Economic Analysis of Modern Irrigation Systems Impact on Sesame Cultivation in Egypt (Case Study of Fayoum Governorate)

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Abstract: Modern irrigation systems play a crucial role in the development of irrigation projects. They are considered essential for optimizing water usage and enhancing agricultural productivity, in line with Egypt's water resource management strategy for 2050. The sesame crop, valued for its protein, calcium, and phosphorus-rich seeds, flourishes in modern irrigation systems and is a significant oil crop in Egypt. The research focuses on the limited irrigation water in Fayoum Governorate, attributed to inefficient water use and traditional flood irrigation methods. This study aims to assess water resources in Egypt during the 2023 study period and evaluate the impact of different irrigation systems on the productivity and economic efficiency of sesame crops in Fayoum. The findings reveal that Egypt and Fayoum Governorate utilized approximately 60.1 billion m3 and 1.99 billion m3 of water for agriculture, respectively, between 2004 and 2023. Statistical analysis of the sesame crop production function, considering the implementation of drip irrigation systems, yielded significant results, with a determination coefficient of around 91% and a total elasticity of approximately 2.181, indicating increased returns to scale. The research concludes with several recommendations, emphasizing the necessity for the government to implement policies facilitating a complete transition to modern irrigation systems, thereby optimizing water consumption and enhancing productive.

Keywords: modern irrigation systems , water rationing , sesame crop.

I. INTRODUCTION

The Nile River serves as Egypt's main water source, providing about 55.5 billion cubic meters each year. Due to the country's limited water resources, managing water effectively is vital for expanding agricultural land. Consequently, irrigation water management is a key focus for agricultural policymakers. The agricultural sector is the largest water consumer, utilizing approximately 60.1 billion cubic meters annually, which accounts for around 81.1% of the total available water resources of 74.14 billion cubic meters. This water irrigates roughly 8.82 million feddan of farmland on average from 2004 to 2023.

To optimize water usage and enhance the economic yield from agricultural land, modern irrigation development projects are essential. These initiatives aim to fulfill the objectives of the Egyptian Water Resources Strategy 2050 by transitioning from traditional flood irrigation to modern systems. This shift is critical due to the disparity between available water resources and their current usage. Various strategies are being employed to bridge this gap, including groundwater extraction, recycling agricultural drainage water, seawater desalination, and implementing modern irrigation techniques such as sprinkler, drip, and subsurface irrigation.

In Fayoum Governorate, most cultivated land is irrigated using Nile water, with around 320 thousand feddan (approximately 72.7% of the total cultivated area of 440 thousand feddan) relying on it during the same period. Sesame is one of Egypt's key oil crops, thriving in newly reclaimed yellow, clay, and sandy soils. It is primarily cultivated for its seeds, which are high in protein, calcium, and phosphorus, with an oil content of 40% to 50%. Modern irrigation systems are particularly effective for sesame cultivation due to their low water requirements. On average, sesame is cultivated on about 74.34 thousand feddan in Egypt, yielding approximately 43.60 thousand tons during the same timeframe. In Fayoum Governorate, sesame is grown on about 5.6 thousand feddan, producing around 3.19 thousand tons.

Research Problem: The research problem focuses on the limited availability of irrigation water in Fayoum Governorate, largely due to water wastage and the dependence on traditional flood irrigation methods. This challenge is exacerbated by the rising demand for water resources needed for new land expansion. Egypt's water resources strategy aims to optimize water use and enhance returns, highlighting the need for improved irrigation systems in both Egypt and Fayoum to increase water efficiency, ensure proper distribution, and achieve savings for land reclamation and expansion. In response, many farmers in Fayoum, particularly those growing sesame, have started using modern irrigation systems, which aim to decrease water usage by about 20-30%. However, the adoption of these systems encounters challenges that raise production costs and diminish net returns per feddan. Therefore, it is crucial to examine the efficiency of modern irrigation systems in Fayoum Governorate.

Research Objectives: The primary aim of this research is to analyze the economic efficiency of modern irrigation methods on sesame production in Fayoum Governorate through the following objectives:

1. Assess the current state of water resources in Egypt during the study period.
2. Examine the productivity and economic indicators of sesame cultivation in Egypt and Fayoum during the study period.
3. Evaluate the impact of different irrigation systems on the productivity and economic efficiency indicators of the crop within the study sample in Fayoum.
4. Identify the key challenges, obstacles, and potential solutions faced by producers using modern irrigation systems for sesame cultivation in Fayoum.

II. Methodology

This research employs descriptive and quantitative analysis to explore the productive and economic impacts of modern irrigation systems, utilizing simple regression, ANOVA analysis, and the Least Significant Difference (LSD) test. To evaluate the application of modern irrigation systems, production and cost functions were estimated based on data collected via questionnaires from the study sample. Various functional forms were analyzed, selecting those that best aligned with economic and statistical principles, while employing several economic efficiency indicators for sesame production in Fayoum.

The research utilized two types of data: first, secondary data from various sources, including the Economic Affairs Sector of the Ministry of Agriculture and Land Reclamation, the Information Center of the Fayoum Agriculture Directorate, the Ministry of Irrigation and Water Resources, and the Fayoum Irrigation Directorate. Second, primary data was collected through a questionnaire distributed to a random sample in Fayoum Governorate.

