Impact of Climate Change on the Agricultural Sector in Egypt

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Abstract The complex interrelationship between environmental change and agricultural production will become one of the most significant policy debates, in both developed and developing countries particularly in the coming decades of the twenty-first century. Global and regional climate changes will modify both agricultural production capacity and locations of production. Also, the increasing intensity of agricultural production will contribute to environmental change at both the regional and global scale. Agricultural production in Egypt depends on irrigation, using surface water coming from the River Nile. Groundwater also contributes with very low amounts. Generally, the agricultural sector is considered the largest consumer of water (80% from total water budgets).

Climate change can have several kinds of impacts on the agricultural sector and stability of food security in Egypt. Crop production will be affected negatively due to the expected increases in temperature, extreme weather events, drought, plant diseases, and pests. Also, the land use will change due to flooding from sea level raising, seawater intrusion, and secondary salinization. Water resources may be affected due to global warming and decreases in precipitation. Moreover, crop water requirements are expected to increase. The confounding effect of all these components represents the main challenge for researchers.

The current infrastructure and cropping systems have to be changed to comply with future demands with regard to the growing population and the threat of climate change. The negative impacts of climate change on agricultural crops can be reduced by the implementation of integrated farm-level adaptation strategies, for instance, changes in the date of planting, cultivars, use of extra fertilization, and changing irrigation intervals. The author will present in this chapter the impact of

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A.M. Negm (ed.), *Conventional Water Resources and Agriculture in Egypt*,
Hdb Env Chem, DOI 10.1007/698_2017_48,

climate change on agriculture in Egypt and some adaptation strategies to reduce these impacts.

Keywords Adaptation, Agriculture, Climate change, Egypt, Greenhouse gases

Contents

1 Introduction

Globally, food demand is expected to increase two- to fivefold from 1990 to 2030; however, agricultural land dedicated to crop production is shrinking due to population growth, urbanization, and soil degradation [1]. Climate change will increase food security problems facing many countries [2]. Direct negative impacts on food security are related to changes in water availability, soil characteristics, and crop productivity. Adverse impacts on soil quality may occur as a result of the depletion of soil organic matter, the decrease in soil fertility, the decline in available water capacity, and degradation in soil structure, crusting, erosion, and salinization. Water resources could be impacted through alterations in the hydrological balance (runoff and evaporation), and high soil erosion may exacerbate nonpoint source pollution. There are numerous indirect impacts of climate change such as a change in farming/cropping systems. For example, the land currently suited for paddy rice in northwestern India may be converted to corn, cotton, soybean, vegetables, or aerobic rice similarly, and corn in the savannah region of Africa may change to sorghum [3].

Climate change impacts on the agricultural sector include production (in terms of quantity and quality), species types, environment, and land use changes. The integration of all these confounding components represents the main challenge for researchers [4]. Africa is likely to be highly impacted by these adverse direct effects due to their high agricultural dependency, and limited capacity to adapt [5]. Egypt is also vulnerable to climate change because of its large traditional agricultural practices, and the limited source of water from the Nile River as the main water source. Also, the coastline of the Nile is already suffering from erosion and intensifying development [6, 7]. Climate change may affect agricultural production in Egypt especially the Nile Delta region. This region is characterized as one of the mostly vulnerable regions in the world to climate change in particularly soil and water degradation, sea level rise, undiversified crop patterns, pests and disease severity, yield reduction, irrigation, and drainage management.

Agriculture plays a vital role in Egypt's economy contributing roughly 15% of the Gross Domestic Product (GDP) and employing about 30% of the national workforce. Smallholder farmers represent the majority of Egypt's farming sector [8]. Thus, adaptation strategies to climate change are vital for sustainable agriculture and food security in Egypt.

