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The Effect of Climate Change on Wheat and Maize Crops in Egypt

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Abstract: The research aimed to identify the development of each of the maximum and minimum temperature and relative humidity of the winter and summer seasons in Egypt and their stability during the period (2000-2021), and the extent of the impact of this development on the feddan productivity of wheat and maize crops in Egypt, and the consequent economic effects. Among the results, the productivity of a feddan of wheat crop decreased by 0.05 tons, with an increase in the maximum temperature in the winter season by one degree Celsius, The productivity of a feddan of the wheat crop decreased by 0.06 tons, with an increase in the minimum temperature in the winter season by one degree Celsius, It also showed a decrease in productivity, The feddan of the wheat crop increased by 0.02 tons, with an increase in relative humidity in the winter season by 1%. The results also showed a decrease in the productivity of the feddan of the maize crop by 0.06 tons, with an increase in the maximum temperature in the summer season by one degree Celsius, and the productivity of the feddan crop decreased. maize by 0.05 tons, with an increase in the minimum temperature in the summer season by one degree Celsius. It also showed a decrease in the productivity of a feddan of maize crop by 0.03 tons, with an increase in relative humidity in the summer season by 1%. The study recommended an increase in spending on agricultural research to develop cultivars. New crops that are able to adapt to climate changes, the Agricultural Extension Agency raises the level of awareness of wheat and maize farmers in order to take the necessary measures to confront climate changes by holding training courses for them, and reconsider changing the planting dates of the two crops in proportion to providing them with climatic needs.

Keywords: Maximum Temperature, Minimum Temperature, Relative Humidity, Winter Season, Summer Season, Coefficient of Instability, Ivanov Evaporation Equation

1. Introduction

The phenomenon of climate change is considered one of the greatest challenges facing humanity in the world, and it is defined as an imbalance in the usual climatic conditions such as heat, humidity, wind and rain that characterize every region on the earth [17], as well as a rise in the temperature of the atmosphere surrounding the earth due to the accumulation of carbon dioxide, methane and nitrous oxide gases, which are What are known as greenhouse gases [9], which are the gases that make the atmosphere trap part of the sun's energy needed to warm the globe, and when these gases exceed a certain limit, the trapped part of the sun's energy increases, which increases the temperature [6].

Egypt is located geographically within the Mediterranean region, whose climate over thousands of years was one of the most stable climates in the world's regions [2], and with the occurrence of what is called climate change and the occurrence of severe climatic upheavals in Egypt's climate [8], a state of sharp climatic fluctuations began to prevail, such as a very short, very cold winter. And a short spring interspersed with more fierce fifty years, a long, sweltering summer, and unseasonal rains that extend and penetrate into the summer months, and their penetration increases with the passing of the years [10].

2. The Study Problem

Given the role of the climate in providing a suitable environment for growing agricultural crops [12], whether winter or summer, according to the need of each crop in terms of heat and moisture, in order to give the best feddan productivity for it, and in light of the climatic changes that swept all countries of the world, including Egypt [4], the matter necessitated a study of the impact of these changes climate on the feddan productivity of wheat and maize crops in Egypt, where the wheat crop is one of the most important winter crops [13], with an area of about 3.21 million feddans, representing about 44.90% of the total area of winter crops, which is about 7.15 million feddans for the average period (2017-2021), While the maize crop is considered one of the most important summer crops [19], with an area of about 2.24 million feddans, representing about 33.38% of the total area of summer crops, which is about 6.71 million feddans for the average of the same period [15].

3. Objectives of the Study

The research aims to identify the development of each of the maximum and minimum temperature and relative humidity of the winter and summer seasons in Egypt and their stability during the period (2000-2021), and the extent of the impact of this development on the productivity of the feddan crops of wheat and maize in Egypt, and the economic implications of that.

4. Research Method and Data Sources

To achieve its objectives, the study relied on the two methods of descriptive and quantitative analysis to analyze the data related to the subject of the study through the use of some mathematical and statistical methods such as arithmetic averages, percentages [14], and the regression analysis method to estimate both the general time trend and multiple regression equations, and the instability coefficient and the Ivanov evaporation equation were used.

The study used secondary statistical data for the time period (2000-2021) available from the Central Department of Agricultural Economics of the Ministry of Agriculture and Agricultural Reclamation, and the Egyptian Meteorological Authority of the Ministry of Civil Aviation, in addition to scientific references related to the subject of the study.

5. Results

Before studying climatic changes, it is necessary to first identify the productive indicators of wheat and maize crops in Egypt, which helps to give an accurate view of the development of the phenomena associated with the two crops, and sheds light on the changes that occurred in them during the study period [20]. In the following, we will learn about the development of these phenomena:

5.1. The Evolution of Some Production Phenomena of the Wheat Crop in Egypt During the Period (2000-2021)

5.1.1. Evolution of the Cultivated Area

By studying the development of the area cultivated with the wheat crop in Egypt during the period (2000-2021), it was found from the data of Table 1 that it fluctuated up and down during the study period between a minimum of about 2.34 million feddan in 2001, and a maximum of about 3.47 million feddan in 2015, i e. an increase rate of about 48.29% over the minimum, and about 37.67% over the average area cultivated with wheat in Egypt, which is estimated at about 3.00 million feddans.

By estimating the general time trend equation for the area cultivated with the wheat crop in Egypt, it is clear from Table 2 that there is a statistically significant annual increase of about 0.05 million feddan annually, representing about 1.67% of the annual average of about 3.00 million feddans. The coefficient of determination (R^2) estimated By about 0.71, indicating that 71% of the changes occurring in the area cultivated with the wheat crop in Egypt are due to the influence of factors reflected by the element of time.

5.1.2. The Development of Feddan Productivity

By studying the development of the feddan productivity of the wheat crop in Egypt during the period (2000-2021), it was found from the data of Table 1 that it fluctuated up and down during the study period between a minimum of about 2.39 tons per feddan in 2010, and a maximum of about 2, 88 tons per feddan in 2017 and 2021, an increase rate of about 20.50% over the minimum, and about 17.95% over the average productivity per feddan of the wheat crop in Egypt, which is estimated at about 2.73 tons per feddan.