III. Results and Discussion

Analysis of Current Irrigation Water Quantities and the Development of Water Resources in Egypt and Fayoum:

The data in Table No. (1) in the appendix illustrates the changes in the total cultivated area, agricultural water usage, irrigation water quantities in Aswan, canal sections, and field irrigation, as well as the overall agricultural land area in Egypt and Fayoum from 2004 to 2023.

An analysis of the total cultivated area in Egypt indicates an average of approximately 8.82 million feddan, with a peak of around 9.43 million feddan and a low of about 8.12 million feddan. The general trend analysis, as detailed in Equation No. (1) of Table No. (1), reveals a statistically significant upward trend, averaging an increase of about 71.1 thousand feddan annually, which constitutes an increase of approximately 0.81% over the study period. The coefficient of determination (R^2) was calculated to be 98%.

The same table also presents data on agricultural water usage, showing an average of about 60.1 billion m^3, with a maximum of approximately 62.3 billion m^3 and a minimum of about 55.1 billion m^3. According to Equation No. (2) in the same table, there is a statistically significant increasing trend of about 0.655 billion m^3, with an annual growth rate of approximately 1.1% during the study period. The coefficient of determination (R^2) for this data is roughly 84%.

Additionally, the data indicates trends in irrigation water quantities in Aswan, where the average was around 49.9 billion m^3, with highs of about 62.2 billion m^3 and lows of approximately 40.1 billion m^3. As shown in Equation No. (3), there is a statistically significant upward trend of about 0.566 billion m^3, with an annual increase of about 1.1% during the study period, and the coefficient of determination (R^2) is about 35%.

The data also reflects the development of irrigation water quantities at canal sections, which averaged approximately 42.1 billion m^3, with the highest recorded value at about 48.9 billion m^3 and the lowest at roughly 34.1 billion m^3. Equation No. (4) indicates a statistically significant increasing trend of about 0.326 billion m^3, with an annual growth rate of about 0.77% over the study period, and the coefficient of determination (R^2) is approximately 26%.

Furthermore, the data shows the evolution of irrigation water quantities in the field, with an average of about 36.9 billion m^3, peaking at around 42.3 billion m^3 and dipping to about

31.2 billion m^3. Equation No. (5) illustrates a statistically significant upward trend of about 0.223 billion m^3, with an annual increase rate of about 0.7% during the study period, and the coefficient of determination (R^2) is estimated at approximately 35%.

Lastly, the data reveals the overall development of water resources in Egypt, with an average of about 74.2 billion m^3, reaching a maximum of approximately 79.88 billion m^3 and a minimum of about 67.27 billion m^3. As indicated by Equation No. (6), there is a statistically significant increasing trend of about 1.71 billion m^3, with an annual growth rate of around 2.3% during the study period, and the coefficient of determination (R^2) is approximately 92%.

The data on irrigation water in Fayoum Governorate shows an average of about 1.99 billion m^3, with a maximum of around 2.33 billion m^3 and a minimum of about 1.75 billion m^3. As described in Equation No. (7), there is a statistically significant increasing trend of about 0.015 billion m^3, with an annual growth rate of approximately 0.75% for the average during the study period.

Current Status of the Sesame Crop's Productive and Economic Capacity in Egypt and Fayoum Governorate:

- **Overview of Productive and Economic Capacity of Sesame in Egypt and Fayoum**

The data in Table No. (2) of the appendix outlines the current productive and economic capacity of the sesame crop in Egypt, revealing fluctuations in production from 2004 to 2023. The analysis of the total cultivated area for sesame in Egypt shows an average of approximately 74.34 thousand feddans, with a peak of about 98.8 thousand feddans and a low of around 59.6 thousand feddans. The general time trend equation, presented in Equation No. (8) in Table No. (1), indicates a statistically significant upward trend of approximately 0.316 thousand feddan, reflecting an annual increase rate of about 0.43% of the average. The coefficient of determination (R^2) is estimated at around 24% for the study period.

Additionally, the data reveals the productivity per feddan, with an average of approximately 0.587 tons per feddan, peaking at about 0.635 tons and dropping to about 0.550 tons. As shown in Equation No. (9), there is a statistically significant upward trend of about 0.011 tons per feddan, with an annual increase rate of approximately 1.9%. The coefficient of determination (R^2) for this data is about 35%.

The total production data indicates an average of approximately 43.6 thousand tons, with a maximum of about 58.78 thousand tons and a minimum of approximately 33.93 thousand tons. Equation No. (10) suggests a statistically significant increasing trend of about 0.217 thousand tons, with an annual growth rate of about 0.52%. The coefficient of determination (R^2) is estimated at approximately 48% for the same study period.

These findings highlight the variability in sesame production capacity, as the cultivated area, productivity per feddan, and total production experienced both highs and lows throughout the study period.

