ASSESSING THE IMPACT OF CLIMATE ON CROP WATER NEEDS IN EGYPT: THE CROPWAT ANALYSIS OF THREE DISTRICTS IN EGYPT.

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PREFACE

The reports in this special series are the result of a multi-country research activities conducted under the GEF funded project: *Climate Change Impacts on and Adaptation of Agro-ecological Systems in Africa*. The main goal of the project was to develop multipliable analytical methods and procedures to assess quantitatively how climate affects current agricultural systems in Africa, predict how these systems may be affected in the future by climate change under various global warming scenarios, and suggest what role adaptation could play. The project has been implemented in 11 countries: Burkina Faso, Cameroon, Ghana, Niger and Senegal in west Africa; Egypt in north Africa; Ethiopia and Kenya in east Africa and South Africa, Zambia, and Zimbabwe in southern Africa. The study countries covered all key agro-climatic zones and farming systems in Africa. This is the first analysis of climate impacts and adaptation in the Africa continent of such scale and the first in the world to combine cross-country, spatially referenced survey and climatic data for conducting this type of analysis.

The analyses reported in this series focus mainly on quantitative assessment of the economic impacts of climate change on agriculture and the farming communities in Africa, based on both the cross-sectional (Ricardian) method and crop response simulation modeling. The cross sectional analysis also allowed for assessing the possible role of adaptation. Moreover, the project employed river-basin hydrology modeling to generate additional climate attributes for the impact assessment and climate scenario analyses such as surface runoff and streamflow for all districts in the study countries.

The Centre for Environmental Economics and policy in Africa (CEEPA) of the University of Pretoria coordinated all project activities in close collaboration with many agencies in the involved countries, the Agriculture and Rural Development (ARD) Department of the World Bank, the World Bank Institute (WBI), the Food and Agriculture Organization (FAO), Yale University, the University of Colorado, and the International Water Management Institute (IWMI). The project received supplemental funding from TFESSD, Finnish TF, NOAA-OPG, and CEEPA. We are grateful for the invaluable contributions of all these institutions and all individuals involved in this project. All opinions presented in this report series and any errors in it are those of the authors and do not represent the opinion of any of the above listed agencies.

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EXECUTIVE SUMMARY

The future of agriculture in Egypt is hard to project even assuming the continuation of current climate conditions. The task is made all the more difficult by the possibility of significant warming expected to result from the greenhouse effect. Egypt appears to be particularly vulnerable to climate change because of its dependence on the Nile as its primary water source, its large traditional agricultural base, and its long coastline, which is already undergoing both intensifying development and erosion.

In this study the potential impact of climate change on crop seasonal evapotranspiration (ET) was evaluated using the CROPWAT model. Wheat, maize and cotton were selected for the study since they represent different growing seasons and water needs. The evaluation was carried out in the three main agricultural regions of Egypt: the Delta (Lower Egypt), represented by the Kafr El-Sheikh Governorate; Middle Egypt, represented by the Giza Governorate; and Upper Egypt represented by the Sohag Governorate. According to the study, the effect of climate warming on the water use of wheat, maize and cotton increased in the three selected locations. Wheat evapotranspiration increased by about 10.8%, 11.4% and 10.3% for Kafr El-Sheikh, Giza and Sohag, respectively, compared with wheat evapotranspiration under current conditions; maize evapotranspiration by 7.8%, 7.8% and 8.0% for these three regions respectively; and cotton evapotranspiration by 8.4% and 7.6% for Kafr El-Sheikh and Sohag respectively. At the same time, increasing temperature under climate change simulations caused some yield reduction, particularly at the third growth stage with the summer crops (maize and cotton).

Climate change could therefore increase crop water use and reduce yields. A number of adaptation policies are suggested in this study. The policies suggest specific measures for water resources and agriculture that could reduce the potential adverse effects of climate change on crop ET and yield.

1. Introduction

Egypt occupies the northeastern corner of Africa. It is bounded in the east by the Red Sea, in the west by Libya, in the north by the Mediterranean Sea, and in the south by Sudan. The total area is about 1,000,000 square kilometers. The country's total area is relatively large, spanning from 32.5^{o} N to 22.0^{o} N of latitude and temperatures increase from north to south.

The inhabited area in Egypt does not exceed 3.5% of the total area and is confined to the narrow strip which borders the main course of the River Nile from Aswan in the south to Cairo in the north, plus the Nile Delta which covers the area from Cairo to the shore line of the Mediterranean Sea between the cities of Damietta in the east and Rosetta in the west.

In 1990, the country reached the so-called poverty line with respect to the per capita share of water of almost 1000 cubic meters per year. This is expected to fall to less than 500 before the year 2030 when the population reaches 100 million. With this state of affairs, the only available solution for the crisis is to add new water resources and to improve water saving management and techniques.

This study aims to 1) assess the impact of climate change on crop water needs in Egypt and 2) analyze and evaluate strategies for adapting to climate change so as to mitigate its negative effects on agriculture in Egypt.

2. Potential impact of climate change on Africa

The increase in greenhouse gas concentrations in the atmosphere has led many scientists to predict that the earth's temperature will increase by several degrees over the next century (IPCC 1992; NAS 1992; Wigley & Raper 1992; Mitchell et al. 1995), with some saying that the effect of the increase in anthropogenic greenhouse gas on global climate is already evident (Thomson 1995). To stabilize concentration of greenhouse gases at current levels and thus reduce the risk of future warming, draconian cuts of 60% to 80% in anthropogenic emission of carbon dioxide would be required (IPCC 1990a). Given that the Framework Convention on Climate Change seeks only to stabilize emission from developed countries (UNEP & WMO 1992), it appears likely that atmospheric levels of greenhouse gases will continue to rise. If they do, warming of the climate is highly likely. If climate change is inevitable, then it is probably also inevitable that the sea level will rise, agricultural production will change, runoff and water supply will change, and the location of forests and other terrestrial vegetation will shift poleward and to higher altitudes (IPCC 1990b; Smith et al. 1995).

Africa may be particularly vulnerable to climate change since African countries tend to have a much higher share of their economy in climate-sensitive sectors, most of them having at least a third to half of their GNP in agriculture (World Bank 1992). Major cities such as Lagos, Nigeria, with a population of eight million people and Alexandria, Egypt, with a population of three million, are vulnerable to sea-level rise (El-Raey et al. 1995; French et al. 1995). Rivers such as the Nile and Zambezi are critical sources of water for irrigation and hydropower and their flows are quite sensitive to climate variability (and hence change) (Gleick 1993).

Climate change effects are likely to be worse for developing African countries whose agriculture and agro-ecological systems are especially prominent in their economies and at the same time less capital- and technology-intensive than those of the industrialized countries. Predictions of effects across regions consequently suggest that these countries will need to make major changes in their agricultural systems.

3. Regions, climate and soils in Egypt

3.1 Regions

The agricultural land in Egypt is determined by climate and water availability. The country is divided into three main agro-ecological zones: Delta (Lower Egypt), Middle Egypt and Upper Egypt. These are further subdivided into nine zones. From north to south these are: 1. Coastal zone, 2. Central Delta zone, 3. East and West zone, 4. Giza zone, 5. Menia zone, 6. Asuitt and Sohag zone, 7. North Qena zone, 8. South Qena zone and 9. Aswan zone.

This study was carried out in the three main agricultural regions of Egypt: the Delta (Lower Egypt), represented by the Kafr El-Sheikh Governorate in the north of the Delta; Middle Egypt, represented by the Giza Governorate, near Cairo; and Upper Egypt, represented by the Sohag Governorate. These were selected to represent the main agro-ecological zones and the old lands in Egypt (Nile Valley and Delta). (See Figure 1.)

The Kafr El-Sheikh governorate is represented by the site Sakha (31.07°N, 30.57°E, elevation 20m). The Giza governorate is represented by the site Giza (30.03°N, 31.13°E, elevation 19m). The Sohag governorate is represented by the site Shandaweel (26.26°N, 31.38°E, elevation 60m).

