

**ASSESSING THE ECONOMIC IMPACTS OF CLIMATE CHANGE ON
AGRICULTURE IN EGYPT: A RICARDIAN APPROACH**

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Correct citation: Eid H, El-Marsafawy S & Ouda S, 2006. Assessing the economic impacts of climate change on agriculture in Egypt: a Ricardian approach. CEEPA Discussion Paper No. 16, Centre for Environmental Economics and Policy in Africa, University of Pretoria.

Core funding for CEEPA comes from the University of Pretoria. CEEPA receives supplementary funding from various donors including the Swedish International Development Cooperation Agency (SIDA), GEF, NRF South Africa, NOAA (USA), IDRC.

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ISBN 1-920160-16-7
First published 2006
Series ISBN 1-920160-01-9

Printed and bound in South Africa by University of Pretoria

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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

This study employed the Ricardian approach to measure the economic impacts of climate change on farm net revenue in Egypt. This approach was based on regressing farm net revenue against climate, soil, socio-economic and hydrological variables to determine which factors influence the variability of farm net revenues. A survey was done by interviewing 900 households from 20 governorates. The standard Ricardian model was applied, in addition to another three models each representing an adaptation option that could be used to reduce the harmful effects of temperature stress. A further adaptation strategy was tested: raising livestock on the farm to cope with the harmful effects of climate change. Besides this, the effects of two climate change scenarios (MAGICC/SCENGEN and GCMs – General Circulation Models) were considered.

The empirical results from the standard Ricardian model (Model 1) showed that a rise in temperature would have negative effects on farm net revenue in Egypt. Adding the linear term of hydrology (Model 2), the linear and quadratic terms of hydrology (Model 3) and the hydrology term and heavy machinery (Model 4) to the analysis improved the adaptability of farm net revenue to high temperature. Marginal analysis indicated that the harmful effect of temperature was reduced by adding the hydrology term and heavy machinery to the analysis. The marginal impact of temperature was -\$968.94, +\$26.17, +\$150.96 and -\$77.78 per hectare for the four models respectively. The results also indicated that raising livestock on the farm to cope with climate change was not effective, probably as a result of small farm ownerships. The results from Models 2 and 3 showed that irrigation could defeat the adverse effect of higher temperatures and increase net revenue, and those from Model 4 showed that using irrigation and investing in heavy machinery could reduce the harmful effects of global warming and improve farm revenue.

The results from the two climate change scenarios showed that high temperatures will constrain agricultural production in Egypt. Irrigation and technology are therefore the recommended adaptation options. However, warming may also affect water resources and that would pose another problem for agricultural production. A policy should be developed to cope with the adverse effects of climate change on agriculture. It should focus on three areas: crop management, water management and land management.

The survey also revealed that Egyptian farmers have noticed a change in temperature and rainfall patterns, through their own experience and/or with the help of the agricultural extension teams. The results indicated that 85% of the selected 900 households noticed a change in temperature in the form of heat waves in the summer, and an increase in the winter minimum temperature. Furthermore, 65% of the sample observed shortages in the amount of rainfall per season. The favored option for adapting to increased temperatures is irrigation. Some farmers adjust their crop sowing dates to avoid the expected high temperatures. To adjust to shortages in rainfall, farmers said they used crop varieties with high water use efficiency and/or early maturing varieties.

1. Introduction

Agriculture is an activity heavily affected by climatic conditions. The impacts of changes in climate on agricultural activities have been shown to be significant for low input farming systems in developing countries in Africa (Rosenzweig & Parry 1994; Reilly et al. 1996; Reilly & Schimmelpfennig 1999; Kates 2000; McGuigan et al. 2002). Furthermore, tropical regions in developing countries are usually characterized by poor marginal soils that cover extensive areas, making them unusable for agriculture, leaving the developing countries particularly vulnerable to potential damage from environmental changes (Mendelsohn & Dinar 1999).

The impacts of climate change on agricultural activities in term of yield losses and increasing of water needs have been studied for the last decade in Egypt. The results have shown Egypt 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 is undergoing intensive development and its long coastline is being eroded. Climate change could do severe damage to agricultural productivity if no adaptation measures are taken (El-Shaer et al. 1997). Previous research on the impact of climate change on agricultural sectors has revealed that yields and water use efficiency will be decreased in comparison with current climate conditions, even when the beneficial effects of CO₂ are taken into account.

Climate change could decrease the national production of rice by 11% and soybeans by 28% by the year of 2050, compared with their production under current conditions (Eid & EL-Marsafawy 2002). It could reduce national maize production by about 19% (Eid et al. 1997b) and barley grain by 20% (Eid et al. 1995). Cotton seed yield would increase by 17% if the temperature increased by 2°C and by 31% with a 4°C increase (Eid et al. 1997a). By the year 2050, climate change could increase water needs by up to 16% for summer crops but decrease them by up to 2% for winter crops (Eid & El-Mowelhi, 1998).

However, despite all the extensive research on the effect of climate change on crop production there has been no research on the economic impacts on the agricultural sector. Heavy economic dependence on agriculture in Egypt means that the effects of climate change are likely to threaten the welfare of the population and hamper economic development. Economic adjustments, such as improving the overall water use efficiency of the agricultural system, soil drainage and conservation, land management, and crop alternatives are essential measures for overcoming the adverse impacts of climate change. If appropriate measures are taken, the negative effects of climate change on agricultural production and other major resource sectors (water and land) may be lessened.

1.1 The objectives of the study

The study objectives follow the general objectives as set by GEF project document. However, they were redefined to focus specifically on the Egyptian conditions. These redefined objectives are as follows:

- a. To develop and estimate a Ricardian model to assess the potential impacts of climate change on agriculture in Egypt;
- b. To use the estimated model to predict the range of impacts on the agricultural sector under various climate change scenarios; and

- c. To evaluate alternative courses of action in terms of policies and strategies that could help mitigate the likely climate change impacts on agriculture in Egypt.

1.2 Background information on Egypt

Egypt lies in the northeastern corner of the African continent with an area about 1 million square kilometers. The Egyptian terrain consists of a plateau interrupted by the Nile Valley and Delta. The inhabited area in Egypt does not exceed 3.5% of the total area and it is confined to a narrow strip, which is the main course of the River Nile from Aswan in the south to Cairo in the north. Furthermore, the Nile Delta covers the area from Cairo to the shoreline of the Mediterranean Sea, between the cities of Damietta in the east and Rashid in the west (Figure 1).