By estimating the equation of the general time trend of the per- feddan productivity of the wheat crop in Egypt, it is clear from Table 2 that the per- feddan productivity of the wheat crop in Egypt has increased by an annual rate that has not been statistically proven.

5.1.3. The Development of Aggregate Production

By studying the development of the total production of the wheat crop in Egypt during the period (2000-2021), it was found from the data of Table 1 that it fluctuated up and down during the study period between a minimum of about 6.25 million tons in 2001, and a maximum of about 9.85 million tons in 2021, i e. an increase rate of about 57.60% over the minimum, and about 43.96% over the average total production of the wheat crop in Egypt, which is estimated at about 8.19 million tons.

By estimating the general time trend equation for the total production of the wheat crop in Egypt, it was found from Table 2, that there is a statistically significant annual increase of about 0.14 million tons annually, representing about 1.71% of the annual average of about 8.19 million tons. The coefficient of determination (R^2) indicates It is estimated at 0.69, indicating that 69% of the changes in the total production of the wheat crop in Egypt are due to the influence of factors reflected by the time factor.

5.2. The Evolution of Some Production Phenomena of the Maize Crop in Egypt During the Period (2000-2021)

5.2.1. Evolution of the Cultivated Area

By studying the development of the area cultivated with the maize crop in Egypt during the period (2000-2021), it was found from the data of Table 1 that it fluctuated up and down during the study period between a minimum of about 1.66 million feddans in 2003, and a maximum of about 2.34 million feddans in 2018, an increase rate of about 40.96%.

Table 1. *The evolution of some production phenomena of wheat and maize crops in Egypt during the period (2000-2021).*

Year	wheat crop			Maize crop		
	Cultivated area (million feddans)	Average productivity of feddan (tons)	Total production (million tons)	Cultivated area (million feddans)	Average productivity of feddan (tons)	Total production (million tons)
2000	2.46	2.67	6.58	1.68	3.36	5.64
2001	2.34	2.67	6.25	1.77	3.44	6.09
2002	2.45	2.70	6.62	1.67	3.40	5.68
2003	2.51	2.73	6.84	1.66	3.43	5.69
2004	2.61	2.76	7.19	1.68	3.47	5.83
2005	2.99	2.73	8.15	1.94	3.54	6.87
2006	3.06	2.70	8.27	1.71	3.60	6.16
2007	2.72	2.72	7.38	1.78	3.45	6.14
2008	2.92	2.73	7.97	1.86	3.39	6.31
2009	3.15	2.71	8.53	1.98	3.36	6.65
2010	3.00	2.39	7.17	2.00	3.14	6.28
2011	3.05	2.75	8.38	1.76	3.35	5.90
2012	3.16	2.78	8.79	2.16	3.34	7.21
2013	3.38	2.80	9.46	2.14	3.32	7.10
2014	3.39	2.74	9.30	2.19	3.31	7.25
2015	3.47	2.77	9.61	2.26	3.12	7.05
2016	3.35	2.79	9.35	2.21	3.25	7.18
2017	2.92	2.88	8.41	2.30	3.33	7.66
2018	3.16	2.64	8.33	2.34	3.18	7.44
2019	3.13	2.73	8.54	2.15	3.24	6.97
2020	3.40	2.68	9.11	2.15	3.30	7.10
2021	3.42	2.88	9.85	2.25	3.32	7.47
average	3.00	2.73	8.19	1.98	3.35	6.62

Source: Collected and calculated from the data of the Ministry of Agriculture and Land Reclamation, Economic Affairs Sector, Bulletin of Agricultural Statistics, separate issues.

Over the minimum and about 34.34% over the average area cultivated with maize in Egypt, which is estimated at about 1.98 million feddans.

By estimating the general time trend equation for the area cultivated with maize crop in Egypt, it is clear from Table 2 that there is a statistically significant annual increase of about 0.03 million feddans annually, representing about 1.52% of the annual average of about 1.98 million feddans, and the coefficient of determination (R^2) indicates It is estimated at 0.80, indicating that 80% of the changes in the cultivated area of the maize crop in Egypt are due to the influence of factors reflected by the time factor.

Table 2. *Equations for the general time trend of the development of some productive phenomena for wheat and maize crops in Egypt during the period (2000-2021).*

The crop	Phenomenon	The equation	(R^2)	(F)	average	(٪)
	cultivated area (million feddans)	$Y_i = 2.48 + 0.05 X_i$ (6.91) **	0.71	47.79**	3.00	1.67
Wheat	feddan productivity (ton)	Yi = 2.68 + 0.004 Xi (1.37)	0.09	1.87	2.73	-
	total production (million tons)	Yi = 6.61 + 0.14 Xi (6.70) **	0.69	44.85**	8.19	1.71
	cultivated area (million feddans)	Yi = 1.61 + 0.03 Xi (8.86) **	0.80	78.41**	1.98	1.52
Maize	feddan productivity (ton)	Yi = 3.48 – 0.01 Xi (-3.65) **	0.40	13.33**	3.35	0.29
	total production (million tons)	Yi = 5.62 + 0.09 Xi (7.39) **	0.73	54.58**	6.62	1.36

Where: Yi = denotes the estimated value of the phenomenon.
Xi = the time factor, where E = (1, 2, 3,....., 22) in years.
( ) The value in brackets below the regression coefficients expresses the calculated (t) value.
** Significant at a significance level of 0.01.
Source: Collected and calculated from the data of Table 1.

5.2.2. The Development of Feddan Productivity

By studying the development of the feddan productivity of the maize crop in Egypt during the period (2000-2021), it was found from the data of Table 1 that it fluctuated up and down during the study period between a minimum of about 3.12 tons per feddan in 2015, and a maximum of about 3.60 tons per feddan in 2006, i e. an increase rate of about 15.38% over the minimum, and about 14.33% over the average productivity per feddan of the maize crop in Egypt, which is estimated at about 3.35 tons per feddan.