3.2 Climate

Egypt is virtually rainless. Abdel Wahed (1983) describes the climate of the northern Delta as typically Mediterranean, with dry mild summers and fair, cool and wet winters. Because of the proximity to the Mediterranean and northern lakes and the prevailing north-easterly wind, the summer heat, so typical of the rest of Egypt, is tempered and the summer in this area is most agreeable. In the rest of the Delta, the climate almost resembles that of the great desert area of north-eastern Africa, the rainfall being extremely low and occurring mostly as occasional thunderstorms. In Cairo, ten or twelve rainy days a year is probably the average, and further south the amount decreases rapidly. The influence of the sea may extend southwards as far as the apex of the Delta, but the air is warmer in summer after its passage over the heated Delta, and colder when the south wind blows in winter. The average maximum temperature of the Delta is 34^{o}C (in July or August), while the minimum is 6.4^{o}C (in December or January), and the mean annual temperature is round 20^{o}C which would place all the Nile Delta soils under the thermic temperature regime. Evapotranspiration is relatively high especially during summer: about 8mm per day in June and about 2mm per day in December. The annual mean evaporation is about 5mm per day or about 1.825m per year. The relative humidity is rather low in summer and high during winter months, about 65% in May and 82% in January. Hagag (1994) notes that the moisture regimes are generally xeric and aquic where the ground water is high and reaches the soil surface, and in some regions the soil moisture regime is torric with thermic soil temperature regimes.

Cairo's rainfall is about 24 mm per year and falls mostly in winter, from November to March. From Cairo to Aswan the rainfall decreases, as the main annual rainfall varies from 1mm to 7 mm, so that this zone is virtually rainless. Summer are very hot (but cool at night) and winter is mild and windy. The mean maximum and minimum summer temperatures are 36.6^oC for Cairo and 19.6^oC for Aswan, and 23^oC and 7.5^oC, respectively, for winter. The mean annual temperature in Upper Egypt is more than 22^oC, which would place the soils in this region under the hyperthermic temperature regime. Humidity is low (ranging from 39% to 70%), evaporation exceeds 2m annually and dust storms are frequent. The average annual rainfall is 90 mm.

The following are the details for the regions in this study.

Sakha region

The total average annual precipitation here is about 62mm. The maximum temperature is about 33.3^oC (in July), the minimum is about 6.6^oC (in January), and the mean annual temperature is 20.2^oC. Evapotranspiration is relatively high during the summer. The maximum evapotranspiration is 6.09mm per day in June and the minimum 1.56 mm per day in December. The relative humidity is rather low during summer and high during winter: on average 59% in May and 82% in January. Wind speeds range from 1.0m/sec in October to 1.7m/sec in March (Table 2).

Giza region

The total average annual precipitation here is 17 mm. The maximum temperature is about 34.7^oC (in June), the minimum is about 6.8^oC (in January), and the mean annual temperature is 21.3^oC. The maximum evapotranspiration is 7.65mm per day in June and the minimum 2.06mm per day in December. The maximum relative humidity is 74% in November and the minimum 53% in May. Wind speeds range from 1.8m/sec in December to 2.9m/sec in June (Table 3).

Shandaweel region

There is no precipitation in this region. The maximum temperature is about 38.5^oC (in June), the minimum is about 6.3^oC (in January), and the mean annual temperature is 23.5^oC. The maximum evapotranspiration is 8.26mm per day in May and the minimum 2.43mm per day in January. The maximum relative humidity is 65% in January and the minimum 29% in May. Wind speeds range from 1.3 m/sec in January to 2.3m/sec in September (Table 4).

The differences between mean monthly precipitation, maximum temperature, minimum temperature, relative humidity, wind speed, sunshine and reference evapotranspiration in these three regions are shown in Figures 2 to 8.

3.3 Soils

The soil of the Nile Valley and Delta originates from Holocene alluvial deposits, which consisted mainly of dark greyish brown sediments suspended in the Nile, the dark color being attributed mainly to the presence of micacous minerals (biotite) and hydrated magnetite. These deposits accumulated to a considerable thickness because for thousands of years the Nile annually overflowed its banks and deposited its loads. The thickness of the deposits varies according to localities because the river from time to time changed its path, with the result that materials which had been deposited were subsequently scoured away and replaced by fine sand from the river itself (Ball 1952).

4 Agriculture in Egypt

4.1 Water use by agriculture

In Egypt, water is a scarce natural resource, of which the agricultural sector uses about 85%. The country's main source of water is the Nile. Its share of the Nile water is 55.5 milliard m^3 per year. Egypt receives low rainfall that averages about 1.0 milliard m^3/ year (about 100–200 mm/ year in the northern coastal area in which few winter crops can be grown). The irrigation system in Egypt is a closed one, starting with one single inlet of irrigation water at the Aswan high dam and ending in the north with the Mediterranean Sea and the coastal lakes, which are indirectly connected with the sea.

With population increasing, serious water shortages are developing and dependence on this limited resource has become a critical constraint on further agricultural progress, which threatens to slow down development, endanger food supplies and aggravate rural poverty (Abu Zeid 1999). The cultivated and cropped areas in Egypt have been increasing over the past few years and will continue increasing because of the government policy of adding more agricultural lands. According to the FAO (2002), the great challenge for the coming decades will therefore be the task of increasing food production with less water, especially in arid and semi-arid regions.

4.2 Cropping intensity

The cropping intensity figures in Table 1 show the relationship between the cultivated area and the cropped area from the 1980s to the beginning of the 1990s, demonstrating a general increase in intensity.

The major crops in Egypt include wheat (used as a staple food crop), maize (used primarily as coarse grain for animal feed), clover, cotton, rice (grown only in the Delta and the Fayoum Governorate in Middle Egypt), sugar cane (grown in Upper and Middle Egypt), fava beans, sorghum and soybeans. The national wheat and maize production do not meet the current demand for these crops, and each year additional amounts have to be imported – up to 50% of total consumption in the case of wheat. The rapid growth in the country's population, the economic stress of relying on food imports, and the limited area for agriculture (most of the country is a desert) require Egyptians to find new ways to increase agriculture productivity.

The agricultural land base of Egypt totals about 7.5 million acres, 3.151 million hectares of the total area. In addition to about 229,000 hectares which are rainfed, of the 3.151 million hectares 75% is old agricultural land and 25% is new agricultural land. The agricultural sector is comprised of various production systems, which are interrelated and complementary. These are described below.

Crop production system

The crops produced in Egypt are field crops, vegetables, fruit and forest trees, and medical, aromatic and ornamental plants. The annual total cropped area is estimated at 14.0 million acres (1996), giving a cropping intensity of about 180% (or 1.8). Crop production contributes about 68% of the total value of agricultural GDP. The value of field crops, however, is estimated at about 66% of the total crop production value. The value of vegetables is estimated at 17% and fruits at 15% of the total crop production value.

Livestock production system

There are three livestock production systems: traditional extensive, semi-extensive and extensive. The traditional extensive, practiced for sheep, goats, cattle, buffalo and poultry, is characterized by low production inputs and outputs. The extensive production subsystem, exotic poultry and cattle, has high inputs and outputs. About 60% of white meat comes from intensive production. The semi-extensive subsystem, practiced for lamb and calf fatting and producing locally improved chickens, depends on improved local breeds and husbandry techniques. The livestock holding in Egypt is almost 2.4 animals per hectare.

Integrated production system

Livestock integrated with crops is a production system where feed crops and agricultural residues provide the feed for animals and in turn manure from the livestock is added to the soil to improve its fertility.

4.3 Major causes of concern in Egyptian agriculture:

Any attempt to assess the future of Egyptian agriculture must consider the complex interaction between the factors that determine the use of the land, the choice of cropping systems and the socio-economic characteristics and limitations. These factors are as follows.

Population and urban growth

The population is now increasing at the rate of 2.3% per annum and threatening the sustainability of the Egyptian agricultural system.

Loss of agricultural land and deterioration of crop yields

With no changes of current trends in crop patterns and water use, agriculture will increasingly lose available land to waterlogging and salinization, as well as to urbanization. Field water application efficiency values (the fraction of the water applied that is actually used, or transpired, by the crop) in Egypt are typically around 50%. Such low values imply that about half of the water applied in the field is lost because the efficiency of the flooding irrigation method is low compared with that of the new irrigation systems. Drainage problems – impeded aeration, leached nutrients, a rise in the water table and salinization – also cause crop yields to fall below their potential. This necessitates expensive improvements in drainage, because a deterioration in the quality of irrigation water decreases in agricultural productivity.

