo in 2040
Nile Delta			
Alexandria	1	3	4
Demiatte	1	2	2
Kafr El-Sheik	2	2	2
El-Dakahlia	1	1	2
El-Behira	1	2	2
El-Gharbia	7	10	19
El-Monofia	5	10	19
El-Sharkia	7	14	17
El-Kalubia	7	11	19
Middle Egypt			
Giza	8	15	16
Fayoum	8	12	16
Beni Sweif	10	13	18
El-Minia	10	15	19
Upper Egypt			
Assuit	11	12	17
Sohag	12	10	18
Qena	11	14	19
Aswan	12	14	19
Average	7	9	13

Source: Ouda et al. (2016b)

ture is expected to rise by 1.8, 2.4 and 2.8 °C, respectively by the end of twenty-first century. These scenarios are also known as AR4 climate change scenarios.

A1B climate change scenario was used to calculate annual evapotranspiration (ETo) values in 2020, 2030 and 2040. ETo values under A1B climate change scenario were calculated for each month in each governorate and annual average values were calculated and compared to ETo values under current climate. The results indicated that the projected annual values of ETo is expected to increase by 7, 9 and 13% under 2020, 2030 and 2040, respectively (Table 7.4) (Ouda et al. 2016b).

Scientific understandings of phenomena are often tested via predictions that are compared against observations. Thus, one way to reduce uncertainty of climate change models is comparison between measured weather data and data from climate scenarios of these models and develops ensemble climate scenarios to improve the assessment of the effect of climate change. Ouda et al. (2016c) compared between measured weather data (2010–2013) and projected data from three global climate models (CSIRO-Mk3.5, ECHAM5 and CNRMCM3), with three climate change scenarios (A1B, A2 and B1) for El-Behira governorate (North Nile Delta) to find out the highest goodness of fit between each measured weather elements and its projected values for the three scenarios developed by the three models. They found out that the projected solar radiation obtained from ECHAM5 model, maximum

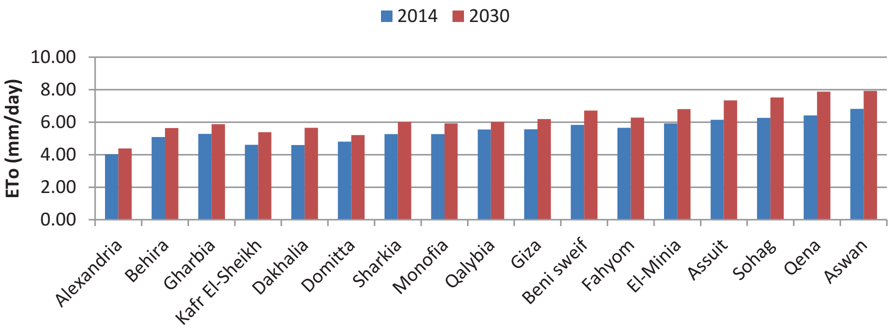

Fig. 7.2 Comparison between ETo values in 2014 and the projected ETo values in 2030. (Source: Ouda 2017)

temperature obtained from CSIRO-Mk3.5 and minimum temperature obtained from CNRM-CM3 had the highest closeness to the measured data. Thus, an ensemble model (ECCM) was developed and composed of solar radiation obtained from ECHAM5 model, maximum temperature obtained from CSIRO-Mk3.5 model and minimum temperature obtained from CNRM-CM3 model for A1B, A2 and B1 climate scenarios. The results also showed that ETc values for wheat and maize using the three climate change scenarios resulted from ECCM model in 2010 were more close to the values calculated from the measured weather values in the same year.

A comparison was made between ETo values in 2014 and the projected ETo values in 2030 using the RCP6.0 scenario developed by CCSM4 as the most suitable scenario for Egypt (Sayad et al. 2015) and it presented in Fig. 7.2. The figure showed that low differences in the values of ETo existed in North Egypt governorates and it gradually increased to be the highest in south Egypt governorates.

7.5 Effect of Climate Change on Seasonal Crop Coefficients

A comparison between crop coefficinets (Kc) values of several field crops in 2016 obtained from Ouda (2019a) and the projected Kc values in 2030 obtained from Ouda (2019b) is presented in Fig. 7.3. The figure showed that the values of Kc_{ini} were lower in 2030, compared to its counterpart values in 2016, except for faba bean. The values of Kc_{med} were higher in 2030, compared to its counterpart values in 2016 and the values of Kc_{end} were higher or similar in 2030, compared to its counterpart values in 2016.

