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Management of Climate Induced Drought and Water Scarcity in Egypt

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Preface

The Intergovernmental Panel on Climate Change states that 'water and its availability and quality, will be the main pressures on, and issues for, societies and the environment under climate change'. Accordingly, it is expected that climate change will induce disruption in food production systems in both rain-fed and irrigated areas in Egypt. Scattered assessment studies were done in Egypt on the effect of climate change on individual crops, in terms of its productivity and water requirements. However, there is a lack of knowledge on the effect of climate change on crops structure, as a whole in Egypt. Thus, the limitation of these previous studies inspired us to write this book. In this book, we suggested new crops structure under rain-fed in North Egypt and under surface irrigation in Nile Delta and Valley, taking into account sustainability of water and soil resources (present and future in 2030).

In Chap. 1, we calculated potential evapotranspiration in four agro-ecological zones in Egypt: rain-fed agriculture in low-quality soils, irrigated agriculture in clay fertile soil with moderate climate, irrigated agriculture in clay fertile soil with hot climate, and irrigated agriculture in salt-affected soil with moderate climate. We also followed a methodology to reduce uncertainty in the projection of the effect of climate change on potential evapotranspiration, which resulted in achieving higher level of certainty in the prediction of weather elements with 92 % degree of accuracy. These values were used in the following chapters to calculate current and future crops water requirements.

In Chap. 2, we tried to close the gap in our understanding on how climate would affect sustainability in rain-fed area. Using integrated modeling approach to simulate the effect of application of supplementary irrigation and addition of manure on growing crops under current and future climate resulted in reducing its vulnerability. The use of crop rotations and interplanting as adaptation to climate change was also assessed.

In Chaps. 3 and 4, we suggested a management package to overcome water scarcity conditions in clay fertile soil in moderate and hot climates in Egypt. It included precise land leveling and cultivation on raised beds to save 20 % of the applied water to surface irrigation, as well as cultivation of legume crop between winter and summer crops and implementing different intercropping systems in both locations. In addition, in Chap. 4, where sugarcane is the main crop, the effect of intercropping winter and summer crops on it was assessed to maximize land and water productivity.

In Chap. 5, we assessed the effect of using crop rotations in salt-affected soils to combat soil deterioration under current climate and climate change. The selected crops for these rotations were either salinity tolerant or tolerant cultivars from sensitive or medium-tolerant crops. Implementing precise land leveling and cultivation on raised beds, in addition to intercropping and cultivation of legume crop in between winter and summer crops, contributed in saving some of the applied irrigation water to these rotations.

I appreciate all the collaboration I got from all the co-authors, where we spent about 12 months to put this book in its final format. I hope this book will help researchers and policy makers in their future thinking and be a base for more research and knowledge.

Giza, Egypt Samiha A.H. Ouda
March 2016

Contents

Chapter 1
Introduction

Samiha A.H. Ouda and Abd El-Hafeez Zohry

Abstract Droughts and water scarcity are important issues related to natural phenomena and affected by climate variability and change. Water scarcity was defined as the lack of sufficient available water resources to meet the demands of water usage within a region. There are many studies were conducted on the assessment of the climate change on crops productivity and its water requirements in Egypt. Droughts and water scarcity affected areas will likely to increase during the 21st century with clear impact on agriculture and water resources. There are two cultivation systems in Egypt: irrigated agriculture and rain fed agriculture. Irrigated agriculture performs in the old cultivated land and new reclaimed land. The rain fed areas in the North Coast of Egypt depends on rain falls from El-Saloum (west of Libya) to Rafah (East of Palestine). The projected adverse consequences of climate change on regional droughts are well established by global and regional studies, internationally. However, there are no local studies on the effect of climate change on rain fed agriculture in Egypt. This book is concerned about criticizing the prevailing crops structure in Egypt under rain fed in North Egypt and under surface irrigation in Nile Delta and Valley. Suggestions on improving crops structure in these areas are investigated, taking into account sustainability of water and soil recourses. Furthermore, improved management options of crops production in both rain fed and irrigated agriculture were explored. Suggestions of more rationale use of irrigation water in irrigated agriculture were also investigated to conserve irrigation water under present climate condition and to help in fulfilling the anticipated demand under climate change conditions in 2030.

Keyword Rain fed agriculture · Irrigated agriculture · Crops structure · Climate change effect

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Droughts and water scarcity are important issues related to natural phenomena and affected by climate variability and change. Extreme events as droughts have very important consequences on human natural systems. It can persist for several years; however, short intense droughts can also cause major damage. Droughts generate substantial adverse impact on natural ecosystems and management systems. Prolonged droughts also have effects on the economic sector, such as damaging crop yields and decreasing farmers' income (Burke et al. 2006). Droughts affect rain fed agricultural production, as well as water supply for domestics.

Water scarcity was defined as the lack of sufficient available water resources to meet the demands of water usage within a region (FAO 2012). There are many regions in the world already experiencing water scarcity situation. Egypt is one of these areas that affected by water scarcity, although Egypt is gifted by the Nile River, which is the main source of water for irrigation and other uses. Egypt has reached a state, where the quantity of water available is imposing limits on its national economic development. Egypt will reach absolute water scarcity (500 m^3/capita/year), with population predictions in 2025 (Ministry of Irrigation and Water Resources 2014).

More than 85 % of the water withdrawal from the Nile is used for irrigated agriculture. Surface irrigation is the major system in Egypt applied to 83 % of the old cultivated land (Nile Delta and Valley). Most of the on-farm irrigation systems are low efficient coupled with poor irrigation management (Ministry of Irrigation and Water Resources 2014). The agriculture strategy of Egypt for 2030 put emphasis on rationalization of irrigation water use, which is carried out through using improved agricultural management practices on farm level to enhance water use efficiency and increase water and land productivity. This situation creates challenges for agricultural scientists to manage water properly, taking into consideration soil and water resources conservation. Thus, innovations are required to increase water and land productivity under water scarcity conditions.

In semi-arid area like Egypt, climate change can have many syndromes, i.e. high temperature and low rain fall. Increased temperatures may accelerate the rate at which plants release CO_2 in the process of respiration, resulting in less than optimal conditions for net growth (Gardner et al. 1985). When temperatures exceed the optimal for biological processes, crops often respond negatively with a steep drop in net growth and yield. Another important effect of high temperature is accelerated physiological development, resulting in hastened maturation and reduced yield (Vu et al. 1997). Furthermore, higher temperatures increase the evaporation rate, thus reducing the level of moisture available for plant growth, which could lead to soil erosion and in extreme case to desertification (Jameel 2004). Increased evaporation from the soil and accelerated transpiration in the plants themselves will cause moisture stress. Thus, water demand for irrigation is projected to rise, bringing increased competition between agriculture and other economic sectors. Falling water tables and the resulting increase in the energy needed to pump water will make the practice of irrigation more expensive (Lanen et al. 2004). Finally, intensified evaporation will increase the hazard of salt accumulation in the soil (Kazi et al. 2002), especially if the soil is already salt-affected.

There are two cultivation systems in Egypt: irrigated agriculture and rain fed agriculture. Irrigated agriculture performs in the old cultivated land and new reclaimed land. The old cultivated land is represented by clay and salt-affected soil. It occupies the Nile Delta and Valley. It is under surface irrigation with 60 % application efficiency, which endures large losses in the applied irrigation water to drainage canals (Abou Zeid 2002). Irrigated agriculture is the main producer of food in Egypt, where many crops are suitable to be cultivated.

The rain fed areas in the North Coast of Egypt depends on rain falls from El-Saloum (west of Libya) to Rafah (East of Palestine). Rainfall rate varies from 130–150 mm and falls in winter only on irregular bases. The soil in these areas is sandy with low fertility. The soil capacity to capture the little amount of rain fall is low. In this region, a few field crops (barley and wheat) are cultivated, as well as few fruit trees (olive, peach and fig) (http://www.emwis-eg.org).

Droughts and water scarcity affected areas will likely to increase during the 21st century with clear impact on agriculture and water resources. The projected adverse consequences of climate change on regional droughts are well established by global and regional studies, internationally (Berry et al. 2006). These studies revealed that risk on food security will exist in the future. However, there are no local studies on the effect of climate change on rain fed agriculture in Egypt. Whereas, many studies were conducted on the assessment of the climate change on crops productivity and its water requirements in Egypt (Khalil et al. 2009; Ouda et al. 2010; Noreldin et al. 2013; Ouda et al. 2014, 2015).

This book is concerned about criticizing the prevailing crops structure in Egypt under rain fed in North Egypt and under surface irrigation in Nile Delta and Valley. Suggestions on improving crops structure in these areas are investigated, taking into account sustainability of water and soil recourses. Furthermore, improved management options of crops production in both rain fed and irrigated agriculture were explored. Suggestions of more rationale use of irrigation water in irrigated agriculture were also investigated to conserve irrigation water under present climate condition and to help in fulfilling the anticipated demand under climate change conditions in 2030.

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Chapter 2
Potential Evapotranspiration Under Present and Future Climate

Mostafa Morsy, Tarek El-Sayed and Samiha A.H. Ouda

Abstract The objective of this chapter was to calculate potential evapotranspiration (PET) values for five governorates in Egypt (North Sinai, Marsa Matrouh, El-Gharbia, El-Sharkia and Sohag) using Penman-Monteith equation with climate normals values (1985–2014). These calculated values of PET was used in next chapters to calculate water requirements for the prevailing and suggested crops structures. Furthermore, the effect of climate change on PET was assessed using comparison between RCPs scenarios developed from four global models and the boundary of the more close scenario to the measured data was input into a regional climate model (WRF-RCM) to develop more accurate weather data to be used in PET calculation under climate change. The methodology described in this chapter resulted in achieving higher level of certainty in the prediction of weather elements with 92 % degree of accuracy. Thus, we used these data to calculate PET values under climate change in 2030. The results indicated that the values of weather elements and PET were slightly higher in North Sinai and Marsa Matrouh. The difference in PET was increase in El-Gharbia and El-Sharkia governorates and in 2030 it was be noticeably high in Sohag governorate. These increases will have its negative implication on water consumption by the cultivated crops in these governorates. Therefore, it is important for policy makers in Egypt to be alert on these anticipated risks associated with climate change in 2030.

Keywords Potential evapotranspiration · RCPs developed from AR5 models · WRF-RCM model

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Introduction

Water is important for all forms of life and will become a scarce natural resource in the future owing to climate variability and change. The relationships between climate, crop, water and soil are complex with many biological processes involved (Rao et al. 2011). The Efficient water management of crops requires accurate irrigation scheduling which, in turn, requires accurate measurement of crop water requirement. Potential evapotranspiration (PET) plays an important role for the determination of water requirements for crops and irrigation scheduling (Kumar et al. 2012). Various equations varying in the degree of complexity are available for estimating PET (Penman-Monteith; Allen et al. 1989; Blaney-Criddle 1950; Hargreaves and Samani 1982, 1985). The Penman-Monteith equation is widely recommended, although it is characterized by its complication because of its detailed theoretical base and its accommodation of small time periods.

Climate change is expected to increase PET due to higher temperature, solar radiation and wind speed (Abtew and Melesse 2013), which will affect the hydrological system and water resources (Shahid 2011). Previous research in Egypt on the effect of climate change on PET values revealed that temperature rise by 1 °C may increase PET rate by about 4–5 % (Eid 2001). Furthermore, Khalil (2013) used SERS scenarios to calculate PET values in the future and indicated that it will increase under climate change compared to current climate. Ouda et al. (2016) indicated that PET values will increase depending on the location of the region, where it will be lower in North Egypt, compare to the middle and south of Egypt. This assessment was done using AR4 scenarios.

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC 2013) is the recent that contained a large number of comprehensive climate models and Earth System Models, whose results form the core of the climate system projections. These models produce new Representative Concentration Pathways (RCP2.6, RCP4.5, RCP6.0 and RCP8.5), which based on Coupled Model Inter-comparison Project Phase 5 (CMIP5) to replace the SRES scenarios in IPCC Fourth Assessment Report (AR4) released in 2007 (Wayne 2013). Even though general circulation models (GCMs) have proven their relative ability to simulate many aspects (e.g. atmospheric circulation, global surface temperature, monsoon circulation, and climate oscillation) of climate variability at large or global scale (Solomon et al. 2007), they still cannot reproduce local-scale climate variability. Furthermore, using global and region models in projection of climate change effects on PET could achieve higher level of certainty.

The objective of this chapter was to calculate PET values in five governorates in Egypt using Penman-Monteith equation with climate normals values (1985–2014). Furthermore, to reduce uncertainty in the projection of the effect of climate change on PET, a comparison between RCPs scenarios developed from four global models was done and the boundary of closer scenario to the measured data was input into a regional model (WRF-RCM) to develop more accurate weather data to be used in PET projection under climate change.

Selected Governorates

Five governorates were selected to represent rain fed and irrigated agriculture in Egypt. Regarding to rain fed areas in North Egypt, North Sinai governorate was selected to represent North East Egypt and Marsa Matrouh to represent North West Egypt. Two governorates were selected to represent old clay soil in Nile Delta and Upper Egypt, i.e. El-Gharbia and Sohag governorates. Furthermore, one governorate was selected in North Nile Delta to represent salt-affected soil, i.e. El-Sharkia. (Table 2.1).

Figure 2.1 showed a map for the selected governorates in North Egypt, Nile Delta and in Upper Egypt.

Calculation of PET Values Under Present Climate

The BISm model (Snyder et al. 2004) was used to calculate monthly PET. The model calculates PET using Penman-Monteith equation (Monteith 1965) as presented in the United Nations FAO Irrigation and Drainage Paper (FAO 56) by Allen et al. (1989). Climate normals (1985–2014) were used to calculate ET values for each governorate. Monthly values of PET in the selected governorates are presented in Table 2.2.

Assessment of the Effect of Climate Change on PET Values

To lower the uncertainty of climate change projections in the future for PET calculation, Morsy (2015) developed a methodology to determine the most suitable global climate model (GCMs) and scenarios for four governorates (Kafr El-Sheik, El-Gharbia, El-Minia and Sohag). Two of these governorates, i.e. El-Gharbia, and Sohag are included in our analysis. In his methodology, he compared measured meteorological data with the projected data from four global climate models

Table 2.1 Latitude, longitude and elevation above sea level for the selected Governorates

Governorate	Latitude (°)	Longitude (°)	Elevation above sea level (m)
North Egypt			
North Sinai	32.07	33.45	17.10
Marsa Matrouh	31.30	27.20	7.00
Nile Delta			
El-Gharbia	30.36	31.01	17.90
El-Sharkia	30.35	31.30	13.00
Upper Egypt			
Sohag	26.36	31.38	68.70

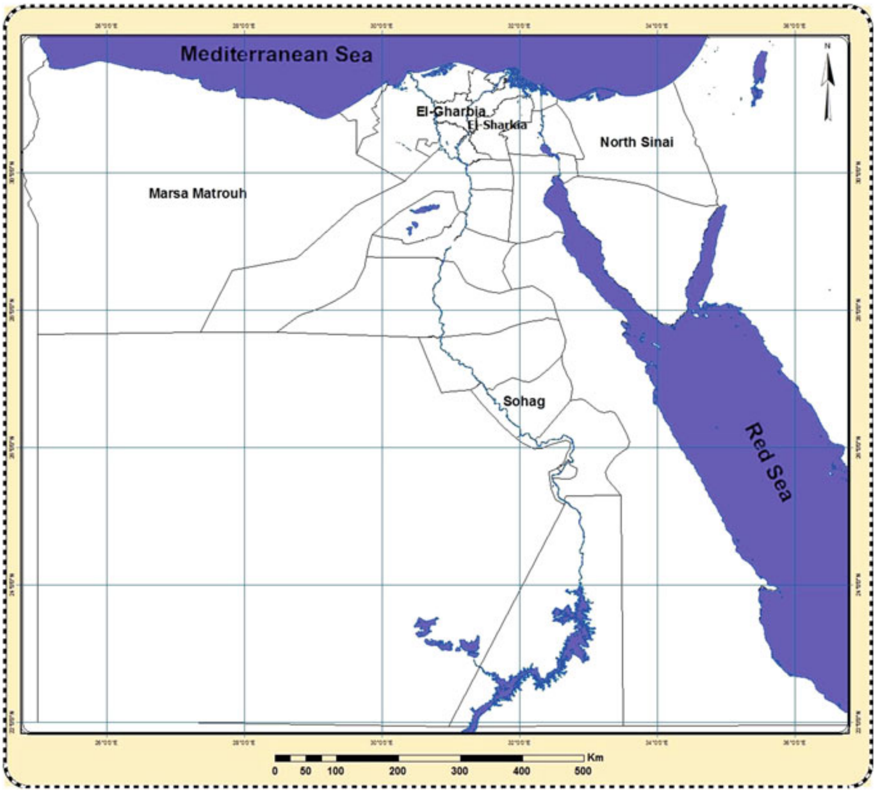

Fig. 2.1 Map of the selected governorates in Egypt

Table 2.2 Monthly PET values (mm/day) for the selected governorates

	Marsa Matrouh	North Sinai	El-Gharbia	El-Sharkia	Sohag
January	2.5	2.4	2.7	2.8	3.0
February	3.0	2.9	3.4	3.8	4.0
March	3.7	3.6	4.4	4.5	5.1
April	4.7	4.6	5.4	5.9	6.5
May	5.6	5.4	6.5	6.6	7.5
June	6.5	6.2	7.2	7.3	8.5
July	6.9	6.4	7.5	7.6	8.2
August	6.5	6.1	6.9	7.3	7.8
September	5.4	5.2	6.2	6.3	7.4
October	3.9	3.9	4.5	4.9	5.5
November	2.9	2.9	3.2	3.2	4.0
December	2.5	2.4	2.8	2.8	3.0
Average	4.5	4.3	5.1	5.3	5.9

represented by its four RCPs scenarios during the period from 2006 to 2012. His results indicated that RCP6.0 scenario from CCSM4 model was more accurate to project the meteorological and climate variables because it achieved the closest values of goodness of fit test. Thus, we will use his results for El-Gharbia, and Sohag and we followed his procedure for the rest of the five studied governorates. His procedure is explained in details in the following section.

CMIP5 Global Climate Models

The selected four models have differing levels of sensitivity to Green House Gases (GHG) forcing, which focused on daily RCPs climate change scenarios. The selected models are listed in Table 2.3.

Each model produces four RCPs scenarios to represent a larger set of mitigation scenarios and have different targets in terms of radiative forcing in 2100. Each RCP defines a specific emissions trajectory. The emission pathway of RCP2.6 is representative of scenarios in the literature that lead to very low greenhouse gas concentration levels. It is a "peak-and-decline" scenario, where its radiative forcing level first reaches a value of around 3.1 W/m^2 by mid-century, and returns to 2.6 W/m^2 by 2100. In order to reach such radiative forcing levels, greenhouse gas emissions and indirectly emissions of air pollutants are reduced substantially over time (Van Vuuren et al. 2006, 2007). Regarding to RCP4.5, it is a stabilization scenario, in which total radiative forcing is stabilized shortly after 2100, without overshooting the long run radiative forcing target level (Smith and Wigley 2006; Clarke et al. 2007; Wise et al. 2009). Furthermore, RCP6.0 is a stabilization scenario, in which total radiative forcing is stabilized shortly after 2100, without overshoot, by the application of a range of technologies and strategies for reducing

Table 2.3 List of selected CMIP5 GCM models and their horizontal resolutions

Model	Institution	Horizontal resolution
BCC-CSM1-1	Beijing Climate Center, China Meteorological Administration, China	2.80º × 2.80º
CCSM4	National Centre for Atmospheric Research (NCAR), Community Climate System Model, USA	1.25º × 0.94º
GFDL-ESM2G	National Oceanic and Atmospheric Administration (NOAA), Geophysical Fluid Dynamics Laboratory (GFDL), USA	2.02º × 2.00º
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	1.40º × 1.40º

greenhouse gas emissions (Fujino et al. 2006; Hijioka et al. 2008). With respect to RCP8.5, it is characterized by increasing greenhouse gas emissions over time, where it is representative of scenarios in the literature that lead to high greenhouse gas concentration levels (Riahi et al. 2007).

Statistical Analysis

Goodness of fit test between the measured and projected meteorological data (solar radiation, maximum, minimum temperatures and wind speed) by the RCPs for selected governorates was done using the following tests.

Willmott Index of Agreement (d-stat)

It is the standardized measure of the degree of model prediction error which varies between 0 and 1. A value of 1 indicates a perfect match, and value of 0 indicates no agreement at all (Willmott 1981).

$$\mathrm{d-stat} = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}\left[(|(S_i - \bar{O})| + |(O_i - \bar{O})|)^2\right]} \tag{2.1}$$

where O_i, $\bar{O}$ and S_i represent the observed, observed average and simulated values.

Coefficient of Determination (R^2)

R^2 tells us how much better we can do in predicting observation by using the model and computing the simulation by just using the mean observation as a predictor (Jamieson et al. 1998).

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \tag{2.2}$$

R^2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable (Santhi et al. 2001; Van Liew et al. 2003; Moriasi et al. 2007).

Root Mean Square Error Per Observation (RMSE/Obs)

It gives the general standard deviation of the model prediction error per observation (Jamieson et al. 1998).

$$\mathrm{RMSE/obs} = \sqrt{\left(\frac{\sum_{i=1}^{n}(S_i - O_i)^2}{n}\right)} \tag{2.3}$$

where n represents the number of observed and simulated values used in comparison.

The Averages of the Goodness of Fit Test

Regarding to North Sinai governorate, the averages of goodness of fit test for each RCP scenario from the selected four GCMs models are shown in Table 2.4. The results revealed that RCP6.0 scenario from CCSM4 model was suitable and more accurate to project the meteorological and climate variables because it achieved the highest d-stat, R^2 and the lowest RMSE/obs.

With respect to Marsa Matrouh, the averages of the goodness of fit tests for each RCP scenario of the four GCMs models are shown in Table 2.5. Similar results were found, where RCP6.0 scenario from CCSM4 model has the highest d-stat and R^2 values and lowest RMSE/obs value.

Regarding to El-Gharbia governorate (Table 2.6), the goodness of fit test revealed that RCP6.0 climate change scenario developed by CCSM4 model produced the highest d-stat and R^2 values and the lowest RMSE/obs values.

Table 2.4 Goodness of fit test between measured and projected meteorological data by the four models in North Sinai governorate

	BCC-CSM1-1 model			CCSM4 model		
	d-stat	R^2	RMSE/obs	d-stat	R^2	RMSE/obs
RCP2.6	0.897	0.758	0.159	0.918	0.759	0.134
RCP4.5	0.906	0.778	0.150	0.920	0.766	0.133
RCP6.0	0.904	0.777	0.153	**0.923**	**0.779**	**0.131**
RCP8.5	0.909	0.787	0.150	0.922	0.768	0.131
	GFDL model			MIROC5 model		
	d-stat	R^2	RMSE/obs	d-stat	R^2	RMSE obs
RCP2.6	0.867	0.671	0.185	0.905	0.710	0.142
RCP4.5	0.864	0.658	0.187	0.902	0.697	0.144
RCP6.0	0.850	0.633	0.199	0.909	0.720	0.139
RCP8.5	0.865	0.671	0.188	0.897	0.686	0.147

Table 2.5 Goodness of fit between measured and projected weather data by the four models in Marsa Matrouh governorate

	BCC-CSM1-1 model			CCSM4 model		
	d-stat	R^2	RMSE/obs	d-stat	R^2	RMSE/obs
RCP2.6	0.920	0.757	0.148	0.926	0.770	0.137
RCP4.5	0.922	0.767	0.144	0.922	0.762	0.138
RCP6.0	0.925	0.775	0.141	**0.927**	**0.776**	**0.136**
RCP8.5	0.851	0.770	0.203	0.923	0.764	0.138
	GFDL model			MIROC5 model		
	d-stat	R^2	RMSE/obs	d-stat	R^2	RMSE/obs
RCP2.6	0.900	0.707	0.166	0.921	0.757	0.145
RCP4.5	0.898	0.699	0.169	0.919	0.751	0.147
RCP6.0	0.899	0.710	0.172	0.922	0.762	0.144
RCP8.5	0.900	0.709	0.169	0.924	0.764	0.143

Table 2.6 Averages goodness of fit test between measured and projected weather data by the four models in El-Gharbia governorate

	BCC-CSM1-1 model			CCSM4 model		
	d-stat	R^2	RMSE/obs	d-stat	R^2	RMSE/obs
RCP2.6	0.845	0.667	0.232	0.886	0.700	0.211
RCP4.5	0.845	0.683	0.227	0.882	0.685	0.211
RCP6.0	0.849	0.688	0.227	**0.888**	**0.702**	**0.206**
RCP8.5	0.852	0.692	0.225	0.883	0.691	0.211
	GFDL model			MIROC5 model		
	d-stat	R^2	RMSE/obs	d-stat	R^2	RMSE/obs
RCP2.6	0.844	0.653	0.238	0.840	0.657	0.227
RCP4.5	0.845	0.657	0.238	0.845	0.668	0.225
RCP6.0	0.846	0.655	0.241	0.845	0.670	0.225
RCP8.5	0.849	0.668	0.236	0.846	0.673	0.223

In El-Sharkia governorate, the same trend was obtained for goodness of fit test, where RCP6.0 developed by CCSM4 model produced the highest d-stat and R^2 values and the lowest RMSE/obs values (Table 2.7).