Climate change

The future of agriculture in Egypt is hard to project even assuming that current climate conditions continue (i.e. fluctuations but not long-term change). The task is made all the more difficult by the possibility of a significant warming expected to result from the enhanced greenhouse effect (IPCC 1990b, 1994). The expected impact of climate change on the supply of water (i.e. on the flow of the Nile) is very uncertain (Strzepek et al. 1995). Egypt appears to be particularly vulnerable to climate change, because of its dependence on the Nile River as the primary water source, its large traditional agricultural base, and its long coastline, which is already undergoing both intensifying development and erosion (Rosenzweig & Hillel 1994; Rosenzweig 1995).

5. Using CROPWAT

Prediction methods for crop water requirements are used owing to the difficulty of obtaining accurate field measurements. The methods often need to be applied under climatic and agronomic conditions which are very different from those under which they were originally developed. Testing the accuracy of the methods under a new set of conditions is laborious, time-consuming and costly, and yet crop water requirement data are frequently needed at short notice for project planning (FAO 1977).

CROPWAT for windows is a program that uses the FAO (1992) Penman-Monteith methods for calculating reference crop evapotranspiration. These estimates are used in crop water requirements and irrigation scheduling calculations. The methods supersede the older FAO 24 procedures published in 1977 which are no longer recommended as they overestimate evapotranspiration. This model has been used to simulate yield reduction percentage as a result of the decrease in evapotranspiration. The basic calculation procedure in this empirical model is:

$$Ya / Ym) = Ky (1- ETa / ETm) \qquad (1)$$

where: Ya = actual harvested yield

Ym = maximum harvested yield

Ky = yield response factor

ETa = actual evapotranspiration

ETm = maximum evapotranspiration

The relationship between crop yield and water supply can be determined when crop water requirements and crop water deficits on the one hand and maximum and actual crop yield on the other can be quantified. Water deficits in crops, and the resulting water stress on the plant, have an effect on crop evapotranspiration and crop yield. Water stress in the plant can be quantified by the rate of actual evapotranspiration (ETa) in relation to the rate of maximum evapotranspiration (ETm). When crop water requirements are fully met from available water supply then ETa = ETm; when water supply is insufficient, ETa < ETm. To evaluate the effect of plant water stress on yield decrease through the quantification of relative evapotranspiration (ETa/ETm), an analysis of research results shows that it is possible to determine relative yield losses if information is available on actual yield (Ya) in relation to maximum yield (Ym) under different water supply regimes. Where economic conditions do not restrict production, and in a constraint-free environment, Ya = Ym when full water requirements are met; when full water requirements are not met available water supply, Ya < Ym (FAO 1979).

The effects of soil water stress on crop ET are described by reducing the value for the crop coefficient. This is accomplished by multiplying the crop coefficient by the water stress coefficient (KS).

$$ETcropactual = Ks * ETcrop \qquad (2)$$

$$ETcrop = Kc * ETo \qquad (3)$$

$$Ks = 1 – 1 / Ky [1 – Ya / Ym] \qquad (4)$$

5.1 CROPWAT data requirements

Climate data

The normal data for each governorate (average of 30 years) were used in calculating ETo and ETcrop (Tables 2–4).

Crop information

Crop information, including area and pattern %, for the various main crops in Egypt at the three selected governorates are shown in Table 5. Crop coefficient, growth stages, sowing and harvesting data, season length and irrigation duration days for the selected crops are listed in Table 6.

Land coverage of the major crops grown in the three governorates

In Kafr El-Sheikh the main winter crops are wheat and sugar beet, which occupy about 33% and 18% respectively of the total area in winter. Of the summer crops, maize occupies the largest area (about 11%). Cotton occupied about 93% of the total area of perennial crops in 2001.

In Giza wheat and tomatoes occupy the largest area of winter crops, about 21% and 9% respectively. In summer, maize and tomatoes occupy about 47% and 9% respectively. Citrus, mango, grapes and date are the main perennial crops in Giza, at about 20%, 14%, 13% and 11% respectively.

In Sohag in winter about 66% is occupied by wheat. In summer, sorghum and maize occupy about 46% and 45% respectively. Sugar cane and cotton are the main perennial crops, occupying about 56% and 24% respectively.

Soil information

The medium soil type was selected and used to estimate the soil moisture content of the major type of soil in Egypt (Table 7). One scheduling criteria scenario for the timing of irrigation was used for the study (irrigation at fixed intervals, in days).

6. Assessment of the impact of climate change on water needs in Egypt using CROPWAT

Climate change scenarios for each site were created by combining the output of three equilibrium 2xCO_2 General Circulation Models (CCCM, GFD3, GF01) with the daily climate data for each site. IPCC technical guidelines endorse this approach (IPCC 1994). The three equilibrium general circulation models used in this study to create the climate change scenarios are at the high end of the IPCC range (1.5^{o}C to 3.5^{o}C).

Outputs of three General Circulation Models (GCMs) were used to evaluate the impact of climate change on the main Egyptian crops. The modified climate data were incorporated into the CROPWAT model and used to evaluate the potential impact of climate change on water needs in Egypt. Wheat, maize and cotton were selected for the study since they represent different growing seasons and water needs.

6.1 Empirical findings on crop evapotranspiration under current and climate change conditions

Wheat

Under current climate conditions, the reference evapotranspiration (ETo) is 426mm, 547mm and 632mm for the Sakha, Giza and Shandaweel regions respectively (Table 8). Shandaweel's ETo is 48% more than Sakha's and 16% more than Giza's. The average crop coefficient (Kc) for the wheat crop is 0.65 and the crop water requirements (ETm) are 351mm, 453mm and 519mm for the three regions respectively. The ETc equals the ETm because the water supply is sufficient. Data of actual yield and maximum yield were obtained from Agricultural Economic Research Institute Bulletins-AERIB (Volumes No.1990 to 2000) and used in Equation 4 to obtain the water stress coefficient (Ks). This allows for the generation of the actual crop evapotranspirations of 288mm, 365mm and 426mm for Sakha, Giza and Shandaweel, respectively.

Under climate change conditions, three GCMs (CCCM, GFD3 and GF01) were used to evaluate the effect of climate change on the wheat crop. The findings as recorded in Table 8 indicate that the smallest decrease in ET was found under the GFD3 scenario. In general, the three GCMs were found to have approximately the same efficiency in predicting wheat ET.

Increasing temperature would increase the wheat ET by 10.8%, 11.4% and 10.3% for Sakha, Giza and Shandaweel respectively, in comparison with current climate conditions. Few yield reductions were obtained under increasing temperature at Shandaweel region only.

Maize

The reference evapotranspiration (ETo) under current climate conditions is 746mm, 900mm and 1009mm for the Sakha, Giza and Shandaweel regions, respectively (Table 9). Shandaweel's ETo is 35% higher than Sakha's and 12% higher than Giza's. The average crop coefficient (Kc) for the maize crop for the various growth stages is 0.75 and the crop water requirement (ETm) is 611mm, 730mm and 817mm for the three regions respectively. The ETc is less than the ETm because the water supply is insufficient as a result of the long period between irrigations (long interval days). The actual crop evapotranspiration (ETa) at Sakha, Giza and Shandaweel is 521mm, 620mm and 731 mm respectively. The total yield reduction for the three regions under current climate conditions is 1.9%, 2.1% and 0.7% respectively as a result of increasing the intervals between irrigations.

Increasing the temperature increases the maize ET by 7.9%, 7.8% and 8% for Sakha, Giza and Shandaweel respectively compared with maize ET under current climate conditions. Increasing temperature reduces the yields further, particularly at the third growth stage of growth. Generally, the effect of climate change on the maize crop is to further increase ET and further decrease yields.

Cotton

Cotton is not grown in the Giza region. The reference evapotranspiration (ETo) under current climate conditions is 1009mm and 1383 mm for Sakha and Shandaweel, respectively (Table 10). The average crop coefficient (Kc) for the cotton crop for the various growth stages is 0.70. The crop water requirements (ETm) for the cotton crop at Sakha and Shandaweel regions are 931mm and 1260 mm respectively. The ETc is less than the ETm because the water supply is insufficient as a result of long intervals between irrigations. The actual crop evapotranspiration (ETa) is 532mm for Sakha and 1040mm for Shandaweel. Few reductions in yield were obtained under current conditions as a result of increasing the intervals between irrigations which caused closure of the stomata and reduction in the uptake of carbon dioxide, photosynthesis and biomass production.

Climate change could increase the crop evapotranspiration by about 8.4% for Sakha and 7.6% for Shandaweel as compared with the cotton ET under current climate conditions. Increasing the temperature leads to further reductions in yields in the two regions, particularly at the third growth stage Generally, the effect on the cotton crop is to increase the ET and reduce the yields.