Furthermore, a comparison between the Kc values of several fruit crops in 2016 (Ouda 2019a) and its values in 2030. Figure 7.4 showed that there were no differences in the value of Kc in its three growth stages in 2030, compared to its counterpart values in 2016. This could be attributed to that fact that fruit trees established ground cover all year long, could make it less responsive to the weather of winter and summer seasons.

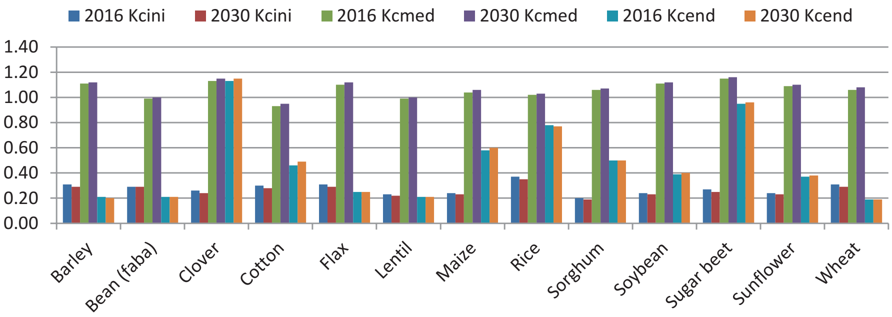

Fig. 7.3 Comparison between Kc values in 2016 and 2030 for several field crops in Egypt. (Source: Ouda 2019b)

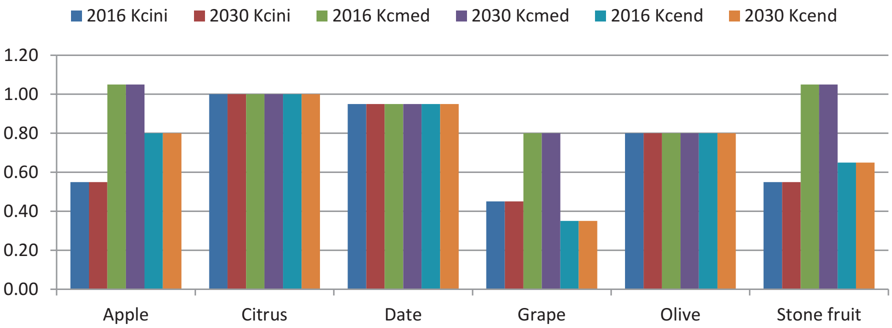

Fig. 7.4 Comparison between Kc values in 2016 and 2030 for several fruit crops in Egypt. (Source: Ouda 2019b)

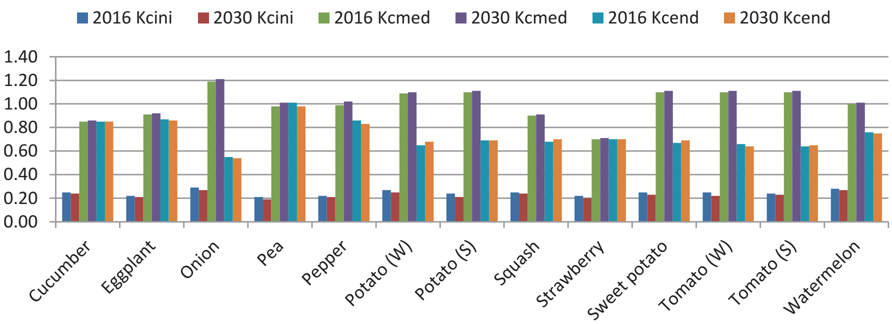

Fig. 7.5 Comparison between Kc values in 2016 and 2030 for several vegetable crops in Egypt. (Source: Ouda 2019b)

The values of Kc for the studied vegetable crops in 2016 (Ouda 2019a), were compared to its counterpart values in 2030 (Ouda 2019b) in Fig. 7.5. The figure showes that the values of Kc_{ini} were lower in 2030, compared to its counterpart values in 2016. The values of Kc_{med} were higher in 2030 and Kc_{end} values were lower in 2030, compared to its counterpart values in 2016, except for potato, squach, and sweet potato. The projected increase in the Kc values, especially in the middle of the growing season, where maximum growth existed, will cause increases in irrigation amounts required to satisfy the needs of these crops.