Egypt's total area spans nine degrees of latitude (from 32.5° N to 22.0° N) and presents north-south gradient temperatures. Hot dry summers and mild winters prevail. Yearly temperatures range from 19.2°C to 21.1°C in Lower Egypt, from 20.5°C to 22.5°C in Middle Egypt and from 22.9°C to 26.9°C in South Egypt (Figure 2). Rainfall is low, irregular and unpredictable. The only region with appreciable rainfall is the northern coast, with 100–200 mm/year. Within the Delta, precipitation is 40–60 mm/year, in Middle Egypt less than 20 mm/year, and in the south and the desert area there is no rain at all (Figure 3).

The main agricultural regions in Egypt are Lower, Middle and Upper Egypt. The agricultural land area is determined by climate and water availability. The cultivated areas in Egypt have been increased over the past few years and will continue to increase due to the government's policy of adding more agricultural lands. Egyptian agriculture is characterized by smallholdings (less than 0.4 of a hectare).

In Egypt, 99.8% of cropland is irrigated. The largest consumers of irrigation water are rice and sugarcane because they have high water requirements, in addition to occupying a considerable area. The average crop consumption for 1995/1996 was estimated to be 40.82 billion cubic meters. The total quantity of water diverted to agriculture from all sources (surface, ground water, drainage reuse and sewage reuse), including conveyance distribution and application losses, was about 55.5 billion cubic meters in 1995/1996. In the 1970s and early 1980s the government significantly promoted the development of new agricultural land.

1.3 Description of different agricultural systems in Egypt

The agricultural land base of Egypt totals about 7.5 million acres (3.151 million hectare) of the total area. In addition, there is about 229,000 hectare, which is a rain fed areas. Out of 3.151 million hectare, old lands representing 75% of agricultural area, and 25% for new land. The agricultural sector is comprised of various production systems, which are interrelated and complementary. It includes the following:

1.3.1 Crop production system

This includes field crops, vegetables, fruit and forest trees, and medical, aromatic and ornamental crops. The total annual cropped area is estimated at 14.0 million acres (1996), giving a cropping intensity of about 180% (or 1.8). Major crops in Egypt include wheat (used as a staple food crop), maize (used primarily as coarse grain for animal feed), clover, cotton,

rice (which grows only in the Delta and the Fayoum Governorate in Middle Egypt), sugar cane (which grows in Upper and Middle Egypt), fava beans, sorghum and soybeans. Crop production contributes about 68% of the total value of agricultural GDP. Field crops are estimated at about 66% of the total crop production value, and vegetables and fruits at 17% and 15% respectively.

1.3.2 Livestock production system

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

1.3.3 Integrated production system

Livestock/crop production is an excellent example of an integrated production system where feed crops and agricultural residues provide the feed for animals and, in turn, livestock manure is added to the soil to improve its fertility.

2. The analytical framework for implementing the Ricardian analysis

Two methods have been developed during the last decade to evaluate the impact of climate change on agricultural sector: the production-function approach (Rosenzweig & Iglesias 1994), and the Ricardian approach (Mendelsohn et al. 1994).

The production-function approach relies on empirical or experimental production functions to predict environmental damage. It takes an underlying production function and estimates impacts by varying one or a few input variables such as temperature, precipitation and CO₂ levels. The estimates might rely on extremely carefully calibrated crop yield models (such as CERES or SOYGRO) to determine the effect on yields. The results often predict severe yield reductions as a result of global warming. This approach has been criticized because of inherent bias, which tends to overestimate the damage, a bias sometimes referred to as the 'dumb farmers scenario', since it fails to take into account the variety of adaptations that farmers make in response to changing economic and environmental conditions (Mendelsohn et al. 1994).

Generally, the Ricardian approach is a cross-sectional model used to study agricultural production by measuring climate change damage as a reduction in net revenue or land value. In addition, it takes into account the costs and the benefits of different adaptation techniques that farmers apply. Cross-sectional observation, where normal climate and soil factors vary, can be used to estimate the effect of farmers' adaptations to climate on crop productivity. The analytical Ricardian framework can be stated as follows (Dinar et al. 1998):

Assuming the existence of a set of well-behaved functions in the form of:

$$Q_i = Q_i (K_i , E), i = 1, \dots, n \quad (1)$$

where:

$K_i = [K_{i1}, \dots, K_{ij}, \dots, K_{iJ}]$ is a vector of all purchased inputs in the production of good i ,

K_{ij} = the purchased input j ($j=1, \dots, J$) in the production of good i ,

$E = [E_1, \dots, E_m, \dots, E_M]$ is a vector of site specific exogenous environmental inputs such as temperature, precipitation, and soils.

Given a set of factor prices w_j for K_j , E , and Q , cost minimization leads to cost function:

$$C_i = C_i (Q_i, W, E) \quad (2)$$

Where:

C_i is the cost of production of good i and

$W = (W_1, \dots, W_i, \dots, W_j)$ is the vector of factor prices.

Assuming a set of utility maximizing consumers with well-behaved utility functions and linear budget constraints, who take prices as given, this leads to a system of inverse demand functions for outputs $i=1, \dots, n$

$$P_i = D^{-1} [Q_1, \dots, Q_i, \dots, Q_n, Y] \quad (3)$$

Where:

P_i and Q_i are respectively the price and quantity of good i and Y is the aggregate income.

Given market prices, profit maximization on a given site yields:

$$\max P_i Q_i - C_i - (Q_i, W, E) - P_L L_i \quad (4)$$

Where:

P_L is the annual cost or rent of land at that site and C_i is the cost function of all purchased inputs other than land. Perfect competition will drive profits to zero:

$$P_i Q_i^* - C_i^*(Q_i^*, W, E) - P_L L_i^* = 0 \quad (5)$$

If i is the best use for land given E and R , the observed market rent on the land will be equal to the net annual profits from the production of good i . Solving Equation (4) for P_L gives land rent per hectare to be equal to net revenue per hectare.

$$P_L = (P_i Q_i^* - C_i^*(Q_i^*, W, E)) / L_i \quad (6)$$

The Ricardian approach is based on the following hypothesis:

- 1) Climate shifts the production function for crops.
- 2) There is perfect competition in both product and input prices (no public intervention on market and no monopoly)
- 3) The land values have attained the long-run equilibrium associated with each region climate.
- 4) Market prices are unchanged as a result of change in environmental conditions.
- 5) Adaptation takes place by all means including the adoption of new crops or farming systems.
- 6) The adaptation cost is not considered in the analysis.