2 The Impact of Global Warming on the Agricultural Sector in Egypt

2.1 Increase Evapotranspiration and Crops Water Requirements

Increased evaporation due to warmer temperatures anticipated with climate change will increase potential evapotranspiration [9]. Climate change will affect crops production indirectly by increasing crops water requirements. Climate change could increase summer crops water requirements 16%; on the other hand, decreases winter crops requirements 2% by the year 2050 [10]. By 2100, water requirements for strategic crops in Egypt are expected to increase by 5–13% [11, 12]. The gross irrigation requirements may increase by 4–18% in all Mediterranean zones due to climate change only [13]. By 2030, water requirements for rice, soybean, tomato, cotton, corn, sunflower, sorghum, wheat, and sugarcane crops will increase 16%, 15%, 14%, 10%, 8%, 8%, 8%, 2.5%, and 2.5%, respectively. However, water requirements for barley crop will decrease 2% under climate change conditions compared with the current situation [14].

2.2 Reduction of Crops Yield

Climate change may cause earlier crops growth and a squeeze of growing season. These responses may help some crops like winter crops to escape summer drought stress, but at the same time an increase in the frequency of extreme weather events like heat waves and frost at sensitive phonological stages may cause bud breaks that will affect the final quality and quantity of the yield [15]. Increasing the number of days of extreme heat may cause large drops in crop yields, especially when they occur during vital stages of plant growth such as flowering and grain filling

[16]. Crops photosynthetic, multiplicative cells, plant growth, grain quality, and crop yields will be affected negatively by extreme heat [16–19].

Many studies were conducted to investigate the impact of climate change on crop production in Egypt; general consensus indicated that the productivity of most crops would be affected negatively. The projected decline in agricultural activities due to increased temperature ranges from 10 to 60% [20]. Higher temperatures due to anticipated climate change will directly affect yields of many crops causing a potential reduction of 10–30% for crop yields such as rice, wheat, barley, maize, soybeans, and sunflower [21, 22]. By 2050, if temperature rises by 2°C, the expected wheat yield will be decreased by 15% [23], rice production will be reduced by 11% [24, 25], maize yields will be reduced by 19% [25, 26], soybean yields will be decreased by 28% [24], and barley yield will be decreased by 20% [27]. Egyptian clover declines as fodder production would be an important challenge for farmers providing to livestock [12]. The predicted productivity of wheat, barley, corn, sorghum, rice, soybean, sunflower, and sugarcane will be decreased by 18%, 18%, 18%, 19%, 11%, 28%, 27%, and 25%, respectively, when temperature increases by 3.5°C. Tomato yield will decrease by 14% and 50% when the temperature rose by 1.5°C and 3.5°C, respectively [14]. However, cotton yield would be increased by 17% and 31% if the temperature increased by 2°C and 4°C, respectively [14, 26]. Cotton and potato yields are expected to be increased 15–40% particularly if it grew in the main seasons [21, 22]. Cotton yield is expected to increase from 15 to 17% in three main agroclimatological regions of Egypt [28].

In Egypt, the projected wheat yield was to be above the baseline of 1970–2000 in 2020 and 2050 by six and five emission scenarios, respectively. However, in 2080 wheat yield expected to be below the baseline level under all emission scenarios. Rice yield reduction was simulated from 2020 up to 2080. Maize yield is expected to decrease with climate change under all emission scenarios [29]. The productivity of wheat and maize will be declined 15–20%, respectively. Seawater intrusion is expected to reduce land productivity in the Nile Delta region. Declines in fish catches resulting from changes in the ecosystem in the northern lakes are also projected [28]. Wheat yield on rainfed areas in Egypt would be decreased by 50% if rainfall were decreased by 20% under the SRES B2 scenario. While, increasing rainfall by 20% will reflect an increase of wheat yield by less than 5% [30].

The direct impacts of climate change that are expected to cause a reduction of crop yields include storms, flooding, heavy rains, eroding soils, rising sea levels, salting soils, and higher ozone levels. In addition, increasing severe, frequent, longer-lasting heat waves, large-scale drought, changing river flows, and thriving plant diseases and pests will also have an impact.

2.3 Plant Disease and Pests

The expected temperature increases in Egypt may cause changes in agroclimatic zones with implications for diseases, pests, and crop suitability. There are many crop pests that can grow and survive in a wide range of higher CO_2 environments and warmer temperatures such as weevils and aphids. Ecological stresses may cause mutations in crop diseases which could potentially increase their volatility. The earlier onset of warm temperatures could result in an earlier threat from disease with the potential for more severe epidemics and increases in the number of fungicide applications needed for control [31].

