Economic Impact of Climate Changes on the Production of Some Agricultural Crops in Fayoum Governorate

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Abstract: Climate change, a major local and global concern, poses a huge danger to sustainable development as a result of "global warming." The purpose of this study was to assess the influence of climate change on rice and sugar beet crop production in Fayoum Governorate. The study indicated that: Rice production was directly affected by the minimum temperature by 49 kg/Feddan with a one-degree Celsius increase within permissible limits, and inversely affected by the maximum temperature by 113 kg/Feddan with a one-degree Celsius increase. Sugar beet output was directly impacted by maximum temperature by 138 kg/Feddan with a one-degree Celsius rise within acceptable limits, whereas rainfall had an inverse effect by 109 kg/Feddan with a one-unit increase in rainfall rate. By estimating the economic losses resulting from the impact of climate change on rice and sugar beet production, it was discovered that the productivity of a Feddan of rice and sugar beet crops decreased in 2023 compared to 2022, by an estimated amount of about 0.470 and 1.570 tons/Feddan, respectively. This drop reduced farm revenue by around 5532.03 and 1956.55 pounds per Feddan, respectively.

Keywords: Climate Elements, Weather, Global Warming, Agricultural Productivity.

I. INTRODUCTION

Climate change, primarily driven by global warming, is a significant global issue that threatens sustainable development. It results from imbalances in climate conditions, leading to changes in weather patterns that affect life. These changes are long-term alterations in climate elements within a specific geographical area or globally.

Climate change encompasses shifts in usual climatic conditions, such as temperature, humidity, wind patterns, dust storms, rainfall, sea level, floods, and droughts. These shifts are linked to the increased emission of carbon dioxide (CO_2), a key greenhouse gas, primarily due to human industrial activities reliant on fossil fuels. Misuse of natural resources contributes to environmental imbalance and increased Earth's surface temperature.

Despite contributing only 0.60% to global greenhouse gas emissions in 2022, Egypt is highly vulnerable to climate change impacts due to its geographical features. Increased droughts, heatwaves, and sea-level rise could lead to flooding in coastal and Nile Delta regions.

These changes pose a threat to Egypt's natural resources, particularly land and water, which are relatively scarce. The agricultural sector, crucial for Egypt's food security, is expected to be severely impacted. Climate change could reduce the productivity of key crops like rice and sugar beets by 11% and 8%, respectively, due to increased temperatures and decreased water availability. Additionally, warmer temperatures could increase pests and diseases, damaging crops and threatening agricultural development efforts.

In 2022, rice, a significant cash and export crop in Egypt, was cultivated on approximately 1.15 million Feddans, yielding about 4.30 million tons. In Fayoum Governorate, rice was cultivated on about 4.97 thousand Feddans, yielding about 17.92 thousand tons, representing about 0.43% and 0.41% of the total cultivated area and production, respectively.

In 2022, sugar beet cultivation in Egypt spanned approximately 597.92 thousand Feddans, yielding about 12.53 million tons. In Fayoum Governorate, the cultivated area was about 35.90 thousand Feddans, producing about 672.1 thousand tons. This accounted for about 6.04% and 5.36% of the total cultivated area and production, respectively. Sugar beets contributed significantly to Egypt's total sugar production, accounting for about 63.51% of the 2.48 million tons produced in 2022.

The United Nations Intergovernmental Panel on Climate Change (IPCC) predicts escalating climate change impacts over the next three decades due to severe weather variations. To mitigate these effects on agriculture, adaptation strategies are necessary. These include reducing greenhouse gas emissions, innovating agricultural practices, optimizing planting dates, and advancing scientific research for developing resilient crop varieties. Additionally, improving irrigation systems and implementing good agricultural practices are crucial.

Research Problem: The research problem focuses on the changes in greenhouse gas composition in the atmosphere, driven by human activities and environmentally harmful practices. These changes have disrupted temperature and rainfall patterns. Egypt is expected to be significantly affected by climate change, leading to agricultural risks due to reduced crop productivity and economic losses. By 2030, Egypt's total cultivated area is projected to reach about 11.5 million Feddans, with a per capita share of agricultural resources decreasing by approximately 3.7%. There is a potential loss of 12%-15% of high-quality agricultural land in the Delta region due to submersion or salinization from a half-meter sea-level rise. This poses a threat to Egypt's food security, as the local production volume of some strategic crops is insufficient to meet consumption, leading to a trade deficit. In Fayoum Governorate, farmers are experiencing the adverse effects of climate change on the productivity of rice and sugar beets, impacting their economic return. Therefore, it is crucial to study and estimate the impact of climate change on the production of these crops.

Research Objectives: The primary aim of this research is to estimate the impact of climate changes on the per-Feddan productivity of rice and sugar beet crops in Fayoum Governorate. This will be achieved by pursuing the following sub objectives:

1. Identify the evolution of carbon dioxide emissions in Egypt, as well as the development of various climate variables, such as changes in maximum and minimum temperatures, the rate of relative humidity, and the rate of rainfall in Fayoum Governorate during the period 2005-2022.
2. Investigate the production status of rice and sugar beet crops in Fayoum Governorate during the period 2005-2022.
3. Conduct an econometrics estimation of the impact of the relationship between climate change and per-Feddan productivity of the study crops in Fayoum Governorate.
4. Examine the impact of climate changes on the productivity of the study crops and estimate the magnitude of the resulting economic losses in the study sample.
5. Extrapolate the opinions of farmers regarding the causes and effects of climate changes on agricultural production and their proposals to mitigate the negative effects resulting from these changes in the study sample.

II. Methodology

The research methodology involved descriptive and quantitative analyses to define study variables. Simple linear regression was used to estimate trend equations and regression relationships among variables, calculate percentages and averages, and perform arithmetic analysis. The seasonal index for climate variables was calculated. Standard Multiple Regression (stepwise) was used for quantitative analysis to identify significant climatic factors affecting crop productivity. The most suitable model, consistent with economic and statistical logic, was selected.