The potential impact of climate change on ET and the yields of some field crops in Egypt has been studied through the DSSAT3 (Tsuji et al. 1995) and COTTAM (Jackson et al. 1988) models (Eid et al. 1992a,b; Eid et al. 1993; Eid & El-Sergany 1993; Eid 1994; Eid et al. 1994a,b; Eid et al. 1995a,b; Eid et al. 1996 and Eid et al. 1997a,b,c,d, El-Shaer et al. 1996). These simulation studies suggest that climate change could decrease national production of many crops (ranging from -11% for rice to -28% for soybean) by the year 2050 compared with their production under current conditions. Yield of cotton would be increased in comparison with current climate conditions. At the same time, water needs for summer crops will be increased up to 8% for maize and up to 16% for rice by the year 2050 compared to their current water needs.

7. Adaptation to climate change in Egyptian agriculture

Adaptation of wheat, maize and cotton productivity (Eid et al. 1996, 1997e) to climate change in Egypt was studied through DSSAT3 and COTTAM models and through the TEAM (Tool for Environmental Assessment and Management decision model) (Susan 1996). Future strategies for adapting to climate change may involve the development of new, more heat-tolerant cultivars, and new crops (more cotton cultivation as an alternative to some maize and more winter legumes instead of some wheat). Changing the cotton crop practices (optimum sowing date, cultivars, water amount and plant density) could allow farmers to benefit from climate change, increasing cotton productivity by about 29%.

Suitable adaptations are modifying the cropping pattern (i.e. partly growing cotton after wheat in the same year and on the same land); reducing or retaining the current area under cultivation for some high water consumer crops (i.e. sugar cane and rice); and changing practices (using optimum sowing dates, more water, more nitrogen, and suitable cultivars for the particular agro-climatological region).

It can be concluded that a strategy that includes transition to more cotton appears to be well supported on the basis of economics, but some caution should be exercised. All our information indicates that under climate change growing incrementally more cotton could have the following strong economic benefits:

1. Cotton productivity may not only increase relative to other major crops, but it may increase absolutely too.

2. Cotton prices are very strong and it appears possible that they will remain strong in a hotter future climate, since cotton is one of the best textiles for use in hot environments.

3. Cotton production also provides more jobs, both in the agricultural sector and in the textiles industry that can expand with cotton growth.

In this case, Egypt may be paying very heavily for food security, given that it appears to be holding back on cotton production so that more wheat can be grown domestically. Apparently some have been arguing in favor of more cotton even today. Looking into a hotter future, the arguments for more cotton may be enhanced: wheat prices may decline on a global basis (e.g. looking at projections by Rosenzweig & Parry 1994), whereas income from cotton may be enhanced (owing to approximately 30% productivity increases projected by the COTTAM model, and possible growth in demand with climate change).

8. General policy options for adaptation to climate change

The policy options could reduce the potential risks of climate change for Africa and the rest of the world. Smith and Lenhart (1996) suggested general adaptation measures and specific measures in water resources, coastal resources (adapting to sea-level rise), forests, ecosystems and agriculture. These measures would enhance the flexibility of resources for adapting to climate change and would have net benefits greater than costs. These measures can be summarized as shown in following table.

A. General policies	**B. Water resources**	**C. Sea-level rise**	**D. Forests**	**E. Ecosystems**	**F. Agriculture**
1. Incorporate climate change in long-term planning	1. River basin planning and coordination	1. Plan urban growth	1. Forest seed banks	1. Integrated ecosystem planning and management	1. New crops and seed banks
2. Inventory existing practices	2. Contingency planning for drought	2. Decrease subsidies to develop sensitive coastal lands	2. Diverse management practices	2. Protect and enhance migration corridors or buffer zones	2. Plant a variety of heat- and drought-resistant crops
3. Tie disaster relief to hazard-reduction programs	3. Marginal changes in construction of infrastructure	3. Use set-backs for coastal development	3. Flexible criteria for intervention	3. Enhance methods to protect biodiversity off–site	3. Avoid production subsidies
4. Promote awareness	4. Use inter-basin transfers	4. Discourage permanent shoreline stabilization	4. Reduce habitat fragmentation, develop migration corridors		4. Increase irrigation efficiency
	5. Options for new dam sites	5. Incorporate marginal increases in the height of coastal infrastructure			5. Conservation management
	6. Conserve water	6. Preserve vulnerable coastal wetlands			6. Liberalize agriculture trade
	7. Use markets to allocate supplies				7. Drought management
	8. Control pollution				

REFERENCES

Abdel Wahed A, 1983. Research report on soil survey. Egyptian Major Cereals Improvement Project (EMCIP). Research Extension Centers. Publication No. 62. Consortium for International Department. Agricultural Research Center (ARC), Cairo, May 1983.

Abu-Zeid M, 1999 Egypt's water policy for the 21st century. 7th Nile 2002 Conference, March 15–19, 1999, Cairo, Egypt.

AERIB (Agricultural Economic Research Institute Bulletins). Volumes No. 1990-2000. Ministry of Agriculture, Cairo, Egypt.

Ball J, 1952. Contribution to the geology of Egypt. Ministry of Finance and Economy, Cairo, Egypt: Government Press.

Eid HM, 1994. Impact of climate change on simulated wheat and maize yields in Egypt. In Rosenzweig C & Iglesias A (eds), *Implications of climate change for international agriculture: Crop modeling study.* (EPA 230-B-94-003). US Environmental Protection Agency, Washington DC.

Eid HM & D. Z. El-Sergany 1993. Impact of climate change on simulated soybean yield and water needs. First Egyptian-Hungarian Conference on Environment, St. Catherine, Sinai, Egypt. April 5-7, 1993, P. 313 - 316.

Eid HM, Ainer NG, Yousef KMR, Ibrahim MA & Gad El-Rab GM, 1992a. Climate change crop modeling study of wheat. Fifth Egypt Botanical Conference, St Catherine, Sinai, Egypt, pp. 113–130.

Eid HM, Ainer NG, Yousef KMR, Sherif MA, Miseha WI & El-Sergany DZ, 1992b. Climate change crop modeling study on maize. Fifth Egypt Botanical Conference, St Catherine, Sinai, Egypt, pp. 93–111.

Eid HM, Bashir NM, Ainer NG & Rady MA, 1993. Climate change crop modeling study on sorghum. *Annals of Agricultural Science* Special Issue 1: 219–234.

Eid HM, Anton NA & Tarrad AM, 1994a. Comparative study on Egyptian wheat cultivars and their response to high temperatures. *Annals of Agricultural Science,* 32 (1): 143–154*, Faculty of Agriculture, Zagazig University* Moshtohor, Egypt.

Eid HM, El-Sergany DZ & McCuistion WL, 1994b. Simulated soybean yield and water requirements in relation to selected agronomic characters in Egypt. Proceedings of 6th Agronomic Conference, Al-Azhar University, Vol. 11: 471–489.

Eid HM, El-Mowelhi NM, Metwally MA, Ainer NG, Abbas FA & Abd El-Ghaffar MA, 1995a. Climate change and its expected impacts on yield and water needs of some major crops. Paper No.17, Second Agricultural Research Center Field Irrigation and Agroclimatology Conference, Cairo, Egypt, January.

Eid HM, Rayan AA, Mohamed KA, ElRefaie MMA, Attia MM, Awad HA, Yousef KMR & El-Koliey MMA, 1995b. Impact of climate change on yield and water requirements of some major crops. 2nd Conference of On- Farm Irrigation and Agroclimatology, Agricultural Research Center, January 2-4, 1995, Egypt, pp. 492–507.

Eid HM, El-Marsafawy SM, Ainer NG, Ali MA, Shahin MM, El-Mowelhi NM & El-Kholi O, 1996. Vulnerability and adaptation to climate change in Egyptian agriculture. Country Study Report (1-53), Country Studies Program (CSP), Washington DC.

Eid HM, El-Marsafawy SM, Shahin MM, Khater AN & Abdel Gelil I, 1997a. Adaptation of Egyptian cotton crop to climate change. Meteorology & Environmental Cases Conference 2–6 March.

Eid HM, El-Marsafawy SM, Ali MA, Ainer NG, Rayan AA & El-Kholi O, 1997b. Vulnerability and adaptation to climate change in wheat crop. Meteorology & Environmental Cases Conference 2–6 March.