In terms of economic indicators, Table No. (2) shows that the average total costs for sesame cultivation amount to approximately 4,351.2 EGP per feddan, ranging from a high of about 13,100 EGP to a low of approximately 1,063 EGP. The general time trend equation, Equation No. (11), indicates a statistically significant upward trend in total costs of about 18.1 EGP per feddan, with an annual increase rate of about 0.42%. The coefficient of determination (R^2) is approximately 81% for the study period.

The data also reflects total revenues, averaging around 8,167.5 EGP per feddan, with a maximum of about 24,110 EGP and a minimum of approximately 2,000 EGP. According to Equation No. (12), the data shows a statistically significant upward trend of about 42.6 EGP per feddan, with an annual growth rate of approximately 0.54%. The coefficient of determination (R^2) is estimated at 95% for the same period.

The net returns have an average of about 3,816.50 EGP per feddan, ranging from a maximum of about 11,010 EGP to a minimum of approximately 937 EGP. Equation No. (13) indicates a statistically significant upward trend of about 9.8 EGP per feddan, with an annual growth rate of about 0.26%. The coefficient of determination (R^2) is 82% for this study period.

The average return on costs is approximately 1.879 EGP, and the average profit per EGP invested is about 0.879 EGP per feddan. Additionally, the average producer incentive rate stands at about 46.3%, while the average economic efficiency rate is around 187.9% during the same period.

These results indicate an increase in net returns and profitability for sesame investors, enhancing their incomes. This growth is reflected in the increasing incentives for producers to expand sesame cultivation in Egypt.

The data in Table No. (2) also outlines the current productive and economic capacity of the sesame crop in Fayoum, showing fluctuations in production during the same period. The analysis of the total area cultivated with sesame in Fayoum reveals an average of about 5.6 thousand feddan, with a maximum of approximately 9.8 thousand feddan and a minimum of about 3.9 thousand feddan. The general time trend equation, Equation No. (14), indicates a statistically significant upward trend of about 0.026 thousand feddan, with an annual growth rate of about 0.47%. The coefficient of determination (R^2) is estimated at 32% for the study period.

Furthermore, the data shows that feddan productivity has an overall average of about 0.580 tons, with maximum values around 0.641 tons and minimum values of about 0.511 tons. Equation No. (15) indicates a statistically significant upward trend of about 0.100 tons per feddan, with an annual growth rate of approximately 1.7%. The coefficient of determination (R^2) is estimated at around 28% during the study period.

Lastly, the total production of sesame in Fayoum averages about 3,290 tons, with maximum values around 6,100 tons and minimums of about 1,950 tons. Equation No. (16) indicates a statistically significant annual upward trend of about 0.022 tons, with an annual growth rate of approximately 0.67% of the general average. The coefficient of determination (R^2) is approximately 55% for the study period.

Table (1): General Time Trend Equations for the Development of Various Agricultural Metrics in Egypt and Fayoum (2004-2023)

The statement	No	variable	General time trend equation	T	R^2	Average	Annual rate of change %
Egypt	1	Total cultivated area	$\hat{Y}i$ = 134005.8 + 71.1Xi	** (4.5)	0.98	8822.8	0.81
	2	The amount of water used in agriculture	$\hat{Y}i$ = 152.1 + 0.655Xi	** (5.1)	0.84	60.1	1.1
	3	Quantity of irrigation water in Aswan	$\hat{Y}i$ = 676.2 + 0.566Xi	* (2.8)	0.32	49.9	1.1
	4	The amount of irrigation water in canal sections	$\hat{Y}i$ = 587.5 +0.326 Xi	* (2.1)	0.26	42.1	0.77
	5	The amount of irrigation water in the field	$\hat{Y}i$ = 489.6 + 0.223 Xi	* (2.4)	0.35	36.9	0.69
	6	Total water resources available in Egypt	$\hat{Y}i$ = 1225.1 + 1.71 Xi	** (15.8)	0.92	74.2	2.3
Fayoum	7	Quantity of irrigation water for Fayoum	$\hat{Y}i$ = 223.1 + 0.015 Xi	**(4.1)	0.58	1.99	0.75
Development of the productive and economic capacity of the sesame crop in Egypt and Fayoum							
Egypt	8	The total area of the crop	$\hat{Y}i$ = 635.6 + 0.316 Xi	* (2.36)	0.24	74.4	0.43
	9	Feddan productivity	$\hat{Y}i$ = 231.8 + 0.011 Xi	*(2.45)	0.35	0.587	1.9
	10	Total production	$\hat{Y}i$ = 452.1 + 0.217 Xi	**(2.88)	0.48	43.6	0.52
	11	Total costs	$\hat{Y}i$ = 1541.7 + 18.1 Xi	**(2.98)	0.81	4351.2	0.42
	12	Total revenue	$\hat{Y}i$ = 6951.1 + 42.6Xi	**(4.68)	0.95	8167.5	0.54
	13	Net return	$\hat{Y}i$ = 569.7 + 9.8 Xi	**(3.11)	0.82	3816.4	0.26
Fayoum	14	The total area	$\hat{Y}i$ = 511.6 +0.026Xi	*(2.75)	0.32	5.6	0.47
	15	Feddan productivity	$\hat{Y}i$ = 198.1+ 0.1Xi	*(2.3)	0.28	0.580	1.7
	16	Total production	$\hat{Y}i$ = 497.7+ 0.022 Xi	**(2.9)	0.55	3.29	0.67
	17	Total costs	$\hat{Y}i$ = 836.9+22.1Xi	**(3.1)	0.91	4326.6	0.51
	18	Total revenue	$\hat{Y}$ I =1547.5 +49.1Xi	**(3.99)	0.90	8177	0.61
	19	Net return	$\hat{Y}i$ =703.2 +10.7Xi	**(3.5)	0.85	3851	0.28