7.6 Effect of Climate Change on Water Consumptive Use/Water Requirements of Crops

MAGICC/SCENGEN model was used to calculate the annual mean global surface air temperature and global-mean Sea-level implications of emissions scenarios for greenhouse gases. SCENGEN model was run using CSIRO-GCM model and climatic data were extracted using regression model for year 2000 and 2050. Eid et al. (1992) indicated that climate change could increase crops water demand for summer and winter crops by 16 and 2%, respectively in the year 2050.

Water requirements for several crops were projected and percentages of increase in its values, compared to its current values are presented in Table 7.5.

Using climate change scenarios of the IPCC third assessment report (TAR) published in 2001, Attaher et al. (2006) calculated national irrigation water demand in 2050 and 2010. Their results indicated that A1 and A2 climate change scenarios will result in the highest increase in national irrigation water demand, compared to B1 and B2 climate change scenarios. Table 7.6 showed the percentage of increase in national irrigation water demand in 2050 and 2010.

Ouda et al. (2009) indicated that maize water consumptive use will increase by 11% under both A2 and B2 climate change scenarios. Furthermore, water requirements for barley will increase by 4 and 5% for the above mentioned climate change scenarios (Ouda et al. 2010).

A comparison was done between the water consumptive use (ETc) of different crops in 2016 presented by Ouda (2019a) and its counterpart values presented by

Table 7.5 Projected percentage of increase in the water requirements of several crops under climate change in 2050 using MAGICC/SCENGEN model

Crop	Percentage of increase (%)	References
Wheat	+3	Eid et al. (1993a, b)
	Not changed	Eid et al. (1994a, b)
	+1	Eid et al. (1997a)
Maize	+8	Eid et al. (1992)
Barley	+1	Eid et al. (1995)
Rice	+16	Eid et al. (1995)
Soybean	+3	Eid and El-Sergany (1993)
	+1	Eid et al. (1994a, b)

Table 7.6 Percentage of increase in national irrigation water demand in 2050 and 2010

Climate change scenario	2050[a]	2100[a]
A1	8	16
A2	7	11
B1	6	7
B2	7	9
Average	7	11

[a]calculated by the authors from Attaher et al. (2006)

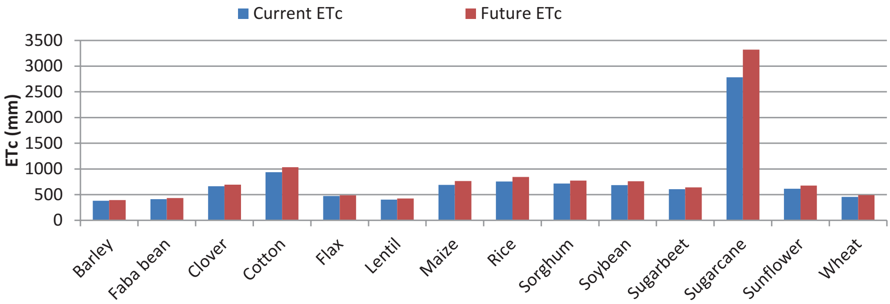

Fig. 7.6 comparison between water consumptive use of different crop in 2016 and 2030. (Source: Ouda 2019b).

Ouda (2019b) in 2030 in Fig. 7.6. A noticeable increase in water consumptive use values in 2030 is shown in the figure under climate change for the studied crops.

7.7 Climate Change and Cultivated Lands

Egypt, as a Mediterranean agricultural area, its soil is characterized by low soil organic carbon contents often degraded and highly vulnerable to environmental changes. Climate change is expected to have a large impact upon these areas (IPCC 2007). The evaluation of climate change impacts on soil organic carbon stocks can be done using carbon models and climate change scenarios (Karmakar et al. 2016).

7.7.1 *Effect of Climate Change on the Soils of Egypt*

Only one study was done on the effect of climate change on the soil of Egypt. For an example, Muñoz-Rojas et al. (2017) applied the CarboSOIL model and global climate models to predict the effects climate changes on soil organic carbon contents in 2030, 2050 and 2100 at standard soil depths (0–25, 25–50 and 50–75 cm) in Northern Egypt under different land use types. Overall decreases of soil organic carbon contents in the topsoil soil layer and increases in the subsoil layers are expected in the short, medium and long term. However, intensity of these changes will depend on the land use type and the results suggested that agricultural land uses relying on irrigation will be particularly vulnerable to losses of soil organic carbon stocks.