Data sources included:

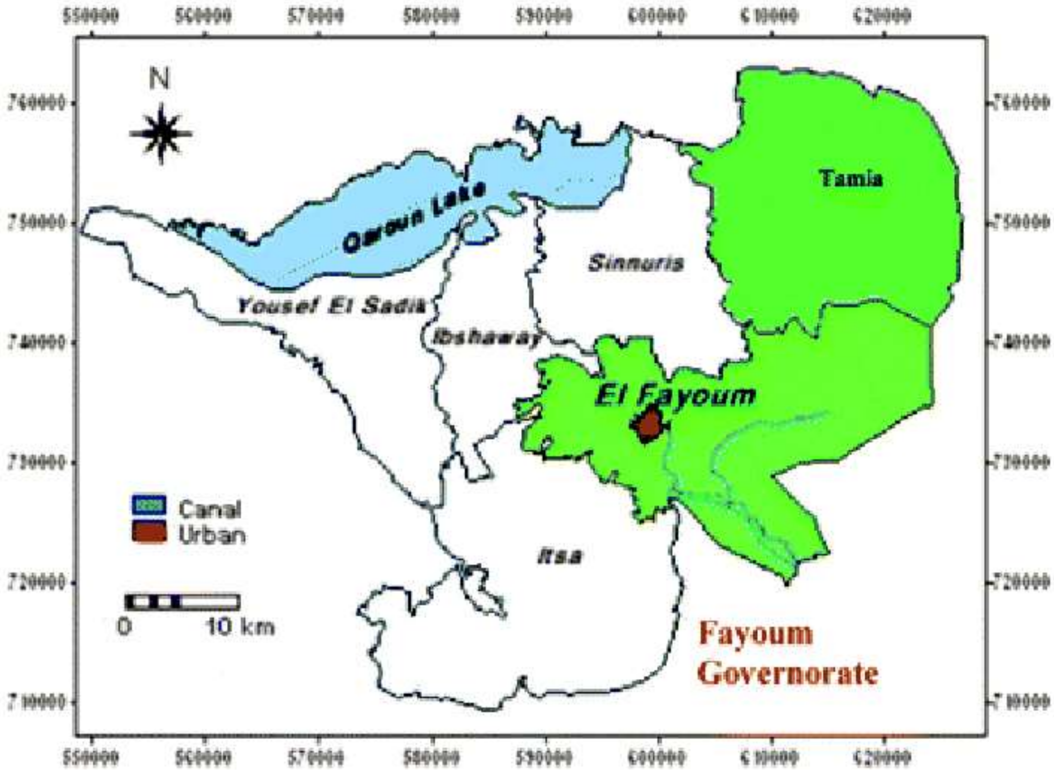
1. Secondary data from various sources such as the Ministry of Agriculture and Land Reclamation, the Central Agency for Public Mobilization and Statistics, the Agricultural Meteorology and Climate Change Research Unit, the International Information Network, the Information and Decision Support Center of the Directorate of Agriculture in Fayoum, and relevant published research, studies, and scientific references.
2. Primary data collected from a sample of farmers in Fayoum Governorate through a specially designed questionnaire and personal interviews conducted in the 2023 season.

Sample Selection for Field Study: To achieve the research objectives, primary data was obtained through a random sample for a field study collected from the original community of the study, who are producers of rice and sugar beets. This covered data for the 2021/2022 and 2022/2023 seasons, given the long-term nature of climate changes. It required information about previous years from farmers with agricultural experience to identify the impact of climate change. Fayoum Governorate includes six administrative centers (Fayoum, Sennurs, Tamiya, Itsa, Abshway, and Youssef Al-Siddiq), was selected to draw the study sample from the centers that represent the governorate. This was done to expose the largest possible agricultural area in the governorate and also understand the climate changes that occur on this cultivated area. Two villages were chosen from each of the centers according to the relative importance of the cultivated area for rice and sugar beet crops. The size of the study sample was determined in light of restricting the data of the (2 services) register to the cooperative societies in the selected villages. Using random tables, farmers were selected for each agricultural cooperative society, with 15 observations for each society. The total sample amounted to about 180 farmers.

Description of the Study Sample Area: The research further explores the geographical characteristics of Fayoum Governorate, situated in Egypt's heart, between the Delta and Upper Egypt in the Western Desert, southwest of Cairo Governorate. It is part of the North Upper Egypt region, surrounded by desert except for its southeast connection to Beni Suef Governorate. Covering an area of 6068.70 square kilometers, it includes six administrative centers: Fayoum, Sennuras, Atsa, Tamia, Ibshway, and Youssef Al-Siddiq.

Fayoum Governorate experiences a hot, dry climate with rare winter rainfall and year-round sunshine. Maximum temperatures in July range between 37-39°C, while winter temperatures vary between 19-23°C (maximum) and 8-10°C (minimum) in January. Relative humidity increases to about 55-63% from December to February due to lower air temperatures and decreases to 47-53% in August due to hot southern winds. These climatic factors are crucial in understanding the impacts of climate change in the region.

Figure (1): An illustrative map of Fayoum Governorate



Source:http://www.fayoum.gov.eg/Lists/List9/Allltems.aspx.

III. Results and Discussion

First: The Evolution of Emissions and Concentrations of Carbon Dioxide (CO2) Causing Climate Change in Egypt During the Period (2005-2022)

Greenhouse gases that contribute to climate change include carbon dioxide, nitrogen oxides, methane, ozone, sulfur dioxide, and chlorofluorocarbons. Given that CO2 is one of the most significant greenhouse gases, the following section will focus on the development of carbon dioxide emissions during the period (2005-2022) by studying their temporal development, in addition to the monthly rates and seasonal index of those emissions.

1. **Evolution of Carbon Dioxide (CO2) Emissions:**

By studying the evolution of the amount of carbon dioxide emissions in Egypt during the period (2005-2022), it was found that it ranged between a minimum of about 130.34 million tons equivalent in 2005, and a maximum of about 208.01 million tons equivalent in 2022, an increase equivalent to about 59.6% over the amount of emissions in 2005. The average amount of emissions during the study period reached about 184.04 million tons equivalent.

2. **Seasonal Record:**

The study of the seasonal index of monthly carbon dioxide (CO_2) emissions in Egypt from 2020 to 2022 revealed that the average CO_2 emissions during this period were approximately 204.91 million tons equivalent. Emissions were above average during February, March, June, August, and September, with average emissions of about 205.04, 204.99, 206.13, 205.04, and 205.57 million tons equivalent, respectively. The seasonal index reached about 100.06, 100.04, 100.60, 100.07, and 100.32, respectively, during these months.