And by estimating the general time trend equation for the feddan productivity of the maize crop in Egypt, it was found from Table 2 that there is a statistically significant annual decrease of about 0.01 tons per feddan annually, which represents about 0.29% of the annual average of about 3.35 tons per feddan, and the coefficient of determination (R^2) indicates It is estimated at 0.40, indicating that 40% of the changes occurring in the cultivated area of the maize crop in Egypt are due to the influence of factors reflected by the time factor.

5.2.3. The Development of Aggregate Production

By studying the development of the total production of the maize crop in Egypt during the period (2000-2021), it was found from the data of Table 1 that it fluctuated up and down during the study period between a minimum of about 5.64 million tons in 2000, and a maximum of about 7.66 million tons in 2017, an increase rate of about 35.82% over the minimum, and about 30.51% over the average total production of the maize crop in Egypt, which is estimated at about 6.62 million tons.

By estimating the general time trend equation for the total production of the maize crop in Egypt, it was found from Table 2 that there is a statistically significant annual increase of 0.09 million tons annually, representing about 1.36% of the annual average of about 6.62 million tons. The coefficient of determination (R^2) and the estimated By about 0.73, indicating that 73% of the changes in the total production of the maize crop in Egypt are due to the influence of factors reflected by the element of time.

Second: The evolution of the most important climate elements for the winter and summer seasons in Egypt during the period (2000-2021):

The maximum and minimum temperature and relative humidity are among the most important elements of the climate for the winter and summer seasons [1]. Relative humidity is a term used to express the mass of water vapor present in a specific mass of air relative to the mass of water vapor needed to saturate the same mass of air at the same temperature [11].

The climate has an important role in affecting negatively and positively the productivity of the crop [3], as the crop goes through different growth periods that make it need different temperatures at each growth stage. If the appropriate temperature and humidity are available, the plant will grow well, but if the temperature and humidity fall below a certain level, this will lead to a decrease in growth or freezing of plant tissues and then the death of the plant, while a rise in temperature and humidity above a certain level will cause Plant death also, hence the importance of climate as one of the determinants of productivity change [7], and below we will learn about the evolution of some climate changes for the winter and summer seasons in Egypt during the period (2000-2021):

5.3. The Evolution of the Most Important Climate Elements for the Winter Season in Egypt

5.3.1. The Evolution of the Average Maximum Temperature of the Winter Season in Egypt

By studying the evolution of the average maximum temperature of the winter season in Egypt during the period (2000-2021), it was found from the data of Table 3 that it fluctuated up and down during the study period between a minimum of about 24.17 degrees Celsius in 2004, and a maximum of about 28.35 degrees Celsius in 2016, an increase rate of about 17.29% over the minimum, and about 16.22% over the average maximum temperature for the winter season in Egypt, which is estimated at about 25.77 degrees Celsius.

By estimating the general temporal trend equation for the average maximum temperature of the winter season in Egypt, it was found from Table 4 that there is a statistically significant annual increase of about 0.12°C annually, representing about 0.47% of the annual average of about 25.77°C. The coefficient of determination (R^2) indicates which is estimated at 0.42, indicates that 42% of the changes in the average temperature of the great winter season in Egypt are due to the influence of factors reflected by the element of time.

5.3.2. The Evolution of the Average Minimum Temperature of the Winter Season in Egypt

By studying the evolution of the average minimum temperature for the winter season in Egypt during the period (2000-2021), it was found from the data of Table 3 that it fluctuated up and down during the study period between a minimum of about 8.52 degrees Celsius in 2017, and a maximum of about 11.93 degrees Celsius in 2006, an increase rate of about 40.02% over the minimum, and about 32.79% from the average minimum temperature for the winter season in Egypt, which is estimated at about 10.40 degrees Celsius.

By estimating the general temporal trend equation for the average minimum temperature of the winter season in Egypt, it was found from Table 4 that there is a statistically significant annual decrease of about 0.11°C annually, representing about 1.06% of the annual average of about 10.40°C. The coefficient of determination (R^2) indicates and estimated at 0.59, indicates that 59% of the changes in the average temperature of the great winter season in Egypt are due to the influence of factors reflected by the time factor.

5.3.3. The Evolution of the Average Relative Humidity for the Winter Season in Egypt

By studying the evolution of the average relative humidity for the winter season in Egypt during the period (2000-2021), it was found from the data of Table 3 that it fluctuated up and down during the study period between a minimum of about 38.41% in 2018, and a maximum of about 52.28%. In 2010, an increase rate of about 36.11% over the minimum and about 30.99% over the average relative humidity for the winter season in Egypt, which is estimated at 44.76%.

By estimating the time trend equation for the average relative humidity of the winter season in Egypt, it was found from Table 4 that there is a statistically significant annual decrease of about 0.40%, representing about 0.89% of the annual average of about 44.76%. The coefficient of determination (R^2), estimated at 0.46, indicates that 46% of the changes in the average relative humidity of the winter season in Egypt are due to the influence of factors reflected by the element of time.

Table 3. *The evolution of the average maximum and minimum temperature and relative humidity for the winter and summer seasons in Egypt during the period (2000-2021).*