Furthermore, the same trend was found for Sohag governorate, where RCP6.0 developed by CCSM4 model produced the highest d-stat and R^2 values and the lowest RMSE/obs values (Table 2.8).

The results existed in Tables 2.4, 2.5, 2.6, 2.7 and 2.8) clearly showed that the RCP6.0 scenario from CCSM4 model will be suitable for the studied governorates. Thus, we use the RCP6.0 from CCSM4 model as initial and lateral boundary conditions to the regional climate model WRF-RCM for regional climate studies over Egypt.

Table 2.7 Goodness of fit test between measured and projected weather data by the four models in El-Sharkia governorate

	BCC-CSM1-1 model			CCSM4 model		
	d-stat	R^2	RMSE/obs	d-stat	R^2	RMSE/obs
RCP2.6	0.881	0.709	0.200	0.915	0.755	0.183
RCP4.5	0.885	0.726	0.193	0.912	0.740	0.182
RCP6.0	0.887	0.729	0.193	**0.918**	**0.757**	**0.177**
RCP8.5	0.891	0.737	0.191	0.913	0.746	0.183
	GFDL model			MIROC5 model		
	d-stat	R^2	RMSE/obs	d-stat	R^2	RMSE obs
RCP2.6	0.876	0.702	0.208	0.893	0.718	0.184
RCP4.5	0.877	0.704	0.209	0.897	0.727	0.181
RCP6.0	0.877	0.705	0.212	0.898	0.729	0.181
RCP8.5	0.880	0.716	0.206	0.899	0.734	0.179

Table 2.8 Goodness of fit test between measured and projected weather data by the four models in Sohag governorate

	BCC-CSM1-1 model			CCSM4 model		
	d-stat	R^2	RMSE/obs	d-stat	R^2	RMSE/obs
RCP2.6	0.854	0.594	0.224	0.872	0.645	0.205
RCP4.5	0.857	0.606	0.217	0.869	0.640	0.203
RCP6.0	0.860	0.609	0.216	**0.876**	**0.655**	**0.198**
RCP8.5	0.860	0.610	0.219	0.874	0.654	0.200
	GFDL model			MIROC5 model		
	d-stat	R^2	RMSE/obs	d-stat	R^2	RMSE/obs
RCP2.6	0.852	0.597	0.220	0.859	0.625	0.222
RCP4.5	0.855	0.610	0.216	0.866	0.639	0.216
RCP6.0	0.857	0.613	0.221	0.860	0.626	0.222
RCP8.5	0.863	0.633	0.211	0.866	0.642	0.217

WRF-RCM Model

WRF-RCM model is a regional climate model used to study specific areas in more details. The recent version of WRF (3.7.1) was released in August 14, 2015. WRF-RCM is a result of a multiagency collaboration, consisting mostly of the National Center for Atmospheric Research (NCAR), the National Center for Environmental Prediction (NCEP), the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory (NRL), Oklahoma University, and the Federal Aviation Administration (FAA). The model is updated each year, sometimes few times a year, and a new version made public (Caldwell et al. 2009; Qian et al. 2010; Bukovsky and Karoly 2009; Bell et al. 2004).

Table 2.9 Average of goodness of fit values between measured and projected values for climate parameters from WRF-RCM and CCSM4-RCP6.0

Locations	WRF-RCM model			CCSM4 model		
	d-stat	R^2	RMSE/obs	d-stat	R^2	RMSE/obs
North Sinai	0.962	0.877	0.090	0.910	0.727	0.138
Marsa Matrouh	0.960	0.905	0.099	0.922	0.784	0.137
El-Gharbia	0.969	0.899	0.104	0.926	0.770	0.165
El-Sharkia	0.969	0.898	0.104	0.924	0.768	0.168
Sohag	0.969	0.898	0.106	0.922	0.744	0.165

Weather data for the same period of time, i.e. 2006–2012 was predicted by WRF-RCM model and compared to the measured metrological data. The same statistical analysis was also used to test the goodness of fit between the measured and projected data. The results in Table 2.9 indicated that the predictions of WRF-RCM model were more close to the measured weather data. The values of d-stat were between 0.956 and 0.969 for WRF-RCM model, whereas it was between 0.910 and 0.926 for CCSM4 model. Similarly, R^2 values for WRF-RCM model was higher that its counterpart for CCSM4 (0.866–0.969 vs. 0.727–0.784). Furthermore, the lowest RMSE/obs was obtained by WRF-RCM model when it was compared to the measured metrological data.

The above results implied that WRF-RCM model has high potentiality to be more accurate in projecting climate variables at all studied governorates. Furthermore, the results also suggested that the model can be used in simulating and projecting climate variables under varied situations with high accuracy and efficiency. Thus, the above results provide a general evaluation of the WRF-RCM model for prediction of climate variables over different locations in Egypt with different latitudes and longitudes. For that reason, the WRF-RCM model was used to predict weather data in 2030 to assess the effect of climate change on PET values more accurately with higher certainty.

Projected Weather Data and PET Values in 2030

The weather elements in 2030 were projected for the five studied governorates by WRF-RCM model. These data were solar radiation (SR, MJ/m^2/day), maximum temperature (T-Max, °C), minimum temperature (T-Min, °C) and wind speed (WS, m/s). BISm model was used to calculate PET (mm/day) values in the studied governorates in 2030. The above values are presented in Tables 2.10, 2.11, 2.12, 2.13 and 2.14.

The results in Tables 2.10 and 2.11 illustrated the projected weather element in North Sinai and Marsa Matrouh in 2030. As a result of being located on the Mediterranean Sea, weather elements and PET values was the lowest in all Egypt.

Table 2.10 Monthly mean values for climate elements projected by WRF-RCM model and PET in 2030 in North Sinai governorate

	SR (MJ/m^2/day)	T-Max (°C)	T-Min (°C)	WS (m/s)	PET (mm/day)
January	12.2	18.2	15.4	5.2	2.4
February	17.1	18.2	15.2	4.4	2.9
March	21.9	19.7	15.0	4.5	3.7
April	25.3	22.8	17.4	3.5	4.7
May	28.5	26.0	18.6	3.8	5.5
June	30.2	28.6	22.0	3.0	6.3
July	29.5	31.6	25.0	3.0	6.5
August	27.2	31.8	26.2	3.2	6.2
September	24.0	30.8	25.7	3.6	5.4
October	19.0	26.7	23.0	4.1	4.0
November	14.4	23.4	20.8	3.6	3.0
December	11.9	19.9	17.3	3.9	2.2

Table 2.11 Monthly mean values for climate elements projected by WRF-RCM model and PET in 2030 in Marsa Matrouh governorate

	SR (MJ/m^2/day)	T-Max (°C)	T-Min (°C)	WS (m/s)	PET (mm/day)
January	12.9	17.4	11.9	4.5	2.7
February	17.4	17.7	12.2	4.5	3.1
March	22.6	17.7	12.4	4.1	3.6
April	26.2	21.0	14.8	3.7	4.6
May	28.8	23.0	16.8	4.0	5.3
June	29.7	27.1	20.4	4.1	6.2
July	29.7	30.5	23.6	4.4	6.9
August	27.2	30.3	23.9	4.2	6.4
September	23.8	27.5	22.3	4.3	5.3
October	19.1	24.8	19.2	3.7	4.1
November	12.8	22.0	16.9	3.9	3.0
December	11.8	18.4	13.4	4.1	2.6

Tables 2.12 and 2.13 showed projected weather elements in 2030, as well as PET values in two Nile Delta governorates. El-Gharbia located in the middle of the Nile Delta and El-Sharkia is located in the north east of Nile Delta. Higher values of weather elements and PET are found in these governorates.

The projected values of weather elements for Sohag governorate, as well as PET values are presented in Table 2.14. These values are the highest, compared to the values of the rest of the studied governorate.

Table 2.12 Monthly mean values for climate elements projected by WRF-RCM model and PET in 2030 in El-Gharbia governorate

	SR (MJ/m^2/day)	T-Max (°C)	T-Min (°C)	WS (m/s)	PET (mm/day)
January	12.7	20.3	8.5	2.5	2.8
February	17.5	21.7	8.8	2.6	3.5
March	22.7	23.8	10.6	2.9	4.6
April	25.9	29.0	13.7	2.8	6.0
May	29.2	33.1	16.2	3.1	6.9
June	29.9	37.0	21.1	3	8.2
July	29.4	39.2	23.4	2.8	8.4
August	26.9	39.6	23.5	2.9	8.2
September	23.7	34.9	21.8	2.8	6.7
October	19.9	30.8	17.8	2.5	4.9
November	15.0	25.2	13.8	2.5	3.5
December	12.5	19.9	9.6	2.4	2.8

Table 2.13 Monthly mean values for climate elements projected by WRF-RCM model and PET in 2030 in El-Sharkia governorate

	SR (MJ/m^2/day)	T-Max (°C)	T-Min (°C)	WS (m/s)	PET (mm/day)
January	12.7	20.3	8.5	2.5	2.8
February	17.5	21.7	8.8	2.5	3.5
March	22.7	23.8	10.6	2.8	4.6
April	25.9	29.0	13.7	2.7	6.0
May	29.2	33.1	16.2	3.0	6.9
June	29.9	37.0	21.1	2.9	8.2
July	29.4	39.2	23.4	2.6	8.4
August	26.9	39.6	23.5	2.8	8.2
September	23.7	34.9	21.8	2.7	6.7
October	19.9	30.8	17.8	2.5	4.9
November	15.0	25.2	13.8	2.4	3.5
December	12.5	19.9	9.6	2.4	2.8

Comparison Between Climate Normals and Its Values in 2030

Regarding to North Sinai, solar radiation (SR), maximum temperature (T-Max) and minimum temperature (T-Min) in 2030 will be slightly higher than its normal value in all the months. High variation in wind speed is expected to occur in 2030. It will be the highest in the winter months and lower than its normal values in June and July (Fig. 2.2). It is expected that these different trends will have its implication on PET values in 2030.

Table 2.14 Monthly mean values for climate elements projected by WRF-RCM model and PET in 2030 in Sohag governorate

	SR (MJ/m^2/day)	T-Max (°C)	T-Min (°C)	WS (m/s)	PET (mm/day)
January	17.0	22.6	8.8	2.9	3.6
February	21.1	24.0	10.6	3.1	4.4
March	25.0	28.2	12.7	3.8	5.6
April	27.3	34.4	18.2	3.5	7.2
May	29.8	37.8	21.8	3.6	7.9
June	30.8	41.3	24.9	4.6	9.1
July	30.0	41.4	25.9	3.5	9.2
August	28.3	41.9	26.4	4.4	9.3
September	26.7	38.9	23.2	4.4	8.3
October	21.7	34.0	20.2	3.1	6.3
November	16.9	28.8	15.5	3.3	4.8
December	15.5	23.3	10.2	3.0	3.6

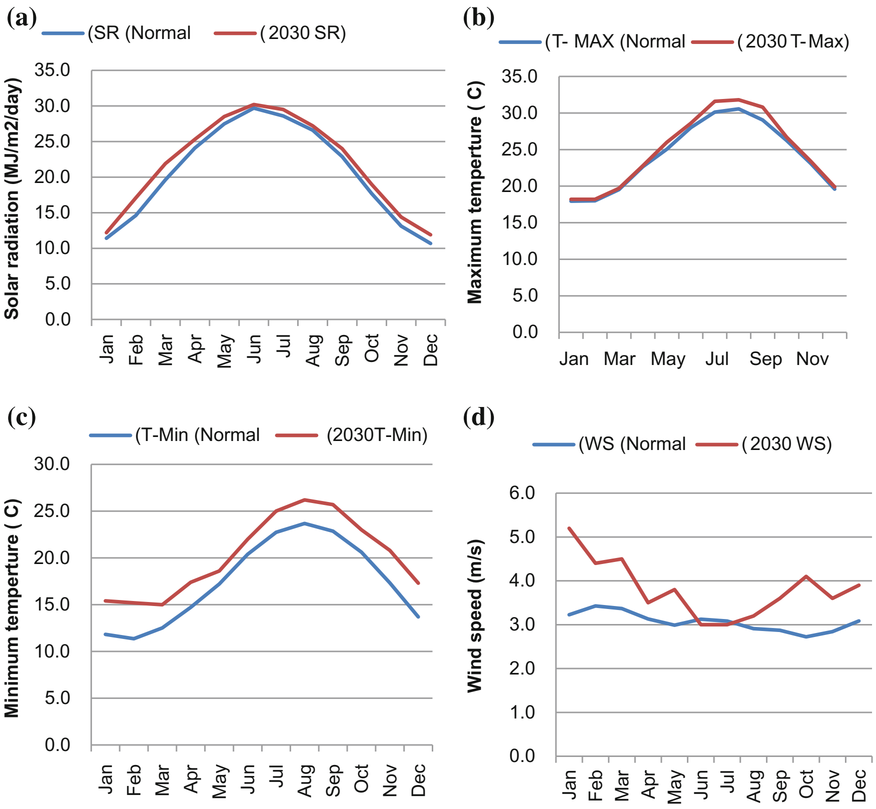

Fig. 2.2 Comparison between climate normals and its value in 2030 for **a** solar radiation, **b** maximum temperature, **c** minimum temperature and **d** wind speed in North Sinai governorate

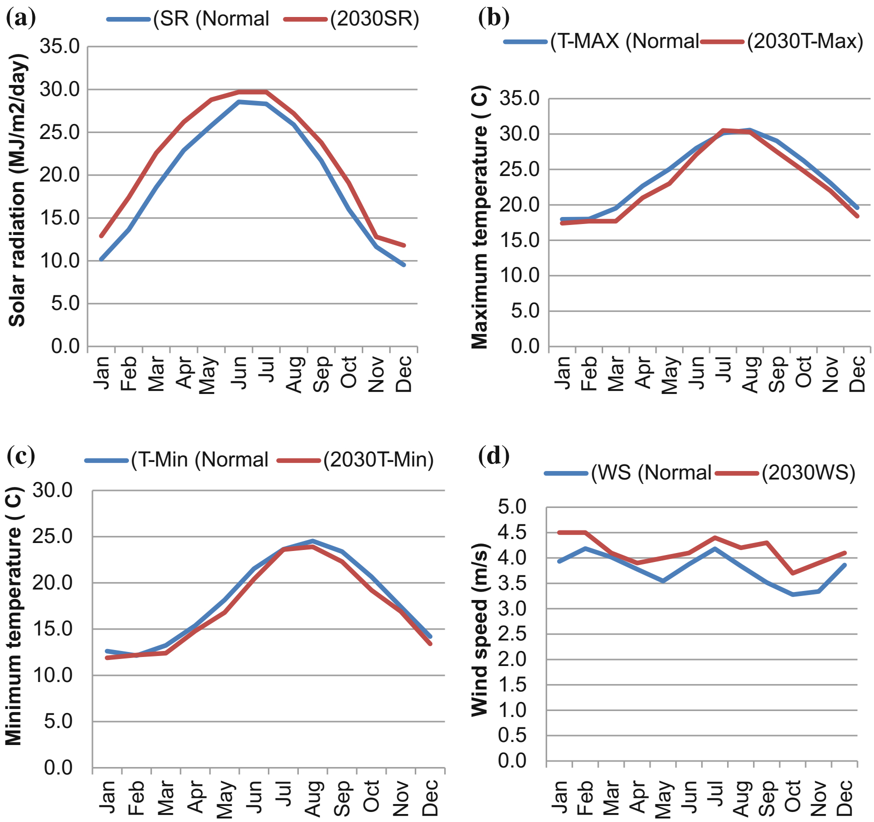

Fig. 2.3 Comparison between climate normals and its value in 2030 for **a** solar radiation, **b** maximum temperature, **c** minimum temperature and **d** wind speed in Marsa Matrouh governorate

Regarding to solar radiation, maximum temperature and minimum temperature in Marsa Matrouh in 2030, its trend was similar to the trend found in North Sinai, i.e. higher than normal values. Lower variation in wind speed will be exist in 2030, compared to its value in North Sinai, however it was higher than its normal values (Fig. 2.3).

Figure 2.4 indicated that in 2030, solar radiation will be higher in all months, whereas maximum temperature in El-Gharbia will be higher only in the summer months. Minimum temperature will be higher from January to August, and then it will be similar to normal minimum temperature. Highly variable trend will exist for wind speed in 2030, compared to its normal values.

Higher increase in the projected weather elements can be observed in 2030 in El-Sharkia governorate, where solar radiation, maximum temperature and minimum temperature will increase. Regarding to wind speed, a variable change will occur in 2030, compared to its normal values (Fig. 2.5).

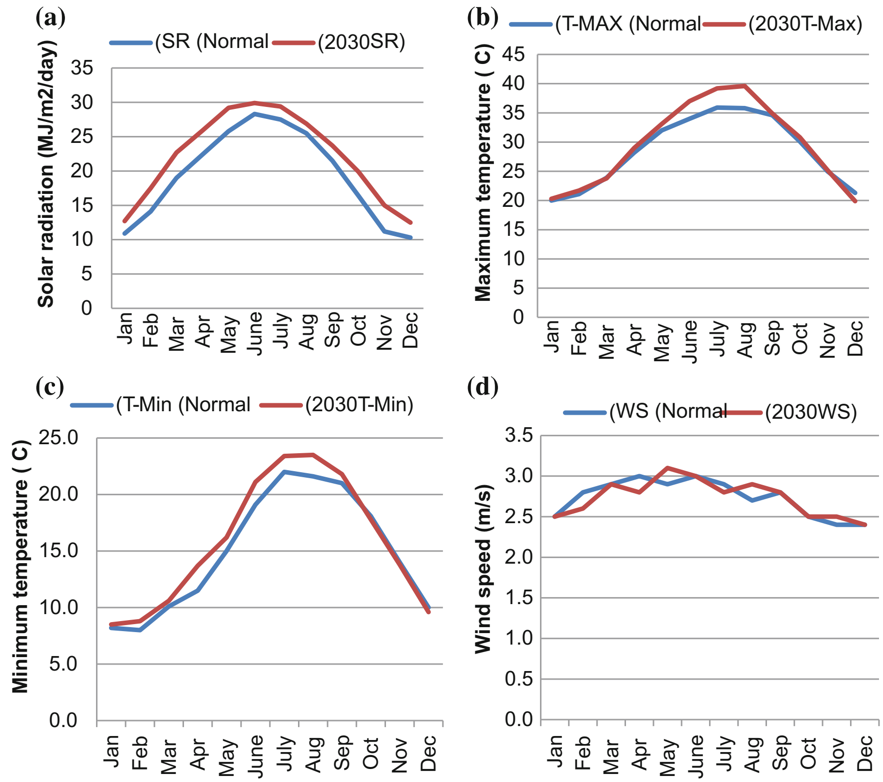

Fig. 2.4 Comparison between climate normals and its value in 2030 for **a** solar radiation, **b** maximum temperature, **c** minimum temperature and **d** wind speed in El-Gharbia governorate

Figure 2.6a–d showed that solar radiation, maximum temperature, minimum temperature and wind speed values will be higher in 2030 than its normal values in Sohag governorate. This could be attributed to its location in south of Egypt, where it will experience higher changes in weather elements in 2030.

Comparison Between Normal and Future PET Values

Figure 2.7a, b indicated that PET will slightly increase in 2030 in North Sinai and Marsa Matrouh governorates. This could marginally increase crops evapotranspiration values in these governorates. Because rain fed agriculture is prevailed there, the main weather element affects crops production is the availability of rain. Thus, the impact of climate change on rain fall in these two governments will be thoroughly analyzed in next chapter.

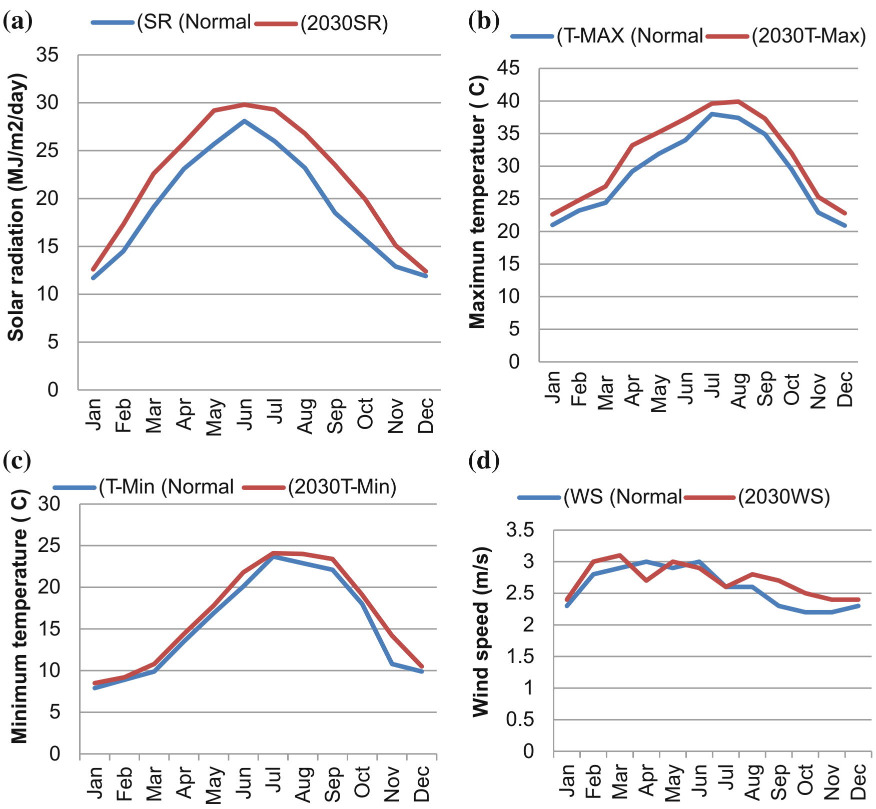

Fig. 2.5 Comparison between climate normals and its value in 2030 for **a** solar radiation, **b** maximum temperature, **c** minimum temperature and **d** wind speed in El-Sharkia governorate

Slight increase in PET values in winter months of 2030 can be noticed in El-Gharbia and El-Sharkia governorates, compared to normal PET values (Fig. 2.8a, b). Whereas, there will be higher increase in PET values in summer months of 2030 in both governorates.

Higher noticeable increase in PET values in Sohag governorate in 2030, compared to normal PET values will exist. These increases will occur in both winter and summer months, where it will be even higher in summer months (Fig. 2.9).