The data also showed variations in CO_2 emissions between different months of each year and throughout the 2020-2022 period. In 2020, the average annual CO_2 emissions were about 201.97 million tons equivalent, which increased to 208.01 million tons equivalent in 2022. This represents an increase of 3.00% and 1.6% compared to 2020 and 2021, respectively. These findings highlight the growing concern of CO_2 emissions and their potential impact on climate change.

Second: The Evolution of Climate Variables in Fayoum Governorate During the Period (2005-2022):

This part deals with the study of climate variables in Fayoum Governorate during the period (2005-2022). These variables include maximum and minimum temperature, relative humidity rate, and rainfall rate, in order to determine their development during that period, as well as their seasonal evidence.

1. **Evolution of Climate Variables:**

- Development of Maximum Temperature:
- The study examined temperature trends in Fayoum Governorate from 2005 to 2022. The maximum temperature varied between a low of approximately 31.86°C in 2018 and a high of about 34.89°C in 2015, representing a 9.51% increase over 2018. The average maximum temperature during this period was about 32.86°C.
- As for the minimum temperature, it ranged from a low of about 15.30°C in 2005 to a high of about 17.80°C in 2012. This represents a 16.34% increase over 2005. The average minimum temperature during the study period was about 16.60°C. These findings highlight the changing temperature patterns in the region, which are crucial for understanding the impacts of climate change.
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Table No. (1) Simple linear regression equations for climate variables in Fayoum Governorate during the period (2005-2022).

Variable	Num	Equation	R^2	F	Annual change rate %
Annual Temperature Average (°C)	1	**$\hat{Y}i$= 96.42 + 0.083 Xi1** (3.42)**	0.42	**11.68	0.33
Annual Rainfall Average (mm/year)	2	**$\hat{Y}i$= 53.28 - 0.022 Xi2** (- 2.87)**	0.37	**8.24	-0.24

Whereas:
Yi = the estimated value of the dependent variables (average temperature, rainfall rate) in year t.
1xi, 2xi = Co2 and temperature factors in years as independent variables in year t, where i = (18, ….., 3, 2, 1).
- The numbers in parentheses below the estimates indicate the calculated (t) value.
(**) indicates significance at the level of (0.01), (*) indicates significance at the level of (0.05), (-) not significant.
Source: Collected and calculated from the data contained in Table No. (1) in the Appendix.

3. **Seasonal Index of Climate Variables.**

- **Seasonal Maximum Temperature Index:**

The study of the seasonal index of maximum temperature in Fayoum Governorate from 2020 to 2022 revealed an average maximum temperature of about 31.90°C. Temperatures exceeded the average during April, May, June, July, August, September, and October, with average temperatures of about 32.35°C, 36.50°C, 39.18°C, 39.76°C, 39.12°C, 37.45°C, and 35.22°C, respectively. The seasonal index reached about 101.41, 114.41, 122.81, 124.62, 122.61, 117.39, and 110.40, respectively, during these months. The data also showed variations in maximum temperatures between different months of each year and throughout the 2020-2022 period. In 2020, the average annual maximum temperature was about 31.36°C, which increased to 32.52°C in 2022, representing a 3.7% increase compared to 2020 and 2021.

As for the minimum temperature, it averaged about 17.35°C during the same period. Temperatures exceeded the average during April, May, June, July, August, September, and October, with average temperatures of about 21.97°C, 22.47°C, 24.63°C, 25.23°C, 22.00°C, and 18.50°C, respectively. The seasonal index reached about 126.58, 129.47, 141.95, 145.41, 126.78, and 106.61, respectively, during these months. The average annual minimum temperature was about 17.27°C in 2020, which increased to 17.56°C in 2022, representing a 1.7% and 3.7% increase compared to 2020 and 2021, respectively. These findings highlight the changing temperature patterns in the region, which are crucial for understanding the impacts of climate change.

- **Seasonal Index of Relative Humidity:**

By studying the seasonal index of relative humidity in Fayoum Governorate during the period (2020-2022), it was found that the average relative humidity rate reached about 52.75%. There was an increase in the relative humidity rate over the average during the months (January, February, September, October, November, December) with an average relative humidity rate of about (57.33, 56.00, 55.00, 54.67, 58.33, 61.00)%, respectively, and a seasonal record number of about (108.69, 106.16, 104.27, 103.63, 110.58, 115.64) respectively. The data also indicates that there is a difference between the relative humidity rate during the period (2020-2022) as well as between the different months of each year, as it was found that the average relative humidity rate for the year 2020 amounted to about 53.42% and decreased to reach 52.92% in 2022, meaning that it decreased by 0.93%, and increased by 2.26% compared to its counterpart in 2020 and 2021, respectively.

- **Seasonal Rainfall Index:**

By studying the seasonal index of rainfall in Fayoum Governorate during the period (2020-2022), it was found that the average rainfall rate reached about 1.89 mm/year. There is an increase in the rainfall rate over the average during the months (January, February, March, December) with an average rainfall rate of about (2.10, 2.46, 2.40, 2.10) mm/year, respectively, and a seasonal record number of about (111.11, 130.2, 126.98, 111.11), respectively.

Third: Development of Productivity Indicators for Rice and Sugar Beet Crops in Fayoum Governorate During the Period (2005-2022)

1. Development of Productivity Indicators for the Rice Crop

- Development of the Cultivated Area:

The cultivated area for rice in Fayoum from 2005 to 2022 varied between a low of approximately 0.391 thousand Feddans in 2015 and a high of about 30.25 thousand Feddans in 2008. This represents an increase of 29.86 thousand Feddanns, or about 7636.6%, over 2015. The average cultivated area during this period was about 9.01 thousand Feddanns.

The general time trend analysis revealed a statistically significant annual decrease in the cultivated area for rice of about 1.44 thousand Feddans, equivalent to about 15.86% of the general average. The coefficient of determination, R^2, indicates that about 54% of the changes in the cultivated area can be attributed to time-related factors. These findings highlight the changing agricultural patterns in the region, which are crucial for understanding the impacts of climate change.