Source:dependent variable, Where yi is the estimated value of the dependent variable, which is represented by the variables (the total cultivated area, the amount of water used in agriculture, the quantities of irrigation water at Aswan, the canal sections, and the field, the number of water resources available in Egypt, and the amount of irrigation water for Fayoum, Total area of sesame crop, feddan productivity,(total production, total costs, total revenue net return)
xi: the time factor in years as an independent variable, where i (1,..............., 20)
The numbers in parentheses below the estimates indicate the calculated t-value **indicates significance at the (0.01) level *indicates significance at (0.05)
Source: Collected and calculated from the data contained in Chart No.(1,2) .

Figure No. (1): Pictures of the Nile River

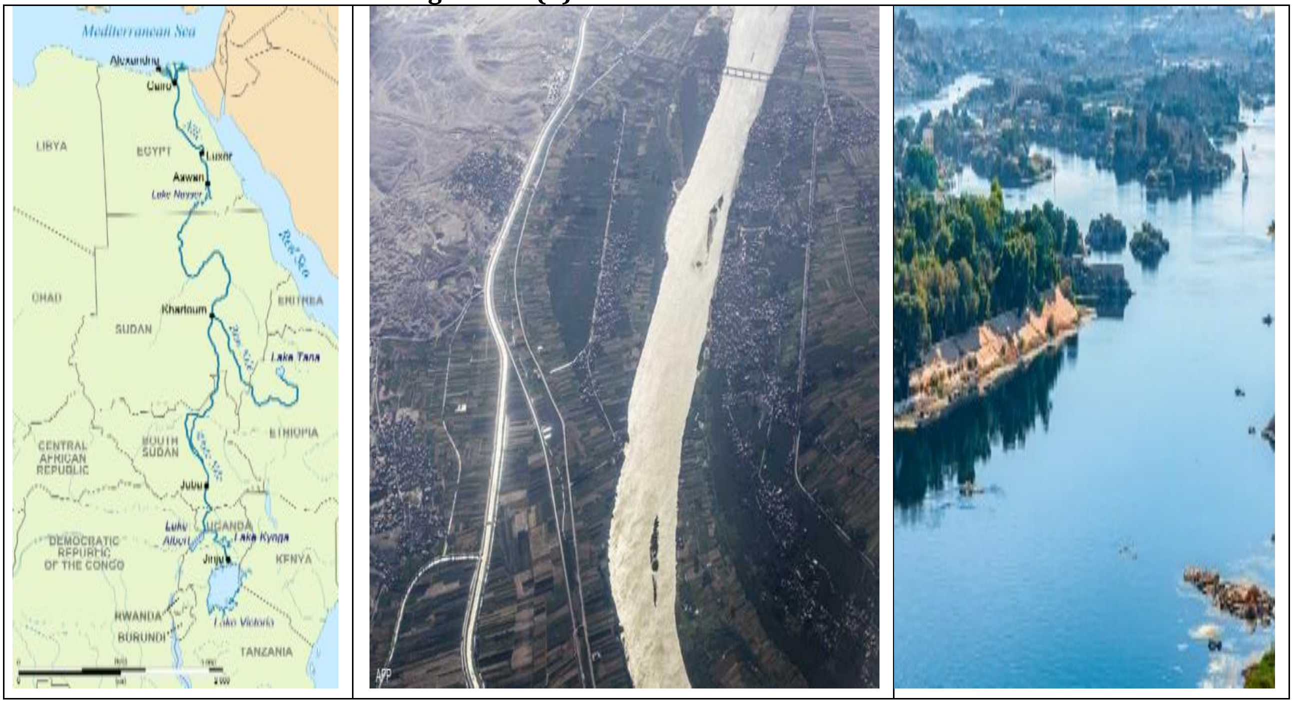
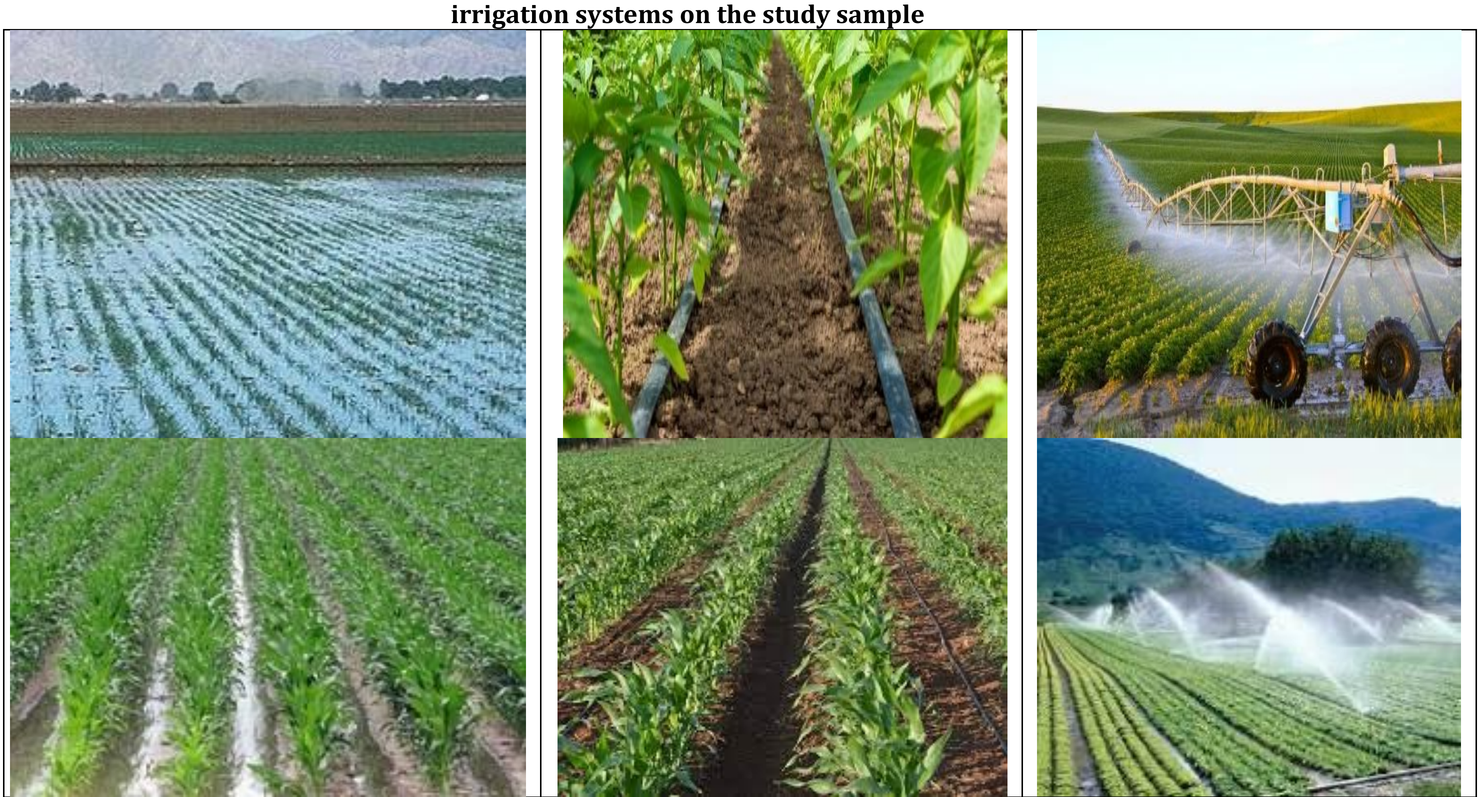