Year	Winter season			Summer season		
	Average temperature (°C)		Average relative humidity (%)	Average temperature (°C)		Average relative humidity (%)
	Max.	Min.		Max.	Min.	
2000	25.52	11.83	47.05	38.84	19.86	49.25
2001	24.58	11.74	47.25	38.16	20.41	49.50
2002	24.61	11.32	48.12	38.21	20.80	49.95
2003	24.40	11.16	47.80	38.90	20.78	49.35
2004	24.17	10.90	47.33	38.57	20.36	49.74
2005	25.12	11.47	47.58	38.29	21.18	47.85
2006	25.27	11.93	47.80	39.16	21.82	46.42
2007	26.18	10.01	47.45	38.87	21.70	44.90
2008	24.84	9.95	47.22	41.53	23.37	42.85
2009	25.11	10.42	48.23	41.57	23.58	42.05
2010	27.80	10.77	52.28	42.36	22.10	46.71
2011	24.62	10.30	43.96	41.11	23.17	48.44
2012	25.10	10.17	41.23	41.24	22.91	49.78
2013	25.81	9.76	40.09	40.38	21.89	44.70
2014	25.44	10.27	41.70	41.76	22.92	42.92
2015	25.26	9.87	40.38	42.53	23.05	42.44
2016	28.35	8.74	41.17	42.28	21.30	42.16
2017	27.18	8.52	39.85	42.85	21.72	42.04
2018	27.56	11.17	38.41	41.91	22.16	47.83
2019	27.53	9.78	39.60	40.37	22.63	47.60
2020	26.11	9.58	44.31	41.12	23.78	41.12
2021	26.37	9.24	45.91	39.81	23.94	41.29
average	25.77	10.40	44.76	40.45	22.07	45.86

Where: Max. = Maximum
Min. = Minimum
Source: Collected and calculated from the data of the Ministry of Civil Aviation, the Egyptian Meteorological Authority, the General Department of Forecasts and Early Warning, the main analysis center, 2022.

5.4. The Evolution of the Most Important Climate Elements for the Summer Season in Egypt

5.4.1. The Evolution of the Average Maximum Temperature of the Summer Season in Egypt

By studying the evolution of the average maximum temperature of the summer season in Egypt during the period (2000-2021), it was found from the data of Table 3 that it fluctuated up and down during the study period between a minimum of about 38.16 degrees Celsius in 2001, and a maximum of about 42.85 degrees Celsius in 2017, an increase rate of about 12.29% over the minimum, and about 11.59% over the average maximum temperature for the summer season in Egypt, which is estimated at about 40.45 degrees Celsius.

Table 4. *Equations for the general time trend of the evolution of the maximum and minimum temperature and relative humidity for the winter and summer seasons during the period (2000-2021).*

The crop	Statement		The equation	(R^2)	(F)	average	(٪)
Winter season	Temp. (°C)	Max.	Yi = 24.37 + 0.12 Xi (3.80) **	0.42	14.47**	25.77	0.47
		Min.	Yi = 11.71 – 0.11 Xi (-5.31) **	0.59	28.24**	10.40	-1.06
	Relative humidity(%)		Yi = 49.34 – 0.40 Xi (-4.11) **	0.46	16.90**	44.76	-0.89
Summer season	Temp. (°C)	Max.	Yi = 38.50 + 0.17 Xi (4.32) **	0.48	18.63**	40.45	0.42
		Min.	Yi = 20.56 + 0.13 Xi (4.54) **	0.51	20.61**	22.07	0.59
	Relative humidity (%)		Yi = 49.54 - 0.32 Xi (-3.75) **	0.41	14.03**	45.86	-0.70

Where: Max. = Maximum
Min. = Minimum
Yi = denotes the estimated value of the phenomenon.
Xi = the time factor, where E = (1, 2, 3,....., 22) in years.
( ) The value in brackets below the regression coefficients expresses the calculated (t) value.
** Significant at a significance level of 0.01.
Source: Collected and calculated from the data of Table 3.

By estimating the general temporal trend equation for the average maximum temperature of the summer season in Egypt, it was found from Table 4 that there is a statistically significant annual increase of about 0.17°C annually, representing about 0.42% of the annual average of about 40.45°C. The coefficient of determination (R^2) indicates and estimated at 0.48, indicates that 48% of the changes in the average maximum temperature of the summer season in Egypt are due to the influence of factors reflected by the time factor.

5.4.2. The Evolution of the Average Minimum Temperature for the Summer Season in Egypt

By studying the evolution of the average minimum temperature for the summer season in Egypt during the period (2000-2021), it was found from the data of Table 3 that it fluctuated up and down during the study period between a minimum of about 19.86 degrees Celsius in the year 2000, and a maximum of about 23.94 degrees Celsius in 2021, an increase of about 20.54% from the minimum, and about 18.49% from the average minimum temperature for the summer season in Egypt, which is estimated at 22.07 degrees Celsius.

By estimating the general time trend equation for the average minimum temperature of the summer season in Egypt, it was found from Table 4 that there is a statistically significant annual increase of about 0.13°C annually, representing about 0.59% of the annual average of about 22.07°C. The coefficient of determination (R^2) indicates) and estimated at 0.51, indicates that 51% of the changes in the average minimum temperature of the summer season in Egypt are due to the influence of factors reflected by the time component.

5.4.3. The Evolution of the Average Relative Humidity for the Summer Season in Egypt

By studying the evolution of the average relative humidity of the summer season in Egypt during the period (2000-2021), it was found from the data of Table 3 that it fluctuated up and down during the study period between a minimum of about 41.12% in 2020, and a maximum of about 49.95%. In 2002, an increase rate of about 21.47% over the minimum and about 19.25% over the average relative humidity for the summer season in Egypt, which is estimated at about 45.86%.

By estimating the time trend equation for the average relative humidity of the summer season in Egypt, it was found from Table 4 that there is a statistically significant annual decrease of about 0.32%, representing about 0.70% of the annual average of about 45.86%. The coefficient of determination (R^2), estimated at 0.41, indicates 41% of the changes in the average relative humidity of the summer season in Egypt are due to the influence of factors reflected by time.

6. The Instability Coefficient for Climate Elements during the Period (2000-2021)

The instability coefficient is important for judging the extent of stability of the maximum and minimum temperature and relative humidity for the winter and summer seasons, and it measures the degree of annual fluctuation in the climate [16]:

$$I = \left| \frac{Y - \hat{Y}}{\hat{Y}} \right| x\ 100$$

Whereas:

I = coefficient of instability

Y = the actual value of both the maximum and minimum temperature and relative humidity for the winter and summer seasons for each year [21].