Eid HM, El-Marsafawy SM, Salib AY & Ali MA, 1997c. Vulnerability of Egyptian cotton productivity to climate change. Meteorology & Environmental Cases Conference, Cairo, Egypt, 2–6 March.

Eid HM, El-Marsafawy SM, Ainer NG, El-Mowelhi NM & El-Kholi O, 1997d. Vulnerability and adaptation to climate change in maize crop. Meteorology & Environmental Cases Conference, Cairo, Egypt, 2–6 March.

Eid HM, S. El-Marsafawy SM, Ainer NG, Ali MA & Shahin MM, 1997e. Assessment of strategy and policy measures for adaptation to climate change in Egyptian Agriculture. Support for National Action Plan of Egypt (SNAP), February.

El-Raey M, Sasr S, Frihy O, Desouki S & Dewidar KH, 1995. Potential impacts of accelerated sea level rise on Alexandria governorate, Egypt. *Journal of Coastal Research* Special Issue 14: 190–204.

El-Shaer MH, Eid HM, Rosenzweig C, Iglesias A & Hellil D, 1996. Agricultural adaptation to climate change in Egypt. Meteorology and Integrated Development Conference, March 24–25, Egypt.

FAO (Food and Agriculture Organization), 1975. Guidelines for predicting crop water requirements. Authors, Doorenbos J & Pruitt WO, Irrigation and Drainage Paper 24. Rome, Italy.

FAO (Food and Agriculture Organization), 1979. Yield response to water. Authors, Doorenbos J & Kassam AH. Irrigation and Drainage Paper 33. Rome, Italy.

FAO (Food and Agriculture Organization), 1992. CROPWAT, a computer program for irrigation planning and management. Author, Smith M. Irrigation and Drainage Paper 46, Rome, Italy.

FAO (Food and Agriculture Organization), 2002. Deficit irrigation practices. FAO Water Reports No. 22, Rome, Italy.

French GT, Awosika LF & Ibe CE, 1995. Sea level rise and Nigeria: Potential impacts and consequences. *Journal of Coastal Research* Special Issue 14: 224–242.

Gleick P (ed.), 1993. *Water in Crisis*. New York: Oxford University Press.

Hagag, AE, 1994. Soil classification of North Coast of Delta. PhD Thesis, Faculty of Agriculture, El- Mansoura University, Egypt.

IPCC (Intergovernmental Panel on Climate Change), 1990a. *Climate Change: The IPCC Scientific Assessment*. Editors, Houghton JT, Jenkins GJ & Ephraums JJ. New York: Cambridge University Press.

IPCC (Intergovernmental Panel on Climate Change), 1990b. *Climate Change: The IPCC Impacts Assessment.* Editors, Tegart WJMcG, Sheldon GW & Griffiths DC. WMO & UNEP (World Meteorological Organization & United Nations Environment Programme), Intergovernmental Panel on Climate Change. Australian Government Publishing Service, Canberra, Australia.

IPCC (Intergovernmental Panel on Climate Change), 1992. *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment.* Editors, Houghton JT, Callander BA & Varney SK. WMO & UNEP (World Meteorological Organization & United Nations Environment Programme), Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

IPCC (Intergovernmental Panel on Climate Change), 1994. *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations.* Editors, Carter TR, Parry ML, Harasawa H & Nishioka S. WMO & UNEP (World Meteorological Organization & United Nations Environment Programme), Intergovernmental Panel on Climate Change. Centre for Global Environmental Research, University College London, UK.

Jackson BS, Arkin GF & Hearn AB, 1988. The cotton simulation model COTTAM: Fruiting model calibration and testing. *Transactions of the American Society of Agricultural Engineers* 31: 846–854.

Mitchell JFB, Johns TC, Gregory JM & Tell SFB, 1995. Climate response to increasing levels of greenhouse gases and sulphate aerosols. *Nature* 376: 501–504.

NAS (National Academy of Sciences), 1992. Policy implications of greenhouse warming., Washington DC: National Academy Press.

Rosenzweig C & Hillel D, 1994. Egyptian agriculture in the 21st century. Collaborative Paper CP-94-12. International Institute for Applied Systems Analysis, Luxembourg, Austria.

Rosenzweig C & Parry ML, 1994. Potential impact of climate change on world food supply. *Nature* 367: 133–138.

Rosenzweig CR, Parry ML & Fischer G, 1995. World food supply. In Strzepek KM & Smith JB (eds), *As Climate Changes: International Impacts and Implications*. Cambridge: Cambridge University Press.

Smith JB & Lenhart SS, 1996. Climate change adaptation policy options. *Climate Research* 6(2), 193–201.

Smith JB et al., 1995. Executive summary. In Strzepek KM & Smith JB (eds), *As Climate Changes: International Impacts and Implications*. Cambridge: Cambridge University Press.

Strzepek KM, Yates DN & El-Quosy DED, 1995. Vulnerability assessment of water resources in Egypt to climatic change in the Nile Basin. *Climate Research* 6(2): 89–95.

Susan HJ, 1996. A multi-criteria decision support tool for water resources managers. Draft paper. Tool for Environmental Assessment and Management (TEAM), Preliminary draft, US Environmental Protection Agency, Climate and Policy Assessment Division.

Thomson DJ, 1995. The seasons, global temperature, and precession. Science 268: 59-68

Tsuji GY, Jones JW, Uhera G & Balas S (eds), 1995. DSSAT3 (Decision Support System for Agrotechnology Transfer) V 3.0. Three Volumes. IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer). University of Hawaii, Honolulu, Hawaii.

UNEP & WMO (United Nations Environment Programme & World Meteorological Organization), 1992. *United Nations Framework Convention on Climate Change*. Climate Change Secretariat, Geneva.

Wigley TML & Raper SCB, 1992. Implications for climate and sea level of revised IPCC emissions scenarios. *Nature* 357: 293–324.

World Bank, 1992. *World Development Report 1992*. Oxford University Press, New York.

Table 1: Cropping intensity 1983–1997

Year	Cultivated (000 ha)	Cropping area (000 ha)	%
1983–1984	2765	4624	167
1984–1985	2753	4601	167
1985–1986	2849	4675	164
1986–1987	2856	4678	164
1987–1988	2893	4758	164
1988–1989	2908	4790	165
1989–1990	2920	4905	168
1990–1991	3178	5127	161
1991–1992	3098	5236	169
1992–1993	2967	5252	177
1993–1994	2991	5336	178
1994–1995	2989	5475	183
1995–1996	3632	5708	157
1996–1997	3151	5712	181

Note: Cropping intensity in the year 1998/1999 was about 189%.

Table 2: Average climatic data for Sakha region (Kafr El-Sheikh Governorate) 1961–1990

Latitude: 31.07, Longitude: 30.57, Elevation: 20m

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Precipitation (mm)	13.9	14.6	6.8	2.4	2.2	0.0	0.0	0.0	0.0	2.6	6.1	13.1	61.8
Temp average (°C)	12.9	13.6	15.4	19.1	22.5	25.2	26.4	26.6	24.8	22.5	18.8	14.7	20.2
Temp mean max °C	19.1	20.2	22.6	27.1	30.7	32.6	33.3	33.1	31.8	29.7	25.4	21.0	27.2
Temp mean min °C	6.6	6.9	8.3	11.1	14.2	17.9	19.5	19.2	17.7	15.3	12.2	8.4	13.1
Relative humidity %	82	82	76	68	59	65	68	75	75	75	76	81	74
Wind speed (m/sec)	1.3	1.4	1.7	1.5	1.5	1.5	1.3	1.3	1.1	1.0	1.1	1.1	1.3
Actual sunshine (hrs)	7.0	7.7	8.6	9.6	10.6	11.9	11.6	11.3	10.3	9.3	8.0	6.6	9.4
ETo (mm/day)	1.67	2.24	3.28	4.48	5.56	6.09	5.92	5.46	4.45	3.29	2.23	1.56	3.85