- **Development of Feddanage Productivity:**

The Feddan productivity of the rice crop in Fayoum from 2005 to 2022 varied between a low of approximately 3.00 tons/Feddan in 2021 and a high of about 4.03 tons/Feddan in 2004, representing an increase of 1.03 tons/Feddan, or about 34.3%, over 2021. The average productivity during this period was about 3.60 tons/Feddan.

The general time trend analysis revealed a statistically significant annual decrease in Feddan productivity of about 0.034 tons, equivalent to about 0.94% of the general average. The coefficient of determination, R^2, indicates that about 44% of the changes in Feddan productivity can be attributed to time-related factors. These findings highlight the changing agricultural productivity patterns in the region, which are crucial for understanding the impacts of climate change.

- **Development of Total Production:**

The total production of the rice crop in Fayoum from 2005 to 2022 varied between a low of approximately 1.37 thousand tons in 2015 and a high of about 116.36 thousand tons in 2008. This represents an increase of 114.99 thousand tons, or about 8393.4%, over 2015. The average total production during this period was about 34.85 thousand tons.

The general time trend analysis revealed a statistically significant annual decrease in total rice production of about 5.76 thousand tons, equivalent to about 16.53% of the general average. The coefficient of determination, R^2, indicates that about 56% of the changes in total production can be attributed to time-related factors. These findings highlight the changing agricultural production patterns in the region, which are crucial for understanding the impacts of climate change.

Table No. (2) General time trend equations for the development of cultivated area, per-Feddann productivity, and total production of rice and sugar beets in Fayoum Governorate during the period (2005-2022).

Crop	Variable	Num	General time trend equation	R^2	F	Annual change rate %
Rice	Cultivated Area	1	$\hat{Y}i$ =2909.61 – 1.44 Xi (- 4.62)**	0.54	**21.38	-15.86
	Feddann Productivity	2	$\hat{Y}i$ =71.38 – 0.034 Xi (- 3.73)**	0.44	**13.91	- 0.94
	Total Production	3	$\hat{Y}i$ =11627.5 – 5.76 Xi (- 4.75)**	0.56	**22.58	-16.53
Sugar Beets	Cultivated Area	4	$\hat{Y}i$ =2709.3+ 1.36 Xi (4.80)**	0.56	**23.05	5.54
	Feddann Productivity	5	$\hat{Y}i$ =285.01 + 0.151 Xi (2.87)**	0.31	**8.25	0.82
	Total Production	6	$\hat{Y}i$ =54989.6 + 24.18 Xi (4.92)**	0.57	**24.18	5.23

Whereas:
Yi = the estimated value of the dependent variables (cultivated area, per-Feddan productivity, total production) in year t.
Xi=time factor in years as an independent variable in year t, where i=(18,....,3,2,1).
- The numbers in parentheses below the estimates indicate the calculated (t) value.
(**) indicates significance at the level of (0.01), (*) indicates significance at the level of (0.05), (-) is not significant.
Source: Collected and calculated from the data contained in Table No. (4) in the Appendix.

2. **Analysis of Production Indicators for the Sugar Beet Crop:**

- **Cultivated Area Expansion**: As indicated in Table (2), the cultivated area expanded from 2.10 thousand Feddans in 2003 to 35.91 thousand Feddans in 2015, a 1610% increase. The average cultivated area was 24.53 thousand Feddans. The annual increase was about 1.36 thousand Feddans, or 5.54% of the average, with time-dependent factors accounting for 56% of the variations.
- **Feddanage Productivity Improvement**: Productivity per Feddan ranged from 15.00 tons/Feddan in 2003 to 20.41 tons/Feddan in 2015, a 36.1% increase. The average productivity was 18.45 tons/Feddan. The annual increase was about 0.151 tons, or 0.82% of the average, with time-dependent factors accounting for 31% of the variations.
- **Total Production Increase**: Total production ranged from 31.50 thousand tons in 2003 to 732.91 thousand tons in 2015, a 2226.7% increase. The average total production was 462.34 thousand tons. The annual increase was about 27.55 thousand tons, or 5.23% of the average, with time-dependent factors accounting for 57% of the variations.
- These findings highlight the significant growth and productivity improvements in sugar beet cultivation over the study period.

Fourth: Economitrics Estimation of the Impact of Key Climatic Factors on the Productivity per Feddan of the Study Crops in Fayoum Governorate.

One of the objective of this study is to ascertain the influence of key climatic variables on the per-Feddan productivity of rice and sugar beet crops in Fayoum Governorate during the period 2005-2022. The variables considered include maximum temperature (X_1), minimum temperature (X_2), relative humidity (X_3), and rainfall rate (X_4). These factors are hypothesized to significantly impact the productivity of the aforementioned crops.

The standard multiple regression (stepwise) method was employed to estimate the relationship between the productivity of the crops and the climatic factors. This was done using three mathematical forms: linear, semi-logarithmic, and double logarithmic, with the aim of identifying the most representative formula. Comparisons were made between these mathematical forms based on economic logic and statistical tests. The double logarithmic form was found to be superior in representing the data used for estimation. The statistical analysis was formulated in the mathematical form of the following function:

$$\hat{Y}_{1t} = \boldsymbol{\alpha_0} + \boldsymbol{\beta_1} X_{1t} + \boldsymbol{\beta}_2 X_{2t} + \boldsymbol{\beta}_3 X_{3t} + \boldsymbol{\beta}_4 X_{4t}$$

Whereas:

$\hat{Y}_{1t}$=represents the estimated value of per-Feddan productivity of the crop in thousand tons during the study period t.

X_{1t}= represents the bone temperature during the study period t (°C).

X_{2t} =represents the minimum temperature during the study period t (°C).

X_{3t} =represents the percentage of relative humidity during the study period (%).

X_{4t} =represents the rate of rainfall during the study period (mm).

1- Standard estimation of the impact of the most important climatic factors on rice crop productivity:

By studying the impact of the most important climatic factors on rice crop productivity in Fayoum Governorate during the period (2005-2022), the following equation and results were obtained:

$$\text{Log } \hat{Y}_{1t} = 2.57 - 0.113 \text{Log } X1t + 0.049 \text{ Log } X2t$$

$$^{**}(-3.17) \qquad ^{*}(2.46)$$

$\bar{R}^{2} = 0.57$ F = 4.31**

Whereas:

$\hat{Y}_{1t}$= the estimated value of per-Feddan productivity of rice crop in thousand tons during the study period t.