3 Drought and Decrease Precipitation

The overall climate trend is a decrease in rainfall, and subsequently an increase in drought frequency and intensity [9]. This may impact the amount of water resources available for agriculture, reducing amounts available for irrigation [32]. However, in Egypt most studies showed that the expected change of climate “will not significantly affect water resources in the Nile River as higher evaporation from drier weather will be compensated by wetter East Africa,” but water requirements of crops will be increased [22, 33, 34].

4 Sea Level Rising and Changing Land Use

The global average of sea level rise rate was around 1.8 mm/year from 1961 to 2003 and about 3.1 mm/year from 1993 to 2003 [35]. It is unclear if the increased rate observed between 1993 and 2003 will reflect in increases in the underlying long-term trend. By 2100, if the mean global temperature increases by 2°C, the mean global sea level will increase to 0.49 m above the present levels. If the mean global temperature increases 4°C, the mean global sea level will increase by 0.71 m above the present levels [36].The Intergovernmental Panel for Climate Change (IPCC) estimated that the mean increase of global seawater levels was between 10 and 20 cm during the last century. It is expected that during the twenty-first century sea levels will rise by 11–88 cm [37, 38].

Rising sea levels will cause the submergence of many parts of the coastal area. With progressively severe, frequent storms and wave demolition, the shoreline retreat will be accelerated. In addition, it is expected that there will be disastrous flooding events caused by high tides, heavy flooding, and windstorms in combination with higher seas [39]. Large parts of the coastal areas of the Nile Delta in Egypt might be flooded by seawater and the coastline might change to land for several kilometers in the western and eastern borders of the delta [40]. Particularly vulnerable areas include Alexandria, Port Said, Damietta, and Beheira governorates. Over this century, if sea level rises from 0.5 to 1.0 m and no action is taken, an area of about 30% of the Alexandria will be lost due to flooding [41]. Alexandria is the second largest city in Egypt, it is revealing a land subsidence of about 2 mm/year, and it is highly vulnerable to erosion and flooding because 35% of the land area is below mean sea level [42]. Increasing sea level by 1 m, an estimated area of about 68% of its land could be inundated [43]. If sea level rises by half a meter, the loss of the agricultural land would be more than 1,800 km^2, affecting about 3.8 million people [44]. A 0.5 m rise in sea level would cause a loss of 19%, and 32% for a 1 m rise, of the total area of the Nile Delta. Although about 33% of the groundwater resources will be lost when sea level rises by 1.0 m, the available volume of the freshwater will be decreased by about 15% assuming that the current pumping rates will be maintained [45]. About 12–15% of the high-quality agricultural land area in the Nile Delta region will be lost as a result of sinking or salinization with a rise of sea level by about 0.5 m [14]. But, if it is increased by 1 m, more than 6 million of people would need to leave their land [46].

Rising sea level is expected to damage weak parts of the sand belts, that are vital for the protection of reclaimed lowlands and lakes. It will affect water quality, freshwater fish, salinization of groundwater resources, and flood valuable agricultural land [47]. It may cause damage to the best productive agricultural lands along the Mediterranean coast with consequences on fish production since 33% of Egypt's fish catches are from Mediterranean lagoons [22, 48].

Rising sea level will have the highest impacts on groundwater resources in coastal aquifers. First, the shoreline will become more exposed and become land (depending on the topography of the area); this movement may be significantly affected by the groundwater in the affected zone. Second, seawater level rising would cause extra pressure at the seaside and hence the seawater would move more inland. Third, decreased precipitation may affect the natural groundwater replenishment [45].

5 Seawater Intrusion and Secondary Salinization

Seawater intrusion means the movement of saltwater from the sea into coastal aquifers due to over pumping of groundwater and it is a dynamic equilibrium of groundwater movement [49]. It is a natural phenomenon that occurs in virtually all coastal aquifers connected to the sea as a consequence of the higher density of the seawater compared to the water in the aquifer. Seawater intrusion is considered one of the chief processes that reduces water quality by increasing salinity. This damage may occur due to human activities like overpumping from the aquifers and/or by natural events as sea level rise, seasonal changes in natural groundwater flow, barometric pressure changes, tidal effects, and seismic waves [50]. Because of the higher density of seawater, it moves inland into freshwater aquifers without any pumping actions [51].