$\hat{Y}$ = the estimated value of each of the maximum and minimum temperature and relative humidity for the winter and summer seasons for each year, and it is calculated by estimating the linear general time trend equations estimated by the least squares method for each of the maximum and minimum temperature and relative humidity for the winter and summer seasons during the study period.

The instability coefficient is expressed regardless of the sign, and when it is equal to zero, it is considered the optimal state of stability, and whenever this value is greater than zero, this indicates an increase in instability.

And by examining the relative stability of the average maximum temperature of the winter season during the period (2000-2021), it was found from Table 5 that it ranged between a minimum of about 0.12% in 2001 and 2005, and a maximum of about 8.21% in 2010. With a geometric average of about 1.86%, as the results in the same table showed, the relative stability of the average minimum temperature for the winter season ranged between a minimum of about 0.53% in 2002, and a maximum of about 16.11% in 2018, with a geometric average of about 2.64%. The results also showed in the same table that the relative stability of the average relative humidity for the winter season ranged between a minimum of about 0.02% in 2004, and a maximum of about 16.33% in 2010, with an engineering average of about 2.46%.

And by examining the relative stability of the average maximum temperature of the summer season during the period (2000-2021), it was found from Table 5 that it ranged between a minimum of about 0.43% in 2018, and a maximum of about 5.75% in 2021, with an engineering average. It reached about 1.95%, as the results showed in the same table. The relative stability of the average minimum temperature for the summer season ranged between a minimum of about 0.46% in 2007, and a maximum of about 7.87% in 2009, with an engineering average of about 2.28%.

The results also showed in the same table that the relative stability of the average relative humidity for the summer season ranged from a minimum of about 0.06% in 2000 to a maximum of about 10.34% in 2019, with an engineering average of about 2.89%.

Table 5. *Instability coefficients for the maximum and minimum temperature and relative humidity for the winter and summer seasons during the period (2000-2021).*

Year	Winter season			Summer season		
	Average temperature (°C)		Average relative humidity (%)	Average temperature (°C)		Average relative humidity (%)
	Max.	Min.		Max.	Min.	
2000	4.21	1.98	3.86	0.44	4.01	0.06
2001	0.12	2.18	2.66	1.75	1.97	1.23
2002	0.49	0.53	0.04	2.05	0.72	2.82
2003	1.81	0.98	0.13	0.71	1.42	2.26
2004	3.20	2.33	0.02	1.98	4.01	3.75
2005	0.12	3.80	1.36	3.11	0.75	0.48
2006	0.24	9.05	2.71	1.34	1.63	1.86
2007	3.36	7.57	2.84	2.48	0.46	4.43
2008	2.40	7.18	3.24	3.75	7.55	8.17
2009	1.80	1.79	6.37	3.41	7.87	9.26
2010	8.21	2.57	16.33	4.93	0.50	1.50
2011	4.61	0.87	1.30	1.41	4.75	6.00
2012	3.20	1.07	6.59	1.30	2.97	9.70
2013	0.92	4.03	8.34	1.22	2.19	0.80
2014	2.79	2.09	3.78	1.73	1.82	4.07
2015	3.92	0.80	5.97	3.18	1.81	4.46
2016	7.35	11.18	3.22	2.15	6.46	4.40
2017	2.45	12.44	5.43	3.10	5.15	3.97
2018	3.41	16.11	7.98	0.43	3.78	10.06
2019	2.84	2.84	4.21	3.65	2.29	10.34
2020	2.90	1.91	8.23	2.26	2.10	3.97
2021	2.37	0.54	13.25	5.75	2.22	2.85
geometric mean	1.86	2.64	2.46	1.95	2.28	2.89

Max. = Maximum
Min. = Minimum
Source: Collected and calculated from the data of Table 3.

7. Estimating the Amount of Water Lost by Evaporation in Egypt

Evaporation means the amount of water lost from a specific area in a specific period of time and under a certain level of temperature and relative humidity [18], and it was calculated through the following Ivanov equation [5]:

$$x = 0.0018\,(h + 25)^2\,(100 - rn)$$

Whereas:

K = average amount of water lost by evaporation (mm/m^2/day).

h = mean annual maximum temperature (°C).

rn = annual mean relative humidity (%).

By calculating the previous equation, the evolution of the average amount of water lost by evaporation is studied as a result of the change in temperature and relative humidity for the winter and summer seasons in Egypt during the period (2000-2021), as follows:

By studying the evolution of the average amount of water lost by evaporation as a result of changing the temperature and relative humidity of the winter season in Egypt during the period (2000-2021), it was found from the data of Table 6 that it fluctuated up and down during the study period between a minimum of about 229.21 mm /m^2/day in 2004, and a maximum of about 306.26 mm/m^2/day in 2018, i e. an increase rate of about 33.62% over the minimum, and about 30.01% over the average amount of water lost by evaporation in the winter season in Egypt, which is about 256.74 mm/m^2/day.

By estimating the time trend equation, the average amount of water lost by evaporation as a result of changing the temperature and relative humidity of the winter season in Egypt during the period (2000-2021), it was found from Table 7 that there is a statistically significant annual increase of about 3.10 m/m^2/day, representing about 1.21% of the annual average, which is about 256.74 mm/m^2/day. The coefficient of determination (R^2), estimated at 0.62, indicates that 62% of the changes in the average amount of water lost by evaporation as a result of the change in temperature and relative humidity of the winter season in Egypt is due to the effect of Factors reflected by the element of time.

And by studying the evolution of the average amount of water lost by evaporation as a result of the change in temperature and relative humidity of the summer season in Egypt during the period (2000-2021), it was found from the data of Table 6 that it fluctuated up and down during the study period between a minimum of about 359.95 mm/m^2/day in 2002, and a maximum of about 480.29 mm/m^2/day in 2017, i e. an increase rate of about 33.43% over the minimum, and about 28.77% over the average amount of water lost by evaporation in the winter season in Egypt, which is estimated at about 418.34 mm/m^2/day.