X_{1t} = bone temperature during the study period t(°C).

X_{2t} = minimum temperature during the study period t (°C).

The numbers in parentheses below the estimates indicate the calculated t value.

**Indicates significance at level (0.01). It indicates significance at the level of (0.05).

Source: Collected and calculated from data in Tables No. (1) and (4) in the appendix.

The results of the estimation for the function presented in the previous equation suggest that the most critical independent variables impacting the per-Feddan productivity of the rice crop during the study period are the maximum temperature. The adjusted coefficient of determination,R^2, is approximately 0.57, implying that about 57% of the variations in per-Feddan productivity can be attributed to changes in the aforementioned independent variables included in the model. The F-value also indicates the overall statistical significance of the model at a significant level of 0.01, with its value being approximately 4.31.

The results of the previous equation also revealed a negative effect (an inverse relationship) between per-Feddan productivity and the maximum temperature. The equation demonstrates a direct relationship between per-Feddan productivity and the minimum temperature (X_2), indicating an increase in per-Feddan productivity by 49 kg/Feddan with an increase in the minimum temperature by one degree Celsius within the permissible limits. However, the statistical significance of the other independent variables was not confirmed. This analysis provides valuable insights into the climatic factors influencing the productivity of rice crops.

2- Economitrics estimation of the impact of the most important climatic factors on sugar beet crop productivity:

By studying the impact of the most important climatic factors on the productivity of the sugar beet crop in Fayoum Governorate during the period (2005-2022), the following equation and results were obtained:

$$\text{Log } \hat{Y}1t = 0.93 + 0.138 \text{Log } X1t - 0.109 \text{ Log } X4t$$

$$^{**}(3.58) \qquad ^{**}(-3.04)$$

$$R^{-2} = 0.42 \qquad F = 8.26^{**}$$

Whereas:

$\hat{Y}_{1t}$=The estimated value of per-Feddan productivity of sugar beet crop in thousand tons during the study period t.

X_{1t} = bone temperature during the study period t(°C).

X_{4t}= rainfall rate during the study period (mm).

The numbers in parentheses below the estimates indicate the calculated t value.

**Indicates significance at level (0.01). It indicates significance at the level of (0.05).

Source: Collected and calculated from data in Tables No. (1) and (4) in the appendix.

The study revealed a direct correlation between per-Feddan productivity and maximum temperature. This is due to the crop's requirement for high temperatures during initial growth stages and lower temperatures towards the end of the growing season for sugar storage. Optimal low temperatures during the harvest months of February and March significantly increase sugar content. Conversely, the study found an inverse relationship between per-Feddan productivity and rainfall rate. Climate change is expected to negatively impact the agricultural sector, affecting the productivity of agricultural land. This begins with alterations to the land's natural, chemical, and biological properties, extends to the proliferation of pests, insects, diseases, and concludes with the impact on crop yield.

Fifth: The impact of climate change on the productivity of agricultural crops and the estimation of the resulting economic losses in the study sample can be summarized as follows:

1. **Expected Impact on Productivity and Water Consumption of the Agricultural Crops Under Study**: The Agricultural Meteorology and Climate Change Research Unit of the Land, Water, and Environment Research Institute at the Agricultural Research Center conducted regionalization experiments. The results of long-range forecasting using simulation models and various climate change scenarios indicate that climate changes and the rise in the Earth's surface temperature will negatively affect the productivity of many Egyptian agricultural crops. This has resulted in a significant decrease in the productivity of most of the main food crops in Egypt, in addition to increasing their water consumption. The results of the acclimatization experiments conducted in this regard were in accordance with future expectations. The productivity and consumption of the agricultural crops under study are expected to be affected by a rise in temperature by about 3.5 degrees Celsius by the year 2050. Specifically:
    - The productivity of the rice crop will decrease by about 11%, and the water consumption of this crop will increase by about 16% compared to its water consumption under current weather conditions.
    - The productivity of the sugar beet crop will decrease by about 8%, and the water consumption of this crop will increase by about 10% compared to its water consumption under current weather conditions.

Impact of Climate Changes on the Production of the Study Crops and Estimating the Size of the Resulting Economic Losses in the Study Sample: Climate changes have impacted the production of crops in Fayoum Governorate, as evidenced by data collected for the 2023/2022 and 2022/2021 seasons. These changes have altered the crop structure, including the cultivated area, per-Feddan productivity, and total production.

- **Productivity Indicators**: Comparing the cultivated area of rice and sugar beet crops in 2023 with 2022, the rice crop saw a 21.64% increase in cultivated area, while the sugar beet crop experienced an 8.9% decrease.
- **Impact on Average Productivity**: Climate change has negatively affected average productivity per Feddan. In 2023 compared to 2022, productivity decreased by 13.02% for rice and 7.98% for sugar beet crops.
- **Impact on Total Production**: In 2023 compared to 2022, total production increased by 5.80% for rice but decreased by 16.16% for sugar beet crops.

These changes have led to an imbalance in the net return per Feddan for farmers, altered the available supply of these crops in the local market affecting consumer prices, and impacted the quantity of exported and imported goods. This has resulted in an imbalance in Egyptian foreign trade and the rate of exports covering imports.

Table No. (3) Productivity indicators and estimation of the size of economic losses based on the variation in Feddan productivity of the study sample crops resulting from the impact of climate changes in Fayoum Governorate, seasonal 2023/2022, 2022/2021.