Seawater intrusion is the main problem in coastal aquifers. Seawater intrusion in the Nile Delta aquifer has expanded inland more than 100 km from the Mediterranean coast [52, 53]. This may be due to the abstraction from wells that were initially in fresh groundwater may then become located in brackish water or saline water [54]. Intrusion might be affected by external factors such as irrigation and recharge practices, increase or decrease in groundwater pumping, land use practices, and possible rising in seawater [45]. The excessive and random pumping from the Nile Delta aquifer would quicken seawater intrusion [51, 55].

Increasing seawater level by 1 m as a global mean by 2100 would cause 0.37 m rising in seawater level at the Nile Delta [56]. An increase in sea level of 0.38 m would result in the movement of the shoreline to the current 0.75 m contour and loss a 5% of the Nile Delta agricultural land by 2060. Agricultural areas which are below 1 m are susceptible to seawater intrusion and salinization, and moreover require water management planning. Rising seawater level by 0.5 m in the Mediterranean Sea under steady-state conditions would cause the equitable concentration lines 35, 5, and 1 g/L to move inland by distances of 1.5, 4.5, and 9 km, respectively [57]. Sea level rise will move the saltwater interface further inland [54]. The continued rise in sea level increases the risk of coastal erosion and intrusion of saline water [58]. Such effects become more obvious in lowland, flat, and coastal alluvial plans where wide areas might be flooded with seawater due to seawater rise [55].

Seawater intrusion has a direct impact on soil salinity, the groundwater resources, quality in the coastal zone, and agricultural productivity [59]. A combination of increased salinity of the soil due to increased evaporation and seawater intrusion resulting from rising sea level is predicted to decrease the quality of shallow groundwater supplies in the coastal regions [60]. The expected increases of sea level by 1 m might cause the worst situation, in which the freshwater might be reduced to about 513 billion m^3 [53]. Rising seawater level has a significant effect on the location of the transition zone [51].

Seawater intrusion can be controlled by injection of freshwater, subsurface barriers, and saltwater extraction [50, 61]. Injection of freshwater by about 10% of the usage rate can successfully push the interface toward the shoreline and keep reducing salinity [61]. Javadi et al. [28] found that using artificial surface recharge that is based on a mixture of saline water near shoreline and recharge of aquifer using surface ponds has good results to control seawater intrusion. Decreasing the groundwater pumping by 50% would mostly sustain the freshwater resources when seawater level rises by 0.5 m [45].

6 Economic Impacts of Climate Change

Egypt is classified as the fifth in the world in relation to the impact of climate change on the total urban areas, GDP, and natural resources such as water resources, coastal zone, water quality, agricultural land, livestock, and fisheries. Also, Egypt may face environmental crises such as saltwater intrusion, shoreline erosion, and soil salinity issues [41]. The coastal areas of Egypt suffer from a number of serious problems, including rapid population growth, extreme erosion rates, land subsidence, water logging, salinization of the soil, lack of management systems, and land contamination and degradation are the main serious problems in coastal areas [62]. A sea level rise of 0.5 m could result in a loss of 8% of the urban area, 13% of the industrial area, 1.6% of the beach area, and other physical and socioeconomic losses in Port Said governorate, costing more than US $2.2 billion [62, 63]. A sea level increase of 1 m could reduce the Egyptian GDP by 6.44% due to the loss of 28,000 km^2 of agricultural land (>13% from all nation), 24,000 km^2 of wetland (>6% of total Egypt area), and 25,000 km^2 of urban area (>5% from total) [46]. A sea level increase of 0.25 m would devastate Alexandria which has 40% of Egyptian industry and drives Egypt's economy. When sea level increases by 0.25 m, 60% and 56.1% of Alexandria's population and Alexandria's industrial sector, respectively, would be below sea level. However, a sea level increase of 0.5 m would be more disastrous, placing 67% of the population, 65.9% of the industrial sector, and 75.9% of the service sector below sea level [25]. Alexandria is one of the most vulnerable cities in the world to the adverse impacts of climate change, such as rising sea level or losing parts of the Nile Delta, reflected in all social and economic damage [64, 65]. By 2030, floods and sea level rise of the Mediterranean may cause displacement of about 6 million citizens in the northern Nile Delta by the expected loss of the agricultural lands, which would lead millions of persons to migrate to new places. Rising sea level by 0.30 m, about 70.4 thousand jobs of the agricultural sector in North Delta would be lost. The Nile Delta is already subsiding about 3–5 mm/year, and rising of 1.0 m would flood about 25% of the Nile Delta, compelling about 10.5% of Egypt's population to leave their homes [20, 66]. The total agricultural output and food security in Egypt will be impacted due to climate change via loss of agricultural land, declining productivity of the agriculture workers, decreased yield of most crops, and labor shortages as a result of displacement [14].