7.7.2 *Effect of Climate Change on Cultivated Area*

The effect of climate change on the cultivated area of Egypt has been studied. Fawaz and Soliman (2016) calculated the loss in the total cultivated area of Egypt in 2030 to be 8%, compared to the current cultivated area. Furthermore, Ouda and Zohry (2018) calculated the loss of the cultivated area of several winter and summer crops, as affected by the increase in water requirements of these cultivated crops and the expected water deficiency in the future in Egypt (Table 7.7). Their results indicated that the highest loss in the cultivated area of winter crops will occur for onion, namely 13% compared to its counterpart value in 2015. Whereas, for the summer

Table 7.7 The cultivated area of different winter and summer crops in 2015, the projected cultivated area in 2030 and percentage of reduction in the cultivated area

	Total cultivated area in 2015 (ha)	Total cultivated area in 2030 (ha)	Percentage of reduction (%)
Winter crops			
Wheat	1,354,844	1,260,005	7
Faba bean	34,418	32,353	6
Clover	624,741	568,514	9
Onion	148,173	128,910	13
Tomato	70,173	64,559	8
Potato	102,285	96,148	6
Sugar beet	231,193	212,697	8
Average			8
Summer crops			
Cotton	100,349	84,665	16
Rice	506,249	445,499	12
Maize	938,329	760,046	19
Soybean	14,130	11,728	17
Sunflower	6585	5465	17
Potato	53,110	43,989	17
Tomato	89,825	71,860	20
Sugarcane	134,656	111,765	17
Fruit trees	524,763	455,565	13
Average			16

Source: Ouda and Zohry (2018)

crops, the highest losses in the cultivated area will occur for tomato, namely 20% compared to its counterpart value in 2015. The overall losses in the national level will reach 8 and 16% compared to its counterpart value in 2015 in the winter and summer crops, respectively.

7.7.3 Effect of Climate Change on the Suitability of Cultivated Area to a Certain Crop

Under climate change, the expected rise in the temperature could limit suitability of a certain area to grow a certain crop, in which very low productivity per hectare will result. Thus, under these circumstances, it will be uneconomical to cultivate that crop in this area. Mahmoud et al. (2016) stated that the cutoff temperature (a temperature value under which plant growth ceases) for rice is 35 °C. They compared between the expected maximum temperature under climate change in 2040 and the cutoff temperature in the cultivated zone of rice in the Nile Delta of Egypt in eight governorates. A summary of their results presented in Table 7.8.

During the growing season of rice in 2040, no yield losses will occur in Alexandria and Demiatte, where both located on the Mediterranean Sea and maximum temperature will not rise above 35 °C. At Kafr El-Sheikh and El-Dakahlia, a rise above 35 °C will occur for few days. Maximum temperature will rise above 40 °C for few days, at El-Behira and El-Gharbia. Governorates south of the above governorates will experience more heat stress as a result of rise in maximum temperature above 40 °C for more days. Thus, the above results implied that climate change risk on rice production will increase in 2040, as a result of heat stress, which will affect physiological process in the growing plants and results in losses in rice productivity and might also result in reduction in the cultivated zone by stopping its cultivation in Sharkia and Kalubia governorates.

Similar study was done for sugarcane by Taha et al. (2016), where they assessed the suitability of south Egypt governorates for sugarcane cultivation in 2040. Cutoff

Table 7.8 Rise above cutoff temperature during rice growing season under climate change in 2040

Governorate	Early season	Middle season	Late season
Alexandria	Below 35 °C	Below 35 °C	Below 35 °C
Demiatte	Below 35 °C	Below 35 °C	Below 35 °C
Kafr El-Sheikh	Few days above 35 °C	Few days above 35 °C	Below 35 °C
El-Dakahlia	Few days above 35 °C	Few days above 35 °C	Below 35 °C
El-Behira	Few days above 40 °C	Few days above 40 °C	Few days above 40 °C
El-Gharbia	Few days above 40 °C	Few days above 40 °C	Few days above 40 °C
El-Sharkia	More days above 40 °C	More days above 40 °C	More days above 40 °C
El-Kalubia	More days above 40 °C	More days above 40 °C	More days above 40 °C

Summarized by the authors from Mahmoud et al. (2016)

Table 7.9 Rise above cutoff temperature during fall sugarcane growing season under climate change in 2040

Governorate	Higher than 38 °C	Reach 44 °C	Higher than 45 °C
Minya	May–September	–	–
Sohag	May–September	–	–
Qena	–	May–September	–
Aswan	–	–.	May–October

Summarized by the authors from Taha et al. (2016)

temperature for sugarcane is above 38 °C, growth seizes (Bonnett et al. 2006). Their results indicated that in Minya and Sohag, a rise in temperature above 38 °C is expected to occur between May and September. In Qena and Aswan governorates, the rise in temperature will reach 44 °C and it will be higher than 45 °C, respectively in 2040 (Table 7.9). These findings implied that sugarcane productivity will be reduced in 2040 in this region as a result of heat stress and it will be still suitable to grow sugarcane.