Table 3: Average climatic data for Giza region (Giza Governorate) 1961–1990

Latitude: 30.03, Longitude: 31.1, Elevation: 19m

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Precipitation (mm)	3.4	2.7	2.9	0.9	0.4	0.0	0.0	0.0	0.0	0.3	1.3	5.3	17.1
Temp average (^{o}C)	13.0	14.3	16.9	20.9	24.4	27.4	28.0	27.9	26.4	23.5	18.7	14.3	21.3
Temp mean max ^{o}C	19.3	20.9	23.8	28.5	32.0	34.7	34.5	34.3	32.9	30.1	25.1	20.3	28.0
Temp mean min ^{o}C	6.8	7.7	10.0	13.4	16.7	20.1	21.5	21.6	19.8	16.8	12.3	8.3	14.6
Relative humidity %	72	67	60	57	53	55	63	66	66	67	74	70	64
Wind speed (m/sec)	2.1	2.4	2.6	2.6	2.8	2.9	2.6	2.2	2.1	2.2	1.9	1.8	2.4
Actual sunshine (hrs)	7.0	7.8	8.6	9.6	10.6	11.9	11.6	11.4	10.3	9.3	8.0	6.7	9.4
ETo (mm/day)	2.21	3.03	4.22	5.58	6.85	7.65	7.01	6.36	5.38	4.24	2.69	2.06	4.77

Table 4: Average climatic data for Shandaweel region (Sohag Governorate) 1961–1990

Latitude: 26.26, Longitude: 31.38, Elevation: 60m

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Precipitation (mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Temp average (^oC)	13.7	16.5	20.5	24.1	28.0	30.4	30.0	29.6	28.3	25.3	20.1	15.3	23.5
Temp mean max. ^oC	21.2	24.5	28.9	32.5	36.3	38.5	37.5	37.1	35.9	32.7	27.3	22.8	31.3
Temp mean min. ^oC	6.3	8.5	12.0	15.7	19.8	22.4	22.4	22.0	20.6	17.8	12.8	7.7	15.7
Relative humidity %	65	64	51	37	29	34	44	46	47	47	58	63	49
Wind speed (m/sec)	1.3	1.6	1.9	1.9	2.2	2.2	1.9	1.9	2.3	1.9	1.6	1.4	1.8
Actual sunshine (hrs)	8.9	9.8	9.9	10.3	11.3	12.3	12.2	11.9	10.8	10.0	9.3	9.0	10.5
ETo (mm/day)	2.43	3.43	4.96	6.26	7.76	8.26	7.52	7.15	6.71	5.10	3.37	2.49	5.45

Note: Climate data were obtained from the Egyptian Meteorological Authority.

Table 5: Crop area and pattern % for Kafr El-Sheikh, Giza and Sohag Governorates 2000/2001

Crops	Kafr El-Sheikh		Giza		Sohag	
	Area (fed)	Pattern (%)	Area (fed)	Pattern (%)	Area (fed)	Pattern (%)
Winter crops						
Barley	3571	0.736	133	0.101	376	0.15
Beans	32452	6.691	1090	0.825	2711	1.078
Cabbage	1010	0.208	2859	2.163	635	0.253
Pepper	32	0.007	2448	1.852	57	0.023
Potato	213	0.044	3265	2.471	654	0.26
Sugar beet	87116	17.963	0	0	2	0.001
Tomato	6338	1.307	12425	9.402	13031	5.183
Wheat	157977	32.574	27928	21.133	165271	65.736
Other winter crops	196272	40.47	82008	62.054	68681	27.317
Total	**484981**		**132156**		**251418**	
Summer crops						
Cabbage	114	0.026	1017	0.692	17	0.006
Groundnut	15	0.003	5257	3.578	5059	1.924
Maize	47678	10.972	68844	46.856	116915	44.46
Pepper	611	0.141	3167	2.155	584	0.222
Potato	241	0.055	5444	3.705	0	0
Sorghum	0	0	988	0.672	120825	45.947
Soybean	96	0.022	0	0	3	0.001
Sunflower	15	0.003	900	0.613	480	0.183
Tomato	9603	2.21	13011	8.855	1081	0.411
Other summer crops	376176	86.567	48299	32.873	18004	6.846
Total	**434549**		**146927**		**262968**	
Perennials						
Banana	174	0.127	3580	6.801	1359	3.634
Citrus	152	0.111	10712	20.348	3119	8.34
Cotton	127144	92.522	0	0	9000	24.065
Date	5870	4.272	5798	11.014	932	2.492
Grapes	186	0.135	6642	12.617	662	1.77
Mango	21	0.015	7395	14.047	283	0.757
Sugarcane	315	0.229	2007	3.812	20927	55.956
Other perennial crops	3558	2.589	16509	31.36	1117	2.987
Total	**137420**		**52643**		**37399**	
Other crops	59550	5.334	97298	22.679	38125	6.463
Cropped area	1116500		429024		589910	

Table 6: Crop coefficient, growth stages, season length and irrigation schedule for crops grown at the three selected governorates

Crop	Crop coefficient (Kc)			Growth stages (day)				Sowing date	Harvesting date	Season length	Irrigation duration days		
	1	2	3	1	2	3	4			(day)	Kafr El-Sheikh	Giza	Sohag
Wheat	0.3	1.15	0.5	30	65	40	30	15 Nov	1 May	165	25	24	24
Maize	0.3	1.2	0.75	25	40	35	20	15 May	15 Sep	120	14	12	10
Cotton	0.35	1.15	0.6	30	50	60	50	15 Mar	20 Sep	190	18	18	15

Table 7: Relevant soil characteristics (soil retention capacity)

Soil description	Medium
Maximum rain infiltration rate (mm/day)	40.0
Maximum rooting depth (m)	2.0
Initial soil moisture depletion (% of total available depletion moisture)	50
Initial available soil moisture (mm/m depth)	55.0
Total available soil moisture (mm/m depth)	110.0

Table 8: Simulated wheat ET under baseline climate (current climate) and GCM climate change scenarios in Sakha, Giza and Shandaweel regions

Site		ETo mm	ETm mm	ETc mm	Ky	Ya t/ fed	Ym t/ fed	Ks	ETa mm	Yield reduction (%) Stage # 1	Stage # 2	Stage # 3	Stage # 4	Total yield reduction (%)	Change % of wheat ET due to climate change
Sakha	Current climate	426	351	351	1.0	2.3	2.8	0.82	288	0.0	0.0	0.0	0.0	0.0	…
Giza	Current climate	547	453	453	1.0	2.5	3.1	0.81	365	0.0	0.0	0.0	0.0	0.0	…
Shandaweel	Current climate	632	519	519	1.0	2.3	2.8	0.82	426	0.0	0.0	0.0	0.0	0.0	…
Sakha	CCCM	473	390	390	1.0	2.3	2.8	0.82	320	0.0	0.0	0.0	0.0	0.0	10.8
	GFD3	470	387	387	1.0	2.3	2.8	0.82	318	0.0	0.0	0.0	0.0	0.0	
	GF01	474	390	390	1.0	2.3	2.8	0.82	320	0.0	0.0	0.0	0.0	0.0	
Average		472	389	389	1.0	2.3	2.8	0.82	320	0.0	0.0	0.0	0.0	0.0	
Giza	CCCM	615	509	509	1.0	2.5	3.1	0.81	410	0.0	0.0	0.0	0.0	0.0	11.4
	GFD3	606	501	501	1.0	2.5	3.1	0.81	404	0.0	0.0	0.0	0.0	0.0	
	GF01	609	504	504	1.0	2.5	3.1	0.81	406	0.0	0.0	0.0	0.0	0.0	
Average		610	505	505	1.0	2.5	3.1	0.81	407	0.0	0.0	0.0	0.0	0.0	
Shandaweel	CCCM	716	589	584	1.0	2.3	2.8	0.82	480	0.0	0.0	0.4	0.8	0.5	10.3
	GFD3	689	567	564	1.0	2.3	2.8	0.82	463	0.0	0.0	0.3	0.5	0.4	
	GF01	697	572	569	1.0	2.3	2.8	0.82	467	0.0	0.0	0.3	0.6	0.4	
Average		701	576	572	1.0	2.3	2.8	0.82	470	0.0	0.0	0.3	0.6	0.4	

Notes: ETo (reference crop evapotranspiration), ETm (maximum crop ET), ETc (crop evapotranspiration), Ky (yield reduction factor), Ya (actual yield), Ym (maximum yield), Ks (water stress coefficient), ETactual (ETcropactual, calculated as Ks*ETc).
CCCM (Canadian Climate Change Model), GFD3 (Geophysical Fluid Dynamics Laboratory, GFDL R-30) and GF01 (GFDL 1%/yr transient).