The estimated impact of climate change on Egypt's GDP exceeds 6% for 1 m rise and 16% for 5 m [7]. "In turn, this will affect the management and access to archaeological sites, reduce tourism, and result in socio-economic impacts on the people who live in these parts" [60]. Climate change could cause a decline in fish catches in the Northern lakes and lagoons in Egypt, which would lead to fishermen seeking new occupations and the consequent decline in Egyptian GDP [60]. Egypt is spending US $300 million to construct concrete sea walls to defend beaches from seas level rising [41]. Seawater level rise by 0.5 m would cost more than $2 billion and eliminate over 33% of the jobs located in Rosetta as another city in the delta [25]. By 2060, the estimated decrease in agricultural production could reach 8–47% and also, the reduction in agriculture related jobs could reach up to 39%. The projected losses in agriculture could range from 40 to 234 billion Egyptian pounds (EGP) in 2060. The economic impact of sea level rising in the Nile River Delta could be 7–16 billion EGP. Increased heat stress and concentration of particular matter could result in about 2,000–5,000 more deaths/year, with an equal loss of 20–48 billion EGP/year. Climate change could cause loss of about 2–6% of future GDP. This loss may be due to their impacts on agriculture, water resources, coastal resources, and tourism. Moreover, thousands of people could die from heat stress and air pollution. Also, millions of people could lose their jobs in agriculture [20].

7 Effect of the Agricultural Sector on Climate Change

The atmospheric emissions of carbon (C) increased globally since 1970s. Some increase were due to soil cultivation and changing land use practices. Changing land use practices include burning biomass, deforestation, drainage of wetlands, conversion from natural to agricultural ecosystems, and soil organic content (SOC) depletion under cultivation. The depletion of soil C is accentuated by soil degradation and by soil mismanagement and land misuse [67]. Agriculture contributed in increasing greenhouse gas emissions through the draining of wetlands, ploughing of rangelands, and clearing of forests which had a significant role in increasing the atmospheric CO_2, as organic carbon was decomposed. Nitrous oxide (N_2O) is created as a by-product from the application of nitrogen fertilizer in waterlogged soils. In high latitudes, spring emissions of N_2O exist with rapid snowmelt and also low-lying areas which have heavy rains cause N_2O emissions. Methane (CH_4) is emitted in the digestive system of cattle and from the microbial breakdown of plant material [4]. Additional anthropogenic disturbances such as overgrazing in rangelands, deforestation, non-sustainable irrigation practices, and extractive farming practices, which produce depletion of stored soil carbon and reduced fertility, may be expediting desertification in North Africa [68].