Table 2.15 showed that the percentage of difference between annual PET values calculated from climate normals and annual PET values in 2030. Our analysis showed that the annual PET value in Marsa Matrouh will not change in 2030. Furthermore, the lowest percentage of difference between normal PET and 2030 PET values was found for North Sinai and the highest percentage of difference was found in Sohag governorate, i.e. 2 and 13 % increase, respectively. Previous research by Ouda et al. (2016) revealed that percentage of increase in PET values in 2030 calculated by A1B climate change scenario developed by ECHAM5 model

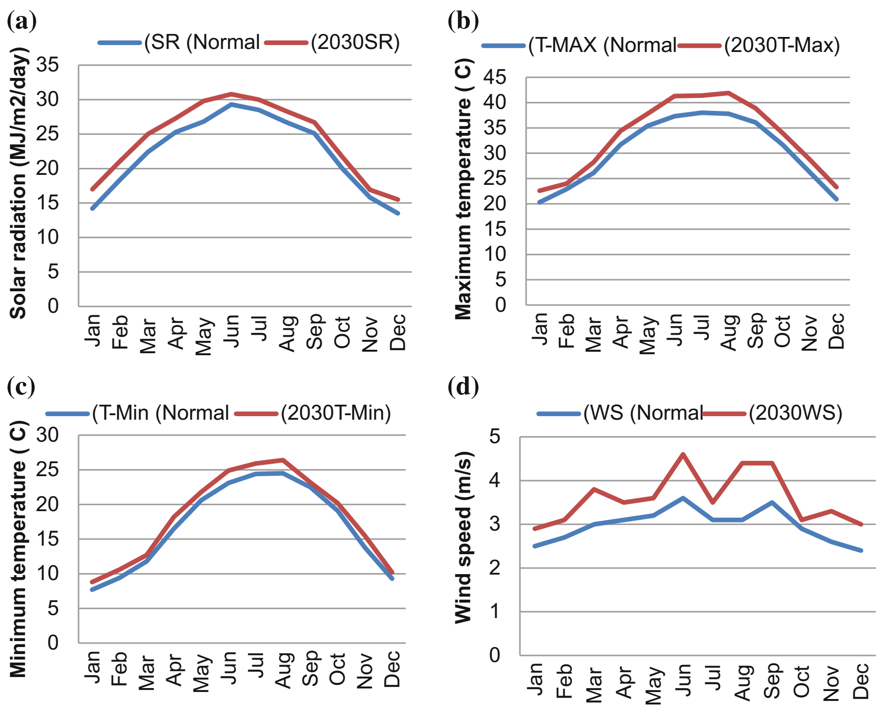

Fig. 2.6 Comparison between climate normals and its value in 2030 for **a** solar radiation, **b** maximum temperature, **c** minimum temperature and **d** wind speed in Sohag governorate

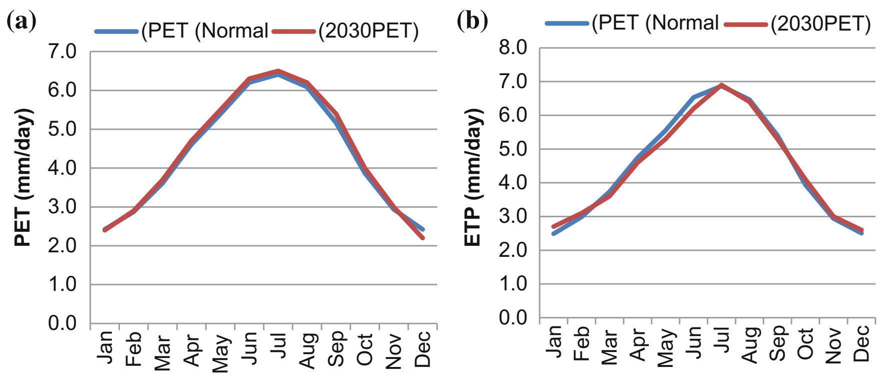

Fig. 2.7 Comparison between normal and future PET values in 2030 in North Sinai (**a**) and Marsa Matrouh (**b**)

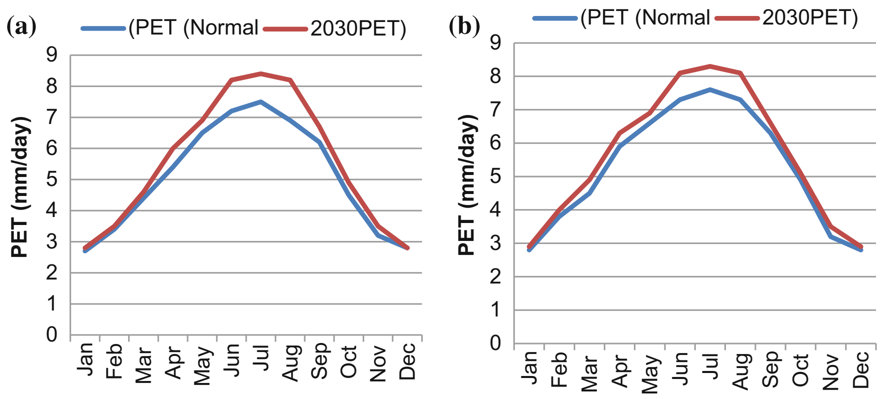

Fig. 2.8 Comparison between normal and future PET values in 2030 for in El-Gharbia (**a**) and El-Sharkia (**b**)

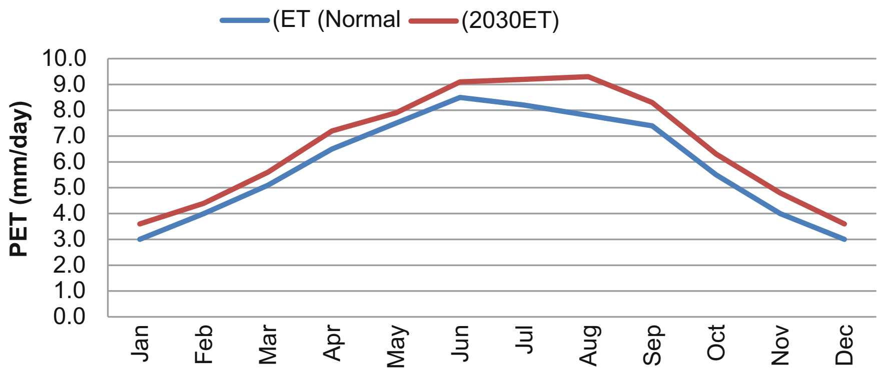

Fig. 2.9 Comparison between normal and future PET values in 2030 in Sohag governorate

Table 2.15 Comparison between annual PET value (mm/day) from climate normals, in 2030, percentage of difference between them (PD %) and percentage of difference using A1B in 2030 (PD1)

Location	PET (normals)	PET (2030)	PD (%)	PD1 (%)*
North Sinai	4.3	4.4	+2	–
Marsa Matrouh	4.5	4.5	0	–
El-Gharbia	5.3	5.6	+7	+10
El-Sharkia	5.1	5.5	+10	+10
Sohag	5.9	6.6	+13	+14

**Source* Ouda et al. (2016)

was higher in El-Gharbia and Sohag and similar in El-Sharkia. Hopefully, this result will be an indication of higher accuracy by our methodology in the projection of the effect of climate change on PET values.

Conclusion

Accurate calculation for PET values is very important procedure to be done to improve water management on field level under irrigated agriculture. Due to the uncertainty associated with climate projection in the future, improvements should be developed to reduce these uncertainties. The implemented methodology in this chapter could be a base for projection of climate change effects on different economic sectors.

Our results revealed that the projection of PET values in 2030 using our methodology were lower than the value projected by Ouda et al. (2016) using A1B climate change scenario of ECHAM5 model for El-Gharbia and Sohag. Furthermore, the projected value of PET for El-Sharkia using our methodology was the same as the value projected by ECHAM5 model. Hopefully, this result will be an indication of higher accuracy by our methodology in projection of the effect of climate change on PET values.

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Chapter 3
Rain Fed Areas in Egypt: Obstacles and Opportunities

Samiha A.H. Ouda, Tahany Noreldin and Alia Amer

Abstract Rain fed agriculture exists in the Egyptian North coast, where North Sinai and Marsa Matrouh are located. Few field crops are cultivated in these areas, in addition to few fruit trees. Most of rain fed areas is farmed using old, traditional and primitive soil and crop management practices. There were scattered studies on crops structure in rain fed area in Egypt and suggested improved management to overcome drought effect. Furthermore, there were no studies on the effect of climate change on it. The objectives of this chapter were to study existing crops structure in the rain fed areas in Egypt. In order to close the gap in our understanding of how climate would affect sustainability in rain fed area, integrated modeling approach was used, where BISm model was used to calculate potential evapotranspiration and crop coefficients. Yield-Stress model was calibrated using these values then used to simulate the effect of application of supplementary irrigation on growing crops in these areas. Under climate change in 2030, weather data were used to run Yield-Stress model to evaluate its effect on crops productivity. Furthermore, simulation of the effect of manure application on these crops was done to explore its effect on improving productivity under drought conditions induced by climate. We also suggested using crop rotation and interplanting as adaptation to climate change. Although we were not able to simulate the effect of all of them, the simulation results of application of supplementary irrigation and manure were encouraging to assume that additive effect of the four suggested practices could overcome the risk of drought under current climate and under the projected climate

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change in 2030. Finally, using modeling to predict rain fall dates and amounts is an important procedure to be done by extension workers in rain fed areas to increase the resilience of these areas to face rain fall variability.

Keywords Barely · Wheat · Olive · Peach and fig trees · Coefficient of variation · Rain fall deviation

Introduction

In rain fed agriculture, where crop production relies on seasonal rain fall often shows a grim picture of a fragile environment due to water scarcity, drought, soil degradation, low rain use efficiency, poor infrastructure and inappropriate policies (Pereira 2005). Rain fed agriculture in the Egyptian north coast constitutes an important part of the existent economic activities. Approximately 300 thousand native inhabitants work in rain fed agriculture, in addition to newcomers who depend highly on rain fed agricultural products. Rainfall rate varies in this area ranging from 130 to 150 mm in the northwestern coast and from 80 mm (west of Al-Arish) to 280 mm (at Rafah) in the northeast. This rate decreases after 20 km south of the Mediterranean in both areas. Although rain falls in winter only, irregularity of rainfall during the precipitation period from October till April makes it difficult to depend on direct use of rain in the area (http://www.emwis-eg.org). Because Egypt is facing many challenges related to its water resources that are intensified by a rapidly growing population, rainfall and flash floods represent another source of water (MWRI 2005).

Two governorates in Egypt are famous by rain fed agriculture, i.e. North Sinai in the North East Coast of Egypt and Marsa Matrouh on the North West Coast of Egypt. Few field crops are cultivated in these areas, mainly barley and wheat, in addition to few fruit trees. There are several serious threats being faced by rain fed areas, where most of it are farmed using old, traditional and primitive soil and crop management practices. The major constraints threaten agricultural sustainability in these areas are moisture stress and/or soil erosion, and nutrient depletion as a result of cereal mono cropping. Low yields per hectare resulted from rain fed areas could be attributed to poor seeds quality, inadequate and imbalanced fertilizers, and poor crop management practices. Khalifa et al. (2004) indicated that in North Sinai, barely is cultivated every year, which resulted in low productivity. Similar situation was found in Marsa Matrouh, where wheat productivity under rain fed conditions is low due to wheat cultivation every year in the same piece of land (Attia and Barsoum 2013).

There were scattered studies on crops structure in rain fed area in Egypt and suggested improved management to overcome drought effect. These improved management included water harvesting, crop diversification (inclusion of legume in particular) and fertility build up by adding manure to the soil.

Water harvesting is a process of collecting and storing water for later beneficial use (Frasier 1994). The collected water can be used for domestic uses and for growing plants. Water harvesting systems are mainly practiced in arid and semi-arid areas with annual rainfall ranging from 100 to 600 mm (Oweis et al. 1999). Two main systems of water harvesting techniques have been widely implemented. The macro-catchment and the micro-catchment water harvesting system. In the first system, the surface runoff is collected from a large area (called the catchment or the contributing area). The collected water is then either stored in reservoir for further use as a supplementary irrigation or directly applied to the soil for use by the crops (Oweis et al. 2001). With respect to micro-catchment water harvesting, it can improve soil moisture storage, prolong the period of moisture availability, and enhance growth of cultivated crops. Examples of these techniques are contour ridges, semi-circular, trapezoidal bunds and ridge-furrow system (El-Sadek and Salem 2015).

Crop diversification by adding legume crops with low water requirements, such as lintel, pea and faba bean can improve productivity of barley and wheat under crop rotation implementation (Khalifa et al. 2004; El-Sadek and Salem 2015). Interplanting lintel under young olive trees or under fig and peach trees (young or mature) increased the yield of the tree as a result of increase in soil fertility. Furthermore, it reduced wind erosion and conserve moisture content (Kamel 2011). Crop rotations, where legume crops followed cereals crops proved to increase productivity of cereal crops, as these cereal crops benefits from nitrogen fixed by legume and decomposition of roots and nodules (Shams and Kamel 2014). Therefore, implementation of crop rotation in rain fed areas, where barley (Khalifa et al. 2004 and Shams and Kamel 2014) or wheat (Shams and Kamel 2014) followed by lentil increased the yield of both crops. Most of famers in rain fed area do not applied manure to the growing crops (Shams and Kamel 2014). However, manure is a source of copious content of major and minor nutrition elements available to plant roots absorption. Furthermore, its acidic effect lowers the pH value of the soil and facilitates nutrients absorption (Esefanous et al. 1997).

The alarming results of climate change studies on rain fall globally implied that, in fragile environment like North Coast of Egypt, climate change could badly affect it. However, there are no local studies on the effect of climate change on rain fed agriculture in Egypt. The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change contained a large number of comprehensive climate models and Earth System Models, whose results form the core of the climate system projections (IPCC 2013). These models produce new Representative Concentration Pathways Scenarios in the future, i.e. RCP2.6, RCP4.5, RCP6.0 and RCP8.5 (Wayne 2013). Using these RCPs could lower the uncertainty in assessment of the effect of climate change on evapotranspiration and crops productivity (Solomon et al. 2007). Morsy (2015) indicated that using global models and region models could achieve higher level of certainty in the projection of the effect of climate change.

The objectives of this chapter were to study the existing crops structure in the rain fed area in Egypt, represented by two governorates, i.e. North Sinai and Marsa

Matrouh. In order to close the gap in our understanding on how climate would affect sustainability in rain fed area, integrated modeling approach was used, where BISm model was used to calculate evapotranspiration and crop coefficient. These values were input in Yield-Stress model and the model was calibrated and used to simulate the effect of application of supplementary irrigation for the growing crops in these areas. Under climate change in 2030, weather data were used to run Yield-Stress model to evaluate its effect on crops productivity. Furthermore, simulation of the effect of manure application to these crops was done to explore its effect on improving productivity under drought conditions induced by climate.

Selected Governorates and Crops

Rain fed agriculture in Egypt is represented by two governorates, i.e. North Sinai in North East of Egypt (latitude 32.07°, longitude 33.45° and elevation above sea level 17.10 m) and Marsa Matrouh in North West of Egypt (latitude 31.30°, longitude 27.20° and elevation above sea level 7.00 m) as shown in Fig. 3.1.

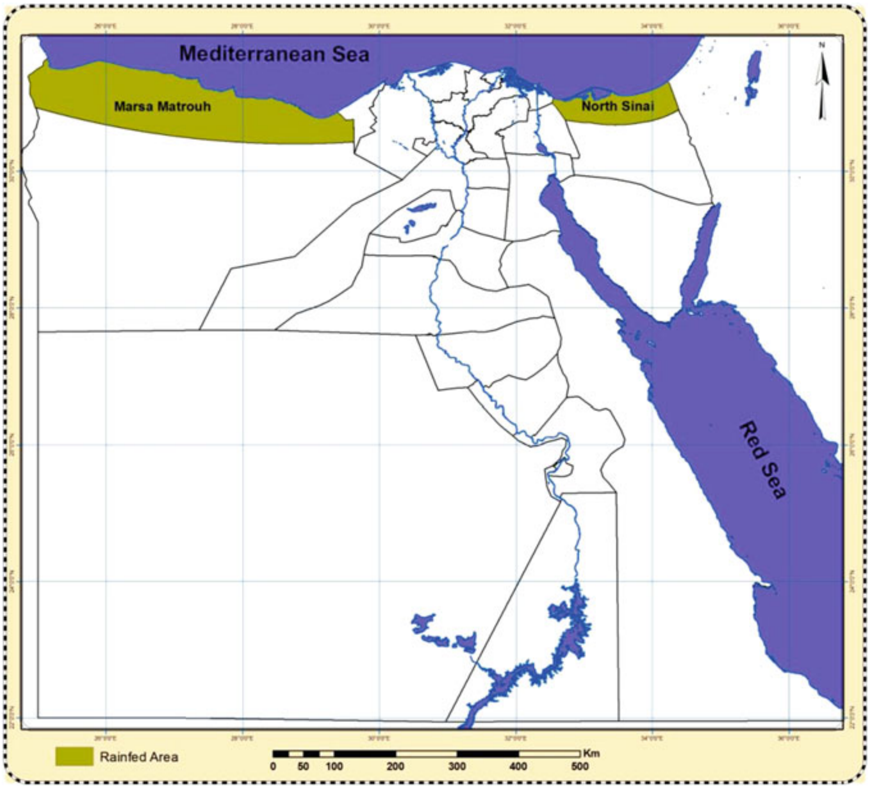

Fig. 3.1 Map of the selected sites under rain fed areas

Table 3.1 Monthly values of rain fall (mm) average over 18 years (1997–2014) in North Sinai and Marsa Matrouh governorates

	Rain fall in North Sinai	Rain fall in Marsa Matrouh
January	44	40
February	27	30
March	18	16
April	9	9
May	5	4
June	1	1
July	0	0
August	0	0
September	1	2
October	9	7
November	20	18
December	34	37
Total	168	164

Current Situation of Rain Fed Areas in Egypt

Values of Rain Fall

Monthly values of rain fall in North Sinai and in Marsa Matrouh governorates were only available from 1997 to 2014. The average monthly values of the rain fall in the 18 years were calculated and presented in Table 3.1. The data in this table indicated that the average rain fall values in North Sinai were slightly higher than its value in Marsa Matrouh. In both sites, the highest average of rain fall was in January. Usually farmers start cultivation of their crops after the fall of large amount of rain from their point of view. Furthermore, the results also revealed that the rain values in February and December were higher in Marsa Matrouh, compared North Sinai.

The amount of annual rain fall values in both governorates is presented in Table 3.2. The range between the highest value and the lowest value of annual rain fall was lower in North Sinai than Marsa Matrouh, i.e. 138 and 145 mm, respectively. The stability of rain fall in both governorates was tested by calculating coefficient of variation (CV %). The results indicated that CV % was slightly lower in Marsa Matrouh than North Sinai, which implied that rain variability was similar in both locations (Table 3.2).

Existing Crops Structure in the Studied Governorates

In North Sinai and Marsa Matrouh, barley and wheat are cultivated before the rain fall in November or December and usually harvested as grain in April or as forage if

Table 3.2 Annual values of rain fall (mm) from 1997 to 2014 in North Sinai and Marsa Matrouh governorates

Year	North Sinai	Marsa Matrouh
1997	204	193
1998	157	224
1999	95	80
2000	233	168
2001	155	160
2002	226	158
2003	172	198
2004	202	157
2005	141	188
2006	143	144
2007	158	160
2008	121	194
2009	150	155
2010	160	131
2011	174	209
2012	210	168
2013	133	130
2014	193	137
Mean	168	164
Range	138	145
Coefficient of variation	0.22	0.21

the rain amount was not enough for the growing plants to continue its life cycle. In North Sinai, the most famous fruit trees are peach and olive, whereas in Marsa Matrouh olive and fig trees are grown. Furthermore, some farmers interplant barley under these trees.

Simulation of Crops Productivity in Rain Fed Area

Yield-Stress model (Ouda 2006) was used in this analysis. The model assumes that there is a linear relationship between available water and yield, in which the reduction in available water limits evapotranspiration and consequently reduces yield. The Yield-Stress model was designed to predict the effect of scheduling deficit irrigation on the yield of several crops and on their water consumptive use. Most importantly, its performance was acceptable, when it was compared to CROPWAT (Khalil et al. 2008). The model uses daily weather data to calculate potential evapotranspiration (PET) and crop evapotranspiration (ETc). The model simulates water depletion from root zone and dry matter accumulation. The model was modified to simulate productivity under rain fed condition. BISm model (Snyder et al. 2004) was used to calculate crop kc value. BISm model contains a list of crops in its database, where it could be used to calculate crop kc value as a percentage of the crop growing season. Sowing and harvest dates are also involve in determining kc value for each growth stage. Yield-Stress model used the value crop kc as input to calculate daily ETc. Available water in soil as a characteristic of soil type was input in the model to calculate the depletion of rain water from the root zone and calculate water stress index, whenever water stress exist. Water stress index is calculated as a reduction factor on transpiration then on assimilates translocation. Water stress index takes a value between 0 and 1. Water stress index equal 0 when there is no moisture in the root zone to fulfill the needs for evapotranspiration. During this time, photosynthesis ceased and no photosynthate translocation or growth occurs (Allen et al. 1998).

The model was calibrated for the selected crops using published data. The calibration process depends on adjustment in crop calibration coefficient (Yc, kg/MJ/day). Yc represents the amount of dry matter in kilograms that is produced per mega joule per day and accumulated in term of biological yield. Thus, Yc is affected by weather conditions in the region and by the growing season of the cultivated crop. Furthermore, using Yc for calibration of Yield-Stress model can allows very accurate simulation for dry matter accumulation, if great effort was made in the calibration procedure. Under this condition, the simulated yield value can be as the same as the measured values in the field, which is required under rain fed cultivation to improve the quality of simulation.

Calibration of Yield-Stress Model for Prevailing Crops Structure in Rain Fed Area

Barley and Wheat

Barley data was obtained from Kamel (2011) in 2006/07 growing season under rain fed in North Sinai. Barley was planted on the 4th of January, where 24.9 mm of rain fall and was harvested on the 14th of April, three weeks after fall of 18.1 mm of rain. The total seasonal rain fall (January to April) was 91.4 mm.

Wheat data was obtained from Hussian (2005) in 2001/02 growing season, where wheat was planted the 2nd of December after 43.5 mm of rain fall and was harvested on the 14th of April three weeks after 31.1 mm of rain fall. Furthermore, the total seasonal rain was 181.9 mm.

Regarding to Marsa Matrouh, field data was obtained from Kamel (2011) for barley grown in 2006/07 growing season. Barley was planted after major rain fall event on 31st of December, where 19.4 mm were fall and was harvested in 25th of April. The total season rain fall was 67.6 mm. Wheat data was obtained from Attia and Barsoum (2013) in 2006/07 growing season too, where the total amount of rain was 67.6 mm.

The collected data for barley and wheat were used to calibrate Yield-Stress model. Table 3.3 showed measured and predicted values of grains and biological yield of

Table 3.3 Measured versus predicted grain and biological yield of barley and wheat in rain fed area

	Crop	Grains yield (ton/ha)			Biological yield (ton/ha)		
		Measured	Predicted	PD %	Measured	Predicted	PD %
North Sinai	Barley	1.69	1.69	0	5.12	5.12	0
	Wheat	1.49	1.49	0	4.25	4.25	0
Marsa Matrouh	Barley	1.01	1.01	0	3.16	3.16	0
	Wheat	0.99	0.99	0	3.01	3.01	0

PD % = Percentage of difference (%)

both crops. The results in that table indicated that Yield-Stress model can be calibrated to predict barley and wheat yield values similar to the measured values in the field, where percentage of difference between measured and predicted values was zero. Similar results were obtained by Khalil et al. (2007) and El-Mesiry et al. (2007).

Olive, Peach and Fig Trees

North Sinai is one of the sites that cultivate olive and peach on rain fall. Olive is characterized by its ability to withstand prolong periods of soil water deficit under rain fall conditions. Peach productivity declined during the past years as a result of decline in the rain fall. In Marsa Matrouh, olive and fig are two important fruit crops. Fig tree is known by its tolerance to water deficit.

Yield-Stress model was calibrated for peach and olive trees in North Sinai, as well as olive and fig trees in Marsa Matrouh using field experiments data in both locations. Regarding to peach in North Sinai, field experiment was conducted in 2010/11 under rain fed conditions where trees was planted at distance of 7 × 7 m (El-Kosary et al. 2013). Furthermore, olive was grown in 2010/11 also at distance of 5 × 5 m (Mohy El-Din et al. 2013). The total seasonal rain in 2010/11 was 140 mm, which produced 4.55 and 8.10 ton/ha peach and olive, respectively.

With respect to olive grown in Marsa Matrouh, trees were grown at 7 × 7 m apart and the yield was 5.10 ton/ha in 2008/09 (Attalla et al. 2011), where total rain fall was 91.6 mm. Fig trees was also grown in Marsa Matrouh at 7 × 7 m apart in 2006/07 growing season with total rain fall equal 63.6 mm and produced 8.78 ton/ha (Al-Desouki et al. 2009). Table 3.4 indicated that the model was able to predict values of fruits yield similar to the measured values in the field.

Table 3.4 Measured versus predicted olive, peach and fig yield in rain fed area

	Crop	Measured	Predicted	PD %
North Sinai	Olive	8.10	8.10	0
	Peach	4.55	4.55	0
Marsa Matrouh	Olive	5.15	5.15	0
	Fig	8.94	8.94	0

PD % = Percentage of difference (%)

The above results implied that Yield-Stress model was capable of predicting the same measured values of barley, wheat, olive, peach and fig yields as a result of fine tuning calibration procedure. This fine tuning will facilitate the use of the model for further investigation on the effect of change in rain fall on these crops.