7.8 Effect of Climate Change on Food Gaps

7.8.1 Wheat Production-Consumption Gap

As a result of reduction in the cultivated area of wheat under climate change, it is expected that wheat production will be reduced under the traditional cultivation and wheat self-sufficiency will reach 37% in 2030, compared to 47% in 2015. Furthermore, implementing the improved management package will increase wheat self-sufficiency to 61%, compared to 82% in 2015 (Table 7.10) (Ouda and Zohry 2017).

7.8.2 Maize Production-Consumption Gap

Table 7.11 showed that maize production is expected to be reduced under the traditional cultivation and its self-sufficiency will reach 42% in 2030, compared to 53% in 2015. Furthermore, implementing the improved management package will increase its self-sufficiency to 69%, compared to 86% in 2015 (Zohry and Ouda 2017a).

7.8.3 Faba Bean Production-Consumption Gap

Similarly, Table 7.12 indicated that faba bean self-sufficiency will be reduced in 2030 under climate change and will reach 18% under traditional cultivation, compared to 21% in 2015. Whereas, faba bean self-sufficiency will increase to reach

Table 7.10 Projected self-sufficiency of wheat in 2030 under traditional cultivation and under using improved management package

	Self-sufficiency under traditional cultivation (%)[a]	Self-sufficiency under improved management (%)[a]
Lower Egypt	40	66
Middle Egypt	32	53
Upper Egypt	37	55
Average	37	61

[a]Calculated by the authors from Ouda and Zohry (2017)

Table 7.11 Projected self-sufficiency of maize in 2030 under traditional cultivation and under using improved management package

	Self-sufficiency under traditional cultivation (%)[a]	Self-sufficiency under improved management (%)[a]
Lower Egypt	38	63
Middle Egypt	54	90
Upper Egypt	39	61
Average	42	69

[a]Calculated by the authors from Zohry and Ouda (2017a)

Table 7.12 Projected self-sufficiency of faba bean in 2030 under traditional cultivation and under using improved management package

	Self-sufficiency under traditional cultivation (%)[a]	Self-sufficiency under improved management (%)[a]
Lower Egypt	27	87
Middle Egypt	2	33
Upper Egypt	8	79
Average	18	74

[a]Calculated by the authors from Zohry and Ouda (2017b)

74% under implementing the improved management practices in 2030. However, in 2015 and under implementing the improved management practices, faba bean could attain surplus production (Zohry and Ouda 2017b).

7.8.4 Edible Oil Crops Production-Consumption Gap

Under climate change in 2030, Zohry and Ouda (2018a) indicated that the total cultivated area of cotton, sunflower, soybean, maize and flax could be increased through implementing intercropping systems and cultivation of three-crop sequences, compared to its value under traditional cultivation. However, it will be lower than the cultivated area attained under intensive cropping, compared to its value in 2015. The cultivated area of these five crops will increase to 1,836,714 ha, which represent an increase by 89% of the total cultivated area, compared to the cultivated area in 2015.

7.8.5 Summer Forage Crops Production-Consumption Gap

In 2030, the total potential cultivated area of summer forage a result of fahl clover cultivation and intercropping cowpea with other summer crops in 2030 is expected to be reduced from 1,382,301 ha to 1,251,567 ha, compared to the value of these two crops under traditional cultivation in 2015, This reduction represents 9% less than its counterpart value attained in 2015 under intensive cropping for these two crops (Zohry and Ouda 2018b).

7.9 Conclusion

Reviewing 67 research papers previously published on the effect of climate change on natural resources related to crops production revealed that Egypt will be vulnerable to climate change as a result of its dependence on the Nile River as the main water resources. Furthermore, the Egyptian population is expected to increase to reach 125 million inhabitants in the future. The expected population increase will put more pressure on water and lands resources to produce more food to provide to the growing population. Thus, adaptation strategies should be applied when possible to reduce the vulnerability associated with climate change.

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