The standard Ricardian model relies on a quadratic formulation of climate:

$$NR/ha = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + u \quad (7)$$

Where:

NR/ha = net revenue per hectare

F = vector of climate variables

Z = set of soil variables

G = set of socio-economic variables

u = error term

The earlier Ricardian studies did not include irrigation in the analysis. However, initial research on United States data by Mendelsohn and Dinar (1999) suggests that water supply

from runoff has an important effect on farms. Farms that can draw from runoff are more likely to use irrigation and earn higher net revenues. Under Egyptian conditions, irrigation is the main method of water application and it is also used as for relief from heat stress. Therefore, modeling runoff across Egypt could reveal the extent to which runoff affects existing farms. Furthermore, it can explicitly capture how runoff changes would interact with direct climate changes and affect farms in the future. The following model is proposed:

$$\text{Revenue/ha} = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + \beta_5 H \quad (8)$$

where

H = relevant hydrology variables.

3. Data for analysis

The data for the analysis was based on a cross-sectional farm household survey at district level for several governorates. The survey used a structured questionnaire and was designed to collect data which would reflect the substantial variation in Egypt's agro-ecological zones, in particular the major and minor crops and livestock production. Small-scale and large-scale production, traditional agriculture and agricultural production based on improved technology were all reflected in the survey.

The survey covered 20 of the country's governorates, which were selected to represent the whole country. (The remaining governorates contribute little to agricultural production in Egypt.) Lower Egypt was represented by 12 governorates: Alexandria, Behaira, Kafr El-Sheikh, Damietta, Dakahlia, Sharkia, Gharbia, Menoufia, Qalyoubia, Port Said, Ismailia and Noubaria; Middle Egypt by four: Giza, Fayoum, Beni Suef and Menia; and Upper Egypt by four: Assuit, Suhag, Qena and Aswan. The mean temperature and precipitation for each governorate are presented in Table 1. A sample of 45 households was collected from each governorate, making a total of 900 (see Table 2).

Farm household data: A farm household questionnaire was used to collect information from the selected household. The questionnaire attempted to capture information on pertinent variables required to calculate net farm revenues and to explain the variation in net farm revenues, land values and income across representative sample districts and agro-climatic regions in the country. The periods of interest were the winter season of 2001/2002 (October to April) and the summer season of 2002 (May to September). Some farmers plant crops in a third season, called the Nili season, stretching from July or August to October or November. The questionnaire also aimed to capture farmers' perception of, knowledge about and attitudes to climate variation and change.

The questionnaire had two main parts and six sections. Part 1 focused on crop production and Part 2 on livestock. Sections 1 and 2 asked about household characteristics and the household head's employment. The questions in Section 3 were about the household's land under farming activities (both crops and livestock), and about the labor used for various farm activities and about their costs. In Section 4 detailed questions were asked about crop farming activities: the type of crops grown, the area of land planted, the quantities harvested and sold,

and various costs such as seeds, fertilizer and pesticides; light, heavy and light and heavy machinery and animals used in agricultural work; and farming related buildings. Section 4 asked about the types of animals farmed and how many were purchased, lost and sold during 2001/02, and about livestock and poultry products, such as milk, beef, wool and eggs. Section 5 asked about the farmers' access to information for farming activities and the sources and cost of this information, and Section 6 asked for an estimate of the farm household's total income (for both farming and non-farming activities), taxes paid and subsidies received during 2001/02. Finally, Section 7 investigated farmers' perceptions of short- and long-term climate change and their adaptation strategies in response to these.

Climate data: Two main sources of climatic data were used: satellite data for temperature and ARTES (Africa Rainfall and Temperature Evaluation System) data for precipitation (wetness). The satellite data comes from the US Department of Defense polar orbiting satellites that pass over the entire earth between 6am and 6pm every day. These satellites are equipped with sensors that detect microwaves that can pass through clouds and detect both surface temperature and surface wetness. The ARTES data is created by the National Oceanic and Atmospheric Association's (NOAA's) Climate Prediction Center of the US and is based on ground station measurements of precipitation and minimum and maximum temperature.

Soil data: These data were obtained from the Food and Agriculture Organization (FAO). The data provides information on major and minor soils by governorate in the country.

Hydrology data: These data were provided by the University of Colorado and the International Water Management Institute (IWMI) as part of the GEF Africa-wide study. Using a hydrological model for Africa, estimates were provided for flow and runoff for each of the sample districts.

4. The empirical model

Alternative adaptation options for reducing the harmful effect of heat stress on farm revenue were explored by developing four Ricardian models. Model 1 is the standard Ricardian model, which includes weather, soil and socio-economic variables. Model 2 contains weather, soil and socio-economic variables, with the addition of the relevant hydrology variable. Model 3 contains the previous variables, with the addition of the quadratic term of the relevant hydrology variable. The rationale for using the quadratic term of the hydrology variable is that increasing the amount of irrigation might help reduce heat stress on growing crops and consequently could increase farm revenue. Model 4 contains the same variables as Model 2, with the addition of technology variables. For each model, a dummy variable for livestock activity was included to examine whether it could be used as an adaptation option. Farms without livestock activity were compared to farms with livestock.

In addition to the abovementioned models, a comparison was made between small- and large-scale farms to assess their response to increased temperature. However, the differences between them were found to be not significant. Furthermore, Egypt was divided into three zones. Lower, Middle and Upper, to also assess their response to increased temperature, but again the differences were not found to be significant. This lack of significant difference could be attributed to the important role that irrigation may play in agricultural production all over the country and also to the different types of farming activity.

4.1 Defining variables

4.1.1 Dependent variable

The absence of a well-functioning land market in Egypt made it difficult for climate response functions to reflect the adjustments made by farmers to normal climate conditions, so net revenue (Kumar & Parikh 2001) was selected to be the dependent variable for the analysis. In addition to four measurements of net revenue, gross revenue was calculated from the household survey, with additional sets of costs being deducted from preceding net revenues. Gross crop revenue is the product of total harvest and price of the crop. The first one is nr1_3, which is gross revenue less the cost of fertilizer and pesticides per hectare of cropped area. The second one is nr2_3, where hired labor cost per hectare was deducted from nr1_3. The third one is nr3_3, where total machinery cost per hectare was also deducted from nr2_3. Other crop farming costs were deducted from nr3_3 to obtain the values of nr4_3. Table 3 summarizes the statistics for these four variables.

The mean value of nr1_3 was the highest compared with the other definition of net revenue. Furthermore, minimum value was negative because some households had higher relative costs and it was the lowest as additional costs were deducted. Therefore, to avoid having several negative data values for the dependent variable we decided to use nr1_3 as the dependent variable for the estimation of our empirical models.