Figure No. (2) The three methods of the impact of implementing the use of modern irrigation systems on the study sample



1-Traditional surface irrigation (by flooding).	**2-Modern irrigation (drip).**	**3-Modern irrigation (by spraying).**

- **Economic Indicators of the Sesame Crop in Fayoum:**

The findings indicate significant fluctuations in production capacity for the sesame crop in Fayoum throughout the study period, with variations in cultivated area, productivity per feddan, and total production.

According to Table No. (2), the analysis of total costs reveals an average of approximately 4,326.6 pounds per feddan, with a maximum of about 13,060 pounds and a minimum of around 1,070 pounds. The general time trend equation (Equation No. 17) shows a statistically significant upward trend in total costs of about 22.1 pounds per feddan, reflecting an annual growth rate of approximately 0.51% of the average. The coefficient of determination (R^2) is about 91% for the study period.

The data also highlights the development of total revenue, averaging around 8,177 pounds per feddan, with a range from a maximum of about 24,120 pounds to a minimum of approximately 2,020 pounds. Equation No. (18) indicates a statistically significant increasing trend of about 49.1 pounds per feddan, with an annual growth rate of approximately 0.61%. The coefficient of determination (R^2) is estimated at 90% during the same period.

Additionally, the development of net return shows an average of approximately 3,850.45 pounds per feddan, with a maximum of about 11,060 pounds and a minimum of around 949 pounds. Equation No. (19) indicates a statistically significant upward trend of about 10.7 pounds per feddan, with an annual growth rate of approximately 0.28%. The coefficient of determination (R^2) is estimated at 85% for the study period.

The average return on costs was approximately 1.895 pounds per feddan, with an average profit per invested pound of about 0.895 pounds. The average producer incentive rate stood at approximately 46.72%, while the average economic efficiency rate was about 189.5% during the study period.

These results suggest an increase in net return and profitability, enhancing producers' incomes and encouraging them to expand sesame cultivation in Egypt.