Year	Indicators	Rice	Sugar beet
2022	Cultivated area (Feddans)(1)	286.15	368.74
	Feddan productivity (tons/Feddan)(2)	3.61	19.67
	Total production (tons)(3)	1033.01	7253.16
2023	Cultivated area (Feddans)(4)	348.07	335.96
	Feddan productivity (tons/Feddan)(5)	3.14	18.10
	Total production (tons)(6)	1092.93	6080.9
*Change Rate	Cultivated area %(7)	21.64	8.9-
	Feddan productivity %(8)	13.02-	7.98-
	Total production %(9)	5.80	16.16-
Productivity differences (tons/Feddan) (10)=(5-(2		0.470	1.570
**Lost production (tons) (11)		149.04	553.2
2022	agricultural price Average ***(pounds/ton)(12)	8851.33	1063.47
2023		14693.48	1428.95
Value of lost production (million pounds)**** ((13)=(11)*(12		1.755	5532.03
Effect on farmer income (pounds/Feddan)***** ((14)=(12)*(10		0.689	1956.55

(*) Change Rate = ((Variable 2022-2023) / Variable 2022) * 100
**To calculate (lost production), the productivity differences were multiplied by the average cultivated area for the two study crops in the years 2022-2023.
***To calculate the average agricultural price, it was estimated per unit crop for the years 2022-2023.
Estimating the loss or gain of the producers of the study crops as a result of climate changes at the sample level is as follows:
The amount of decrease in crop production as a result of climate changes (lost production) = the average cultivated crop area for the two years of the study x (productivity differences), that is, the amount of decrease per Feddan of the crop as a result of climate changes.
*****The value of the loss of crop producers at the sample crop level (the value of lost production) = the amount of decrease in crop production as a result of climate changes
*****The effect on farm income (pounds/Feddan) = productive crops x average farm price
Source: Collected and calculated from data from a field study sample in Fayoum Governorate during the year 2023.

Estimation of Economic Losses Due to Climate Change in the Sample Study: As indicated in table (3), climate change has led to economic losses in Fayoum Governorate's rice and sugar beet production during the 2021/2022 and 2022/2023 seasons.
For rice, a decrease in productivity by approximately 0.470 tons/Feddan was observed in 2023 compared to 2022. Given the average cultivated area of about 317.11 Feddans over the two years, the total decrease in rice production was about 149.04 tons. This resulted in an estimated

loss in agricultural production value of approximately 1.755 million pounds and a negative impact on farmer income of about 5532.03 pounds/Feddan.

For sugar beets, productivity decreased by an estimated 1,570 tons/Feddan in 2023 compared to 2022. With an average cultivated area of about 352.35 Feddans over the two years, the total decrease in sugar beet production was about 553.2 tons. This led to an estimated loss in the value of agricultural production of about 0.689 million pounds and a negative impact on farmer income of about 1956.55 pounds/Feddan. These findings highlight the economic impact of climate change on agriculture.

- **Farmers' Perspectives on the Causes of Climate Change and Proposed Solutions in the Sample Study in Fayoum Governorate:**

  This section aims to identify the primary causes of climate change from the perspective of the respondents in the sample study in Fayoum Governorate, and their proposed solutions to mitigate its negative effects on the agricultural sector. The data was collected over the 2021/2023 and 2022/2021 seasons.

Farmers' Perspectives on the Causes of Climate Change: Data in Table No. (4) presents the farmers' perspectives on the causes of climate change in the field study sample in Fayoum Governorate in 2023. The first axis deals with the sources of climate change and includes five elements that contribute to climate change, arranged according to their relative importance. The burning of agricultural waste was identified as the primary cause, with a relative frequency of about 86.70% of the total frequency of the sample. Car exhaust was the second most significant cause, with a relative frequency of about 75%. The removal of trees was the third cause, with a relative frequency of about 67.80%. Factory smoke was the fourth cause, with a relative frequency of about 53.33%. Other sources, which include the excessive use of pesticides and natural disasters, were the fifth and final cause, with a relative frequency of about 32.22%.

The second axis dealt with the impact of temperature change on agricultural production. It includes two elements: the first confirms the effect of temperature change on agricultural production with a relative frequency of 91.1%, and the second represents the percentage of those who did not confirm that effect, with a relative frequency of 8.9% of the total sample observations. Third axis: manifestations of the impact of temperature changes on agricultural production this axis includes seven elements, arranged according to their relative importance. The decline in agricultural production was the most significant manifestation, with a relative frequency of about 88.9% of the total frequencies of the sample. The delay or cessation of growth was the second most significant manifestation, with a relative frequency of about 82.22%. Other manifestations included plant wilting and flower fall (74.4%), infection with diseases (63.9%), increased irrigation operations (49.4%), stock decay (33.9%), and increased use of pesticides (26.11%).

Fourth axis: source of knowledge of temperatures and weather conditions This axis includes six elements, arranged according to their relative importance. Knowledge via television was the primary source, with a relative frequency of about 87.8% of the total frequencies of the sample. Other sources included knowledge via radio (65%), through neighbors (46.7%), via the Internet (38.3%), through feeling the atmosphere (29.4%), and through newspapers (22.8%).

Fifth axis: means of controlling temperatures this axis includes six elements, arranged according to their relative importance. Reducing the intervals between watering was the primary means, with a relative frequency of about 90.55% of the total frequencies of the sample. Other means included greenhouse agriculture (83.33%), increasing the irrigation rate (76.11%), increasing municipal fertilization (63.33%), expanding the cultivation of wood forests and trees (46.11%), and other methods (28.9%).

Farmers have observed that recent climate changes are abnormal deviations from natural patterns. These changes include temperature fluctuations, such as frequent heat and cold waves, high relative humidity, heavy to torrential rains, increased summer droughts, strong winds, and sandstorms. These changes occur at unexpected times, resulting in phenomena like heat waves in February (winter) and rain in May. Plants exposed to a wide temperature range during growth may mature prematurely, and their production may decline or they may die if temperatures exceed certain thresholds. The most vulnerable stages for crops are pre-flowering, flowering, fruit setting, and maturity.

Table No. (4) Farmers' opinions regarding the causes of the problem of weather change in the study sample in Fayoum Governorate, seasonal 2022/2023, 2022/2021.

Axis/element	Frequencies	Relative %importance	Axis/element	Frequencies	Relative %importance
(Sources of climate change) (1)			Information Source of temperatures and)(4) (weather conditions		
Burning agricultural waste	156	86.70	Television	158	87.8
Automobile exhaust	135	75.00	the radio	117	65.00
Tree removal	122	67.80	Neighbors	84	46.7
Factory smoke	96	53.33	Internet	69	38.3
Another	58	32.22	Feeling the atmosphere	53	29.4
Change in temperature affects agricultural)(2) (production			Newspaper	41	22.8
Yes	164	91.1	(means of temperature control)(5)		
No	16	8.9	Reducing the intervals between irrigations	163	90.55
Manifestations of the impact of temperature)(3) (change on agricultural production			Planting in the greenhouse	150	83.33
production decrease	160	88.9	Increase irrigation rate	137	76.11
Stopped or delayed growth	148	82.22	Increase municipal fertilization	114	63.33
Plant wilting and flowers falling	134	74.4	Planting wood forests and trees	83	46.11
Having Diseases	115	63.9	Another	52	28.9
Increase irrigation operations	89	49.4			
Stock decay	61	33.9			
Increased use of pesticides	47	26.11			

Source: Collected and calculated from data from the questionnaire form for the study sample in 2023.