4.1.3 Explanatory variables

Climate data

The climate set that gave the best results came from ARTES. These data were for temperature and precipitation. The analysis showed that consecutive months are highly correlated and performed poorly in the models, so seasonal averages were used instead. A season was defined as an average of three months. Winter was defined as December through February, spring as March through May, summer as June through August and fall as September through November. In our analysis, the linear and quadratic terms of temperature only were included in the analysis. The seasonal wetness index was excluded from the model because it violates the condition of the OLS (Ordinary Least Squares) models, which must have a value for the F-stat to ensure that the model is a full rank. Because precipitation levels are very low in Egypt, all the farmers use irrigation for their crops.

Soil data

Soil data for the 20 governorates under study were provided by the FAO. These data provide information about the major and minor soil types. Similar soil types were grouped into 12 sets and used in the analysis to obtain the best results in terms of significant and positive effect on revenue. Insignificant soil types were excluded from the analysis. Of the 12 sets, only two soil types were found significant and used in the analysis: soil_rc, calcareic regosols, and soil_z, solonchaks.

Socio-economic data

Socio-economic data were obtained from the survey, such as household size, farm size, distance to nearest market to buy inputs, total cost for farm labor, amount of crops sold, amount of crops consumed by livestock, quantity of light machinery and a control variable for livestock.

Hydrology data

Data for several runoff and flow terms were obtained from University of Colorado and the IWMI. Each hydrological term was tested in the models. Flow sum gave the best results and was therefore used in revenue calculations.

Technology data

Technology data was also obtained from the survey. It represents the quantity of heavy machinery that the farmers used on their farms.

4.2 Statistical analysis

OLS estimation procedures using the Stata Statistical and Econometric software were used to fit the abovementioned models. To overcome the problem of heteroscedasticity, a robust estimation of the standard errors was undertaken, and to overcome the problem of multicollinearity, identified correlated variables were dropped from the model.

Several runs were done with different explanatory variables. Most of these variables were dropped from the model because of their low significance level and their low contribution in improving the overall significance of the estimated models. The marginal impact of seasonal temperature was estimated for each of the four proposed models. Furthermore, two climate change scenarios were used to assess the effect of heat stress on farm revenue. These two scenarios were MAGICC/SCENGEN results, which propose a 1.5°C rise in temperature and GCM results, which propose a 3.6°C rise. The expected reduction in farm revenue as a result of these two scenarios was then calculated.

5. Results and discussion

5.1 Farm net revenue determination

Farm net revenue is defined in the model as household crop gross revenue less fertilizers and pesticide costs per hectare of total cropped area. Four models were developed to assess the impact of increased temperature on farm net revenue and to explore different adaptation options to reduce the harmful effect of these temperatures. ARTES temperature data was used in these four models.

5.1.2 Net revenue determination using Model 1

Model 1 is the standard Ricardian model, including weather, soil and socio-economic variables. The results in Table 4 show that the linear and quadratic terms of both spring and fall temperatures have a U-shaped relationship with farm net revenue. Spring is when winter crops develop their seeds and any rise in temperature can consequently reduce the yield. Similarly, the temperature in the fall is still relatively high, particularly in September and October, when summer crops develop their seeds, so any increase could reduce revenues. Results also showed that winter and summer temperatures have an inverse U-shaped relationship with crop area / net revenue. The inverse U-shaped relationship between summer temperatures and net revenue was not expected, given that summer temperature is already hot. The results also showed that the linear term of winter and summer temperature negatively affects net revenue, as does the quadratic term of spring and fall temperature.

The two types of soils that were found to be relevant in the model were not significant, probably because their formulation in the model was not accurately done.

Farm size, household size, distance to nearest market to buy input, amount of crops sold and quantity of light machinery positively affected net revenue, whereas total cost for labor per farm and amount of crop consumed by livestock negatively affected it.

5.1.3 Net revenue determination using Model 2

Model 2 is the standard Ricardian model, including weather, soil and socio-economic variables, and the hydrology term. This model was designed to test the efficacy of irrigation in reducing the harmful effect of increased temperature. The results in Table 5 show that all the independent variables behave the same as in Model 1. Flow sum was found to be positively and significantly correlated with net revenue, which proves that irrigation plays an important role in overcoming heat stress.

5.1.4 Net revenue determination using Model 3

Model 3 includes weather, soil and socio-economic variables, and the linear and quadratic term flow sum. The results in Table 6 show that all the independent variables behave the same as in Model 1. They also show that flow and its quadratic term have a U-shaped relationship with net revenue when farms do not keep livestock and a linear relationship with net revenue when livestock are kept. In the first case, the U-shape can be attributed to applying more irrigation: water might be harmful to the crop and thus reduce net revenue, but as heat stress prevails applying more irrigation could increase net revenue. In the second case, the linear response is, probably, a result of a certain threshold, where applying more irrigation could relieve heat stress.

5.1.5 Net revenue determination using Model 4

Model 4 includes weather, soil and socio-economic variables, and flow sum and quantity of heavy machinery. This model was developed to assess the effect of using heavy machinery in the farm as an adaptation option to help overcome the harmful effects of climate change. The quantity of heavy machinery was found to positively and significantly affect net revenue (Table 7), thus indicating that the more money farmers can spend on farm equipment, the more revenue they can gain.

5.2 Marginal impacts of temperature on farm net revenue

The critical value for marginal impacts is the annual temperature because the season's alternate signs offset each other throughout the year, i.e. we do not examine the sign for each season's weather to see whether it is positive or negative, but rather examine the sign for annual temperature: if it is positive, net revenue will increase; if negative, net revenue will decrease. With respect to the standard Ricardian model (Model 1), the results in Table 8 show that an increase in temperature of 1°C would reduce net revenue by \$968.94 per hectare without livestock and by \$1044.28 per hectare when livestock is included.

Furthermore, including irrigation in the analysis (Model 2) reduces the harmful effect of increased temperature and increases net revenue by \$26.17 per hectare without livestock and reduces it by \$1680.14 per hectare when livestock is included (see Table 9).

Similarly, including the linear and quadratic term of flow in the analysis (Model 3) reduces the harmful effect of increased temperature and increases net revenue by \$150.96 per hectare without livestock and decreases it by \$1412.41 per hectare when livestock is included (see Table 10).

Finally, including the quantity of heavy machinery per hectare in the analysis reduces the harmful effect of increased temperature by \$77.78 per hectare without livestock and by \$1837.17 per hectare when livestock is included (see Table 11).

The option of raising livestock on the farm as an adaptation for coping with the harmful effect of increased temperature was not effective. In fact, it increased the losses in farm net revenue (Tables 8, 9, 10 and 11). This might be attributed to the fact that many of the farmers in the survey were smallholders, who could not afford to use part of their small area to raise livestock.