Management Practices to Improve Productivity in Rain Fed Areas

Application of Supplementary Irrigation

Some farmers who performed macro-catchment water harvesting technique can apply supplementary irrigation to increase productivity of their cultivated crops under rain fed conditions. Hussian (2005) indicated that application of 30 mm as supplementary irrigation during heading stage increased yield of wheat by 30 % in North Sinai. In Marsa Matrouh, application of 60 mm for wheat increased grains yield by 75 % (Attia and Barsoum 2013).

Furthermore, several micro-catchment harvesting technique can be used by farmers, such as ridge-furrow water harvesting system, in which the rainfall water is harvested through the mulched ridges and the crop is planted in furrows between the ridges (Li and Gong 2002). In this method, the planting zone can be covered in order to prevent evaporation from the soil. El-Sadek and Salem (2015) implemented this method under the rain fed conditions in Marsa Matrouh for faba bean. Two ridge-furrow ratios of 120:60 and 60:60 cm were used and compared to the conventional cultivation in a flat plot. The results indicated that 18 and 47 % increase in the yield occurred under 120:60 and 60:60 cm ridge-furrow ratio, respectively.

Using Yield-Stress model, we simulated the effect of application of 60 mm as a supplementary irrigation divided into two equal amounts applied one month after planting and two months after planting. The results in Table 3.5 indicated that application of extra 60 mm increased barley and wheat yield by 61 and 58 %, respectively in North Sinai. Furthermore, in Marsa Matrouh, application of supplementary irrigation amount of 60 mm in two doses increased barley and wheat grain yield by 53 and 51 %, respectively.

Table 3.5 Simulated potential grains and biological barley and wheat yield under the application of supplementary irrigation in both sites

	Crop	Grain yield (ton/ha)			Biological yield (ton/ha)		
		Measured	Predicted	PD %	Measured	Predicted	PD %
North Sinai	Barley	1.69	2.72	61	5.12	8.24	61
	Wheat	1.49	2.35	58	4.25	6.7	58
Marsa Matrouh	Barley	1.01	1.55	53	3.16	4.85	53
	Wheat	0.99	1.49	51	3.01	4.51	50

PD % = Percentage of difference (%)

Table 3.6 Simulated potential yield of fruit trees (ton/ha) under the application of supplementary irrigation in both sites

	Crop	Measured	Predicted	Percentage of difference (%)
North Sinai	Olive	8.10	11.52	42
	Peach	4.55	6.43	41
Marsa Matrouh	Olive	5.15	10.61	106
	Fig	8.94	16.18	81

Regarding to the application of supplementary irrigation to fruit trees grown under rain fed conditions, El-Kosary et al. (2013) indicated that supplementary irrigation amount of 60 mm applied to peach trees grown in North Sinai increase tree yield by 24 %. Attalla et al. (2011) reported that application of 60 mm of supplementary irrigation to olive tree grown in Marsa Matrouh increase tree yield by 8 %. For fig trees in Marsa Matrouh, introduction of supplemental irrigation resulted in increase in fig yield by 11 %, as compared to what obtained under rain fed conditions only (Allam et al. 2007).

Simulation of the effect of supplementary irrigation on olive, peach and fig yield is presented in Table 3.6. Olive and fig trees in Marsa Matrouh responded to the application of 60 mm of supplementary irrigation with high yield increase, compared to olive and peach trees in North Sinai (Table 3.6). This could be attributed to low rain fall in Marsa Matrouh, where water stress was higher there, compared to the conditions prevailed in North Sinai. Thus, application of 60 mm to olive trees planted in North Sinai and Marsa Matrouh increase yield by 42 and 106 %, respectively. Peach yield can be increased by 41 % in North Sinai and fig yield can be increased by 81 % in Marsa Matrouh.

Use of Interplanting and Crop Rotation

Interplanting and intercropping are considered as important way to increase the yield of unit area especially in developing countries. Sanchez (1976) pointed out that intercropping generally produces more total yield of mixed crops per hectare than when the individual crops are grown in single-stand and that increase varies from 20 to 50 % more yield per hectare as commonly obtained by intercropping annual crops. An increase in fig yield by 6–8 % occurred when lintel was interplanted under it in Marsa Matrouh (Allam et al. 2007; Kamel 2011).

Crop rotation is one of most effective agricultural strategies to sustain soil and water resources. Previous research conducted by Khalifa et al. (2004) on comparing barley monoculture and barley grown in two-year crop rotation, where it was followed by pea or lentil, indicated that barley yield was significantly increased, compared to barley monoculture. Furthermore, the yield of barley grown after pea or lentil increased by 113 and 104 %, respectively compared to barley monoculture. These results implied that continuation of barley cultivation exhausted the soil and depleted nutrients from it. Furthermore, including legumes in the crops rotation is recommended for sustaining soil productivity and improving barley productivity under rain fed conditions. Shams and Kamel (2014) indicated that using two year rotation for wheat grown under rain fed conditions, where wheat was followed by lintel or pea increased wheat yield, compared to wheat mono cropping.

Application of Manure as Fertilizer

Few researchers highlighted the benefits of using manure as fertilizer under rain fed conditions in Egypt. Shams and Kamel (2014) indicated that manure application to barley and wheat grown solely in Marsa Matrouh increased its yield by 15 and 25 %, respectively. Whereas, manure application to barely in North Sinai increase yield by 12 %, compared to barely cultivation without application (Khalifa et al. 2004). Furthermore, Application of manure to peach trees grown in North Sinai increased yield per tree by 37 % (El-Kosary et al. 2013). Manure application often results in increased soil aggregate stability, which reduced runoff and erosion (Wortmann and Shapiro 2008), and that explain its positive effect on cultivated crops under rain fed areas.

Future of Rain Fed Agriculture in Egypt

Rain fed agriculture is generally risky due to high spatial and temporal variability of rainfall. Evidence is emerging that climate change is making the variability more intense, with increased frequency of extreme events, such as drought (IPCC 2001). Thus, the future of rain fed agriculture in Egypt is mainly dependent on the amount and frequency of rain fall. As stated previously, there were no studies on the effect of climate change on rain fed agriculture in Egypt. Furthermore, there is a need to project the incidence and the quantity of rain fall under climate change. The effect of climate change on the cultivated crops was assessed using comparison between RCPs scenarios developed from four global models and the boundary of the closer scenario to the measured data was input into a regional climate model (WRF-RCM) to develop more accurate weather data to be in the assessment.

Comparison Between Past and Future Annual Rain Fall

Deviation of rainfall from normal (long term mean) is the most commonly used indicator for drought monitoring. On the basis of rainfall deviations, four categories are used for monitoring and evaluating the rainfall patterns: ±10 % deviation is normal, −10 to −60 % deviation is deficit, less than −60 % deviation is scanty and greater than 20 % deviation is excess (Kumar et al. 2009).

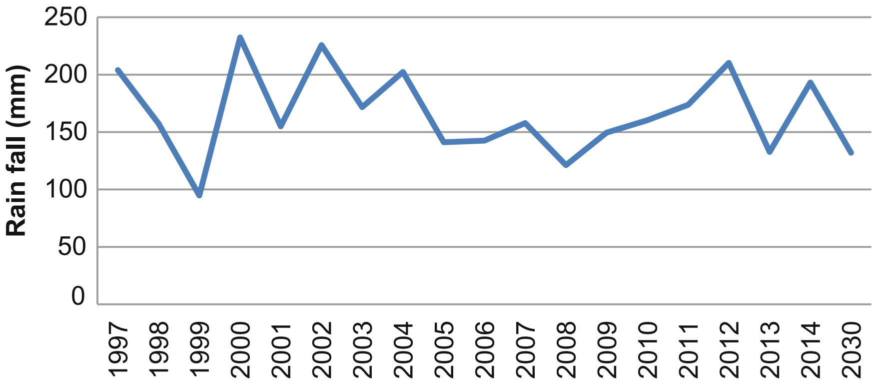

Fig. 3.2 Annual rain fall amount from 1997 to 2014 and in 2030 in North Sinai

For comparison purposes, the projected annual rain value in 2030 was graphed with annual rain values starting from 1997 to 2014 in North Sinai (Fig. 3.2). Figure 3.2 indicated that the projected value of annual rain fall value in 2030 will be the lowest than what was recorded from 1997 to 2014, except for the amount in 1999, which was the lowest. Rain fall deviation in 2030 from the average of 18 years was −27 %, which considered deficit.

Comparison between monthly rain fall values for the studied field data and projected rain fall data in 2029/30 in North Sinai revealed that the lowest monthly rain fall was found in 2029/30 (Fig. 3.3).

Similarly, the projected annual rain fall value in 2030 will be lowest compared to the recorded value from 1997 to 2014 (Fig. 3.4). Rain fall deviation in 2030 from

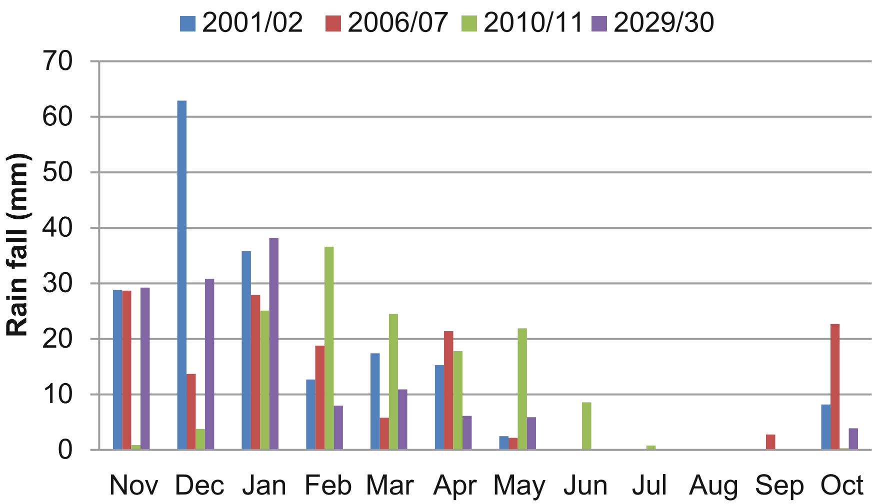

Fig. 3.3 Monthly rain fall amounts for the studied field data and in 2029/30 in North Sinai

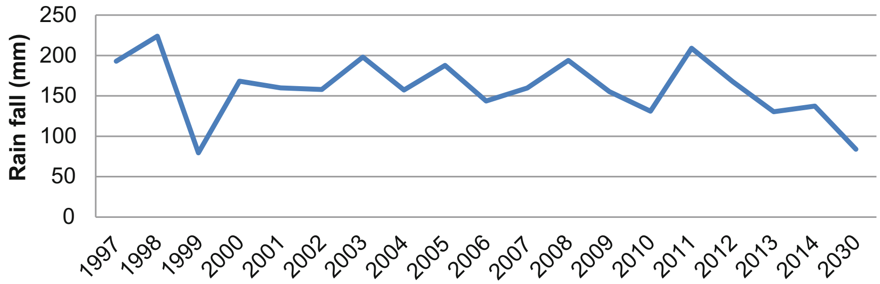

Fig. 3.4 Annual rain fall amount from 1997 to 2014 and in 2030 in Marsa Matrouh

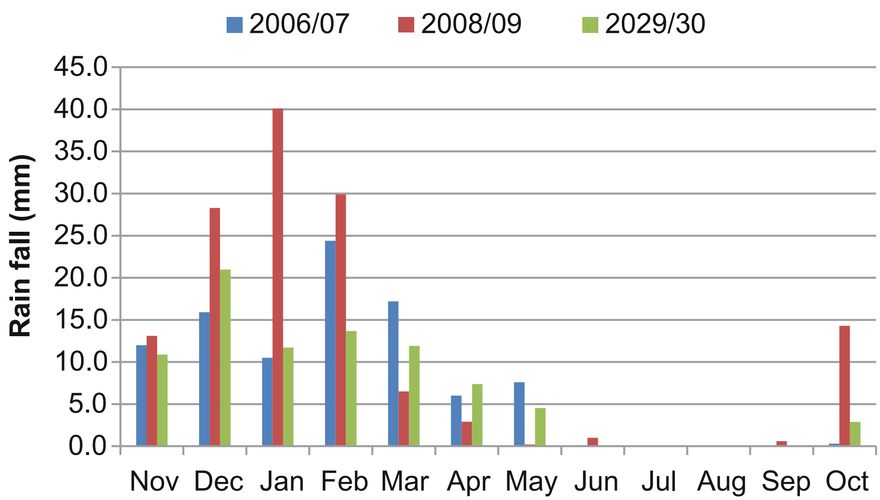

Fig. 3.5 Monthly rain fall amount for the studied field data and in 2029/30 in Marsa Matrouh

the average of 18 years was −95 %, which considered scantly. This result implied that drought will highly affect Marsa Matrouh, compared to North Sinai.

Furthermore, monthly rain fall values for the studied field data was higher than projected rain fall data in 2029/30 in Marsa Matrouh (Fig. 3.5).

Projected Daily Rain Fall in 2029/30 Season

The above results indicated that the projected annual amount of rain fall in the studied sites will decrease. Thus, the daily values of rain fall in the two studied locations was graphed and presented in Figs. 3.6 and 3.7 to show the frequency and the daily amounts. Figure 3.6 indicated that the frequency of rain fall in North Sinai will increase in 2029/30; however the amount will be much lower. The highest

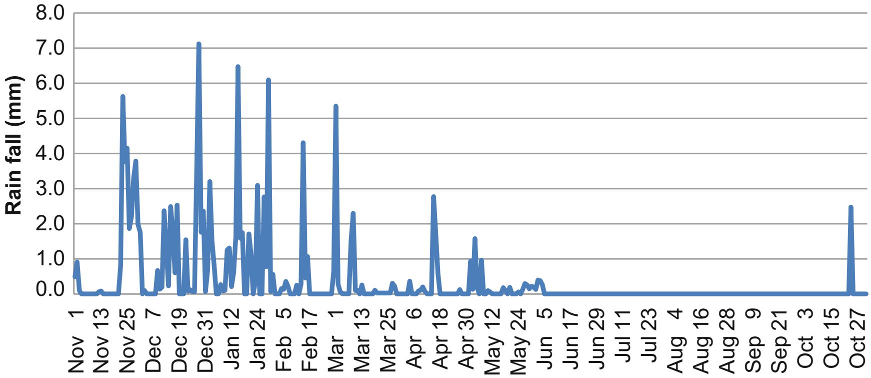

Fig. 3.6 Daily projected rain fall at North Sinai in 2029/30 growing season

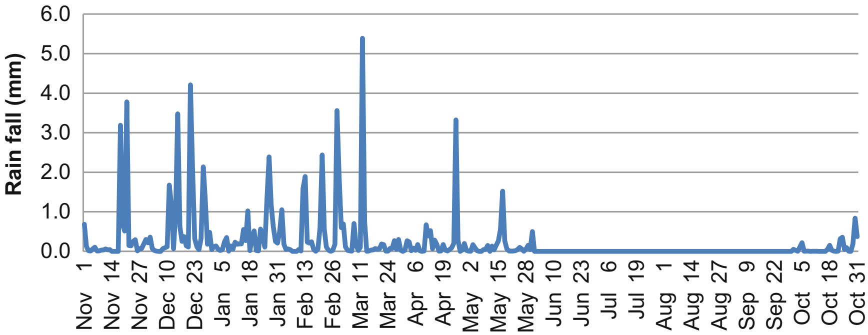

Fig. 3.7 Daily projected rain fall at Marsa Matrouh in 2029/30 growing season

amount of rain in the whole season will be 7.2 mm in December 2029. However, lower values in rain fall are projected and last for few days (Fig. 3.6).

Similar trend was observed in Marsa Matrouh, where the frequency increased and the amount decreased (Fig. 3.7). The highest value was 5.4 mm fall in March.

Assessment of the Reduction of Rain Fall on Crops Productivity

Yield-Stress model was used to simulate the effect of projected rain fall amount in 2030 on barley and wheat growing seasons. Thus, we started the growing season in North Sinai in 23rd of November 2029, where rain fall continued for 8 consecutive days with low amount (the highest was 5.6 mm and the lowest was 2.9 mm). Furthermore, we ended the growing season of barley and wheat in 23rd of March

Table 3.7 Predicted grain and biological yield of barley and wheat in 2029/30 in North Sinai

	Grain yield (ton/ha)			Biological yield (ton/ha)		
Crop	Measured	Predicted	PD %	Measured	Predicted	PD %
Barley	1.69	0.88	−48	5.12	2.67	−48
Wheat	1.49	0.57	−62	4.25	1.58	−63

PD % = Percentage of difference (%)

Table 3.8 Predicted biological yield of barley and wheat in 2029/30 under climate change in Marsa Matrouh

Crop	Measured	Predicted	PD %
Barley	3.16	0.46	−85
Wheat	3.01	0.29	−90

PD % = Percentage of difference (%)

Table 3.9 Predicted yield of fruit trees in 2029/30 under climate change in both sites

	Crop	Measured	Predicted	PD %
North Sinai	Olive	8.10	6.11	−25
	Peach	4.55	3.32	−27
Marsa Matrouh	Olive	5.15	2.26	−56
	Fig	8.94	4.99	−44

PD % = Percentage of difference (%)

2030, three weeks after 5.3 mm of rain fall. Table 3.7 showed predicted grain and biological yield of barley and wheat in projected 2029/30 growing season. The results indicated that, as a result of lower rain amount in 2030, barley yield will be reduced by 48 % and wheat yield will be reduced by 62 %.

More drastic consequences are expected to occur in Marsa Matrouh in 2029/30, where barley and wheat will not produce any grains as a result of low rain fall. The biological yield will be reduced by 85 and 90 % for barley and wheat, respectively (Table 3.8). The above results are very disturbing and implied that famers lives in Marsa Matrouh will be not able to cultivate barley and wheat in 2092/30.

The results in Tables 3.7 and 3.8 proved that barley is more tolerant to water stress than wheat. Samarah (2005) indicated that barley plants exposed to mild water stress produced yield lower than well watered plants by 20 %.

The simulation procedure was done for fruit trees in 2029/30 in both sites using Yield-Stress model. The simulation results indicated that fruit trees grown in the two sites will be more tolerant to drought and its yield will be reduced by lower percentage, compared to cereal crops (Table 3.9). Olive yield will be reduced by 25 and 79 % in North Sinai and Marsa Matrouh, respectively. Sofo et al. (2008) indicated that olive trees developed a series of physiological mechanisms to tolerate drought stress and grow under adverse climatic conditions. However, under high water stress, its yield was reduced.

The peach yield will be reduced by 27 %, which could be attributed to its ability to withstand low moisture availability in the root zone area (Abrisqueta et al. 2012). The fig yield will be reduced by 44 %. Fig tree is characterized by its tolerance to water deficit. However, Allam et al. (2007) and Al-Desouki et al. (2009) indicated that the growth and yield of fig trees was reduced under severe drought stress.

Adaptation of Crops Structure in Rain Fed Areas to Climate Change

The Intergovernmental Panel on Climate Change defines adaptation as 'adjustment in natural or human systems to a new or changing environment (IPCC 2007). The previous analysis indicated that climate change will reduce rain fall amounts in the two studied sites, which implies that the amount of rain that can be harvested will be low and might not be enough to be used in supplementary irrigation for growing crops in these areas. Thus, to reduce the risk of climate change on rain fed areas, improved management package, or in another word adaptation strategies should be implemented. These strategies include interplanting, crop rotation and using manure for fertilizer. Cultivation of legume crops in sequence with cereal crop in the following year either under monoculture planting or interplanting under fruit trees is suggested to prevent soil deterioration and increase its fertility. Using manure as fertilizer could be a method for soil and water conservation, as well as moisture retention through enhancing soil water storage ability (Mosavi et al. 2012). Wortmann and Shapiro (2008) observed reduction in bulk density, increase in hydraulic conductivity and increase in available soil water holding capacity by 56 % compared to the control and after application of compost or manure for 5 years.

Thus, we assumed that if we started to apply manure now, the available water in the soil can be increased from 0.09 to 0.15 m/m by 2030. Then, we simulated the yield of the cultivated crops under using the above value of available water in the soil under climate change in 2029/30. The simulation results in Table 3.10 indicated that the additive effect of the application of manure under rain fed in both sites can reduce yield losses of barley and wheat in 2029/30. Potential barley yield losses can be reduced from 48 and 85 % in North Sinai and Marsa Matrouh, respectively (Tables 3.7 and 3.8), to 12 and 71 % (Table 3.10). Wheat yield losses can be

Table 3.10 Predicted grain yield of barley and wheat (ton/ha) in North Sinai and biological yield of barley and wheat with application of manure in 2029/30

	Crop	Measured	Predicted	PD %
North Sinai	Barley	1.69	1.49	−12
	Wheat	1.49	0.93	−38
Marsa Matrouh	Barley	1.01	0.29	−71
	Wheat	0.99	0.18	−82

PD % = Percentage of difference (%)

Table 3.11 Predicted yield of fruit trees (ton/ha) with application of manure in 2029/30 in both sites

	Crop	Measured	Predicted	PD %
North Sinai	Olive	8.10	7.10	−12
	Peach	4.55	3.93	−14
Marsa Matrouh	Olive	5.15	3.04	−41
	Fig	8.94	7.75	−13

PD % = Percentage of difference (%)

reduced from 62 and 90 % in North Sinai and Marsa Matrouh, respectively (Tables 3.7 and 3.8) to 38 and 82 % (Table 3.10). This result can be attributed to the fact that barley is adapted to a severe water regime compared with other cereals (Samarah 2005).

Regarding to olive, its yield losses will be reduce from 25 and 56 % (Table 3.9) to 12 and 41 % (Table 3.11). Similarly, peach and fig yield losses will lowered from 27 and 44 % (Table 3.9) to 14 and 13 % (Table 3.11), respectively as a result of additive effect of manure application on soil water retention.

Water and Land Productivity in Rain Fed Areas

Crop water productivity (kg/m^3) and land productivity (kg/m^2) measurements are quantitative terms used to define the relationship between crop produced with the amount of applied irrigation water or unit of land involved in crop production. They are useful indicators for quantifying the impact of management on final crop yield (FAO 2003). Water and land productivity were used in this analysis as indication for the success of the suggested management under current climate and adaptation strategy under climate change in 2030 and drought stress. Table 3.12 indicated that, in general, water and land productivity were higher in North Sinai, compared to Marsa Matrouh under current situation, under supplementary irrigation, under climate change and under manure application. This could be attributed to the higher amount of rain fall in North Sinai, compared to Marsa Matrouh. Furthermore, water and land productivity for barely was higher than wheat under all studied options, as a result of shorter growing season and lower water requirements for barely in both sites. Supplementary irrigation increased water and land productivity values for barley with higher value than wheat under current situation in both sites. Climate change effect highly reduced water and land productivity for both crops in both sites due to low rain fall. However, application of manure increased water and land productivity owing to the role that manure do in increasing water holding capacity in the soil.

Table 3.12 Water and land productivity in rain fed areas using management practices

	Crop	North Sinai		Marsa Matrouh	
		WP (kg/mm)	LP (kg/m^2)	WP (kg/mm)	LP (kg/m^2)
Current situation	Barley	0.183	0.169	0.149	0.101
	Wheat	0.082	0.149	0.146	0.099
Supplementary irrigation	Barley	0.277	0.272	0.211	0.155
	Wheat	0.125	0.235	0.202	0.149
Climate change effect	Barley	0.077	0.088	0.029	0.015
	Wheat	0.050	0.057	0.016	0.009
Climate change +manure	Barley	0.131	0.149	0.056	0.029
	Wheat	0.081	0.093	0.032	0.018
Current situation	Olive	5.786	0.810	0.562	0.515
	Peach/fig	3.250	0.455	1.406	0.894
Supplementary irrigation	Olive	8.229	1.152	1.087	1.061
	Peach/fig	4.593	0.643	2.325	1.618
Climate change effect	Olive	4.364	0.611	0.440	0.226
	Peach/fig	2.371	0.332	0.971	0.499
Climate change +manure	Olive	5.071	0.710	0.591	0.304
	Peach/fig	2.807	0.393	1.508	0.775

Regarding to fruit trees, high difference between the two sites in water and land productivity was found (Table 3.12), which could be attributed to higher rain fall in North Sinai, compared to Marsa Matrouh. Furthermore, similar trend to field crops was observed for fruit crops regarding to water and land productivity.