Table 6. *The evolution of the average amount of water lost by evaporation as a result of the change in temperature and relative humidity for the winter and summer seasons in Egypt during the period (2000-2021).*

Year	Winter season		Summer season	
	Average amount of water lost by evaporation (mm/m^2/day)	Relative importance (%)	Average amount of water lost by evaporation (mm/m^2/day)	Relative importance (%)
2000	243.26	94.75	372.30	88.99
2001	233.40	90.91	362.62	86.68
2002	229.83	89.52	359.95	86.04
2003	229.30	89.31	372.27	88.99
2004	229.21	89.28	365.59	87.39
2005	237.02	92.32	376.01	89.88
2006	237.44	92.48	397.01	94.90
2007	247.77	96.51	404.59	96.71
2008	235.99	91.92	455.33	108.84
2009	233.99	91.14	462.26	110.50
2010	239.46	93.27	435.23	104.04
2011	248.36	96.74	405.62	96.96
2012	265.52	103.42	396.63	94.81
2013	278.40	108.44	425.49	101.71
2014	266.99	103.99	457.92	109.46
2015	271.09	105.59	472.48	112.94
2016	301.40	117.39	471.27	112.65
2017	294.79	114.82	480.29	114.81
2018	306.26	119.29	420.41	100.49
2019	300.00	116.85	403.05	96.34
2020	261.86	101.99	463.35	110.76
2021	256.93	100.07	443.88	106.10
Average	256.74	100.00	418.34	100.00

Source: Collected and calculated from the data of Table 3.

By estimating the time trend equation, the average amount of water lost by evaporation as a result of changing the temperature and relative humidity of the summer season in Egypt during the period (2000-2021), it was found from Table 7 that there was a statistically significant annual increase of about 4.57 mm/m^2/day, representing about 1.09% of the annual average of about 418.34 mm/m^2/day. The coefficient of determination (R^2), estimated at 0.54, indicates that 54% of the changes in the average amount of water lost by evaporation as a result of the change in temperature and relative humidity of the winter season in Egypt is due to the effect of Factors reflected by the element of time.

Table 7. *Equations for the general time trend of the evolution of the average amount of water lost by evaporation as a result of the change in temperature and relative humidity for the winter and summer seasons in Egypt during the period (2000-2021).*

phenomenon	The equation	(R^2)	(F)	average	(٪)
Average amount of water lost by evaporation in the winter season (mm/m^2/day)	$Y_i = 221.10 + 3.10\ X_i$ (5.69) **	0.62	32.31**	256.74	1.21
Average amount of water lost by evaporation in the summer season (mm/m^2/day)	Yi = 365.83 + 4.57 Xi (4.83) **	0.54	23.34**	418.34	1.09

Where: Yi = denotes the estimated value of the phenomenon.
Xi = the time factor, where E = (1, 2, 3,....., 22) in years.
( ) The value in brackets below the regression coefficients expresses the calculated (t) value.
** Significant at a significance level of 0.01.
Source: Collected and calculated from the data of Table 6.

8. The Effect of Climate Change on the Productivity of an Acre of Wheat and Maize Crops in Egypt

The average production costs per feddan for wheat and maize crops at fixed prices were added to the climate elements, which means the addition of production factors, in order to separate the impact of production factors from climatic factors, so that the impact of climatic factors on the productivity of a feddan is calculated away from the influence of production factors.

Table 8 shows the effect of climate change on the productivity of a feddan of wheat crop in Egypt during the period (2000-2021), as it was found that the model is statistically significant at a significant level of 1%, and that the model is free from measurement problems, as shown by the model. The productivity of a feddan of wheat crop increases by 0.73 tons, with an increase in the average costs of producing feddan of wheat crop by one thousand pounds, while the productivity of a feddan of wheat crop decreases by 0.05 tons with an increase in the maximum temperature in the winter season by one degree Celsius, and the productivity of feddan of wheat crop decreases by one degree Celsius. The wheat crop increased by 0.06 tons with an increase in the minimum temperature in the winter season by one degree Celsius, and the productivity of an feddan of wheat crop decreased by 0.02 tons with an increase in relative humidity in the winter season by 1%.

Table 8 also shows the effect of climate change on the productivity of a feddan of maize crop in Egypt during the period (2000-2021), as it was found that the model is statistically significant at a significant level of 1%, and that the model is free from measurement problems, as it was shown From the model, the productivity of feddan of maize crop increases by 0.58 tons, with an increase in the average production costs of feddan of maize crop by one thousand pounds, while the productivity of feddan of maize crop decreases by 0.06 tons with an increase in the maximum temperature in the summer season by one degree Celsius. The productivity of feddan of maize crop decreases by 0.05 tons, with an increase in the minimum temperature in the summer season by one degree Celsius, and the productivity of feddan of maize crop decreases by 0.03 tons, with an increase in relative humidity in the summer season by 1%.

Table 8. *The impact of climate change on the productivity of a feddan of wheat and maize crops in Egypt during the period (2000-2021).*

The crop	The equation	F	(R^2\)
Wheat	Pw = 4.10 + 0.73 Cw – 0.05 Fr – 0.06 Kr – 0.02 Hr (8.91)** (-9.21)** (-7.76)** (-9.15)**	62.23**	0.92
maize	Pm = 7.29 + 0.58 Cm – 0.06 Fs – 0.05 Ks – 0.03 Hs (7.86)** (-8.34)** (-3.94)** (-6.61)**	42.28**	0.89

Where Pw = average productivity of a feddan of wheat crop in tons, Pm = average productivity of a feddan of maize in tons, Cw = average costs of producing a feddan of wheat at fixed prices and in thousands of pounds, Fr = average maximum temperature in the winter season, Kr = average temperature The minimum temperature in the winter season, Hr = the average relative humidity in the winter season, Cm = the average production costs per feddan of maize crop at constant prices and in thousands of pounds, Fs = the average maximum temperature in the summer season, Ks = the average minimum temperature in the summer season, Hs = average relative humidity in the summer season.

( ) The numbers in the brackets below the regression coefficients refer to the calculated "t" values.