5.3 Effect of climate change on farm net revenue

Two climate change scenarios were used in the analysis to predict the reduction in farm net revenue by the year 2050. These two scenarios were MAGICC/SCENGEN results, which predict a 1.5°C rise in temperature, and GCM results, which predict a 3.6°C rise by the year 2050. The results from Models 1 and 4 indicate that warming will reduce net revenue (Tables 8 and 11). However, the results from Models 2 and 3 show that warming will increase it (Tables 9 and 10). The results in Table 12 suggest that temperature increases of 1.5°C or 3.6°C will greatly reduce farm net revenue per hectare calculated from Model 1. The reductions in net revenue are \$1453.41 and 3488.18 per hectare for increases of 1.5°C and 3.6°C respectively, if no adaptation options are undertaken into consideration (Model 1).

However, reductions in net revenue could be less severe if farmers used more heavy machinery on their farms (Model 4). The reductions in net revenue here were \$116.67 and \$280.01 per hectare for 1.5°C and 3.6°C increases respectively, showing that expenditure on farm machinery could reduce the harmful effect of temperature increase. The results for Model 2 show that irrigation could increase farm net revenues by \$39.26 and \$94.21 per hectare for 1.5°C and 3.6°C increases respectively, and for Model 3 by \$226.44 and \$543.46 per hectare for 1.5°C and 3.6°C increases respectively.

Regarding raising livestock on the farms, the results in Table 13 show that large losses in farm net revenue would occur using this management practice.

5.4 Farmers' adaptation strategies to cope with climate change

The survey also revealed that Egyptian farmers have noticed a change in temperature and rainfall patterns, through their own experience and/or with the help of the agricultural extension teams. The results show that 85% of the selected 900 households noticed a change in temperature in the form of heat waves in the summer, and an increase in the winter minimum temperature. Furthermore, 65% of the sample observed shortages in the amount of rainfall per season. Several adaptation options were chosen by these farmers to overcome the harmful effects of climate change.

The most common adaptation to increased temperatures is irrigation, either by increasing the frequency of irrigation (short irrigation duration) or by increasing the quantity. Another procedure is to irrigate early in the morning or late in the evening and avoid irrigating in the afternoon, when the temperature is at its highest. Some farmers change their crop sowing dates to avoid the expected high temperatures, and some farmers said they use heat tolerant varieties. Other management practices mentioned by the farmers were managing pesticide and fertilizer applications, planting trees as fences around the farm, using intercropping between crop plants of different heights, and fruit mulching for vegetables.

To adjust to changes in rainfall, farmers said that using varieties with high water use efficiency and/or early maturing varieties could help in coping with rainfall shortage, and some said that using underground or drainage water for irrigation and improved drainage could also be important.

6. Conclusions and policy implications

The growing interest in measuring climate change damage to agricultural revenue motivated us to participate in this study. In Egypt, most of the recent work on measuring the effect of climate change has focused on damage to crop yields, changes in availability of water or damage to soil. However, a more important issue is to study how farm outputs and net revenues are affected by a range of temperature and precipitation changes. The Ricardian approach was chosen for this study because it implicitly takes into account farmers' adaptations to climate change. The standard Ricardian model was applied (Model 1), as were three other models, each representing an adaptation option to be used to reduce the harmful effects of temperature stress. Model 2 examined the role of the linear term of hydrology. Model 3 the role of the linear and quadratic term of hydrology, and Model 4 the role of the linear hydrology term and expenditure on heavy machinery.

The empirical results suggest that irrigation is one of the most important adaptation options used to overcome heat stress, either the linear term (Model 2), the linear and quadratic terms (Model 3) or the linear term and technology term (Model 4). Irrigation could alter the relationship between farm revenue and climate, because it could help crops to grow well under warmer temperatures. The marginal impact of temperature was improved from \$968.94 per hectare for Model 1 to \$+26.17 per hectare for Model 2 and to \$+150.96 per hectare for Model 3, whereas results from Model 4 suggested that using irrigation and expenditure on heavy machinery could reduce the harmful effects of global warming from \$-968.94 per hectare to \$-77.78 per hectare. Irrigation is therefore the recommended adaptation option, with expenditure on heavy machinery being another alternative.

The survey also revealed that Egyptian farmers have noticed a change in temperature and rainfall patterns. The results indicated that 85% of the selected 900 households noticed a change in temperature in the form of heat waves in summer, and an increase in the winter minimum temperature. Furthermore, 65% of the sample observed shortages in the amount of rainfall per season. Many farmers adjust their crop sowing dates to avoid the expected high temperatures. However, the survey revealed that irrigation is the Egyptian farmers' favored method of fighting heat stress.

Unfortunately, warming may also affect water resources and that would pose another problem for agricultural production. Adaptation policies should therefore be developed to cope with the adverse impacts of climate change and should address three areas: crop management, water management and land management.

First, there should be careful selection and/or breeding for heat tolerant, salinity tolerant, and water conserving cultivars. Crop rotation should be practiced so as to use high revenue crops with low water needs, such as all-season vegetables and fruits. Another alternative is to plant tomatoes, onions or potatoes as winter crops before cotton in the rotation instead of wheat, which could conserve irrigation water and increase cash return. In addition, efforts should be made to promote the preferential adoption of high-return and water conserving crops, such as sugar beet, instead of the presently grown water-profligate crops such as rice.

Second, water resources should be appropriately managed. This could be done by improving both technical water application efficiency and agronomic water use efficiency. This would involve revamping the entire system of water delivery and control and ensuring effective monitoring and regulation to avoid water losses.

Third, a further set of measures should be taken into consideration involving the management of low-lying lands at the northern fringe of the Delta, where the consequences of sea-level rise are causing submergence and increasing the salinity of these soils. Some of these lands must be retired from agriculture, and the water that was assigned to them should be made available for irrigating new lands outside the New Valley and the Delta.

This study quantified the economic impacts of climate change on farm revenue, using the Ricardian approach. Moreover, it took into consideration two adaptation options, irrigation and expenditure on heavy machinery. However, the various adaptation practices used by individual farmers should be explored too, such as using high-yielding varieties. It is important that future research consider micro-level analysis of adaptation strategies, using behavioral models to capture farmer behavior in choosing among various adaptation options.