Conclusion

Innovative approaches need to be adapted to management of such fragile resources under rain fed conditions in Egypt. We suggested four practices to face drought stress occurrence in rain fed area in Egypt: application of supplementary irrigation and manure, as well as using crop rotation and interplanting. Although we were not able to simulate the effect of all of them, the simulation results of application of supplementary irrigation and manure were encouraging to assume that additive effect of the four suggested practices could overcome the risk of drought under current climate and the projected climate change in 2030.

Using modeling to predict rain fall dates and amounts is an important procedure to be done by extension workers in rain fed areas to increase the resilience of these areas to face rain fall variability. Furthermore, the government should allocate more funds for these areas to increase its sustainable development.

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Chapter 4
Crops Intensification to Face Climate Induced Water Scarcity in Nile Delta Region

Abd El-Hafeez Zohry and Samiha A.H. Ouda

Abstract Irrigation water management has become very important task to be implemented in Egypt due to the prevailing conditions of water scarcity. Thus, technologies are required to increase water and land productivity. The objective of this chapter was to suggest management package to overcome water scarcity conditions. It included precise land leveling and cultivation on raised beds to save 25 % of the applied water to surface irrigation, as well as changing crops sequence from two crops per year to three crops per year and implementing different intercropping systems. We suggested to cultivate short season clover, soybean or bean between winter and summer crops and to implement intercropping in one season and in two seasons. Similar procedure was done under climate change effect in 2030 to examine whether the suggested management can reduce climate change risk on food production. The results indicated that cultivating short season clover can be implemented because its water requirements will be available as a result implemented precise land leveling and cultivation on raised beds. The results also indicated that either intercropping in one season or two seasons can be implemented to increase land and water productivity. In addition, short season clover can be also cultivated between summer and winter seasons in some of these intercropping systems. Under climate change in 2030, water requirements for the cultivated crops will increase, which could lead to reduction in the cultivated area of these crops by different percentages. Implementing the suggested production package can reduce the required water to irrigate these crops. Furthermore, intercropping can maximize land and water productivity under climate change. Thus, our proposed management

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of crops intensification can be the solution for food gaps problems under current water scarcity situation in Egypt and under the anticipated climate change effects.

Keywords Precise land leveling · Cultivation on raised beds · Cultivation of three crops per year · Intercropping in one or two seasons

Introduction

Egypt is characterized by limited water and soil resources, in addition to high population rate. Irrigation water management has become very important task to be implemented in Egypt due to the prevailing conditions of water scarcity. In addition to, low application efficiency of surface irrigation, which is the prevailing irrigation system in the old lands in the Nile Delta and Valley (AbouZeid 2002). This situation creates challenges for agricultural scientists to manage water more efficiently, taking into consideration soil and water resources conservation. Thus, innovations are required to increase water and land productivity under water scarcity conditions. Furthermore, these innovations need to easy to be implemented by farmers to increase their adoption to these new technologies.

Precise land leveling is one of these technologies that can be used to reduce the applied water to surface irrigation without any losses in crops productivity. Previous research indicated that precise land leveling increased water use efficiency for several crops in Egypt. Furthermore, it can save 5 % of the applied irrigation water (El-Raie et al. 2004; Bahnas and Bondok 2010). Another management option is the cultivation on raised beds, which can save 20 % of the applied irrigation water to surface irrigation. It was also reported that cultivation on raised beds increased productivity by 15 %, as a result of increase in radiation used efficiency as crops are more exposed to solar radiation, increase nitrogen use efficiency and increase water use efficiency (Abouelenein et al. 2010; Karrou et al. 2012; Majeed et al. 2015). Thus, under these practices, 25 % of the applied water to surface irrigation can be saved.

Another innovation can be done, which is to changing crop sequence from two crops per year (winter then summer crop) to three crops per year (winter, fall then summer crop) or (winter, early summer then late summer crop). The saved irrigation water from the above innovations can be used to irrigate the third crop. The major benefits resulted from the use of these practices is to improve and sustain soil fertility and increase farmers' income (Sheha et al. 2014). Furthermore, implementing intercropping, where one crop share its life cycle or part of it with another crop (Eskandari et al. 2009) can be used as a way to save on the applied irrigation water, improve soil fertility and increase farmers' income (Kamel et al. 2010). The advantages of intercropping are: it increase unit land productivity (harvest two types of crops from the same area), increase water productivity (use less water to irrigate two crops) and increase farmers' income (reduce risks from crop failure) (Andersen 2005).

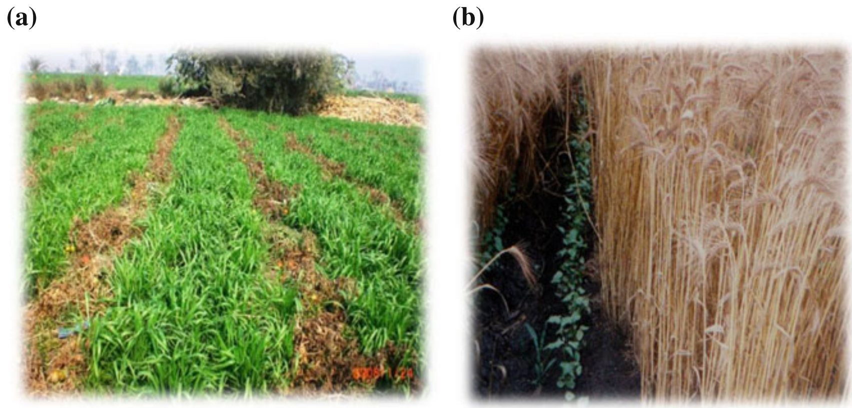

Fig. 4.1 Wheat intercropped with tomato (**a**) and relay intercropping cotton on wheat (**b**)

Several papers have been published in Egypt to highlight the role of intercropping systems on soil and water sustainability. Two intercropping systems on wheat were implemented and reported in Egypt. The first system was intercropping wheat with tomato (Fig. 4.1a) by cultivating tomato in the end of September on the raised bed with 100 % planting density. After 45 days, wheat was cultivated in four rows in the top of the raised beds, with 75 % planting density and its productivity will be 80 %, compared to wheat sole planting. Under this system, wheat plants use the applied amounts of water and fertilizer to tomato and tomato continued to give fruits until the end of March, whereas when it is planted solely it finished its life cycle in the end of December (Abd El-Zaher et al. 2013).

Another successful intercropping system was reported, which is relay intercropping cotton on wheat (Fig. 4.1b), where wheat was cultivated in November on the top of raised beds and cotton is cultivated in March on both edges of the raised beds. Thus, cotton shares two month of its life cycle with wheat (wheat was harvested in April) (Zohry 2005). The benefits of these two intercropping systems are the increase in wheat cultivated area by the area assigned to be cultivated by tomato and cotton.

Regarding to maize, several intercropping systems were implemented. Intercropping soybean with maize (Fig. 4.2a) can increase land and water productivity. In this case, soybean is cultivated in first of May on the top of the raised beds in four rows and maize is cultivated on the edges of the raised beds after 21 days from soybean planting. No irrigation water will apply to maize because it will take its water requirements from the applied water to soybean. Planting density are 50 and 80 % for maize and soybean of its sole planting, respectively. Final yield is 90 and 60 % maize and soybean of its sole planting, respectively (Sherif and Gendy 2012).

The other effective intercropping system is cowpea intercropped with maize (Fig. 4.2b), which proved to increase maize yield and reduced associated weeds. No additional water will be applied for cowpea under this system. Maize productivity

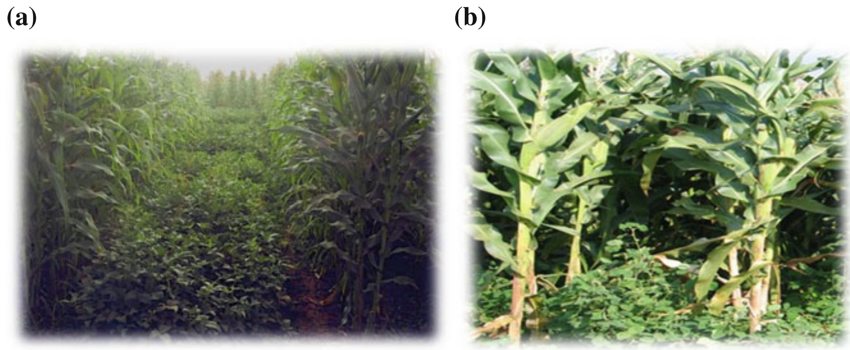

Fig. 4.2 Maize intercropped with soybean (**a**) and maize intercropped with cowpea (**b**)

increases by 10 % under this system and no reduction in cowpea productivity occurred (Hamd-Alla et al. 2014).

Relay intercropping potato on maize is another successful system (Fig. 4.3a), where maize is cultivated in June with 100 % planting density, 90 days after maize planting on one side of the raised beds, and potato is cultivated on the other side in September with 100 % planting density. Thus, this system allows early cultivation for potato, where maize plants provide warmth to potato plants and that allowed early harvest when its price is high. Under this system, potato will share its first two irrigations with maize (Ibrahim 2006).

Lastly, maize can be intercropped with tomato (Fig. 4.3b), where maize is cultivated 35–40 days after tomato, each plant species planted on one side of the raised beds. Maize planting density is 70 % of the recommended, whereas tomato planting density is 100 %. The benefits of using this system is that maize plants perform as sheds over tomato plants and protect its fruits from damage by sun rays.

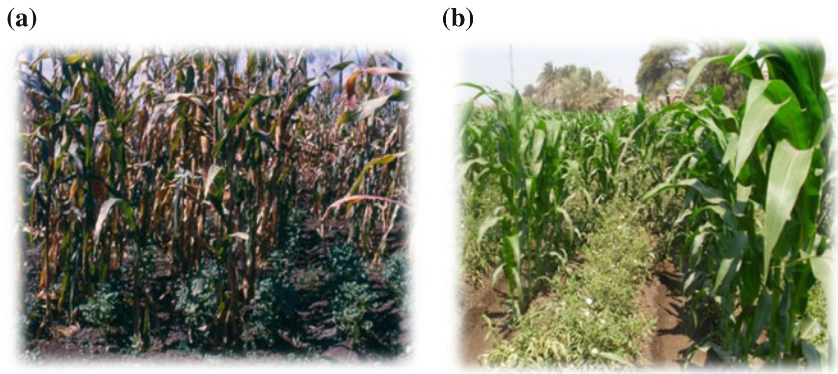

Fig. 4.3 Maize intercropped with potato (**a**) and maize intercropped with tomato (**b**)

This system saved 100 % of the applied water for maize as it use the applied water to tomato plants (Mohamed et al. 2013).

Intercropping onion with sugar beet system is also beneficial. Sugar beet is planted in October on both sides of the raised beds with 100 % planting density and onion is planted in November in two rows on the beds, with 33 % of its recommended planting density. The final yield of onion is 50 % of its yield obtained from sole planting and sugar beet yield is 90 % of its sole planting. Furthermore, the farmer obtained high profit from selling the onion and sugar beet (Gadallah and Badr 2008).

In Egypt, there is a large gap between production and consumption of faba bean. This gap can be overcome by intercropping it with other crops, such as tomato (Fig. 4.4a) and sugar beet (Fig. 4.4b). Regarding to faba bean intercropped with tomato, tomato is cultivated in the beginning of September, with 100 % planting density and faba been is cultivated in November with 50 % of recommended planting density. Both crops are harvested in the same date, which increase tomato season length by 2 months. Thus, this system increases the farmer's profit (Ibrahim et al. 2010).

Faba bean intercropped with sugar beet increases land and water productivity because no extra irrigation water or fertilizer is applied to faba bean. Sugar beet is cultivated to maintain 100 % of its recommended planting density and faba bean is cultivated by 12.5 % of its recommended planting density. As a result, the farmer can obtain 100 and 25 % of sugar beet and faba bean, respectively (Abd El-Zaher and Gendy 2014).

Thus, cultivating three crops per year and/or intercropping integrates the advantages of well-developed eco-agricultural techniques (Kaixian and Bozhi 2014), which need more evaluation of its potential contribution to agricultural sustainability. Thus, the objective of this chapter was to suggest management package include precise land leveling, cultivation on raised beds, changing crops

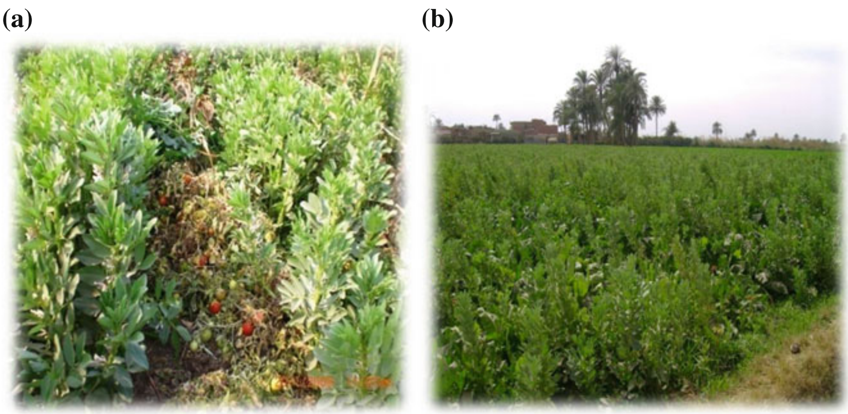

Fig. 4.4 Faba bean intercropped with tomato (**a**) and faba bean intercropped with sugar beet (**b**)

sequence from two crops per year to three crops per year and implementing different intercropping systems to overcome water scarcity and climate change conditions in Egypt.

The Selected Site

El-Gharbia governorate (latitude 30.36°, longitude 30.01° and elevation above sea level 17.99 m) is located in the middle of the Nile Delta and was selected to represent clay soils. The clay soils in Egypt are the most fertile soils in the Nile Delta and Valley. However, poor management of these soils reduced its organic matter content due to continual growing of exhaustive crops like cereals. Surface irrigation is prevailing with 60 % application efficiency. The cultivated crops are grown on either basins or on rows, where two crop sequence practice (a winter crop followed by a summer crop) is prevailing for either field crops or vegetables.

The Studied Crops

A list of the cultivated field and vegetable crops in winter and summer seasons, as well as their sowing and harvest dates are presented in Tables 4.1 and 4.2. These crops occupy high percentage of current crops structure in Egypt. In addition, they are favorable to farmers.

Many of the listed crops in Tables 4.1 and 4.2 are sown and harvested on different dates as they have a range for suitable sowing period. Planting and harvest dates for the studied crops were obtained from bulletins published by Agricultural Research Center in Egypt.

Table 4.1 Sowing and harvest dates for winter field crops and vegetables planted in the Nile Delta of Egypt

	Sowing date	Harvest date
Wheat	15-Nov	18-Apr
Clover (short season)	15-Sep	5-Nov
Clover (2 cuts)	15-Sep	28-Feb
Clover (full season)	15-Sep	15-Mar
Sugar beet	15-Nov	12-May
Sugar beet	15-Sep	12-Mar
Sugar beet	15-Oct	12-Apr
Flax	15-Nov	13-Apr
Flax	1-Nov	30-Mar
Faba bean	25-Oct	25-Mar
Garlic	15-Sep	15-Feb
Garlic	1-Sep	2-Feb
Tomato	1-Oct	1-Mar
Tomato	15-Sep	1-Mar

Table 4.2 Sowing and harvest dates for summer field and vegetable crops planted in Nile Delta of Egypt

	Sowing date	Harvest date
Maize	15-May	1-Sep
Maize (late)	15-Jul	5-Nov
Maize (forage)	15-Aug	15-Oct
Rice	15-May	10-Sep
Soybean	15-Apr	13-Jul
Sunflower	15-Apr	17-Jul
Pepper	1-Apr	8-Aug
Eggplant	1-Apr	8-Aug
Beans	15-Mar	15-May
Cotton	15-Mar	1-Sep
Potato	1-Aug	28-Nov
Tomato	1-May	1-Sep

Calculation of Crops Water Requirements Using BISm Model

The required irrigation water need to be applied to the studied crops was calculated using BISm model (Snyder et al. 2004) using climate normals data (1985–2014). The model requires planting and harvest dates as input to calculate crop coefficient (kc). It also requires to input total water holding capacity and available water in the soil to accounts for water depletion from root zone. Thus, it was used to calculate water requirements for the studied crops under surface irrigation and under 25 % saving in the applied water to surface irrigation.

The effect of climate change, in 2030, on the cultivated crops was assessed using comparison between RCPs scenarios developed from four global models and the boundary of the closer scenario to the measured data was input into a regional climate model (WRF-RCM) to develop more accurate weather data to be in the assessment. Water requirements for the selected crops were calculated under surface irrigation and with 25 % saving in the applied water to surface irrigation in 2030.

Suggested Crops Structure

Changing Crops Sequence

Regarding to the prevailing crops sequences, cultivation of wheat followed by maize or rice is exhausting to the soil. Furthermore, sugar beet followed by rice or maize have the same negative effect on the soil, similarly flax followed by maize (Table 4.3).

Table 4.3 Prevailing and suggested crops sequences, their water requirements (WR) and increase or decrease in total water requirements in the Nile Delta

	Prevailing crops sequence	WR (m^3/ha)	Suggested crops sequence	WR (m^3/ha)	Deviation[a] (m^3/ha)
1	Wheat then maize	16,075	Clover (short season), wheat then maize	16,050	+25
2	Wheat then rice	18,800	Clover (short season), wheat then rice	18,137	+662
3	Sugar beet then maize	18,566	Sugar beet, soybean then maize (late)	18,013	+553
4	Sugar beet then rice	21,316	Clover (short season), sugar beet then rice	21,391	−75
5	Flax then maize	16,100	Flax, soybean then maize (late)	16,400	−300
6	Faba been then maize	15,933	Faba bean, bean then maize (late)	16,287	−354
7	Garlic then maize	16,400	Garlic, soybean then maize (late)	17,125	−725
8 and 9	Clover (full season) then maize	21,066	Clover (full season), pepper then maize (forage)	20,513	+554
			Clover (full season), eggplant then maize (forage)	19,550	+1517

[a](+) before the number means saved on the applied irrigation water and (−) before the number means saved on the applied irrigation water

With respect to suggested crop sequences, it involves cultivation of third crop in between winter and summer crops. Thus, we suggested that the management package should be implemented to save an amount of irrigation water to be applied to the middle third crop. Furthermore, when suggesting a crop sequence, cereal crops should be followed by legume crops and crops with shallow roots should be followed by crops with deep roots to maintain soil fertility. Table 4.3 showed that instead of cultivation of two soil exhausted (wheat or sugar beet and maize or rice), short season clover can be cultivated as early winter crop in September after a summer crop and harvested in the beginning of November before the cultivation of a winter crop. Under this system, the three crops are cultivated on raised beds to use less irrigation water than traditional cultivation. Cultivation of short season clover after rice and before wheat increased soil fertility, compared to wheat and rice cultivation only (Sheha et al. 2014).

The results in Table 4.3 also indicated that some of the suggested crop sequences could save some of the applied irrigation water to it, as a result of implementing the management package. The suggested crop sequences number 1, 2, 3, 8 and 9 saved 25–1517 m^3/ha of applied irrigation water, compared to the applied amount under traditional cultivation methods. Regarding to the suggested crops sequences number 4, 5, 6 and 7; the applied water was less than what is required for full irrigation of the middle crop. Therefore, to solve this problem we suggested applying deficit irrigation to the middle crop, where we get the benefits of cultivating legume crop in between two exhausting crops. Short season clover cultivation between sugar beet and rice can be irrigated with 98 and 94 % of full irrigation in crop sequence number 5 and 7, respectively. In crops sequence number 5, the applied water to soybean can be 98 % of full irrigation. Cultivating bean between faba bean and maize will result in reduction in the applied water to bean to be 93 % (Table 4.3).

Thus, changing crop sequence from two to three crops per year can be achieved by the saving in applied irrigation water to crops grown under surface irrigation. Furthermore, using this system can face water scarcity, increase crops production and consequently increase food availability.

When sugar beet is cultivated before maize or rice, it will be cultivated in 15th of October and harvested in 12th of April, then in 15th May maize or rice will be cultivated. Inclusion of soybean or short season clover in these above systems will require in the first system cultivating sugar beet in the 15th of September and harvest it in 12th of March, where soybean will be cultivated in 15th of April and harvested in July then maize will cultivated. In the second system, sugar beet will be cultivated in 15th of November to allow the cultivation of short season clover before it in 1st of September and be harvested in the 5th of November.

Intercropping in One Growing Season

Different intercropping systems can be used to replace monoculture crops without any increase in the applied irrigation water; on the contrary, an amount of irrigation water can be saved as a result of implementing the suggested management package. Several intercropping systems are suggested to replace monoculture planting in Table 4.4. Furthermore, the results in that table implied that saving in the applied irrigation water can be attained if we replace cultivation of two crops per year by cultivating three crops, one is a mono-cropped and two are intercropped. The saved amount will be between 262 and 6609 m^3/ha. We suggested investing some of these amounts to cultivate short season clover between the summer and the winter crops if the saved amount is equal to or higher than 4038 m^3/ha, which is water requirements for short season clover. Thus, short season clover can be cultivated before onion intercropped with sugar beet then rice. Similarly, short season clover can be planted before flax then soybean will be intercropped with maize. Short season clover can be also cultivated before garlic then cowpea intercropped with maize could be implemented. In the case of clover (full season) then maize intercropped with tomato and cotton relay intercropped with wheat, we cannot cultivate short season clover before the winter crops. For the first system, short season clover cannot be cultivated before full season clover as both are legumes. For the second system, wheat and cotton will stay in its cultivated area for the whole year (Table 4.4).

Extra irrigation water can be saved as a result of intercropping. In intercropping soybean with maize, maize will use the applied water to soybean, which is lower

Table 4.4 Prevailing crops structure, suggested intercropping systems in one growing season and their water requirements in the Nile Delta

Prevailing crops	WR (m^3/ha)	Suggested intercropping system	WR (m^3/ha)	Deviation[a] (m^3/ha)
Wheat then soybean	14,384	Wheat then soybean intercropped with maize	10,788	+3596
Wheat then rice	18,800	Wheat intercropped with tomato then rice	14,513	+4838
Sugar beet then maize	18,566	Sugar beet then potato intercropped with maize	18,920	−354
Sugar beet then rice	21,316	Onion intercropped with sugar beet then rice	15,987	+5329
Flax then maize	16,100	Flax then soybean intercropped with maize	10,826	+5275
Faba been then maize	15,933	Faba bean intercropped with sugar beet then maize	13,313	+2621
		Faba bean intercropped with tomato then maize	11,963	+3971
Garlic then maize	16,566	Garlic then cowpea intercropped with maize	12,425	+4142
Clover (full season) then maize	21,066	Clover (full season) then maize intercropped with tomato	16,812	+4254
Clover (2 cuts) then cotton	24,366	Cotton relay intercropping with wheat	17,758	+6609

[a](+) before the number means saved on the applied irrigation water and (−) before the number means saved on the applied irrigation water

than the applied water to maize. In this case the cultivated area of maize will be increase by the area assigned to cultivate soybean.

Cultivating sugar beet then potato relay intercropped with maize will use more irrigation water than cultivating sugar beet then maize because the applied irrigation water will compose of applied water to sugar beet, full applied water to maize and the applied water to potato minus the first and second irrigations, where potato will share it with the last two irrigations applied to maize. The total applied water to this system will be higher than the applied water for sugar beet then maize by 354 m^3/ha, which can be compensated from saved water from other systems.

It was reported that onion roots emit substances that reduces nematode numbers in the soil (Toaima et al. 2014). As a result, intercropping onion with sugar beet increased sugar beet yield without applying any extra irrigation water. Similarly, faba bean intercropped with sugar beet or with tomato will not require applying extra water (Table 4.4). Furthermore, this system will increase the cultivated area with faba bean by a percentage of the cultivated area of sugar beet and tomato, in addition it improved the quality of sugar beet tubers (Mohamed 2014) and tomato fruits quality (Mohamed et al. 2013).