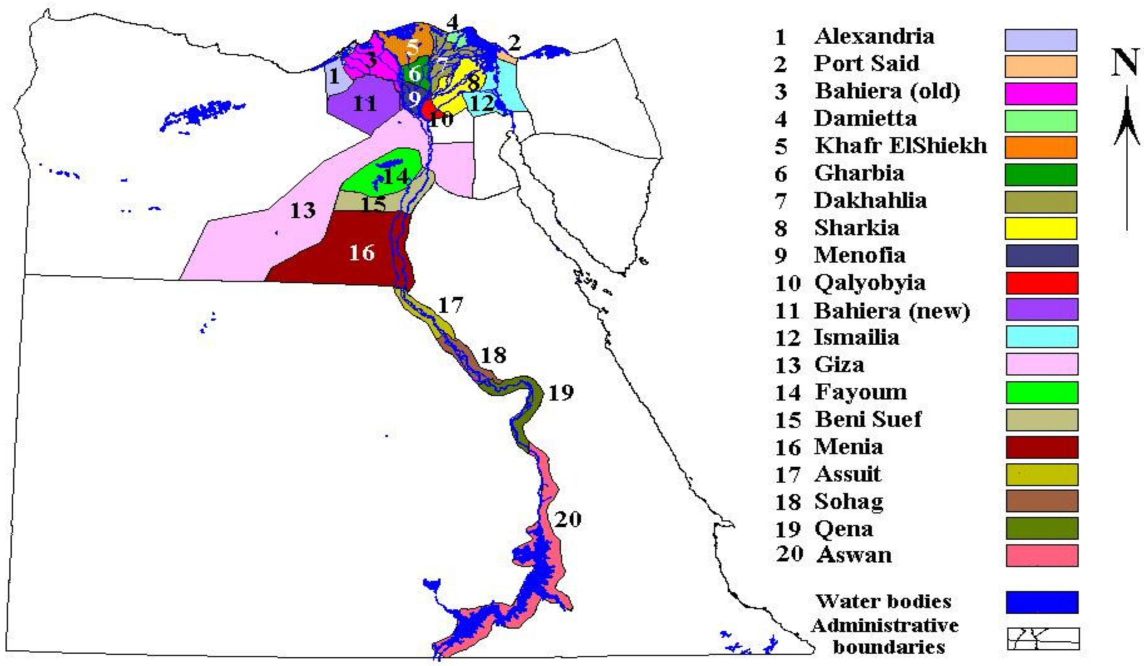
Table 9: Simulated maize ET under baseline climate (current climate) and GCM climate change scenarios in Sakha, Giza and Shadaweel regions

Site		ETo mm	ETm mm	ETc mm	Ky	Ya t/ fed	Ym t/ fed	Ks	ETa mm	Yield reduction (%) Stage # 1	Stage # 2	Stage # 3	Stage # 4	Total yield reduction (%)	Change % of maize ET due to climate change
Sakha	Current climate	746	611	601	1.25	3.0	3.6	0.87	521	0.0	0.1	4.3	0.0	1.9	…
Giza	Current climate	900	730	718	1.25	2.9	3.5	0.86	620	0.0	0.3	4.0	0.3	2.1	…
Shandaweel	Current climate	1009	817	812	1.25	2.8	3.2	0.90	731	0.0	0.0	1.7	0.0	0.7	…
Sakha	CCCM	814	669	650	1.25	3	3.6	0.87	563	0.0	0.3	7.7	0.2	3.6	7.9
	GFD3	815	669	649	1.25	3	3.6	0.87	562	0.0	0.3	7.7	0.2	3.6	
	GF01	809	664	646	1.25	3	3.6	0.87	560	0.0	0.2	7.2	0.2	3.4	
Average		813	667	648	1.25	3.0	3.6	0.87	562	0.0	0.3	7.5	0.2	3.5	
Giza	CCCM	992	807	779	1.25	2.9	3.5	0.86	672	0.0	0.7	7.5	1.2	4.4	7.8
	GFD3	986	800	774	1.25	2.9	3.5	0.86	668	0.0	0.7	7.1	1.1	4.1	
	GF01	979	794	770	1.25	2.9	3.5	0.86	664	0.0	0.6	6.6	1.1	3.8	
Average		986	800	774	1.25	2.9	3.5	0.86	668	0.0	0.7	7.1	1.1	4.1	
Shandaweel	CCCM	1108	903	887	1.25	2.8	3.2	0.90	798	0.0	0.2	4.6	0.2	2.2	8.0
	GFD3	1097	889	876	1.25	2.8	3.2	0.90	788	0.0	0.2	4.0	0.1	1.9	
	GF01	1085	879	868	1.25	2.8	3.2	0.90	781	0.0	0.1	3.6	0.1	1.6	
Average		1097	890	877	1.25	2.8	3.2	0.90	789	0.0	0.2	4.1	0.1	1.9	

Table 10: Simulated cotton ET under baseline climate (current conditions) and GCM climate change scenarios in Sakha and Shandaweel regions

Site		ETo mm	ETm mm	ETc mm	Ky	Ya t/ fed	Ym t/ fed	Ks	ETa mm	Yield reduction (%) Stage # 1	Stage # 2	Stage # 3	Stage # 4	Total yield reduction (%)	Change % of cotton ET due to climate change
Sakha	Current climate	1009	931	930	0.85	0.7	1.1	0.57	532	0.0	0.0	0.1	0.0	0.1	…
Shandaweel		1383	1260	1250	0.85	1.2	1.4	0.83	1040	0.0	0.0	0.9	0.0	0.7	…
Sakha	CCCM	1104	1017	1010	0.85	0.7	1.1	0.57	578	0.0	0.0	0.6	0.1	0.5	8.4
	GFD3	1101	1017	1010	0.85	0.7	1.1	0.57	578	0.0	0.0	0.7	0.1	0.6	
	GF01	1096	1011	1004	0.85	0.7	1.1	0.57	574	0.0	0.0	0.7	0.1	0.6	
Average		1100	1015	1008	0.85	0.7	1.1	0.57	577	0.0	0.0	0.7	0.1	0.6	
Shandaweel	CCCM	1520	1382	1358	0.85	1.2	1.4	0.83	1130	0.0	0.1	1.9	0.0	1.5	7.6
	GFD3	1500	1368	1345	0.85	1.2	1.4	0.83	1119	0.0	0.1	1.8	0.0	1.5	
	GF01	1486	1354	1331	0.85	1.2	1.4	0.83	1107	0.0	0.1	1.8	0.0	1.4	
Average		1502	1368	1345	0.85	1.2	1.4	0.83	1119	0.0	0.1	1.8	0.0	1.5	

Figure 1: Map of governorates in the agro-ecological zones in Egypt



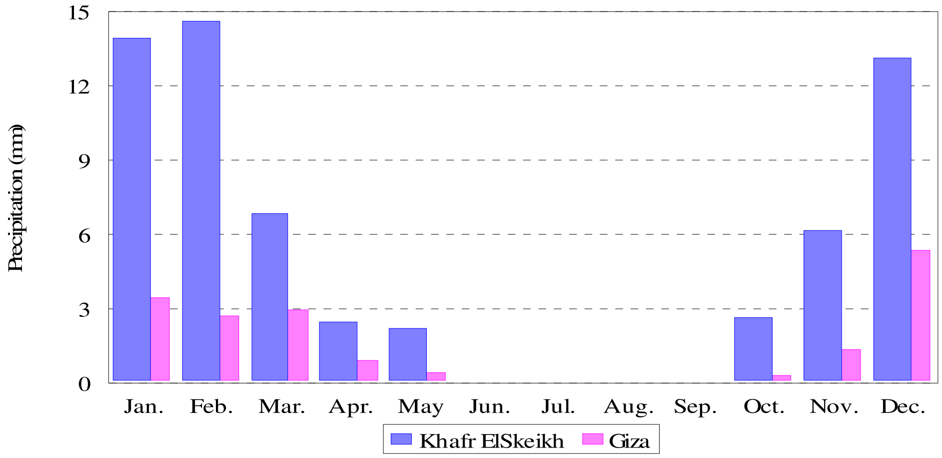


Fig. (2): Mean monthly precipitation in the study zones.