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Table 1: Mean temperature and precipitation for the 20 Egyptian governorates used in the survey (normals for 40 years)

Zone	Governorate	Mean temp (°C)	Precip (mm/year)
Lower Egypt	Alexandria	20.20	15.50
	Port Said	20.00	93.00
	Behaira	20.70	93.60
	Damietta	20.20	104.30
	Kafr El-Sheikh	19.20	67.00
	Gharbia	20.40	51.00
	Dakahlia	20.90	54.00
	Sharkia	20.70	20.00
	Menoufia	21.20	34.20
	Qalyoubia	21.10	22.60
	Noubaria	20.40	35.00
	Ismailia	20.70	38.00
	Mean	20.48	52.35
Middle Egypt	Giza	20.50	19.00
	Beni Suef	21.50	8.00
	Fayoum	22.00	13.70
	Menia	21.10	4.00
	Mean	21.28	11.18
Upper Egypt	Assuit	22.90	0.00
	Suhag	22.90	0.00
	Qena	24.90	5.20
	Aswan	26.90	1.00
	Mean	24.40	1.55

Source: Egyptian Meteorological Authority

Table 2: Distribution of governorates and households (HH) in the agro-ecological zones in Egypt

	Zone name	Representative governorates	Number of households
Lower Egypt	Coastal	1. Alexandria	45
		2. Port Said	45
	Central Delta	3. Behaira (Old)	45
		4. Damietta	45
		5. Kafr El-Sheikh	45
		6. Gharbia	45
		7. Dakahlia	45
		7. Sharkia	45
		9. Menoufia	45
		10. Qalyoubia	45
East & West Delta	11. Behaira (New)	45	
	12. Ismailia	45	
Middle Egypt	Giza	13. Giza	45
		14. Fayoum	45
		15. Beni Suef	45
	Menia	16. Menia	45
	Upper Egypt	Assiut & Sohag	17. Assuit
North Qena		18. Suhag	45
South Qena		19. Qena	45
Aswan		20. Aswan	45
Total			900

Table 3: Estimated crop net revenues in Egypt (US\$) for 2001/2002

Variable	Observation	Mean	Standard deviation	Minimum	Maximum
nr1_3	689	1394.65	896.60	-118.61	5231.67
nr2_3	646	1233.80	880.73	-227.29	4890.69
nr3_3	646	1142.14	904.00	-1393.57	4889.09
nr4_3	617	1073.51	859.88	-1393.57	4654.94

Source: GEF Farm Household Survey Data (2001/2002)

Table 4: Regression coefficients obtained for net revenue/ha based on cropped area using ARTES temperatures (Model 1)

Net revenue	Regression coefficients	Regression coefficients (with livestock included)
Winter mean temperature	-18857.84	-19206.94***
Winter mean temperature squared	580.94	607.24***
Spring mean temperature	42317.62	35529.81*
Spring mean temperature squared	-915.34	-785.39*
Summer mean temperature	-47320.17	-45789.33***
Summer mean temperature squared	808.60	800.98***
Fall mean temperature	32765.83	30760.63*
Fall mean temperature squared	-673.94	-654.44*
Soil_rc	1411.33	1745.46
Soil_z	364.56	-544.89
Household size	85.18***	4.95
Farm size	68.77	121.12***
Distance to market (hours)	5.18	358.58
Total cost for farm labour	-0.01	-0.03*
Amount of crop sold	0.002***	0.001
Amount of crop consumed by livestock	-0.01	-0.0001
Number of light machinery	16.31	6.00*
Constant	-40871.3	44088.96
R2	0.2258	0.1873
N	140	549
F	33.97	7.05

* Significant at 10% *** significant at 1%

Table 5: Regression coefficients obtained for net revenue/ha based on cropped area using ARTES temperatures (Model 2)

Net revenue	Regression coefficients	Regression coefficients (with livestock included)
Winter mean temperature	-20633.74	-19783.79***
Winter mean temperature squared	638.25	621.48***
Spring mean temperature	36562.31	42664.45***
Spring mean temperature squared	-791.58	-939.76***
Summer mean temperature	-43483.39	-48898.50***
Summer mean temperature squared	744.34	853.83***
Fall mean temperature	34690.04	26988.72***
Fall mean temperature squared	-719.22	-571.26***
Soil_rc	1597.48	2162.15
Household size	85.89***	6.99
Farm size	65.85	137.75***
Distance to market (hours)	8.03	344.92
Total cost for farm labor	-0.01	-0.04*
Amount of crop sold	0.002***	0.001
Amount of crop consumed by livestock	-0.01	-0.0001
Number of light machinery	15.30	5.72*
Flow sum	0.003*	0.02***
Constant	-37695.76	55506.54
R2	0.2251	0.1947
N	140	549
F	33.48	7.05

* Significant at 10% *** significant at 1%

Table 6: Regression coefficients obtained for net revenue/ha based on cropped area using ARTES temperatures (Model 3)

Net revenue	Regression coefficients	Regression coefficients (with livestock included)
Winter mean temperature	-20310.80	-18863.13***
Winter mean temperature squared	629.79	597.29***
Spring mean temperature	35346.82	39961.78***
Spring mean temperature squared	-765.59	-882.16***
Summer mean temperature	-42126.67	-45771.15***
Summer mean temperature squared	721.58	801.60*
Fall mean temperature	34208.47	25836.48***
Fall mean temperature squared	-710.43	-550.44***
Soil_rc	1641.89	2218.01
Household size	85.57***	6.24
Farm size	66.07	136.62***
Distance to market (hours)	7.94	331.76
Total cost for farm labor	-0.01	-0.04***
Amount of crop sold	0.002***	0.001
Amount of crop consumed by livestock	-0.01	-0.0001
Number of light machinery	15.33	5.76*
Flow sum	-0.0002	0.01
Flow sum squared	2E-07	0.000001
Constant	-40213.2	47556.31
R2	0.2251	0.1951
N	140	549
F	33.67	6.59

* Significant at 10% ** significant at 5% *** significant at 1%

Table 7: Regression coefficients obtained for net revenue/ha based on cropped area using ARTES temperatures (Model 4)

Net revenue	Regression coefficients	Regression coefficients (with livestock included)
Winter mean temperature	-21587.33	-18973.72***
Winter mean temperature squared	666.06	592.97***
Spring mean temperature	38128.71	42459.69***
Spring mean temperature squared	-823.34	-933.60***
Summer mean temperature	-46485.62	-48196.69***
Summer mean temperature squared	795.03	840.03***
Fall mean temperature	37142.48	25438.36***
Fall mean temperature squared	-770.62	-535.51***
Soil_rc	1584.76	2226.85
Household size	81.33***	8.18
Farm size	45.88	152.86***
Distance to market (hours)	6.38	347.43
Total cost for farm labor	-0.01	-0.04*
Amount of crop consumed by livestock	-0.002***	0.001***
Number of light machinery	0.01	0.0002***
Number of heavy machinery	21.57*	6.11*
Flow sum	0.004	0.03*
Constant	-33603.74	59198.15
R2	0.2141	0.184
N	140	549
F	29.79	6.82