Table 4.5 Prevailing crops structure, suggested intercropping systems in two growing seasons and their water requirements in the Nile Delta

Prevailing crops	WR (m^3/ha)	Suggested intercropping system	WR (m^3/ha)	Deviation[a] (m^3/ha)
Wheat then maize	16,050	Wheat intercropped with tomato then soybean intercropped with maize	13,050	4350
Sugar beet then maize	18,566	Onion intercropped with sugar beet then soybean intercropped with maize	12,675	5891
Faba been then maize	15,933	Faba bean intercropped with sugar beet then potato intercropped with maize	18,920	−2987
	15,933	Faba bean intercropped with tomato then cowpea intercropped with maize	11,963	3971

[a](+) before the number means saved on the applied irrigation water and (−) before the number means saved on the applied irrigation water

Intercropping in Two Growing Seasons

More intensive cultivation system can be implemented, where intercropping preformed in every growing season. Few examples for that system are presented in Table 4.5. The saved water ranged between 3971 and 5891 m^3/ha. This large amount of saved water can be used to expand the national cultivated area and reclaim new lands. Furthermore, it could be used to cultivate short season clover before winter crops and after summer crops. Thus, short season clover can be cultivated before sugar beet and after potato intercropped with maize, which will improve soil fertility. The only intercropping system that used more irrigation water is faba bean intercropped with sugar beet then potato relay intercropped with maize (Table 4.5).

Effect of Climate Change on Water Requirements of Crops Structure

Using BISm model to calculate water requirements for the prevailing and suggested crops structure in 2030 revealed that it will increase for both winter and summer crops (Table 4.6). The increase in water requirements for these crops could result in decrease in its cultivated area. Previous research on the effect of A1B scenario developed from ECHAM5 model on water requirements of wheat (Ouda and Zohry 2016), maize (Noreldin et al. 2016), rice (Mahmoud et al. 2015), cotton and clover (Ouda et al. 2015) indicated that its water requirements will increase with values close to what was found in Table 4.6.

Table 4.6 Water requirements for prevailing field crops and vegetables in the Nile Delta under current climate and in in 2030

Winter crops	CWR (m^3/ha)	WR2030 (m^3/ha)	PI (%)	Summer crops	CWR (m^3/ha)	WR2030 (m^3/ha)	PI (%)
Wheat	6567	6833	4	Maize	9723	10,567	9
Clover	5383	5767	7	Maize (late)	8118	8650	7
Sugar beet	8267	8717	5	Maize (forage)	4400	4700	7
Flax	6617	7050	7	Rice	11,432	12,517	9
Faba bean	6450	6650	3	Soybean	7817	8300	6
Garlic	7083	7583	7	Sunflower	8583	9133	6
Tomato	6467	7000	8	Pepper	11,630	12,283	6
				Eggplant	10,364	10,917	5
				Beans	7333	7717	5
				Cotton	15,531	16,617	7
				Potato	7556	7867	4
				Tomato	10,875	12,033	11

CWR Current water requirements; *WR*2030 Water requirements under climate change; *PI %* Percentage of increase

Reduction of Climate Change Risk on the Selected Crops

Changing Crops Sequence

Table 4.7 revealed that percentage of increase in water requirements for prevailing crops sequences will be the same or lower than the suggested crops sequences in 2030, except when rice is cultivated. The results also suggested that if we continue using surface irrigation and cultivate two crops per year, its water requirements will increase by 3–9 %. Whereas, water requirements in 2030 for the suggested three crops per year, will be between 4 and 8 %, if the management package was implemented. In this case, we will gain the benefit of maximizing productivity by unit of land and producing more food under climate change.

Intercropping in One Growing Season

Similarly, percentages of increase in water requirements when suggested inter-cropping systems was implemented were the same or lower than its counterpart for

Table 4.7 Percentage of increase in water requirements (PI %) in 2030 for prevailing and suggested crops sequence in the Nile Delta

Prevailing crops sequence	PI (%)	Suggested crops sequence	PI (%)
Wheat then maize	8	Clover (short season), wheat then maize	8
Wheat then rice	3	Clover (short season), wheat then rice	4
Sugar beet then maize	7	Sugar beet, soybean then maize	7
Sugar beet then rice	3	Clover (short season), sugar beet then rice	3
Flax then maize	9	Flax, soybean then maize (forage)	7
Faba been then maize	8	Faba bean, bean then maize	6
Garlic then maize	9	Garlic, soybean then maize	7
Clover (full season) then maize	7	Clover (full season), pepper then maize (forage)	6
		Clover (full season), eggplant then maize (forage)	6

two crops sequences, except when faba bean intercropping with tomato then maize to replace garlic then maize. These results attributed to the effect of implementing the management package on saving on the applied irrigation water, compared to using surface irrigation (Table 4.8).

Table 4.8 Percentage of increase (PI %) in water requirements in 2030 for prevailing crops sequences and suggested intercropping systems in one season in the Nile Delta

Prevailing crops	PI (%)	Suggested intercropping system	PI (%)
Wheat then soybean	5	Wheat then soybean intercropped with maize	5
Wheat the rice	3	Wheat intercropped tomato with then rice	3
Sugar beet then maize	17	Sugar beet then potato intercropped with maize	8
Sugar beet then rice	11	Onion intercropped with sugar beet then rice	0
Flax then maize	9	Flax then soybean intercropped with maize	6
Faba been then maize	8	Faba bean intercropped with sugar beet then maize	9
	8	Faba bean intercropped with tomato then maize	10
Garlic then maize	10	Garlic then cowpea intercropped with maize	10
Clover (full season) then maize	7	Clover (full season) then maize intercropped with tomato	7
Clover (one cut) then cotton	11	Relay intercropping cotton on wheat	11

Table 4.9 Percentage of increase (PI %) in water requirements in 2030 for prevailing crops sequences and suggested intercropping systems in two seasons in the Nile Delta

Prevailing crops	PI (%)	Suggested intercropping system	PI (%)
Wheat then maize	8	Wheat intercropped with tomato then soybean intercropped with maize	6
Sugar beet then maize	7	Onion intercropped with sugar beet then soybean intercropped with maize	6
Faba been then maize	8	Faba bean intercropped with sugar beet then soybean intercropped with maize	10
	8	Faba bean intercropped with tomato then cowpea intercropped with maize	10

Intercropping in Two Growing Season

Increasing crops intensification by implement intercropping system in two growing seasons resulted in lower percentage of increase in water requirements, compared to cultivation of two crops per year, except when faba bean was intercropped with sugar beet or tomato, where it became the secondary crop and obtained its water requirements from the applied water to sugar beet or tomato (Table 4.9).

Still, we can change the suggested intercropping system to save on the applied irrigation water. The above results also suggested that there are benefits can be attain if we increase crops intensification, as long as irrigation water can be conserved by implementing precise land leveling and cultivation on raised beds. Crops intensification also can improve soil fertility as a result of inclusion of legume crop in two crops sequence or in the intercropping systems.

Conclusion

Food insecurity and water scarcity are highly correlated problems. Our results showed that crops intensification through using our suggested management package to save irrigation water and use it to cultivate three crops per year instead of two crops per year can be implemented to increase food production, maintain soil fertility and increase farmer's income. Our results also showed that intercropping can use less irrigation water and increase water productivity as two crops are using the applied water to one of them. Furthermore, intercropping can help in solving food insecurity problem through increase land productivity.

Under climate change in 2030, water requirements for the cultivated crops will increase, which will lead to reduction in the cultivated area of these crops by different percentages. Implementing precise land leveling and cultivation on raised beds can reduce the required applied water to the cultivated crops. Furthermore, intercropping can maximize land and water productivities under climate change.

Thus, our proposed management of crops intensification can be the solution for food gaps problems under current water scarcity situation in Egypt and under the anticipated climate change effects.

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Chapter 5
Upper Egypt: Management of High Water Consumption Crops by Intensification

Abd El-Hafeez Zohry and Samiha A.H. Ouda

Abstract Upper Egypt is characterized by mild winters and hot summers, which leads to high water consumption by the cultivated crops. Sugarcane plantation is prevailing, in addition to field and vegetable crops. It is expected that climate change will affect Upper Egypt more than the Nile Delta. The objective of this chapter was to quantify the effect of using management package include precise land leveling, cultivation on raised beds, changing crops sequence from two crops per year to three crops per year and implementing different intercropping systems on the required water to cultivate crops in Sohag governorate as a representative of Upper Egypt region in the present time and under climate change in 2030. Our results revealed that the percentage of increase in water requirements in 2030 will depend on crop growing season (winter or summer), growing season length (short or long), sowing date (early, regular or late) and the morphological characteristics of the crop. Regarding to sugarcane, precise land leveling can be implemented and intercropping summer and winter crops with spring and fall sugarcane. Under climate change, sugarcane water requirements will increase by 12 %. Changing crops sequence to three crops can be implemented when using the management package under current climate. However, it will consumed large amount of water in 2030. Furthermore, intercropping can save large amount of water under current climate and still can be implemented under climate change in 2030 and save some of the applied water.

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Introduction

Upper Egypt is located in southern part of Nile valley. It is characterized by hyper-arid climate with mild winters and hot summers. From the administration point of view, Upper Egypt is composed of five governorates: Assuit, Sohag, Qena and Aswan. The cultivated area in Upper Egypt is mainly located in the Nile valley, Luxsor where its soil is fertile. These lands are under surface irrigation with 60 % application efficiency. Crops structure in Upper Egypt is somewhat different than what is prevailing in the Nile Delta and Middle Egypt. Sugarcane plantation is prevailing in three governorates. Furthermore, rice cultivation is prohibited by the law. Sorghum is a poplar crop there, as well as cowpea.

The wasteful use of irrigation water is the main problem in Upper Egypt too. The prevailing conditions of water scarcity in Egypt motivated the agricultural scientists to develop management practices that reduce the applied water to surface irrigation. Therefore, there is a need to use management procedures to use irrigation water more rationally with no or low costs. It has been documented that precise land leveling and cultivation on raised beds can save 25 % of the applied irrigation water to surface irrigation (Bahnas and Bondok 2010; Majeed et al. 2015). Furthermore, crops intensification can play an important role on using irrigation water more efficiently, where it can increase land and water productivities to attain the sustainable use of water and soil resources (Zohry and Ouda 2015). Changing crops sequences to three crops per year (winter, fall then summer crop) or (winter, early summer then late summer crop) can improve soil fertility (Sheha et al. 2014). Furthermore, intercropping can save on the applied irrigation water, maintain soil fertility and increase farmer's net revenue (Kamel et al. 2010).

It is expected that Upper Egypt will suffer more than North Egypt from the effect of climate change, as a result of its geographic location. Furthermore, a concern is now exists about the future of the cultivated area in 2030 under climate change. It is expected that there will be no enough irrigation water to cultivate that same area that is cultivated now (Ouda and Zohry 2016; Noreldin et al. 2016). Sugarcane cultivated area is expected to decrease under climate change effect as a result of increasing its water requirements by 17 % (Taha et al. 2016). Under these circumstances, it is a must to manage irrigation water more efficiently to overcome water scarcity induced by climate change effects.

The objective of this chapter was to quantify the effect of using management package include precise land leveling, cultivation on raised beds, changing crops sequence from two crops per year to three crops per year and implementing different intercropping systems on the applied water to the cultivated crops in Sohag governorate as a representative of Upper Egypt region in the present time and under climate change in 2030.

Sohag Governorate

Sohag governorate (latitude 26.36°, longitude 31.38° and elevation above sea level 68.70 m) was chose to represent Upper Egypt. It is bordered by Assuit governorate in the North, by Qena governorate in the South, by the Red Sea governorate in the East and by the New Valley governorate in the West. The total area of Sohag is 1547 km^2, where the cultivated area is 12,830,417 hectare. As a result of its geographic location, the average yearly maximum temperature of Sohag is 30.4 °C, its yearly average minimum temperature is 17.0 °C and average yearly PET is 5.9 mm/day (Table 5.1).

Many field and vegetable crops are cultivated in Sohag governorate; however the main and most favorable crop is sugarcane. Table 5.2 shows sowing and harvest

Table 5.1 Monthly mean values for climate elements and potential evapotranspiration in Sohag governorate

	SR ($MJ/m^2/day$)	T-Max (°C)	T-Min (°C)	WS (m/s)	PET (mm/day)
January	14.2	20.3	7.7	2.5	3.0
February	18.4	22.9	9.4	2.7	4.0
March	22.4	26.1	11.8	3.0	5.1
April	25.3	31.7	16.5	3.1	6.5
May	26.8	35.4	20.6	3.2	7.5
June	29.3	37.3	23.1	3.6	8.5
July	28.5	38.0	24.4	3.1	8.2
August	26.7	37.8	24.5	3.1	7.8
September	25.1	36.1	23.5	3.5	7.4
October	20.0	31.7	19.1	2.9	5.5
November	15.8	26.3	13.8	2.6	4.0
December	13.5	20.9	9.3	2.4	3.0
Average	22.2	30.4	17.0	3.0	5.9

Table 5.2 Sowing and harvest dates for winter crops and vegetables planted in Sohag governorate

	Sowing date	Harvest date
Wheat	10-Nov	18-Apr
Clover (short)	1-Sep	5-Nov
Clover (2 cuts)	13-Sep	28-Feb
Clover (full)	1-Oct	15-Apr
Faba bean	10-Oct	25-Mar
Garlic	18-Sep	15-Feb
Onion	15-Nov	15-May
Tomato	21-Sep	1-Mar
Pea	1-Sep	30-Nov
Lentil	1-Oct	15-Mar
Sugarcane (fall)	15-Sep	14-Dec (16 months)

Table 5.3 Sowing and harvest dates for summer crops and vegetables planted in Sohag governorate

	Sowing date	Harvest date
Maize	10-May	1-Sep
Maize (late)	17-Jul	5-Nov
Maize (forage)	12-Aug	15-Oct
Soybean	1-Apr	13-Jul
Sunflower	12-Apr	17-Jul
Sesame	17-Apr	7-Aug
Sorghum	12-May	1-Sep
Pepper	1-Apr	8-Aug
Eggplant	1-Apr	8-Aug
Bean	1-Apr	15-May
Tomato	1-Apr	1-Sep
Sugarcane (spring)	15-Feb	14-Feb (12 months)

dates for some of the winter field and vegetables crops cultivated in Sohag governorate. Table 5.3 presents sowing and harvest dates for summer field and vegetable crops grown in Sohag governorate.

Water Requirements Calculation for Crops Structures

BISm model (Snyder et al. 2004) was used to calculate the required irrigation water need to be applied to the studied crops using climate normals (1985–2014). The model calculates PET crop using Penman-Monteith equation. It calculates ETc by estimating crop coefficients as a percentage of the growing season. It also accounts for water depletion from root zone to schedule irrigation. Water requirements for the above crops were calculated under surface irrigation and under 25 % saving in the applied water to surface irrigation.

The effect of climate change in 2030 on the cultivated crops was assessed using comparison between RCPs scenarios developed from four global models and the boundary of the closer scenario to the measured data was input into a regional climate model (WRF-RCM) to develop more accurate weather data to be in the assessment. Water requirements for the selected crops were calculated under surface irrigation and with 25 % saving in the applied water to surface irrigation.

Table 5.4 revealed that the percentage of increase in water requirements in 2030 will depend on crop growing season (winter or summer), growing season length (short or long), sowing date (early, regular or late) and the morphological characteristics of the crop. Regarding to winter crops, the percentage of increase in water requirements tends to be higher for long season crops, such as wheat, full season clover, faba bean and tomato. Low percentage of increase in water requirements can be noticed in onion, as a result of low crop evapotranspiration, which is attributed to the morphology of its leaves, fleshy, hallow and cylindrical (Brewster 1994).

Table 5.4 Water requirements for prevailing field crops and vegetables in Sohag under current climate, in 2030 and percentage of increase in Sohag governorate

Winter crops	CWR (m^3/ha)	WR2030 (m^3/ha)	PI (%)	Summer crops	CWR (m^3/ha)	WR2030 (m^3/ha)	PI (%)
Wheat	7500	8376	12	Maize	10,583	11,896	12
Clover (short)	6517	7363	13	Maize (late)	8983	10,184	13
Clover (full)	13,400	15,274	14	Maize (forage)	5267	5736	9
Faba bean	7167	8352	17	Soybean	10,308	10,976	6
Garlic	6273	7249	16	Sunflower	9650	10,297	7
Onion	11,535	12,639	10	Sesame	11,033	11,975	9
Tomato	7283	8381	15	Sorghum	11,133	12,499	12
Lintel	7467	8541	14	Pepper	12,717	13,829	9
Pea	5650	6459	14	Eggplant	11,317	12,306	9
Fall sugarcane	43,743	49,383	13	Tomato	15,200	16,827	11
				Bean	3733	4022	8
				Spring sugarcane	39,767	44,712	12

CWR current water requirements; *WR*2030 water requirements under climate change; *PI* % percentage of increase

Regarding to summer crops, early sowing and short growing season will reduce the percentage of increase in water requirements for forage maize, soybean, sunflower, sesame and bean. Long season crops, such as maize and sorghum will has high percentage of increase in water requirements (Table 5.4).

Cultivation of Sugarcane Crop

Sugarcane is main source of sugar in Egypt. It is produced in Upper Egypt only in four governorates, where the prevailing weather conditions are suitable to its production. Many industries are dependent on sugarcane cultivation in Upper Egypt. There are two growth cycles for sugarcane in Egypt: spring and fall sugarcane. Spring sugarcane is cultivated in February and harvested in February in the following year, where its growing season is 12 months. Fall sugarcane in cultivated in September and harvest 16 month later.

Sugarcane is a high water-consuming crop, not only because it has long growing season, but also it has large above ground biomass. Its average productivity in Egypt was estimated to be 116.6 ton/ha in 2012/13, which is comparable to the world average, (80–150 ton/ha) (Watto and Mugera 2015). However, its average water productivity in Egypt is lower than the world average, i.e. 2.92 kg/m^3 for Egypt (Taha et al. 2016) versus 3.5–5.5 kg/m^3 (Watto and Mugera 2015) for world average. Unfortunately, this low water productivity is due to its high applied irrigation water under surface irrigation. Although, irrigation application efficiency for surface irrigation in Egypt is 60 %, it is 50 % for sugarcane crop. In the meantime, cultivation on raised beds cannot be implemented for sugarcane as a result of its huge above ground biomass. Therefore, precise land leveling can only be implemented to save 5 % of the applied irrigation water. Furthermore, intercropping of summer crops can be done for both spring and fall sugarcane. Nazir et al. (2002) indicated that sugarcane offers a unique potential for intercropping. It is planted in wide rows (100 cm), and takes several months to develop its canopy, during which time the soil and solar energy goes to waste. The growth rate of sugarcane during its early growth stages is slow, with leaf canopy providing sufficient uncovered area for growing of another crop. In this case, the intercropped crop will not need any extra irrigation water as it will use the applied water to sugarcane to fulfill its required water. Furthermore, intercropping on sugarcane provide extra income for farmers during the early growth stage of sugarcane.

Intercropping with Spring Sugarcane

Regarding to intercropping on spring sugarcane, sunflower, sesame and soybean are the candidates for that. All these crops are summer oil crops and intercropping it with sugarcane can reduce production-consumption gap in edible oil in Egypt (estimated by 97 %). Intercropping summer oil crops with spring sugarcane is very common practice done by Egyptian farmers. These crops are cultivated in April and harvested in July before 100 % of sugarcane ground cover established.

Sunflower oil is considered premium oil because of its light color, mild flavor, low saturated fat levels and the ability to withstand high cooking temperatures (Weiss 2000). 50 % of sunflower recommended planting density is intercropped with sugarcane. El-Gergawi et al. (2000) indicated that land productivity was increased when sunflower was intercropped with spring sugarcane. However, Abou-Kreshe et al. (1997) indicated that competition over solar radiation between sunflower plants and sugarcane plants was high because sunflower plants are longer than sugarcane plants in that growth stage (Fig. 5.1a).

Sesame is an important edible oilseed crop. The seed contains all essential amino acids and fatty acids. It is a good source of vitamins (pantothenic acid and vitamin E) and the seed cake is also an important nutritious livestock feed (Balasubramaniyan and Palaniappan 2001). Abou-Kreshe et al. (1997) intercropped sesame with spring sugarcane and both indicated that competition over solar radiation between sesame plants and sugarcane plants was low and does not negatively affect sugarcane yield because of the morphological characteristics of sesame leaves being erect and does not cause any shading over the growing sugarcane plants. 50 % of sesame recommended planting density is intercropped with sugarcane.

Soybean is a very important oil and protein crop in the world. According to Sundara (2000), soybean is one of the important intercrop suitable and compatible

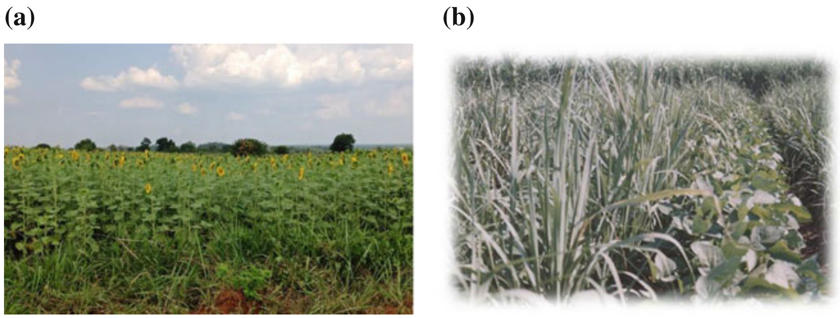

Fig. 5.1 Sunflower intercropped with sugarcane (**a**) and soybean intercropped with sugarcane (**b**)

Table 5.5 water requirements (WR m^3/ha) for spring sugarcane under traditional cultivation method and under using precise land leveling and intercropping in Sohag governorate

Traditional method	WR	Precise land leveling	WR	Saving
Spring sugarcane	39,767	Sunflower intercropped with sugarcane	37,778	1988
	39,767	Sesame intercropped with sugarcane	37,778	1988
	39,767	Soybean intercropped with sugarcane	37,778	1988

with sugarcane. This is mainly due to the fact that soybean has adapted well to the climatic conditions of the sugarcane producing areas and has the greatest potential to fix nitrogen (Shoko and Tagwira 2005). Since nitrogen fertilizer is a substantial cost component of sugarcane cropping system, the use of soybean as intercropping plays a considerable role in reduction of production costs. Intercropping soybean (50 % of its recommended planting density) with spring sugarcane (Fig. 5.1b) increased sugarcane yield, as well as land productivity (El-Geddawy et al. 1988; Zohry 1994; Eweida et al. 1996; Abou-Kreshe et al. 1997).

Table 5.5 showed that saving 5 % of the applied water as a result of precise land leveling to sugarcane will amount for 1988 m^3/ha. Whereas, intercropping sunflower, sesame or soybean with sugarcane will not need any more irrigation water to grow it. In this case, land and water productivities were maximized.

Intercropping with Fall Sugarcane

Three winter crops can be intercropped with fall sugarcane (cultivated in September), i.e. faba been, onion and wheat. Faba bean is cultivated in October in two rows with 50 % of its recommended planting density (Farghly 1997) (Fig. 5.2a). Regarding to onion intercropped with sugarcane, it is planted with

(a) (b)

Fig. 5.2 Faba bean intercropped with sugarcane (**a**) and wheat intercropped with sugarcane (**b**)

Table 5.6 Water requirements (WR m^3/ha) for fall sugarcane under traditional cultivation method and under using precise land leveling and intercropping in Sohag governorate

Traditional method	WR	Precise land leveling	WR	Saving
Fall sugarcane	43,743	Faba bean intercropped with sugarcane	41,556	2187
	43,743	Onion intercropped with sugarcane	41,556	2187
	43,743	Wheat intercropped with sugarcane	41,556	2187
	43,743	Tomato intercropped with sugarcane	41,556	2187

80 % of its recommended planting density (Zohry 1997). Wheat is intercropped with sugarcane with 50 % of its recommended planting density in November and harvested in April (Ahmed et al. 2013). Figure 5.2b showed wheat after harvest and the growing sugarcane plants.

A saving in the applied water to fall sugarcane by 5 % as a result of precise land leveling will amount for 2187 m^3/ha (Table 5.6). Furthermore, intercropping winter crops with fall sugarcane will contribute in reduction of production-consumption gap of faba bean and wheat. It can produce extra income for the farmers at time where sugarcane is not giving any profit, in case of onion and tomato intercropping. Furthermore, land and water productivities were maximized.