- **Farmers' Opinions and Suggestions to Mitigate the Impact of Climate Change in the Sample Study** This section identifies the opinions and suggestions of farmers to mitigate the impact of climate change in the sample study in Fayoum Governorate. The suggestions are divided into two categories: those for high temperatures and those for low temperatures, as shown in Table No. (5).
- **Suggestions for High Temperatures** The farmers' suggestions to mitigate the impact of high temperatures were divided into ten proposals, arranged according to their relative importance. The most common suggestion was to increase irrigation operations, with a relative frequency of about 87.8% of the total frequencies of the sample. Other suggestions included foliar fertilization (69.4%), planting windbreaks and trees (53.9%), using new breeds (46.7%), preventing the burning of waste (43.9%), early planting (32.2%), planting in greenhouses (25.6%), planting at appropriate times (23.3%), biological resistance (15%), and pesticide spraying (7.8%).
- **Suggestions for Low Temperatures** The farmers' suggestions to mitigate the impact of low temperatures were divided into nine proposals, arranged according to their relative importance. The most common suggestion was to reduce irrigation operations, with a relative frequency of about 78.9% of the total frequencies of the sample. Other suggestions included increasing municipal fertilization rates (73.9%), greenhouse agriculture (65.6%), heating with rice straw (45%), planting windbreaks (41.11%), early planting (29.9%), using new strains (20.6%), planting on schedule (16.11%), and pesticide spraying (12.8%).

- **Table No. (5) Farmers' opinions and suggestions to reduce the problem of weather change in the study sample in Fayoum Governorate, seasons 2022/2023, 2022/2021.**

Element / Axes	Frequencies	Relative Importance %	Element / Axes	Frequencies	Relative Importance %
Farmers' proposals to resist rising (1) temperatures			Farmers' proposals to resist falling (2) temperatures		
Increase irrigation operations	158	87.8	Reduce irrigation operations	142	78.9
Foliar fertilization	125	69.4	Increase municipal fertilization	133	73.9
Planting windbreaks and trees	97	53.9	Agriculture in greenhouses	118	65.6
Use of new strains	84	46.7	Heating with rice straw	81	45.00
Prevent burning of waste	79	43.9	Planting windbreaks	74	41.11
Early agriculture	58	32.2	Early Planting	52	28.9
Agriculture in greenhouses	46	25.6	Use of new strains	37	20.6
Planting at the appropriate times	42	23.3	Planting at the appropriate times	29	16.11
Bioresistance	27	15.00	Spraying with pesticides	23	12.8
Spraying with pesticides	14	7.8			

- **Source:** Collected and calculated from data from the questionnaire form for the study sample in 2023.

Based on the study results, the following recommendations are proposed to mitigate the impacts of climate change on agriculture in Fayoum Governorate:

1. **Climate Adaptation**: Develop new rice and sugar beet varieties resistant to climate changes. Adapt these crops to new weather conditions and adjust planting dates. Cultivate dry rice varieties that consume less water, saving about 30% of irrigation water.
2. **Early Planting**: Plant sugar beet crops early, from mid-August to mid-September. This promotes rapid, strong germination and prevents insect infestation. The crop requires temperatures between 20-30°C for growth and root formation, and 10-20°C for sugar storage.

3. **Agricultural Extension**: Enhance the educational role of agricultural extension to inform farmers about important agricultural practices. This includes appropriate planting times, reducing irrigation water losses, and raising awareness about the dangers of air pollution and climate change.
4. **Reducing Negative Effects**: Collaborate with individuals and community institutions to reduce the negative effects of climate change. This includes reducing car exhausts, factory fumes, and irrigation machines to lower air pollution rates.
5. **Crop Protection**: Protect crops from temperature changes using straw or burlap in the summer and plastic covers in the winter.
6. **Environmentally Friendly Technology**: Promote the use of environmentally friendly technology in agriculture. This includes early agricultural warning systems for sudden climate changes, expanding green economy projects, and using renewable energy sources to reduce carbon emissions.
7. **Support for Farmers**: Provide financial and in-kind support to farmers to help them cope with the negative effects of climate change.
8. **Role of the Agricultural Sector**: Enhance the role of the agricultural sector in reducing its contribution to carbon dioxide emissions. This can be achieved by improving soil fertilization, adding amendments, plowing the soil, managing water, expanding the cultivation of wood forests, and afforestation projects.

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Appendices

Table No. (1) Evolution of the amount of Egypt's carbon dioxide emissions and climate variables in Fayoum Governorate during the period (2005-2022).

Years	Quantity of Egypt's carbon emissions (in million tons (equivalent	Bone temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall rate (mm/year)
2005	130.34	33.15	15.30	54	7.6
2006	139.11	32.55	15.94	55	11.5
2007	147.68	34.70	16.85	55	11.1
2008	155.04	33.60	15.90	57	8.9
2009	162.71	32.47	17.75	54	7.5
2010	174.60	34.34	15.60	55	7.8
2011	181.95	31.55	16.66	51	9.5
2012	187.73	31.87	17.80	53	10.7
2013	196.90	33.96	16.55	56	8.8
2014	197.14	31.57	15.90	53	7.1
2015	201.34	34.89	17.47	52	11.3
2016	206.20	33.71	16.63	54	8.4
2017	209.96	33.18	15.87	53	7.3
2018	206.75	31.15	15.36	55	7.6
2019	199.90	33.13	17.33	53	8.4
2020	201.97	31.36	17.27	53	10.1
2021	204.74	31.83	16.94	52	9.8
2022	208.01	32.52	17.56	53	9.4
Average	184.04	32.86	16.60	53.78	9.04

Source: Collected and calculated from data from the Central Agency for Public Mobilization and Statistics, Annual Statistical Book, Annual Bulletin of Environmental Statistics, (Part Two), Environmental Quality and Energy, various issues.