- **Water Needs and Availability in Fayoum Governorate**

Table No. (2) outlines the water needs for irrigation in 2023, indicating a total requirement of about 2.27 billion m^3. The available irrigation water was estimated at approximately 2.03 billion m^3, resulting in a water deficit of about 0.238 billion m^3. The total cultivated area for the two study crops was about 9.02 thousand feddan, distributed among different irrigation systems as follows: 5.21 thousand feddan (57.8%) for flood irrigation, 2.61 thousand feddan (28.98%) for drip irrigation, and 1.19 thousand feddan (13.22%) for sprinkler irrigation.

- **Description of the Study Sample**

The variables for the study sample in Fayoum Governorate for the 2023 agricultural season were gathered through a questionnaire. A simple random sampling method was employed, representing modern irrigation systems. As shown in Table No. (2), the sample consisted of 230 items, including 120 producers of sesame and peanut crops. Among these, approximately 47.1% utilized flood irrigation systems.

The study sample includes a group of producers utilizing drip irrigation systems, which account for approximately 32.3% of the total participants, as well as those employing sprinkler irrigation systems, representing about 20.6%. The Fayoum Governorate comprises six administrative centers: Atsa, Fayoum, Abshway, Sennuras, Tamiya, and Youssef Al-Siddiq. The average water availability for field irrigation in these centers is estimated at 18.80%, 16.61%, 19.62%, 15.68%, 15.69%, and 13.60%, respectively, from the total available water resources for irrigation in the governorate. The cultivated area for sesame in these centers is represented according to their relative importance within the total cultivated area for the study sample in Fayoum.

The Impact of Modern Irrigation Systems on Production Variables, Costs, and Economic Indicators of Sesame:

- **Effects of Irrigation Systems on Sesame Crop Production Variables, Costs, and Economic Indicators**

From Table No. (3), it is evident that there were about 54 observations of producers using flood irrigation systems, with an average observed area of approximately 1 feddan. The average productivity per feddan was around 570 kg, with an official water rating of about

3,250 m^3 per feddan. The actual irrigation water used per feddan averaged about 3,550 m^3, leading to an estimated wastage of about 300 m^3 per feddan. The efficiency rate of irrigation water usage was approximately 91.55%. The cost of irrigation represented about 10.7% of total costs, with the average cost of the used irrigation water being approximately 1,970 pounds per feddan. Additionally, the average labor hours were about 7.2 hours per feddan, costing around 1,350 pounds. The average quantity of municipal fertilizer used was about 14 m^3 per feddan at a cost of approximately 1,384 pounds. Seed usage averaged around 3.5 kg per feddan, costing about 511 pounds. The average quantities and costs for phosphate and nitrogen fertilizers were about 62.8 units (940 pounds) and 112.5 units (1,350 pounds) per feddan, respectively, while potassium fertilizer averaged 32.6 units at a cost of 1,000 pounds. Human labor averaged about 43 men per feddan, costing approximately 4,203 pounds. Other costs included about 360 pounds for pesticides, 5,100 pounds for rent, and 350 pounds for miscellaneous items, leading to total costs of around 18,482 pounds per feddan. In comparison, total revenue averaged about 40,012 pounds per feddan, resulting in a net return of approximately 21,530 pounds per feddan. The average return on costs was about 2.165, with an average profit of 1.165 per invested pound, and a monthly net return of around 5,383 pounds per feddan. The average producer incentive rate was about 53.81%, and the economic efficiency rate was approximately 216.49%.

Table No. (2) Development of the rate of water needs, available irrigation water, water balance, and the total cultivated area of the sesame crop in Fayoum Governorate 2023

Modifying water needs, available irrigation water, water balance, and different irrigation systems for sesame												
Centers	The average water requirement for irrigation is one million m3/year	%	The rate of available irrigation water is one million m3/year	%	Water balance: million m3/year	Crops Average water requirements, available irrigation water, water balance, and different irrigation systems for the study crop						
						Flood irrigation An area of one thousand feddan	%	Drip irrigation, area of one thousand feddan	%	Sprinkler irrigation of an area of one thousand feddan	%	The total number of different irrigation systems for the area of the two study crops
Atsa	425.2	18.85	381.8	18.80	-43.4	0.855	20.5	0.605	28.4	0.434	36.02	1.894
Fayoum	401.2	17.78	337.28	16.61	-63.92	0.736	17.7	0.494	23.2	0.386	32.03	1.616
Upshway	438.6	19.44	398.38	19.62	-40.22	0.705	16.9	0.418	19.6	0.155	12.86	1.278
Snors	372.1	16.49	318.33	15.68	-53.77	0.653	15.7	0.359	16.9	0.111	9.21	1.123
Tamiya	305.7	13.55	318.5	15.69	12.8	0.616	14.8	0.141	6.6	0.075	6.22	0.832
Prophet Yusuf	325.8	14.44	276.18	13.60	-49.62	0.601	14.4	0.112	5.3	0.044	3.65	0.757
Total	2268.6	100	2.03	100	-238.13	4.166	100.0	2.129	100.0	1.205	100.00	7500

The total cultivated area of the sesame crop							
Centers	The total cultivated area is one thousand feddan	%	Number of holders	%	Geometric mean	The modified geometric mean	Sample size
Atsa	1.821	24.28	321	26.59	25.41	25.43	35
Fayoum	1.437	19.16	237	19.64	19.40	19.41	26
Upshway	1.254	16.72	204	16.90	16.81	16.82	22
Snors	1.116	14.88	165	13.67	14.26	14.27	16
Tamiya	0.996	13.28	147	12.18	12.72	12.73	13
Prophet Yusuf	0.876	11.68	133	11.02	11.34	11.35	8
Total	7500	100	1207	100.0	99.94	100.00	120

Source:1- Ministry of Water Resources and Irrigation - General Administration of Irrigation in Fayoum - Field Irrigation Development Sector - Records of Levels and Dispositions, Unpublished Data 2022.
2-Collected and calculated from data from the Fayoum Agriculture Directorate - Information and Decision Support Center - unpublished data.