Effect of Climate Change on Sugarcane Water Requirements

The projected climate change in 2030 is expected to increase water requirements for spring sugarcane by 12 % and fall sugarcane by 13 %. Intercropping either summer or winter crops on sugarcane will not change the percentage of increase in the water

Table 5.7 Percentage of increase (PI %) in sugarcane water requirements under climate change in 2030 in Sohag governorate

Traditional method	PI (%)	Precise land leveling	PI (%)
Spring sugarcane	12	Sunflower intercropped with sugarcane	12
	12	Sesame intercropped with sugarcane	12
	12	Soybean intercropped with sugarcane	12
Fall sugarcane	13	Faba bean intercropped with sugarcane	13
	13	Onion intercropped with sugarcane	13
	13	Wheat intercropped with sugarcane	13
	13	Tomato intercropped with sugarcane	13

requirements (Table 5.7). Taha et al. (2016) indicated that water requirements for spring sugarcane will increase by 16 % in Sohag governorate under climate change in 2040. Still, intercropping maximizes productivity of water and land unit, compared to mono culture.

Prevailing and Suggested Crops Structure

We proposed to cultivate three crops sequences and intercropping in one growing season to maximize productivity of unit land and water. Quantification of the effect of climate change on these crops structures was also implemented in Sohag governorate as a representative to Upper Egypt.

Changing Crops Sequence

Changing crops sequences involves cultivation of three crops per year instead of two crops. This system will use more irrigation water. To overcome this problem, we suggest implementing the management package to save 25 % of the applied water under surface irrigation and use it to irrigate the third crop. All the suggested crop sequences in Table 5.8 saved on the applied irrigation water, except when short season clover cultivated before wheat and after maize or sorghum. In this case, deficit irrigation can be applied to short season clover, where 92 and 98 % of full irrigation can be applied for the first and the third crop sequence, respectively. Otherwise, we can replace short season clover with pea or lentil to get the same benefit of including a legume crop in the crops sequence. Regarding to soybean cultivation after garlic and before maize, 70 % of full irrigation can applied to soybean. Either pepper or eggplant can be cultivated between long season clover and maize cultivated as forage. However, pepper requires more irrigation water than eggplant (Table 5.8).

Table 5.8 Prevailing and suggested crops sequences and their water requirements in Sohag governorate

Prevailing crops	WR	Suggested crops sequence	WR	Dev*
Wheat then maize	18,083	Clover (short season), wheat then maize	18,450	−367
Wheat then maize	18,083	Pea, wheat then maize	17,800	+283
Wheat then sorghum	18,633	Clover (short season), wheat then sorghum	18,863	−229
Wheat then sorghum	18,633	Pea, wheat then sorghum	18,213	+421
Faba been then sorghum	18,300	Faba bean, bean then sorghum	16,525	+1775
Lentil then maize	18,050	Lentil, bean, maize	16,338	+1713
Lentil then sorghum	18,600	Lentil, bean, sorghum	16,750	+1850
Garlic then maize	16,857	Garlic, soybean then maize	19,174	−2317
Clover then maize	23,983	Clover (full season), pepper then maize (forage)	23,538	+446
	23,983	Clover (full season), eggplant then maize (forage)	22,488	+1496

WR Water requirements (m^3/ha), *Dev* Difference between WR for prevailing and suggested crop sequences (m^3/ha)
*(+) before the number means saved on the applied irrigation water and (−) before the number means saved on the applied irrigation water

Table 5.9 revealed that percentage of increase in water requirements for the prevailing crops sequences were between 12 and 14 %. Whereas, the percentage of increase in water requirements for the suggested crop sequences will increase by 11–13 %. Suggested crop sequences including pea will be higher in their water requirements than the value of its counterpart prevailing crop sequence. In this case,

Table 5.9 Percentage of increase (PI %) in water requirements for prevailing and suggested crop sequences under climate change in 2030 in Sohag governorate

Prevailing crops	PI (%)	Suggested crops sequence	PI (%)
Wheat then maize	12	Clover (short season), wheat then maize	12
Wheat then maize	12	Pea, wheat then maize	13
Wheat then sorghum	12	Clover (short season), wheat then sorghum	12
Wheat then sorghum	12	Pea, wheat then sorghum	13
Faba been then sorghum	14	Faba bean, bean then sorghum	13
Lentil then maize	13	Lentil, bean then maize	12
Lentil then sorghum	13	Lentil, bean then sorghum	12
Garlic then maize	14	Garlic, soybean then maize	11
Clover then maize	13	Clover (full season), pepper then maize (forage)	11
	13	Clover (full season), eggplant then maize (forage)	11

deficit irrigation can be applied for pea to reduce the percentage of increase in water requirements for this sequence.

Intercropping in One Growing Season

Table 5.10 indicated the suitable intercropping systems that can be implemented in Sohag governorate as a representative for Upper Egypt.

Implementing the management package and intercropping in one season can save a large amount of irrigation water between 1058 and 4452 m^3/ha (Table 5.11). Water requirements for short season clover is 4888 m^3/ha. Thus, the saved irrigation water over 4000 m^3/ha in the second, fourth and fifth suggested crop sequences (Table 5.11) can be used to apply deficit irrigate short season clover to be cultivated before the winter crop. This practice will increase the productivity of wheat and garlic in the second and fifth suggested crop sequences and it will improve soil fertility for the second crops sequences.

Table 5.10 Suggested intercropping systems in Sohag governorate

Intercropping system	Reference
Tomato intercropped with maize	Mohamed et al. (2013)
Soybean intercropped with maize	Sherif and Gendy (2012)
Soybean intercropped with sunflower	El-Yamani et al. (2010)
Faba bean intercropped with tomato	Ibrahim et al. (2010)
Cowpea intercropped with sorghum	Abou-Keriasha et al. (2011)

Table 5.11 Prevailing crops and suggested intercropping systems and their water requirements (m^3/ha) in Sohag governorate

Prevailing crops	WR	Suggested crops sequence	WR	Saving
Wheat then maize	18,083	Wheat then tomato intercropped with maize	17,025	1058
Wheat then soybean	17,808	Wheat then soybean intercropped with maize	13,356	4452
Wheat then sunflower	17,150	Wheat then soybean intercropped with sunflower	13,356	3794
Faba been then maize	17,750	Faba bean intercropped with tomato then maize	13,400	4350
Garlic then sorghum	17,407	Garlic then cowpea intercropped with sorghum	13,055	4352
Clover then maize	23,983	Clover then tomato intercropped with maize	21,450	2533

WR Water requirements (m^3/ha), *Saving* Difference between WR for prevailing and suggested crop sequences (m^3/ha)

Table 5.12 Percentage of increase (PI %) in water requirements for prevailing and suggested crop sequences under climate change in 2030 in Sohag governorate

Prevailing crops	PI (%)	Suggested crops sequence	PI (%)
Wheat then maize	12	Wheat then tomato intercropped with maize	11
Wheat then soybean	9	Wheat then soybean intercropped with maize	9
Wheat then sunflower	9	Wheat then soybean intercropped with sunflower	9
Faba been then maize	14	Faba bean intercropped with tomato then maize	13
Garlic then sorghum	13	Garlic then cowpea intercropped with sorghum	13
Clover then maize	13	Clover then tomato intercropped with maize	12

Effect of Climate Change on Intercropping in One Growing Season

In 2030, percentage of the increase in the water requirements of suggested crops sequences was lower or similar to its counterpart for prevailing crop sequence (Table 5.12).

Furthermore, implementing the management package and intercropping can reduced the applied irrigation water for suggested crops sequences in 2030, compared to prevailing crop sequence under surface irrigation (Table 5.13). The total water requirements for only two suggested crops sequences were higher in 2030 than current climate, i.e. wheat then tomato intercropped with maize and full season clover then tomato intercropped with maize by 819 and 92 m^3/ha, respectively. The rest of crops sequences saved an amount between 2542 and 3294 (Table 5.13).

Table 5.13 Comparison between current water requirements for prevailing crops and water requirements for the suggested crops sequences in 2030 in Sohag governorate

Prevailing crops	CWR	Suggested crops sequence	WR2030	Dev*
Wheat then maize	18,083	Wheat then tomato intercropped with maize	18,902	-819
Wheat then soybean	17,808	Wheat then soybean intercropped with maize	14,514	+3294
Wheat then sunflower	17,150	Wheat then soybean intercropped with sunflower	14,514	+2636
Faba been then maize	17,750	Faba bean intercropped with tomato then maize	15,208	+2542
Garlic then sorghum	17,407	Garlic then cowpea intercropped with sorghum	14,811	+2595
Clover (full) then maize	23,983	Clover (full) then tomato intercropped with maize	24,075	-92

CWR Water requirements under current climate (m^3/ha), *WR*2030 Water requirements in 2030 (m^3/ha), *Dev* Difference between CWR and WR2030 (m^3/ha)

*(+) before the number means saved on the applied irrigation water and (−) before the number means saved on the applied irrigation water

These amounts of saved water can be used to complete the required water to irrigate the suggested three-crop sequence systems. Furthermore, it can be used to cultivate new areas with other crops to reduce the existing food gaps.

Conclusion

Sugarcane is the main crop cultivated in Upper Egypt, in addition to field and vegetable crops. It is expected that Upper Egypt will suffer more from the consequences of climate change as a result of its geographic location. As a result of high above biomass of sugarcane, it cannot be cultivated on raised beds to save on the applied irrigation water. Two other options can be implemented, i.e. precise land leveling and intercropping with spring and fall sugar can to increase land and water productivity. Under climate change in 2030, these options resulted in saving lower amount of applied water.

Changing crops structures in Sohag governorates to three crops per year and to intercropping in one growing season under using the management package resulted in saving in the applied irrigation water under current climate and under climate change. Thus, implementing improved management practices on farm level is the only way to face the expected water scarcity.

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Chapter 6
Combating Deterioration in Salt-Affected Soil in Egypt by Crop Rotations

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Abstract Crop rotation can be used as a technique to save on the applied water, improve soil fertility and combat soil deterioration under current climate and under climate change. Five crops rotations were suggested to be implemented in salt-affected soil in the North Nile Delta of Egypt. The selected crops for these rotations are either salinity tolerant, or tolerant cultivars were selected from sensitive or medium tolerant crops. Precise land leveling and cultivation on raised beds were suggested to save 25 % of the applied water to surface irrigation. Furthermore, three-crop sequence and intercropping systems were also used. Total water requirements for each rotation were calculated using 30 year climate normals and in 2030 under climate change. The results indicated that total water requirements for the suggested crop rotations will increase under climate change in 2030, in addition to more water will need to be applied as leaching requirements for the cultivated crops in salt-affected soils. Thus, using the management package resulted in applying less water to the suggested rotations in 2030, compared to the applied water to these rotations under present climate and surface irrigation. The saved irrigation amounts can be used as leaching requirements under climate change.

Keywords Intercropping systems · Three-crop sequence · Total water requirements · Climate change effect

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Introduction

The expression “salt-affected soils” refers to soils, in which salts interfere with normal plant growth. Salt-affected soils can be divided into saline, saline-sodic and sodic, depending in salt amounts, type of salts, amount of sodium present, and soil alkalinity. Each type of these soils has different characteristics, which determine the way it can be managed (Richards 1954). The majority of salt-affected soils in Egypt are located in the Northern-Central part of the Nile Delta and on its Eastern and Western sides. In some coastal areas the extraction of ground water has proceeded to the point where intrusion of saline sea water into aquifers has degraded the quality of these resources. The recycling of agriculture drainage water, a deficient drainage system and inappropriate in-field management of applied water contribute to salt loading of the system that has significant negative effects on its productivity. Soil degradation due to salinization and agricultural land-loss from desertification is also a challenge. Continued irrigation with low quality groundwater has contributed to the expansion of land salinization.

Shalaby et al. (2012) studied land degradation as one of the main problems that threaten the limited highly fertile land in the Nile Delta of Egypt using the rate of salinization and water logging estimated using Landsat TM satellite images of 1984 and 1992, and ETM+ of 2006. The results revealed that the water logged areas cover 7461 km^2 concentrated in the Northern part of the Delta. The soils of moderate rate and very high risk of water logging occupied an area of 1929 km^2 in the north of the Nile Delta. The soils characterized by moderate rate and high risk of water logging covering an area of 5533 km^2. These soils are found mainly at the western and eastern parts of the Delta, also a small strip is found at the north of the Nile Delta.

Thus, as large areas in the Delta are salt-affected, and in view of the limited available cultivable areas, it become necessary to find out ways and methods of utilizing and maintaining this natural resource. In general, poor soil and water management and intrusion of seawater are the main causes of salinization in addition to the use of slightly saline water (agricultural drainage or mixed water) for irrigation without proper management and agronomic practices (Gehad 2003). Furthermore, saline shallow water tables in the cultivated land cause many problems.

Since there is no single way to control salinity and sodicity, several practices should be combined into systems that function satisfactory (Gehad 2003). These practices are hydro-technical methods (remove salts by mechanical ways, flushing and leaching), drainage (surface, subsurface and mole drainage), chemical methods (application of gypsum), biological management (application of compost, organic fertilizer and bio-fertilizers) and physical methods (land leveling, tillage, deep ploughing and sub-soiling) (Hanna 2000).

Leaching is the application of excess water allowing it to pass downwards to leach salts from root zone. However, Mohamedin (2012) stated that applying leaching alone to salt-affected soil in North Nile Delta was not effective enough to reduce EC of the soil. Furthermore, application of gypsum increased the percolation of water through the gypsum treated soil profile, which implied that gypsum was the main factor to percolate process. Furthermore, compost combined with gypsum treatment was more effective than compost alone. Other research indicated that flushing after 7 days and subsequent gypsum application improved soil physical properties through dispersible clay content, water stable aggregates and saturated hydraulic conductivity (Mohamedin and Mona 2011). Incorporation of gypsum or other amendments that liberate calcium might be applied in a suitable amount to be replaced with the exchangeable sodium from exchange complex (Mohamedin et al. 2005 and Moustafa 2005).

The need for drainage became obvious soon after controlled irrigation replaced the flooding technique. The drainage system in Egypt consists of surface, subsurface and mole drains. Many researchers reported the positive results that can be obtained after applying adequate mole drain system, especially in heavy clay salt-affected soils. The mole network filled with sand and application of gypsum and farm manure were the best combination treatments to obtain favorable physical and chemical properties and consequently high yield at North Delta region. This system improved infiltration characteristics of soil better than empty moles and led to the lowest values of salinity and sodicity. Moreover, mole drains perpendicular to open drain accelerated downward water movement to the depth of mole. Soil salinity and alkalinity in the root zone was maintained under the permissible level to sustain a convenient production (Abo Soliman 2000; Moukhtar et al. 2003; and Antar et al. 2008). Furthermore, tile drains combined with sub-soiling treatments were more effective on lowering the values of total soluble salts than either tile drainage only or sub-soiling method only. The best drain spacing treatment was 15.0 m combined with net sub-soiling treatment. Drain spacing and sub-soiling type treatments had highly significant effect on soil moisture content. Soil bulk density values decreased with decreasing drains spacing and sub-soiling type (Moukhtar et al. 2003). El-Sanat (2012) found that sub-soiling at 2.0 m spacing with the addition of nitrogen fertilizer, resulted in the highest production of wheat and maize. He concluded that the installation of sandy moles at 2.0 m spacing was more effective in leaching of soil salts as compared to that with or without sub-soiling.

Threat of salinization because of saline groundwater is often overcome through combined use of low-salinity surface water and saline ground water. However, when fresh water supplies are limited an appropriate crop rotation is the only means for managing salt-affected soils and maintaining crop yields (Kaur et al. 2007). Furthermore, crop rotation can play an important role in the reclamation of salt-affected soil, where appropriate rotation can influence the location and accumulation of salts by reducing evaporation and upward salt transport in the soil (Brady and Well 2008). The use of crop rotation results in several improvements in the soil properties and it is also recommended for saline environments, particularly when crops with varying degrees of salinity tolerance are used (Lacerda et al. 2011). Moreover, crop rotation systems had significant influence on some soil quality indicators (Yao et al. 2013). Thus, we have to strive to develop technologies that are acceptable to the farmers both in economic and the environment terms. The selection of crops during the reclamation of salt-affected soils involves choosing the most tolerant crop, with high economic value (Kishk 2000).

Soil salinization in irrigated areas is a degradation process that harms both crop productivity and environment. Climate change can affect soil salts build up due to an increase of the evapotranspiration due to the increase of temperature (Yu et al. 2002). The degradation cause by climate change was summarized by Várallyay (2010) in increasing soil erosion; therefore it should be balanced by the increasing soil conservation effect of more dense and permanent vegetation. Salinization can also be a consequence of expected climate change, as the rise of sea level and sea water intrusion. Higher rate of evapotranspiration will increase capillary transport of water and solutes from the groundwater to the root zone. Under climate change, crop rotation can play an important role in reduction of GHGs fluxes from the soil by more efficient management of carbon and nitrogen flows in agricultural ecosystems (Cerrie et al. 2004).

Thus, the objective of this chapter was to develop suitable crops rotations for salt-affected area to maximize the productivity of lands and water under current climate and under climate change in 2030.

The Selected Site

The southern part of El-Hussinia plain, Sharkia Governorate (latitude 30.35°, longitude 31.30°, and elevation above sea level 13.00 m), Egypt covering an area of about 142 km^2. The soils are degraded by the problems of salinity and sodicity. Harmful effects of high alkalinity are manifested through non-availability of nutrients like micronutrients in salt-affected soils (Elbordiny and El-Dewiny 2008). In Salt-affected soil of El-Sharkia governorate, surface irrigation is prevailing with 60 % application efficiency. Furthermore, application of leaching requirements to remove salts away from root zone is dependent on salinity level in the soil. The main preferable crops in this area are sugar beet as winter crop, in addition to rice and cotton as summer crops.

Cultivation of Sugar Beet Crop

Sugar beet is considered the second source for sugar production in Egypt. It has the ability to grow in the new soils that usually suffer from salinity and poor quality of irrigation water. Sugar beet can be grown in soils varying in texture from light sands to heavy clays that supply adequate amounts of plant nutrients, as well as water (Abdel-Mawly and Zanouny 2004). Sugar beet is a deep-rooted, salt-tolerant crop that can be used as part of a cyclic reuse program to reduce drainage-water volume and conserve high-quality water (Kaffka et al. 1999). Rhoades (1990) indicated that sugar yield of sugar beet was not affected by salinity level of 7.0 dS/m. The success of sugar beet as a crop depends on seed germination, early seedling establishment, and the rapid development of a leaf canopy, which is able to utilize the available solar radiation efficiently. There is considerable evidence that crop yield and sugar production is directly related to the amount of radiation intercepted by sugar beet foliage between sowing and harvest, where the greater the incident of radiation, the higher the yields that may be expected (Blackburn 1984). However, continuous cultivation of sugar beet in the same area of land increase nematode numbers and root fusarium, which significantly reduce roots yield (Hanson and Hill 2004). Thus, it is important to follow crop rotation to combat these diseases.

Cultivation of Rice Crop

The cultivation of rice in El-Sharkia governorate is favorable to prevent sea water intrusion. Rice crop in many cases is used among the soil reclamation process, where it is planting with standing water. The conventional system for irrigating rice is to flood and maintain free water in the field. Initial flooding provides favorable conditions for land preparation and rapid crop establishment through transplanting and efficient weed management. Continual flooding provides a favorable water and nutrient supply under the anaerobic conditions (Mahmoud et al. 2016). During growth stages of rice, the standing water could be disposed through drainage system and replaced with fresh water. This process could reduce the salinity of both soil and ground water. Furthermore, both organic matter as composted rice straw and gypsum could ameliorate the alkali soil characteristics, but addition of decomposed organic matter might be better than rice straw (Moustafa 2005). Rice yield was improved in salt-affected soil when gypsum and manure were combined and applied to rice (Mohamedin et al. 2005). Moreover, flushing after 7 days and subsequent gypsum application significantly increased the average yield of rice by 25 %, comparing with the conventional treatment (Mohamedin and Mona 2011).

However, the conventional cultivation system of rice uses a large amount of water, which causes high water loss through evaporation, seepage and percolation. A challenge for sustainable rice production is to decrease its applied water and maintain or increase yield through improved water productivity (IRRI 2007). Thus, in saturated soil culture system, water is added to raised beds using flood irrigation to form water table that fluctuated between 8 and 15 cm below the bed surface. Saturated soil culture system saved water by up to 32 % compared with permanent flooding (Tuong et al. 2004; Humphreys et al. 2004). Seedlings transplanted in beds and furrows saved approximately 60 cm of irrigation water than planting seedlings in flat puddles (Devinder et al. 2005).

Irrigation water saving in rice can be attained by changing cultivation method from basins to wide furrows. Planting in bottom of beds could be applied for the rice cultivars because it increased rice productivity by 4 %, enhanced furrows water use efficiency by 66 % and saved water by 38 %, compared to traditional planting (Meleha et al. 2008). Naresh et al. (2014) indicated that wide raised beds saved about 15–24 % of irrigation water and grain yield increase by about 8 %. Transplanting in the bottom of beds increased productivity of irrigation water by 46 and 33 %, compared to transplanting flooded soil and transplanting in bottom of furrows respectively. Transplanting rice in the bottom of beds saved water by 33 %, compared to transplanting under flooding, which normally practiced in North Delta, Egypt (Mahmoud 2012).

The intensive rice cultivation for the purpose of salts leaching away from root zone exists in the North Nile Delta. However, it resulted in soil exhaustion and depleting of soil nutrients, especially when wheat or sugar beet is preceding rice.

Cultivation of Cotton Crop

Cotton is one of the most salt tolerant crops and was outstanding for successful cropping on salt-affected (Rhoades et al. 1980). In the Nile Delta, cotton has shown greater more sensitivity to soil salinity than rice either because of the cotton species and variety grown (G. barbadense 'Giza 72' in particular) or because of the salt ionic composition with dominance of NaCl (El-Falaky and Rady 1993). Cotton usually does not come first in the reclamation of salt-affected soils. Decline in its yield may be caused by reduction of germination, delayed emergence and slow seedling growth (El-Saidi 1997). Young cotton seedlings appeared particularly sensitive to soil salinity when B is present in excessive amount in the soil solution (Mamani et al. 1998). In general, the most sensitive stage to salinity is flower bud formation, when growth can be completely arrested and high shedding induced. Cotton plants are much more resistant after flowering to salt concentration in the soil (El-Saidi 1997). However, cotton shows good compensation of plant number with plant size was found for soil EC up to 7.0 dS/m (Mamani et al. 1998). The irrigation of cotton with saline water containing up to 8000 ppm of soluble salts may produce acceptable yields in sandy soils, despite yield reductions with increasing salinity levels (Ahmad and Abdullah 1982). Cycles of irrigation with discontinuous use of saline water may help to prevent saline build up in the soil over time (Shennan et al. 1995). Favorable salt redistribution can be obtained with furrow irrigation that appeared effective for supporting cotton yields in saline conditions in Chile (Mamani et al. 1998).

Suggested Crop Rotations

Crop rotation is one of most effective agricultural control strategies. It involves arrangement of crops planted on same field; the succeeding crops should belong to different families (Huang et al. 2003). Crop rotation improved soil structure

Table 6.1 Proposed cropping pattern during land reclamation

	Winter	Summer
1st year	Barley/rye grass/clover	Rice/sorghum
2nd year	Wheat/clover	Rice/cotton
3rd year	Clover/wheat	Cotton/rice
4th year	Clover/beans/wheat	Cotton/corn/rice

(Raimbault and Vyn 1991), increased soil organic matter levels (Bremer et al. 2008), increased water use efficiency (Tanaka et al. 2005), enhanced mycorrhizal associations (Johnson et al. 1992), improved grain quality (Kaye et al. 2007), and reduced grain yield variability (Varvel 2000). Crop rotations also provide better weed control, interrupt insect and disease cycles, and improve crop nutrient use efficiency (Karlen et al. 1994). Furthermore, crop rotation can save on the applied irrigation water to crops. Kamel et al. (2010) stated that appreciable difference in water consumptive between the prevailing rice rotation and proposed rotation, where water consumption of the prevailing rotation exceeded those of the proposed rotation by 25 and 42 %, in case of the short and long term crop rotations, respectively. In salt-affected soil, appropriate crop rotation increases organic matter in the soil, improves soil structure, reduces soil degradation, and resulted in higher yields and greater farm profitability in the long-term (Yazar 2008). Furthermore, inclusion of clover in a rotation implemented in salt-affected soil improves soil fertility more than application of farm yard manure due to improvement in organic matter and physical conditions of the soil (Bhatti and Khan 2012). West and Post (2002) reported that use of crop rotation with legume crops reduce reliance on external inputs of nitrogen in salt-affected soils. Abd El-Aal (1995) stated that the selection of crops during the reclamation of salt-affected soils should be based on tolerance to salt and waterlogging and its economic value. In the northern part of the Nile Delta, where soil salinity is somewhat higher than normal, crop rotation includes rice and cotton as the main summer crops, and wheat and clover as the main winter crops. All these crops have proved to be salt-tolerant or semi-tolerant. Furthermore, Gehad (2003) suggested the following cropping pattern during the reclamation of salt affected soils (Table 6.1).