**Significant at the level of 0.01

Source: Collected and calculated from the data of Table 1 and Table 3 and Table A1.

9. The Economic Effects of the Decline in Wheat and Maize Crops Due to Climate Change in Egypt

9.1. The Economic Effects of the Decrease in the Productivity Per Feddan of the Wheat Crop Due to Climate Change in Egypt During the Period (2000-2021)

Table 9 shows that the total amount of lost production from the wheat crop due to the change in the average maximum and minimum temperature, relative humidity, and total climate elements amounted to about 150, 180, 60, and 390 thousand tons, respectively, which means that the total The lost agricultural area amounted to about 54.95, 65.93, 21.98, 142.86 thousand feddan, and the total lost production costs amounted to about 299.45, 359.34, 119.78, and 778.57 million pounds, and the total lost production value was about 488.46, 586.15, 195.38, and 1269.99 million pounds. The total amount of water lost was about 114.84, 137.80, 45.93 and 298.57 million cubic meters, respectively.

9.2. The Economic Effects of the Decrease in the Productivity Per Feddan of Maize Due to Climate Change in Egypt During the Period (2000-2021)

Table 10 shows that the total amount of lost production from the maize crop due to the change in the average maximum and minimum temperature, relative humidity and total climate elements amounted to about 118.80, 99.00, 59.40, 277.20 thousand tons, respectively, which means that the total The lost agricultural area amounted to about 35.46, 29.55, 17.73, 82.74 thousand feddan, and the total lost production costs amounted to about 176.96, 147.47, 88.48, and 412.91 million pounds, and the total lost production value was about 267.39, 222.82, 133.69, and 623.90 million pounds. The total amount of water lost was about 128.02, 106.68, 64.01 and 298.71 million cubic meters, respectively.

Table 9. *The economic effects of the decrease in the productivity per feddan of the wheat crop due to climate change in Egypt during the period (2000-2021).*

Statement	Winter Season			
	Average temperature (°C)		Average relative humidity(%)	total climate elements
	Max.	Min.		
Lost feddan productivity (tons)	0.05	0.06	0.02	0.13
Total cultivated area (thousand feddans)	3000	3000	3000	3000

Statement	Winter Season			
	Average temperature (°C)		Average relative humidity(%)	total climate elements
	Max.	Min.		
The total amount of lost production (thousands of tons)	150.00	180.00	60.00	390.00
Average productivity of feddan (tons)	2.73	2.73	2.73	2.73
Total agricultural area lost (thousand feddans)	54.95	65.93	21.98	142.86
Average production costs per feddan (thousand pounds)	5.45	5.45	5.45	5.45
Total lost production costs (million pounds)	299.45	359.34	119.78	778.57
Average revenue per feddan (thousand pounds)	8.89	8.89	8.89	8.89
Total value of lost production (million pounds)	488.46	586.15	195.38	1269.99
Water standard per feddan (thousand m^3)	2.09	2.09	2.09	2.09
Total amount of water lost (million m^3)	114.84	137.80	45.93	298.57

Max. = Maximum
Min. = Minimum
Total amount of lost production = lost feddan productivity * total cultivated area
Total lost agricultural area = total amount of lost production / average yield of feddan.
Total lost production costs = total lost agricultural area * average production costs per feddan.
Total lost production value = total lost agricultural area * average feddan revenue.
The total amount of water lost = total agricultural area lost * water ration per feddan.
Source: Collected and calculated from the data of the Ministry of Agriculture and Agricultural Reclamation, Central Administration of Agricultural Economics, Agricultural Statistics Bulletin, Water Resources Bulletin, Cost and Net Yield Statistics Bulletin, separate issues, and Table 8.

Table 10. *The economic effects of the decrease in the productivity per feddan of the maize crop due to climate change in Egypt during the period (2000-2021).*

Statement	summer season			
	Average temperature (°C)		Average relative humidity(%)	total climate elements
	Max.	Min.		
Lost feddan productivity (tons)	0.06	0.05	0.03	0.14
Total cultivated area (thousand feddans)	1980	1980	1980	1980
The total amount of lost production (thousands of tons)	118.80	99.00	59.40	277.20
Average productivity of feddan (tons)	3.35	3.35	3.35	3.35
Total agricultural area lost (thousand feddans)	35.46	29.55	17.73	82.74
Average production costs per feddan (thousand pounds)	4.99	4.99	4.99	4.99
Total lost production costs (million pounds)	176.96	147.47	88.48	412.91
Average revenue per feddan (thousand pounds)	7.54	7.54	7.54	7.54
Total value of lost production (million pounds)	267.39	222.82	133.69	623.90
Water standard per feddan (thousand m^3)	3.61	3.61	3.61	3.61
Total amount of water lost (million m^3)	128.02	106.68	64.01	298.71

Max. = Maximum
Min. = Minimum
Total amount of lost production = lost feddan productivity * total cultivated area.
Total lost agricultural area = total amount of lost production / average yield of feddan.
Total lost production costs = total lost agricultural area * average production costs per feddan.
Total lost production value = total lost agricultural area * average feddan revenue
The total amount of water lost = total agricultural area lost * water ration per feddan.
Source: Collected and calculated from the data of the Ministry of Agriculture and Agricultural Reclamation, Central Administration of Agricultural Economics, Agricultural Statistics Bulletin, Water Resources Bulletin, Cost and Net Yield Statistics Bulletin, separate issues, and Table 8.

10. Conclusion

Given the role of the climate in providing a suitable environment for growing agricultural crops, whether winter or summer, according to the need of each crop in terms of heat and moisture, in order to give the best feddan productivity for it and in light of the climatic changes that swept all countries of the world, including Egypt, the matter necessitated a study of the impact of these changes Climate on the productivity per feddan of wheat and maize crops in Egypt.

The research aimed to identify the development of each of the maximum and minimum temperature and relative humidity for the winter and summer seasons in Egypt and their stability during the period (2000-2021), and the extent of the impact of this development on the feddan productivity of wheat and maize crops in Egypt, and the economic implications of that.