* Significant at 10% ** significant at 5% *** significant at 1%

Table 8: Marginal impact of temperature on net revenue/ha based on cropped area obtained from Model 1

Net revenue (US\$/ha)	Marginal impact	Marginal impact (with livestock included)
Winter temperature	3554.69	4220.38***
Spring temperature	-190.74	-943.86
Summer temperature	-7229.5	-6076.76
Fall temperature	2896	1755.97
Annual temperature	-968.94	-1044.28

*** Significant at 1%

Table 9: Marginal impact of temperature on net revenue/ha based on cropped area obtained from Model 2

Net revenue (US\$/ha)	Marginal impact	Marginal impact (with livestock included)
Winter temperature	3989.85	4192.95***
Spring temperature	-189.88	-978.41
Summer temperature	-6579.25	-6565.61***
Fall temperature	2814.33	1670.66
Annual temperature	26.17	-1680.14

*** Significant at 1%

Table 10: Marginal impact of temperature on net revenue/ha based on cropped area obtained from Model 3

Net revenue (US\$/ha)	Marginal impact	Marginal impact (with livestock included)
Winter temperature	3986.61	4180.19***
Spring temperature	-207.04	-1005.91
Summer temperature	-6350.65	-6027.64***
Fall temperature	2722.04	1440.95
Annual temperature	150.96	-1412.41

* Significant at 10%; *** significant at 1%

Table 11: Marginal impact of temperature on net revenue/ha based on cropped area obtained from Model 4

Net revenue (US\$/ha)	Marginal impact	Marginal impact (with livestock included)
Winter temperature	4109.17	3902.98***
Spring temperature	-107.32	-896.67
Summer temperature	-7068.05	-6547.89***
Fall temperature	2988.43	1704.41
Annual temperature	-77.78	-1837.17

*** Significant at 1%

Table 12: Impact of two climate change scenarios on farm net revenue (without livestock)

Net revenue	Model 1	Model 2	Model 3	Model 4
Under current temperature	-968.94	+26.17	+150.96	-77.78
Under current temperature +1.5°C	-1453.41	+39.26	+226.44	-116.67
Under current temperature +3.6°C	-3488.18	+94.21	+543.46	-280.01

Table 13: Impact of two climate change scenarios on farm net revenue (with livestock)

Net revenue	Model 1	Model 2	Model 3	Model 4
Under current temperature	-1044.28	-1680.14	-1412.40	-1837.20
Under current temperature +1.5°C	-1566.42	-2520.20	-2118.60	-2755.80
Under current temperature +3.6°C	-3759.41	-6048.50	-5084.68	-6613.80