- **Effects of Drip Irrigation Systems on Sesame Crop Production Variables, Costs, and Economic Indicators:**

  The same table indicates that there were about 42 observations of producers using drip irrigation systems, with an average area of 1 feddan. The average productivity per feddan was approximately 735 kg, with an official water rating of 3,250 m^3 per feddan. The actual irrigation water used per feddan averaged around 2,900 m^3, with a deviation of about 10.8% from the water standard. The productivity per water unit was around 3.95 m^3 per feddan, with a cost of about 0.64 pounds per m^3. The total revenue per irrigation water unit was approximately 17.6 pounds per m^3. The efficiency rate of irrigation water use was about 112.1%, while the irrigation cost represented about 10% of total agricultural costs. The average cost of irrigation water used was about 1,843 pounds per feddan.

  Labor hours averaged 8 hours per feddan at a cost of about 1,200 pounds. The average quantity of municipal fertilizer was around 16 m^3 per feddan, costing about 1,370 pounds. Seed usage averaged 3 kg per feddan at a cost of 450 pounds. The average quantities and costs for phosphate and nitrogen fertilizers were about 58 units (966 pounds) and 111 units (1,217 pounds), respectively, while potassium fertilizer averaged 37 units at 1,155 pounds. Human labor averaged about 50 men per feddan, costing around 4,752 pounds. Other costs included about 450 pounds for pesticides, 4,801 pounds for rent, and 420 pounds for miscellaneous items, leading to total costs of approximately 18,505 pounds per feddan. Total revenue averaged about 52,922 pounds per feddan, resulting in a net return of around 34,417 pounds per feddan. The average return on costs was about 2.860, with an average profit of 1.860 per invested pound, and a monthly net return of approximately 8,604 pounds per feddan. The average producer incentive rate was about 65.03%, and the economic efficiency rate reached about 286%.
- **Effects of Sprinkler Irrigation Systems on Sesame Crop Production Variables, Costs, and Economic Indicators**

The same table shows the impact of using sprinkler irrigation systems on production variables, costs, and economic indicators for the sesame crop. There were about 24 observations of producers using sprinkler systems, with an average area of 1 feddan. The average productivity per feddan was about 624 kg, with an official water rating of 3,250 m^3 per feddan. The average irrigation water used per feddan was approximately 3,000 m^3, with an estimated wastage of about 250 m^3. The deviation from the water standard was around 7.7%. The productivity per water unit was about 4.81 m^3 per feddan, costing about 0.60 pounds per m^3, with total revenue per irrigation water unit at approximately 15.2 pounds per m^3. The efficiency rate of irrigation water use was about 108.3%, while the irrigation cost represented about 10.3% of total costs. The average cost of the irrigation water used was approximately 1,891 pounds per feddan. The average number of automated work hours was about 8 hours per feddan.

The average cost of automated work hours was about 1,260 pounds per feddan. Additionally, the average quantity of municipal fertilizer used was approximately 15 m^3 per feddan, costing around 1,350 pounds. The average seed quantity was about 3.2 kilograms per feddan, with a cost of approximately 500 pounds. For phosphate fertilizer, the average usage was around 60.10 units per feddan, costing about 955 pounds. The average nitrogen fertilizer application was about 111.50 units per feddan, costing approximately 1,290 pounds, while potassium fertilizer averaged 34.2 units per feddan at a cost of about 1,110 pounds.

Human labor averaged around 45.7 men per feddan, costing approximately 4,560 pounds. The average expenditure on pesticides was about 350 pounds per feddan, with rent averaging around 4,950 pounds per feddan. Miscellaneous expenses averaged about 400 pounds per feddan. Overall, the average total costs were estimated at about 18,536 pounds per feddan, while the average total revenue was approximately 45,251 pounds per feddan, resulting in an average net return of about 26,715 pounds per feddan. The average rate of return on costs was around 2.404, with an average profit of 1.404 per invested pound and an average monthly net return of about 6,506 pounds per feddan. The average producer incentive rate was about 58.40%, and the average economic efficiency rate was approximately 240.40%.

Table No. (3) The effect of using modern irrigation systems on characterizing production variables, costs, and economic indicators for the sesame crop in the study sample in 2023 Fayoum for the agricultural season.