By estimating the general time trend equation for the average maximum temperature of the winter season in Egypt, it was found that there was a statistically significant annual increase of about 0.12°C annually, representing about 0.47% of the annual average of about 25.77°C. The minimum temperature of the winter season in Egypt shows that there is a statistically significant annual decrease of about 0.11°C annually, representing about 1.06% of the annual average of about 10.40°C, and by estimating the temporal trend equation for the average relative humidity of the winter season in Egypt, it was found that there is a statistically significant annual decrease of about 0.40%, representing about 0.89% of the annual average of about 44.76%.

By estimating the general time trend equation for the average maximum temperature of the summer season in Egypt, it was found that there is a statistically significant annual increase of about 0.17°C annually, representing about 0.42% of the annual average of about 40.45°C, and by estimating the general time trend equation for the average minimum temperature For the summer season in Egypt, it was found that there was a statistically significant annual increase of about 0.13°C annually, representing about 0.59% of the annual average of about 22.07°C. By estimating the time trend equation for the average relative humidity of the summer season in Egypt, it was found that there was a statistically significant annual decrease of about 0.32%, representing about 0.70% of the annual average of about 45.86%.

Through the Ivanov equation for calculating the amount of water lost by evaporation, the time trend equation estimated the average amount of water lost by evaporation as a result of changing the temperature and relative humidity of the winter season in Egypt during the period (2000-2021), where it was found that there was a statistically significant annual increase of about 3.10 mm/ m 2 / day, representing about 1.21% of the annual average of about 256.74 mm / m 2 / day. The time trend equation was estimated as the average amount of water lost by evaporation as a result of the change in temperature and relative humidity of the summer season in Egypt during the same period, as it was found that there was an annual increase Statistically significant, it amounted to about 4.57 $mm/m^2/day$, representing about 1.09% of the annual average of about 418.34 $mm/m^2/day$.

The results also showed a decrease in the productivity of an feddan of wheat crop by 0.05 tons with an increase in the maximum temperature in the winter season by one degree Celsius, and the productivity of a feddan of wheat crop decreased by 0.06 tons with an increase in the minimum temperature in the winter season by one degree Celsius, as it was also shown The productivity of a feddan of wheat crop decreased by 0.02 tons, with an increase in relative humidity in the winter season by 1%.

The results also showed a decrease in the productivity of a feddan of maize crop by 0.06 tons with an increase in the maximum temperature in the summer season by one degree Celsius, and a feddan productivity of maize crop decreased by 0.05 tons with an increase in the minimum temperature in the summer season by one degree Celsius. It was also shown that the productivity of an feddan of maize crop decreased by 0.03 tons, with an increase in relative humidity in the summer season by 1%.

The results also showed that the total amount of lost production from the wheat crop, due to the change in the average maximum and minimum temperature, relative humidity, and the total climate elements, amounted to about 150, 180, 60, and 390 thousand tons, respectively, and that the total amount of lost production of the maize crop, due to the change in the average maximum and minimum temperature, relative humidity, and the total climate elements, has reached about 118.80, 99.00, 59.40, and 277.20 thousand tons, respectively.

In light of the results of the study, the study recommended the following:

1. Increasing spending on agricultural research to develop new varieties that are able to adapt to climate change.
2. The Agricultural Extension Authority raises the level of awareness of wheat and maize farmers in order to take the necessary measures to confront climate changes by holding training courses for them.
3. Reconsider changing the planting dates of wheat and maize crops, in a way that is commensurate with providing them with climatic needs.

Appendix

Table A1. *The evolution of the average production costs per feddan of wheat and maize crops at current and fixed prices in Egypt during the period (2000-2021).*

Year	Average costs of producing an feddan of wheat crop (current prices and thousand pounds)	Average costs of producing an feddan of maize crop (at current prices and in thousands of pounds)	Production inputs price index (2000=100)	Average costs of producing an feddan of wheat crop (at fixed prices and in thousands of pounds)	Average costs of producing feddan of maize crop (at fixed prices and in thousands of pounds)
2000	2.00	1.64	100.00	2.00	1.64
2001	2.05	1.91	101.95	2.01	1.87
2002	2.15	1.97	107.11	2.01	1.84
2003	2.21	2.02	110.23	2.01	1.83
2004	2.30	2.11	112.68	2.04	1.87
2005	2.38	2.27	116.43	2.05	1.95
2006	2.54	2.54	123.16	2.06	2.06
2007	2.81	2.44	139.73	2.01	1.75
2008	3.45	3.15	176.57	1.95	1.78
2009	3.76	3.46	195.82	1.92	1.77
2010	3.99	3.68	211.19	1.89	1.74
2011	4.35	5.07	232.41	1.87	2.18
2012	4.60	5.39	249.03	1.85	2.16
2013	4.96	4.81	267.99	1.85	1.79

Year	Average costs of producing an feddan of wheat crop (current prices and thousand pounds)	Average costs of producing an feddan of maize crop (at current prices and in thousands of pounds)	Production inputs price index (2000=100)	Average costs of producing an feddan of wheat crop (at fixed prices and in thousands of pounds)	Average costs of producing feddan of maize crop (at fixed prices and in thousands of pounds)
2014	5.47	5.27	291.78	1.88	1.81
2015	5.78	4.63	308.26	1.87	1.50
2016	7.58	6.05	379.13	2.00	1.60
2017	9.71	8.99	492.62	1.97	1.83
2018	10.29	9.63	536.37	1.92	1.80
2019	11.65	11.33	618.23	1.88	1.83
2020	11.87	10.64	624.12	1.90	1.70
2021	13.94	10.82	647.35	2.15	1.67
average	5.45	4.99	279.19	1.96	1.82

Average production costs per feddan of wheat and maize crops at fixed prices = (average production costs per feddan of wheat and maize crops, current prices ÷ the price index of production inputs) * 100.

Source: Collected and calculated from the data of the Ministry of Agriculture and Land Reclamation, Economic Affairs Sector, Statistics Department records, 2022.

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