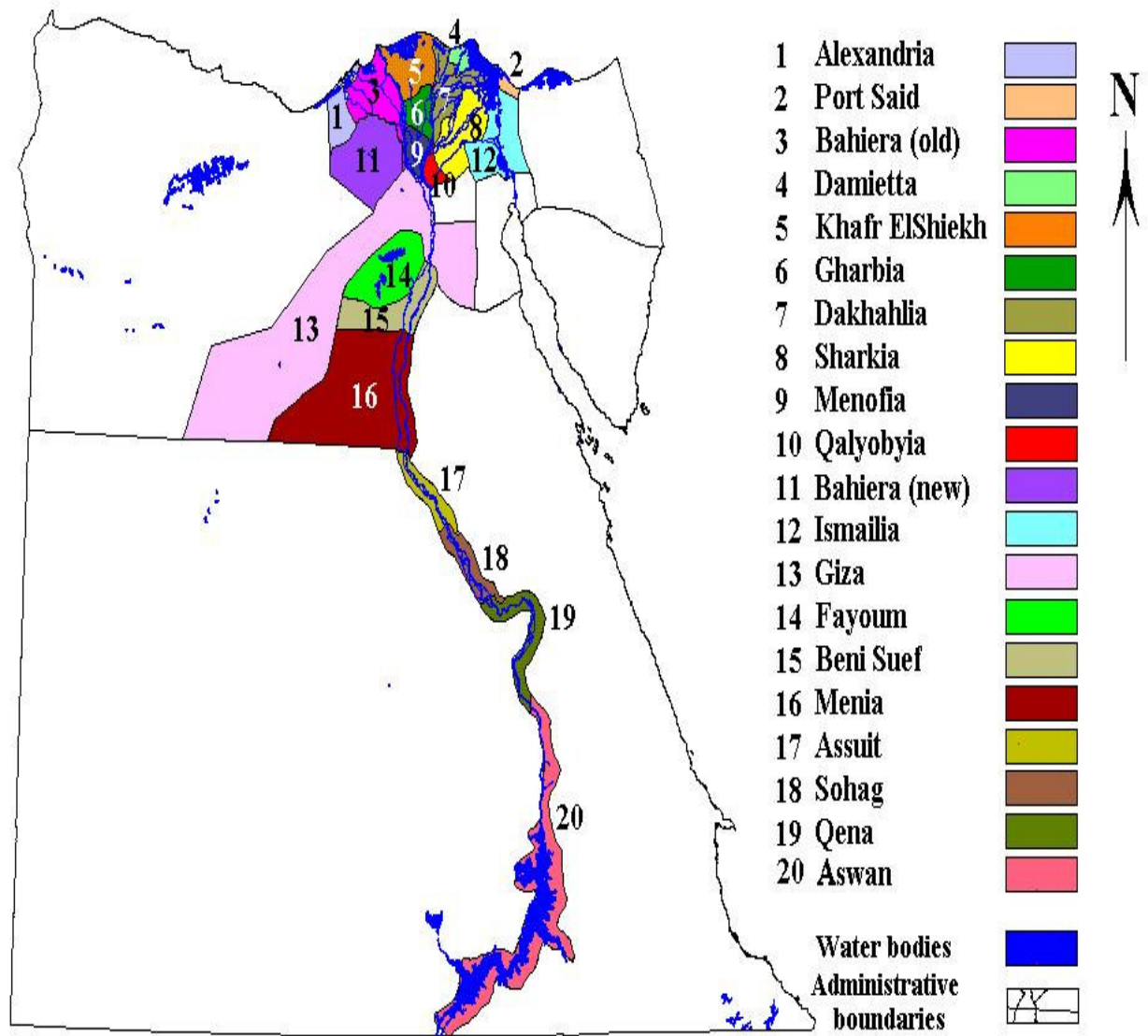
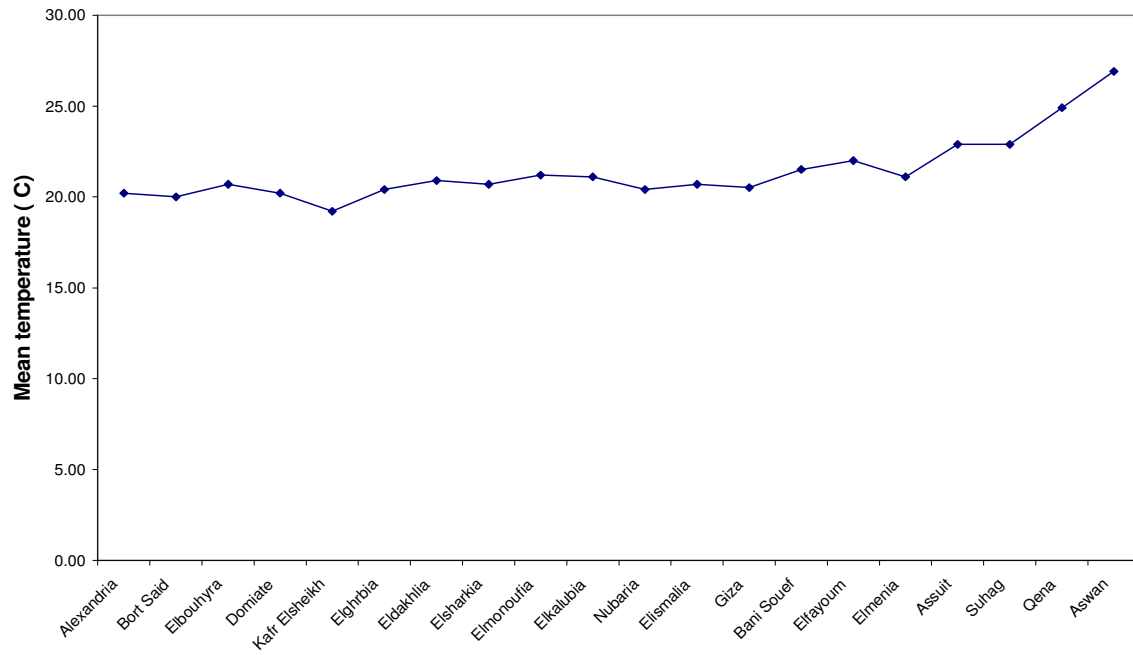
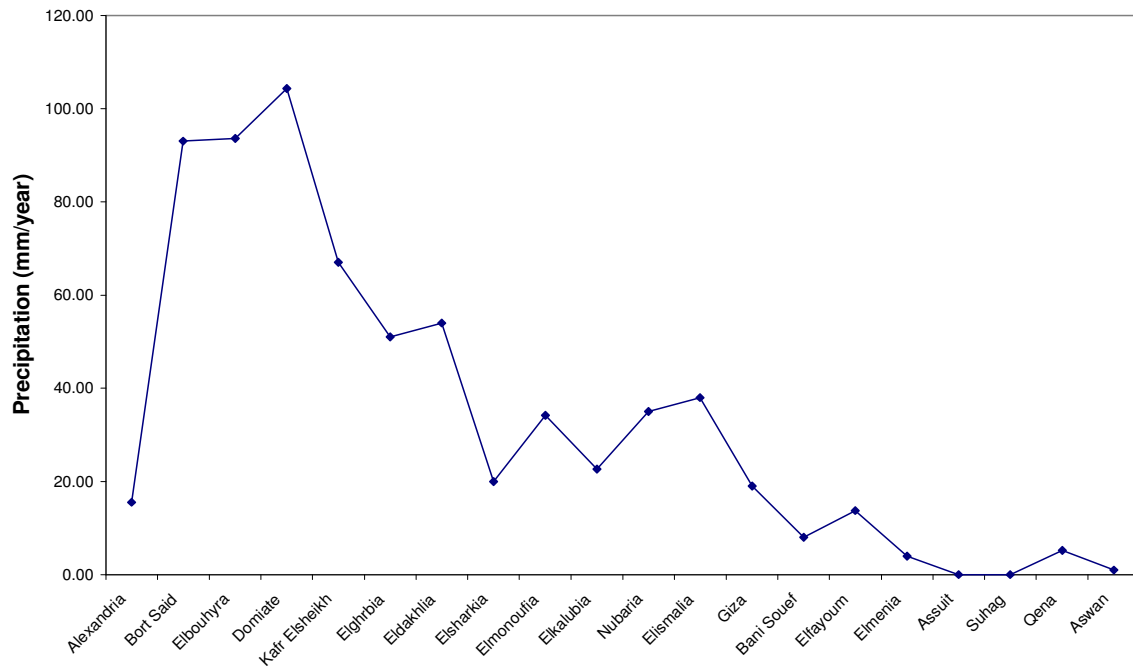


Figure 1: Map of governorates in the agro-ecological zones in Egypt



Source: Egyptian Meteorological Authority

Figure 2: Mean temperature (°C) for the 20 governorates used in the survey from north to south Egypt (normals for 40 years)



Source: Egyptian Meteorological Authority

Figure 3. Precipitation (mm/year) for the 20 governorates used in the survey from north to south Egypt (normals for 40 years)

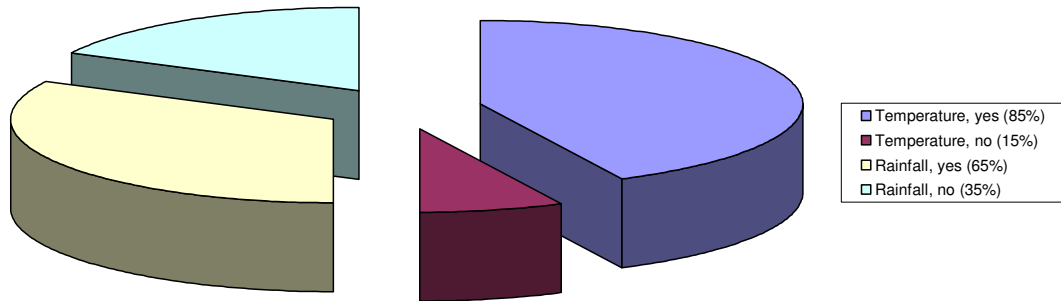


Figure 4: Farmers' perceptions of temperature and rainfall change in Egypt