Agriculture can both mitigate and worsen global warming. Lowering of the soil water content leads to a decrease of methane emissions or even to a small uptake of methane (CH_4) from the atmosphere [69]. Rice fields are sources of the greenhouse gases methane (CH_4) and nitrous oxide (N_2O). CH_4 and N_2O budgets of rice fields were affected by structure and dynamics of anaerobic/aerobic conditions in the soil. CH_4 emissions increase under continuous flooding while N_2O is primarily emitted in pulses after fertilization and strong rainfalls [70]. Moreover, drainage may result in the release of high amounts of organically fixed N and N_2O (nitrous oxide) may emerge as a result of the nitrification and denitrification processes [71]. "Some of the increase in CO_2 in the atmosphere comes from the decomposition of organic matter in the soil, and much of the methane emitted into the atmosphere is caused by the decomposition of organic matter in wet soils such as rice" paddies [22]. Net CO_2 emissions at the cropland and grassland sites were similarly high, taking into account changes in management and the change from corn for silage to corncob mix led transiently to rather small greenhouse gas emissions [72].

8 Adaption Strategies of Climate Change

Egypt is one of the most highly vulnerable countries in the world to climate change impacts, especially in coastal areas; thus, adaptation strategies are imperative. However, the slow economic growth and the high population growth, etc. are reducing Egypt's adaptive capacity. Adaptation is important for reducing the impacts of climate change on food production [73]. In Egypt, climate change adaptation is a main issue from the perspectives of food production, water resources development, and stabilization of the rural population [41]. Egypt, without enough adaptation measures, will likely suffer from negative impacts on several main crops which are important for large food security. Adaptation strategies for Egypt face many limitations and barriers such as information and policy perceptions, the weak adaptive capacity of the rural societies, limited existing scientific data, lack of financial support, and deficient institutional frameworks [34]. The vital sectors for climate change adaptation in Egypt include agriculture, water resources, health, tourism, and coastal resources. Egypt should develop a national plan for adaptation [20].

Eitzinger et al. [74] suggested some adaptation actions to face the rise of sea level which include intensification of planting salinity tolerant crops and shifting cropping activates to aquaculture gradual and establishing a field drainage system supported with a suction pumping unit to control water table level. The adaptation techniques for impacts of climate change on coastal areas in Egypt include: tightening legal regulations, construction of groins and breakwaters, integrated management of the coastal zone, and changing land use [41]. Climate change adaptation strategies in the Nile Delta region include changing cropping patterns, growing salinity tolerant crops in areas close to Mediterranean Sea, preparing plans for integrated management of coastal areas considering natural coastal protection (sand dunes, the coastal highway, and other structures such as seawalls), and developing policies for coastal protection. Such policies should identify a distance from the coast where the danger is predictable [75]. The expansion of planting rice in saline areas and cultivating salt tolerant crops are suitable in Egypt to face groundwater salinization [76].

Increasing nitrogen fertilizers, increasing the amount of applied irrigation water, and delaying sowing dates could be used as adaptation strategies to climate change for crops [10, 24, 27, 77]. The highest benefits will likely result from more expensive methods including the improvement of new crop varieties and the expansion of irrigation [21]. Crop phenology changes and their relationship with the environmental changes were a basis for expressing reliable adaptation policies [15]. Improvement of wheat yield and saving irrigation water could be attained using the proposed adaptation strategies in the year 2038 [78].

9 Future Vision

A study of the dynamic interactions of land and water regionally and globally is necessary to offer more reasonable predictions of both irrigation water efficiency and cost as a function of water scarcity; these studies should include challenges faced by other sectors [79]. There is a need for a parallel implementation of adaptation strategies and mitigation actions in order to diminish the negative effects of climate change on human activities and ecosystems. Society must learn to respond to climate change pressures over the approaching decades [80].

Collecting regular information about the ecosystem (phonological observations, inventories of land use per species, production statistics, etc.), and their development over the precedent few decades on a large scale is needed to understand the effects of climate change on cultivation and forestry and also to improve our understanding of certain mechanisms. Analyzing the comprehensive series of climatic data on national territories over a period extending from the end of the nineteenth century to the present day is an important thing. It is necessary to complement these data by phonological series coming either from observations of the natural vegetation or forest species, or from the cultured species, especially the perennial species (fruit trees, vines, etc.) [4]. There must be a quick adaptation of cultivation to meet the challenge of maintaining food security. Although there is a countless number of strategies for doing so, one of these strategies is taking the benefit of the extra CO_2 put into the Earth's atmosphere [81].

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