Calculation of Water Requirements for Each Crop Rotation

The required irrigation water need to be applied to the studied crops was calculated by BISm model (Snyder et al. 2004) using normal climate data (1985–2014). The model requires planting and harvest dates as input. The model calculates crop coefficient (kc) and accounts for water depletion from root zone. Therefore, it requires to input total water holding capacity and available water in the soil.

Water requirements for the studied crops were calculated under surface irrigation and under 25 % saving in the applied water to surface irrigation as a result using precise land leveling and cultivation on raised beds. It has been reported that precise land level decease salt accumulation (Khan et al. 2007) and helps distribution of soluble salts in salt-affected soils (Hosseini et al. 2014). Raised bed planting gained importance for row-spaced crops in many parts of the world (Sayre 2007). It was reported that raised beds can save 20–25 % of irrigation water, increasing water use efficiency (Ahmad et al. 2009) and providing better opportunities to leach salts from the furrows (Bakker et al. 2010).

Several crop rotations were suggested and water requirements for the whole rotation was calculated twice, the first time for sole crop planting under surface irrigation and for intercropping systems cultivated on raised beds. In the second time, we calculated crops water requirements assuming that all crops are cultivated on raised beds.

The effect of climate change on the cultivated crops was assessed using comparison between RCPs scenarios developed from four global models and the boundary of the closer scenario to the measured data was input into a regional climate model (WRF-RCM) to develop more accurate weather data to be in the assessment. Water requirements for the selected crops were calculated under surface irrigation and with 25 % saving in the applied water to surface irrigation.

Description of the Suggested Crop Rotations

The suggested crop rotations to be implemented in salt-affected soil take duration of 3 years. In each year, the cultivated area is composed of three hectares. Each hectare is divided into three parts and each part is cultivated with winter and summer crops. The traditional cultivated method prevailing in salt-affected soil is cultivation on narrow furrows or flat cultivation. This cultivation method is characterized by high applied irrigation water and high fertilizer consumption. Thus, we proposed to implement precise land leveling and cultivation on raised beds, which the main characteristic of the proposed crop rotations, where 25 % of the applied water to surface irrigation can be saved. Furthermore, different intercropping systems were suggested to be implemented in each crop rotation.

The suggested crops in salt-affected soil rotation are characterized by being tolerant to salinity, such as sugar beet, barley, rice, cotton, sorghum and cowpea. Other cultivated crops might be moderately tolerant to salts, however high tolerant cultivars are used, such as for wheat and clover.

Suggested Crop Rotation Number (1)

In the first part of the suggested crop rotation number (1), cotton is relay intercropped with onion on raised beds (Fig. 6.2). In this system, onion is cultivated in November in four rows on the top of the raised beds and cotton is cultivated relay on onion in March on both sides of the raised beds and it continued until

Year 1	Year 2	Year 3
Cotton/onion	Sugar beet Sunflower Maize (late)	Wheat Rice Clover (short)
Wheat Rice Clover (short)	Cotton/onion	Sugar beet Sunflower Maize (late)
Sugar beet Sunflower Maize (late)	Wheat Rice Clover (short)	Cotton/onion

Fig. 6.1 Suggested rotation number (1) for salt-affected soil

Fig. 6.2 Cotton relay intercropped with onion

September. Onion is harvested in May, thus cotton shares its first two irrigations with the last two irrigations of onion. Planting density of onion is 33 % and planting density of cotton is 100 % (Zohry 2005). In the second part of the rotation, cultivation of short season clover as early winter crop before winter crop and after summer can maintain soil fertility, compared to wheat and rice cultivation only (Sheha et al. 2014). Accordingly, cultivation of short season clover before wheat and after rice can have the same above effect. In the third part of the rotation, sugar beet is cultivated in early in September and harvested in March, which allow the cultivation of sunflower in April and harvest it in June. Then maize can be cultivated in July as late cultivation and harvested in November before the cultivation of winter crops (FCRI 2014). The benefits of this system are: it increase land productivity, it reduce oil production-consumption gap and it increase farmer's net revenue (Fig. 6.1).

Table 6.2 Water requirements for crop rotation number (1) under current climate and under climate change

	Water requirements under current climate (m^3/ha)		Water requirements under climate change (m^3/ha)	
	Surface	Package	Surface	Package
Cotton/onion	18,050	18,050	19,516	19,516
Wheat	6781	5086	7197	5398
Rice	18,234	13,676	19,924	14,943
Clover (short season)	5886	4415	6158	4619
Sugar beet	9272	6954	9830	7372
Sunflower	8308	6231	9026	6770
Maize (late)	7835	5877	8702	6526
Total	74,367	60,288	80,353	65,144
Saved water for 3 ha (m^3)	14,079		15,209	
Saved water (m^3/ha)	4693		5070	

The above rotation is recommended for soil with low salinity level because it contains one legume crop, i.e. short season clove. Furthermore, onion is sensitive to salinity. Water requirements for crop rotation number (1) under current climate using normal climate data and under climate change in 2030 are included in Table 6.2. The results showed that under surface irrigation, water requirements for all cultivated crops were higher by 4693 m^3/ha than water requirements when the production package was used. Similar situation was found under climate change, where 5070 m^3/ha can be saved.

Suggested Crop Rotation Number (2)

This suggested rotation contains variety of crops, which could grant good profit to the farmer and it can fulfill all his needs for cash crops, food crops and feed crops (Fig. 6.3). The first part of the rotation includes three-crop sequence, i.e. wheat, rice then short season clover. The second part of the rotation contains faba been intercropped with sugar beet and cowpea intercropped with maize. Regarding to faba bean intercropped with sugar beet, it will not require applying extra water to faba bean. Furthermore, this system will increase the cultivated area with faba bean by a percentage of the cultivated area of sugar beet, in addition it improve the quality of sugar beet tuber (Mohamed 2014). Intercropping cowpea with maize can be implemented in summer season, where both crops are cultivated in the same time

Year 1	Year 2	Year 3
Wheat Rice Clover (short season)	Cotton/wheat	Faba bean/sugar beet Cowpea/Maize
Faba bean/sugar beet Cowpea/maize	Wheat Rice Clover (short season)	Cotton/wheat
Cotton/wheat	Faba bean/sugar beet Cowpea/Maize	Wheat Rice Clover (short season)

Fig. 6.3 Suggested rotation number (2) for salt-affected soil

Table 6.3 Water requirements for crop rotation number (2) under current climate and under climate change

	Water requirements under current climate (m^3/ha)		Water requirements under climate change (m^3/ha)	
	Surface	Package	Surface	Package
Wheat	6781	5086	7197	5398
Rice	18,234	13,676	19,924	14,943
Clover (short season)	5886	4415	6158	4619
Faba bean/sugar beet	6954	6954	7372	7372
Cowpea/maize	7152	7152	7864	7864
Cotton/wheat	16,274	16,274	17,592	17,592
Total	45,008	37,282	48,516	40,196
Saved water for 3 ha (m^3)	7725		8320	
Saved water (m^3/ha)	2575		2773	

(Hamd-Alla et al. 2014). In the third part of the rotation, cotton is relayed intercropped with wheat, where this system is similar to cotton relay intercropped with onion. However, wheat is cultivated with 70 % planting density and produce 80 % of its production, compared to wheat sole planting (Zohry 2005).

The above rotation is suitable for soil with medium salinity because it contains rice, where its applied water will help in leaching salts. It also contains three legume crops, short season clover, faba been and cowpea. These three crops can improve soil structure and fertility. The total water requirements for the suggested crops included in crop rotation number (2) were 45,008 and 37,282 m^3/ha under surface irrigation and implementing the package, respectively. The total water requirements will be higher under climate change in 2030, i.e. 48,516 and 40,196 m^3/ha under surface irrigation and implementing the package, respectively. The saved amount of irrigation water when the package was implemented was 2575 and 2773 m^3/ha under current climate and in 2030, respectively (Table 6.3).

Suggested Crop Rotation Number (3)

This rotation is characterized by the presence of three-crop sequence in two parts of it and there is no intercropping systems. In the first part of this rotation, short season clover is cultivated before wheat and after rice to improve soil fertility. Sunflower is cultivated as early summer crop after sugar beet, where sugar beet will be cultivated in October and harvested in end of March, where sunflower can be cultivated in April. Sunflower will be harvested in July then maize can be cultivated as late summer crop and it will be harvest in October before cultivation of winter crops (FCRI 2014). In the third part of the rotation, full season clover can be cultivated and followed by rice. This rotation can give the farmer high net revenue because it contains rice (cultivated twice) and it also contains sugar beet (Fig. 6.4).

The above rotation is recommended to soil with high salinity level, where rice is cultivated twice and full season clover; both required large amount of water, which will help in leaching salts. Furthermore, cultivation of short season clover and full season clover will improve organic matter and physical conditions of the soil.

Because this rotation cultivates rice twice, in addition to full season clover in each year, it consumes a large amount of irrigation water, i.e. 86,969 m^3/ha under surface irrigation (Table 6.4). However, using the management package instead of surface irrigation can save 7247 m^3/ha. Similar situation will be exist in 2030 under climate change, where total water requirements for the rotation under implementing the management package, i.e. 70,467 versus 93,956 m^3/ha under surface irrigation and the package, respectively. Thus, under climate change the management package must be used to face the expected water scarcity under climate change (Table 6.4).

Year 1	Year 2	Year 3
Wheat Rice Clover (short season)	Clover (full season) Rice	Clover (full season) Rice
Sugar beet Sunflower Maize (late)	Wheat Rice Clover (short season)	Sugar beet Sunflower Maize (late)
Clover (full season) Rice	Sugar beet Sunflower Maize (late)	Wheat Rice Clover (short season)

Fig. 6.4 Suggested rotation number (3) for salt-affected soil

Table 6.4 Water requirements for crop rotation number (3) under current climate and under climate change

	Water requirements under current climate (m^3/ha)		Water requirements under climate change (m^3/ha)	
	Surface	Package	Surface	Package
Wheat	6781	5086	7197	5398
Rice	18,234	13,676	19,924	14,943
Clover (short season)	5886	4415	6158	4619
Sugar beet	9272	6954	9830	7372
Sunflower	8308	6231	9026	6770
Maize (late)	7835	5877	8702	6526
Clover (full season)	12,417	9313	13,196	9897
Rice	18,234	13,676	19,924	14,943
Total	86,969	65,227	93,956	70,467
Saved water for 3 ha (m^3)	21,742		23,489	
Saved water (m^3/ha)	7247		7830	

Suggested Crop Rotation Number (4)

In this rotation (Fig. 6.5), intercropping barley with sugar beet is implemented. Sugar beet is cultivated in October and barley is intercropped on sugar beet one month later. Planting density for sugar beet is 100 % and barely planting density is 33 %. Barley used the applied irrigation water to sugar beet and both crops will be harvest in April (Abd El-Zaher et al. 2009). Furthermore, intercropping cowpea with sorghum (Fig. 6.6) can improve soil fertility, in addition to provide forage for the farm animals. In this system, cowpea and sorghum are cultivated in the same time with 100 % planting density and harvested in the same time. Cowpea uses the applied water to sorghum to fulfill its needs. The benefits of this system are reduction of associated weeds and increase sorghum yield (Abou-Kreshe et al. 2011).

Year 1	Year 2	Year 3
Wheat Maize Clover (short season)	Clover (full season) Rice	Barley/sugar beet Cowpea/sorghum
Barley/sugar beet Cowpea/sorghum	Wheat Maize Clover (short season)	Clover (full season) Rice
Clover (full season) Rice	Barley/sugar beet Cowpea/sorghum	Wheat Maize Clover (short season)

Fig. 6.5 Suggested rotation number (4) for salt-affected soil

Fig. 6.6 Cowpea intercropped with sorghum

This rotation can be recommended for medium soil salinity level, as it contained three legume crops and rice. Furthermore, it contained barley, which is highly tolerant to salinity. The total water requirements for this rotation under surface irrigation are 67,189 m^3/ha. However, if we implement the management package, the total water requirements will be 53,975 m^3/ha, with 4405 m^3/ha savings in the applied water. Under climate change the total water requirements will increase to be 72,609 m^3/ha. Using the management package under climate change can save 4747 m^3/ha (Table 6.5).

Table 6.5 Water requirements for crop rotation number (4) under current climate and under climate change

	Water requirements under current climate (m^3/ha)		Water requirements under climate change (m^3/ha)	
	Surface	Package	Surface	Package
Wheat	6781	5086	7197	5398
Maize	9536	7152	10,485	7864
Clover (short season)	5886	4415	6158	4619
Barley/sugar beet	6954	6954	7372	7372
Cowpea/sorghum	7380	7380	8276	8276
Clover (full season)	12,417	9313	13,196	9897
Rice	18,234	13,676	19,924	14,943
Total	67,189	53,975	72,609	58,369
Saved water for 3 ha (m^3)	13,214		14,240	
Saved water (m^3/ha)	4405		4747	

Suggested Crop Rotation Number (5)

In this rotation (Fig. 6.7), onion is intercropped with sugar beet (Fig. 6.8) with 33 % planting density. Sugar beet is cultivated in October and one month later onion is cultivated. The benefit of this system is onion reduces the number of nematodes in the soil and improves sugar beet quality (Farghaly et al. 2003).

The above rotation is suitable for soils with low to medium salinity level because it contained rice, full season clover and cowpea. The total water requirements for this crop rotation using the management package will be lower in 2030 under climate change, i.e. 53,750 m^3/ha in 2030 versus 61,302 m^3/ha under present climate (Table 6.6).

The above suggested rotations contained diversity of crops, such as cash crops (cotton, sugar beet and onion), cereals crops (wheat, sorghum, rice and maize), forage crop (clover and cowpea) and oil crop (sunflower). Thus, these rotations can supply the needs of the farmers and provide them with good profits.

Year 1	Year 2	Year 3
Onion/sugar beet Rice	Wheat Maize	Clover (full) Cowpea/sorghum
Wheat Maize	Clover (full) Cowpea/sorghum	Onion/sugar beet Rice
Clover (full) Cowpea/sorghum	Onion/sugar beet Rice	Wheat Maize

Fig. 6.7 Suggested rotation number (5) for salt-affected soil

Fig. 6.8 Onion intercropped with sugar beet

Table 6.6 Water requirements for crop rotation number (5) under current climate and under climate change

	Water requirements under current climate (m^3/ha)		Water requirements under climate change (m^3/ha)	
	Surface	Package	Surface	Package
Onion/sugar beet	6954	6954	7372	7372
Rice	18,234	13,676	19,924	14,943
Wheat	6781	5086	7197	5398
Maize	9536	7152	10,485	7864
Clover (full season)	12,417	9313	13,196	9897
Cowpea/sorghum	7380	7380	8276	8276
Total	61,302	49,560	66,450	53,750
Saved water for 3 ha (m^3)	11,742		12,700	
Saved water (m^3/ha)	3914		4233	

Even though total water requirements under climate change were higher than its value under present climate in all the above rotations, using the management package under climate change will require less water than if we continue to use surface irrigation under current climate. As it shown in Table 6.7, implementing the management package for each one of the rotation in 2030 can save an amount of irrigation water between 4812 and 16,501 m^3 per 3 hectares. This irrigation water amount represents 11–19 % of the applied water under surface irrigation and current climate. This saved irrigation amount can be used as leaching requirements because it is expected that soil salinity will increase under climate change.

Table 6.7 Total water requirements (WR) for suggested crop rotations under surface irrigation and current weather, under using the management package in 2030 and the saved amount

Crop rotation	WR under surface (current, m^3)	WR under package (2030, m^3)	Saved amount (m^3)	Percentage of saved amount (%)
Crop rotation (1)	74,367	65,144	9223	12
Crop rotation (2)	45,008	40,196	4812	11
Crop rotation (3)	86,969	70,467	16,501	19
Crop rotation (4)	67,189	58,369	8820	13
Crop rotation (5)	61,302	53,750	7552	12

Conclusion

Soil salinity will affect the sustainability of irrigated agriculture, as a result of using more water as leaching requirements, which will worsen the current situation of water scarcity. Thus, appropriate soil and water management practice should be developed and tested and its effect should be quantified, in term of crops production and soil fertility. Previous research on the effect of cultivation on raised beds in salt-affected soils revealed that it provide better opportunities to leach salts away from the furrows. Furthermore, using crop rotation in salt-affected soil can improve soil structure and reduces soil degradation. It was also reported that inclusion of legume crops in a rotation implemented in salt-affected soil improves soil fertility more than the application of farm yard manure due to improvement in organic matter and physical conditions of the soil. Furthermore, crop rotations are easy to be implemented by the farmers. Thus, we proposed five rotations to be implemented in salt-affected soil depending on salinity level. We also included three-crop sequences to improve soil fertility and intercropping systems to save on the applied irrigation water. Using the management package, we can save a large amount of irrigation water, compared to using surface irrigation.

We also found that total water requirements for the suggested crop rotations will increase under climate change in 2030, in addition to more water will need to be applied as leaching requirements for the cultivated crops in salt-affected soils. Thus, using the suggested management package resulted in applying less water to the suggested rotations in 2030, compared to the applied water to these rotations under present climate and surface irrigation. The saved irrigation amounts can be used as leaching requirements under climate change.

Finally, it can be concluded that crop rotation can be used as a technique to save on the applied water, improve soil fertility and combat soil deterioration under current climate and under climate change.

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Chapter 7
General Conclusion

Samiha A.H. Ouda and Abd El-Hafeez Zohry

Abstract Climate induced drought and water scarcity poses as massive risks on food security in Egypt, where there is a gap between production and consumption in many crops. However, cultivation of new areas outside the Nile Delta and valley is expensive. Furthermore, implementing breeding programs to produce new high yielding varieties need long period of time and it is also expensive. Therefore, unconventional procedures are needed to increase crops productivity, manage irrigation water more efficiently and increase national crops production in short time. Management of rain fed agriculture in Egypt need to adapt very innovative approaches to reduce its vulnerability. We suggested four practices to face drought stress occurrence in rain fed area in Egypt: application of supplementary irrigation and manure, as well as using crop rotation and interplanting. These practices are expected to be effective under climate change conditions. Managing irrigation water more efficiently through implementing precise land leveling and cultivation on raised beds, can increase crops productivity by 15 % and save on the applied water by 25 %. Our assessment indicated that the saved water under suggested management package was enough to irrigate a third crop per year. Furthermore, intercropping can also help in solving food insecurity problem through maximizing land and water productivity. Even though high-consuming water crops such as, rice and sugarcane are prevailing in Egypt, the suggested crops structures and management practices proved to use its applied irrigation water more efficiently. Furthermore, using crop rotation in salt-affected soils can improve soil structure and

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reduces soil degradation. Inclusion of legume crops in a rotation implemented in salt-affected soil improves soil fertility more than the application of farm yard manure due to improvement in organic matter and physical conditions of the soil.

Keyword Drought · Water scarcity · Reduction of food insecurity

The main objective of "Egypt's National Strategy for Adaptation to Climate Change and Disaster Risk Reduction, 2011" is "***increase the flexibility of the Egyptian community when dealing with the risks and disasters that might be caused by climate change and its impact on different sectors and activities***". It also aims at strengthening the capacity to absorb and reduce the risks and disasters caused by such changes. Thus, climate induced drought and water scarcity poses as massive risks on food security in Egypt, where there is a gap between production and consumption in cereal crops, oil crops, sugar crops and forage crops. However, cultivation of new areas outside the Nile Delta and valley is expensive. Furthermore, implementing breeding programs to produce new high yielding varieties need long period of time and it is also expensive. Therefore, unconventional procedures are needed to increase crops productivity, manage irrigation water more efficiently and increase national crops production in short time. These procedures need to be easy implemented by farmers, does not involve extra cost (or low cost can be compensated by the government) and result in an increase in farmer's net revenue.

Management of rain fed agriculture in Egypt need to adapt very innovative approaches to reduce its vulnerability. We suggested four practices to face drought stress occurrence in rain fed area in Egypt: application of supplementary irrigation and manure, as well as using crop rotation and interplanting. Although we were not able to simulate the effect of all of them, the simulation results of application of supplementary irrigation and manure were encouraging to assume that additive effect of the four suggested practices could overcome the risk of drought under current climate and the projected climate change in 2030.

Since, surface irrigation is prevailing in Egypt, it is important to test options to increase its low application efficiency. Managing irrigation water more efficiently through implementing precise land leveling and cultivation on raised beds, can increase crops productivity by 15 % and save on the applied water by 25 %. Our assessment indicated that the saved water under suggested management package was enough to irrigate a third crop per year. Furthermore, intercropping can also help in solving food insecurity problem through maximizing land and water productivity. Therefore, our assessment focused on different crops structures in the Nile Delta and South Egypt for clay soil, and for salt-affected soil in the Nile Delta. It was concluded that in these studied regions, the suggested crops structures can use irrigation more efficiently, which allow production of more crops per unit of land and water. Even though high-consuming water crops such as, rice and sugarcane are prevailing in Egypt, the suggested crops structures and management practices proved to use its applied irrigation water more efficiently. For example, rice cultivation on raised beds saves on the applied water and intercropping on sugarcane increases water productivity.

Our assessment showed that soil salinity will affect the sustainability of irrigated agriculture, as a result of using more water as leaching requirements, which will worsen the current situation of water scarcity. Thus, using crop rotation in salt-affected soils can improve soil structure and reduces soil degradation. Inclusion of legume crops in a rotation implemented in salt-affected soil improves soil fertility more than the application of farm yard manure due to improvement in organic matter and physical conditions of the soil. Furthermore, crop rotations are easy to be implemented by the farmers. Thus, the proposed crops rotations can include three-crop sequence to improve soil fertility and intercropping systems to save on the applied irrigation water. Furthermore, using the suggested management package resulted in applying less water to the suggested rotations in 2030, compared to the applied water to these rotations under present climate and surface irrigation. Thus, the saved irrigation amounts can be used as leaching requirements under climate change condition.

We should also be concern by the future of water availability and food security in Egypt, as many studies showed that Egypt will suffer from reduction in water supply and losses in crops productivity. Thus, quantification of the impact of climate change on prevailing crops structures is very important for policy makers when developing future plans. Our assessment revealed that an increase in water requirements for the prevailing crops structures will exist under climate change conditions, which consequently will reduce its cultivated area and national production. In addition, population is expected to increase, which will worsen the already bad situation of water and food. Thus, we need to start, ***now***, to implement these suggested management practices to reduce vulnerability of crops structures to climate change and reduce food gaps in Egypt.

As our concern in this book is “drought, water scarcity and climate change impact on food production”, we should focus on suggestions for encouraging a triple dividend in agriculture: increased food security, reduced emissions, and improved adaptive capacity. Thus, GHG emission can be reduced by crops intensification, i.e. increasing crops sequence to three crops per year, where legume crop grows between the other two crops to improve soil fertility and reduce CO_2 emission from the soil. Furthermore, intercropping increase carbon sequestration in the soil and prevent it from escaping to the atmosphere.

Using short season rice cultivars and cultivation on raised bed or strips to reduce the applied irrigation water, can reduce the decomposition of soil organic matter under anaerobic conditions, which produces methane that escapes into the atmosphere Furthermore, changing cultivation method for crops from flat or narrow rows to raised beds reduces nitrogen fertilizer application by 15 %, thus reduce methane emissions. Furthermore, methane emissions from manure and from burning of agricultural residues can be reduced through the application of technologies designed to capture the methane and use it as an energy source by producing bio-gas. Using bio-gas units will reduce the need for other energy sources for houses illumination and gasoline to run farm machinery. In addition, methane capture will improve the profitability of the livestock operation by offsetting the need for fossil fuel energy from outside sources. Furthermore, the residual part after obtaining the bio-gas can be used as high quality organic fertilizer to replace mineral fertilizer, and consequently reduce the emission.

Thus, the suggested innovative water management practices need to be transfer to farmers to help them using irrigation water more rationally to grant high farm profits for them. These innovations can improve farmer's adaptive capacity to face climate change risks. However, there is a need to enhance agricultural extension sector by training. Establish a link between research, extension and farmers is also needed to improve adaptive capacity.