Table No. (2): Seasonal index of monthly carbon dioxide emissions in Egypt during the period (2020-2022).

Months	2020	2021	2022	Monthly Average	Seasonal guide
January	201.36	205.43	207.65	204.81	99.95
February	202.07	204.56	208.49	205.04	100.06
March	202.66	205.14	207.16	204.99	100.04
April	201.71	204.31	207.52	204.51	99.81
May	201.91	204.42	208.34	204.89	99.99
June	203.27	206.2	208.93	206.13	100.60
July	200.05	204.25	207.83	204.04	99.58
August	202.91	203.33	208.89	205.04	100.07
September	203.73	204.26	208.71	205.57	100.32

October	201.94	203.54	207.88	204.45	99.78
November	200.42	205.35	208.49	204.75	99.92
December	201.59	206.14	206.24	204.66	99.88
Average	201.97	204.74	208.01	204.91	100

Source: Collected and calculated from data from the Central Agency for Public Mobilization and Statistics, Annual Statistical Book, Annual Bulletin of Environmental Statistics, (Part Two), Environmental Quality and Energy, various issues.

Table No. (3): Seasonal index of climate variables in Fayoum during the period (2020-2022).

Months	**Bone temperatures (°C)**			**seasonal guide**	**seasonal guide**	**Minimum temperatures (°C)**			**Monthly average**	**Seasonal Guide**
	2020	2021	2022			2020	2021	2022		
January	21.3	22.2	22.68	22.06	69.15	8.3	8.6	8.6	8.60	49.56
February	22.6	22.3	22.97	22.62	70.91	9.2	9.5	9.8	9.70	55.90
March	25.6	25.3	25.76	25.55	80.10	12.4	12.3	12.4	12.37	71.26
April	28.7	33.51	34.85	32.35	101.41	14.1	14.4	14.7	14.60	84.13
May	33.9	37.7	37.9	36.50	114.41	21.9	22.1	21.9	21.97	126.58
June	38.9	38.7	39.94	39.18	122.81	22.5	22.4	22.5	22.47	129.47
July	39.8	39.64	39.83	39.76	124.62	24.3	24.5	24.7	24.63	141.95
August	38.5	39.00	39.85	39.12	122.61	25.2	24.5	25.6	25.23	145.41
September	37.8	37.6	36.95	37.45	117.39	22.1	21.2	22.4	22.00	126.78
October	36.1	33.67	35.89	35.22	110.40	18.2	18.1	18.7	18.50	106.61
November	29.00	29.6	29.73	29.44	92.29	17.4	16	17.8	17.20	99.12
December	24.1	22.79	23.87	23.59	73.93	11.3	9.2	11.6	10.80	62.24
Average	31.36	31.83	32.52	31.90	100	17.27	16.94	17.56	17.35	100
Months	**Relative humidity %rate**			**Monthly average**	**Seasonal Guide**	**Rainfall rate (mm)**			**Monthly average**	**Seasonal Guide**
	2020	2021	2022			2020	2021	2022		
January	58	58	56	57.33	108.69	2.5	-	1.7	2.10	111.11
February	54	56	58	56.00	106.16	2.3	2.9	2.2	2.46	130.2
March	54	50	53	52.33	99.21	1.8	3.9	1.5	2.40	126.98
April	48	43	47	46.00	87.20	-	-	1.4	1.40	74.1

May	43	46	44	44.33	84.04	-	-	-	-	-
June	53	43	51	49.00	92.89	-	-	-	-	-
July	52	46	49	49.00	92.89	-	-	-	-	-
August	53	47	50	50.00	94.79	-	-	-	-	-
September	58	53	54	55.00	104.27	-	-	-	-	-
October	56	55	53	54.67	103.63	-	-	-	-	-
November	55	61	59	58.33	110.58	1.3	0.1	1.4	0.93	49.21
December	59	63	61	61.00	115.64	2.2	2.9	1.2	2.10	111.11
Average	53.42	51.75	52.92	52.75	100	2.52	2.45	2.35	1.89	100

Source: Collected and calculated from data from the Central Agency for Public Mobilization and Statistics, Annual Statistical Book, Annual Bulletin of Environmental Statistics, (Part Two), Environmental Quality and Energy, various issues.

Table No. (4) Development of the cultivated area, per-Feddan productivity, and total production of rice and sugar beets in Fayoum Governorate during the period (2005-2022).

Years	**Rice**			**Sugar beet**		
	Cultivated area thousand) (Feddans	**Feddan productivity) tons/Feddan (**	**Total production thousand) (tons**	**Cultivated area thousand) (Feddans**	**Feddan productivity) tons/Feddan (**	**Total production thousand) (tons**
2005	20.24	3.92	79.33	6.78	18.37	124.56
2006	24.48	3.91	95.88	12.65	18.48	233.97
2007	28.01	3.87	108.61	24.58	19.82	487.38
2008	30.25	3.82	116.36	20.98	16.20	340.02
2009	1.57	3.41	5.35	20.56	15.49	318.46
2010	1.24	3.63	4.50	30.45	16.62	506.03
2011	0.813	3.37	2.74	31.74	18.12	575.38
2012	0.746	3.87	2.89	27.22	19.20	522.86
2013	1.45	3.72	5.41	30.05	19.85	596.72
2014	1.83	3.33	6.08	32.17	19.99	643.1
2015	0.391	3.50	1.37	35.91	20.41	732.91
2016	2.69	3.51	9.47	35.80	20.28	726.1
2017	1.38	3.10	4.28	30.82	19.45	599.61
2018	0.479	3.14	1.51	18.49	19.39	358.71
2019	3.55	3.48	12.39	35.25	19.14	674.70
2020	2.68	3.81	7.18	27.02	18.65	504.14
2021	1.81	3.00	5.44	28.01	18.94	530.58
2022	4.97	3.60	17.92	35.90	18.72	672.1
Average	9.08	3.60	34.85	24.53	18.45	462.34

Source: Collected and calculated from data from the Ministry of Agriculture and Land Reclamation, Central Administration for Agricultural Economics, Bulletin of Agricultural Statistics, various issues.