Figure 2: Mean monthly precipitation in the study zones

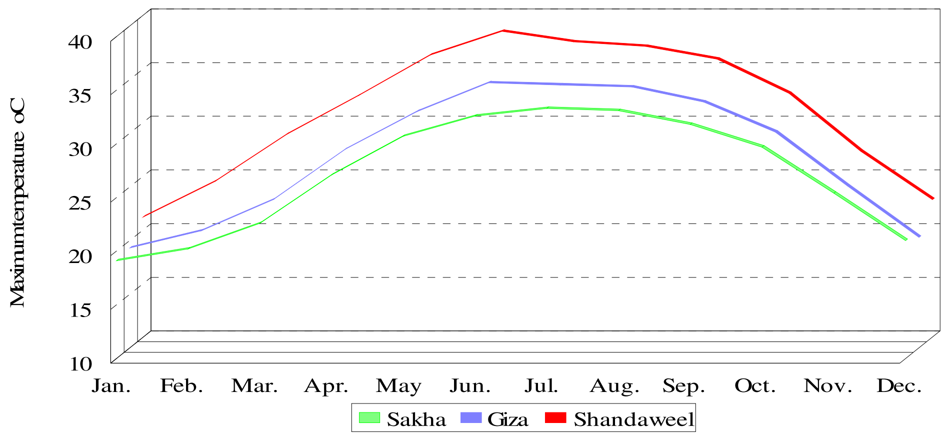


Fig. (3): Mean maximum temperature in the study zones.

Figure 3: Mean maximum temperature in the study zones

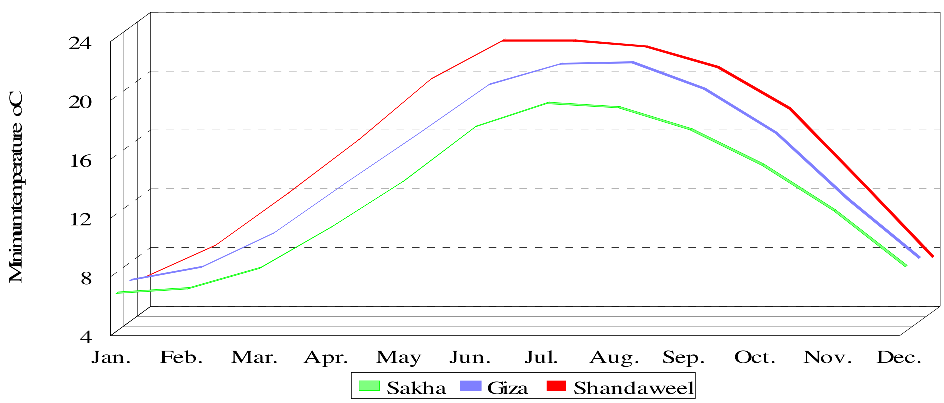


Fig. (4): Mean minimum temperature in the study zones.

Figure 4: Mean minimum temperature in the study zones

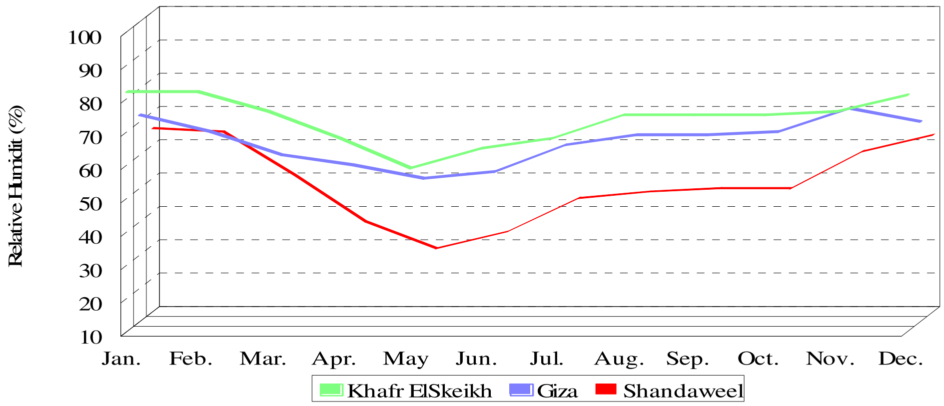


Fig. (5): Mean monthly relative humidity in the study zones.

Figure 5: Mean monthly relative humidity in the study zones

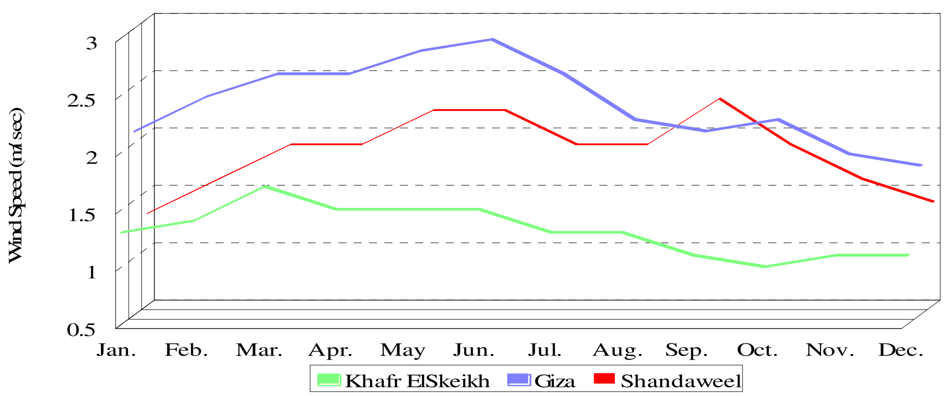


Fig. (6): Mean monthly wind speed in the study zones.

Figure 6: Mean monthly wind speed in the study zones

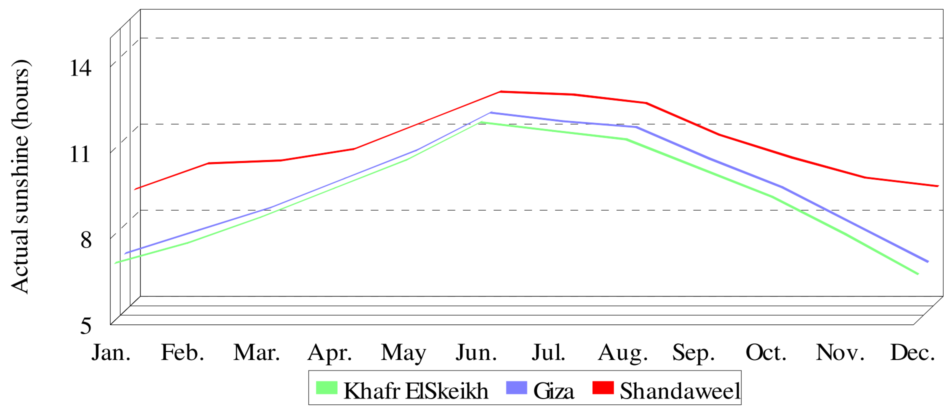


Fig. (7): Mean monthly actual sunshine in the study zones.

Figure 7: Mean monthly actual sunshine in the study zones

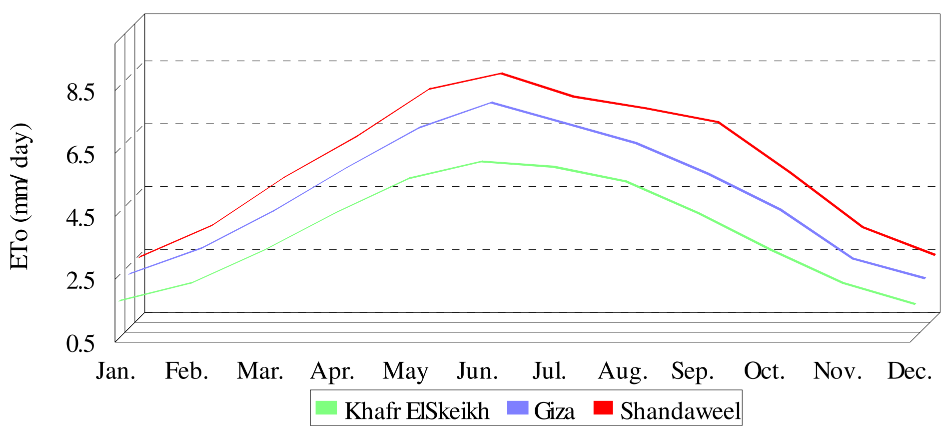


Fig. (8): Mean monthly reference evapotrtanspiration (ETo) in the study zones.

Figure 8: Mean monthly reference evapotranspiration (ETo) in the study zones