Variables	Sesame					
	Flood irrigation		Drip irrigation		Sprinkler irrigation	
	Quantity	the value	Quantity	the value	Quantity	the value
First: indicators of water restrictions						
1) Number of observations in the sample	54		42		24	
2) Average cultivated area (feddan).	1		1		1	
3) Average food productivity (sesame kg, peanut tons/feddan)	570		735		624	
4) Average official water rating (m3) per feddan	3250		3250		3250	
(5) The average amount of irrigation water actually used for irrigation (m3) per feddan	3550		2900		3000	
(6) Deviation from the water standard = (4 – 5) (m3) per feddan	-300		350		250	
(7) Percentage of deviation from the water standard % = (6/4*100).	-9.2		10.8		7.7	
(8) Water unit productivity per feddan = (3/5) (m3) per feddan	6.23		3.95		4.81	
(9) The cost of a unit of water (m3) per feddan = (13 / 5) pounds (m3) per feddan	0.55		0.64		0.60	
(10) Revenue from irrigation water unit = (25/5) pounds (m3) per feddan	11.3		17.2		15.1	
(11) Irrigation water use efficiency rate per feddan %= (4/5*100)	91.55		112.1		108.3	
(12) Irrigation cost is attributed to the total costs per feddan % = (13/24 * 100) pounds per feddan	10.7		10		10.3	
(13) The total cost of irrigation actually used (m3) per feddan	1970		1843		1891	
Second: Productive and economic indicators						
(14) Average mechanical labor hours/feddan for the season	7.2	1350	8	1200	8	1260
(15) Average amount of municipal fertilizer, m3 per feddan	14	1348	16	1370	15	1350
(16) Average quantity of seeds, kg per feddan	3.3	511	3	450	3.2	500
(17) Average phosphate fertilizer unit per feddan	62.8	940	58	966	60.10	955
(18) The average nitrogen fertilizer is one unit per feddan	112.5	1350	111	1217	111.50	1290
(19) The average potassium fertilizer is one unit per feddan	32.6	1000	37	1155	34.2	1110
(20) Average human labor per feddan (man/season).	43	4203	50	4752	45.7	4560
(21) The average value of pesticides is pounds per feddan	360		331		350	
(22) The average rent is one pound per feddan	5100		4801		4950	
(23) The average petty cash items is one pound per feddan	350		420		400	
(24) Average total costs are pounds per feddan	18482		18505		18536	
(25)The average total revenue is one pound per feddan	40012		52922		44561	
(26) The average net return is one pound per feddan	21530		34417		26025	
(27)Average rate of return for costs	2.165		2.860		2.404	
(28) Average profitability of the invested pound	1.165		1.860		1.404	
(29) Average monthly net return	5383		8604		6506	
(30)Average product incentive rate %	53.81		65.03		58.40	
(31) Average economic efficiency rate, %	216.49		285.99		240.40	

Source: Data from the study sample in Fayoum Governorate for the season. 2023
*The average official water rating (m3) per feddan for sesame crop is (3250 m^3)

Statistical Estimation of Production Functions for Sesame Crop:

This section presents the statistical estimation results of production functions for the sesame crop in the study sample. It examines the relationship between the quantity of sesame production (y) and key independent factors affecting it, including: (x1) mechanical work hours per feddan, (x2) municipal fertilizer quantity (m^3/feddan), (x3) seed quantity (kg/feddan), (x4) irrigation water quantity (m^3/feddan), (x5) phosphate fertilizer units (feddan), (x6) nitrogen fertilizer units (feddan), (x7) potassium units (feddan), (x8) nutrient quantity (liters/sample), (x9) pesticide value (pounds/sample), and (x10) human labor (man-days/sample). Stepwise regression analysis was utilized, revealing that the double logarithmic form is most effective in identifying the primary factors influencing production.

- **Statistical Estimation of the Production Function for Sesame Based on Flood Irrigation Systems**

Estimating the sesame production function shows statistically significant results, indicated by an F-value of approximately 64.4, confirming the overall significance of the model at the 0.01 probability level. The coefficient of determination (R^2) suggests that about 61% of the variation in production quantity can be explained by the independent factors included in the model. The estimated function reveals a positive and statistically significant impact from the following independent variables: (X1) mechanized labor hours, (X2) municipal fertilizer quantity (m^3/feddan), and (X3) seed quantity (kg/feddan). Specifically, a 1% increase in these factors leads to increases in sesame production of approximately 0.216%, 0.667%, and 0.211%, respectively, assuming all other factors remain constant. The total elasticity of the model is around 1.094, indicating increasing returns to scale, meaning a 1% increase in these production inputs results in a 1.094% increase in sesame production.

$$LogYI = 2.417 + 0.216 Logx_1 + 0.667 Logx_2 + 0.211 Logx_3 \quad \ldots\ldots(1)$$

$$^{**}(2.9)^{**} \quad (4.8) \quad ^{**}(3.6)$$

$$R^2 = 0.61 \qquad F = 64.4^{**}$$

- **Statistical Estimation of the Production Function for Sesame Crop Using Modern (Drip) Irrigation Systems**

The estimation of the sesame production function reveals significant statistical results, with an F-value of approximately 86.8, indicating the overall significance of the model at a 0.01 probability level. The coefficient of determination (R^2) suggests that around 91% of the variations in production quantity can be attributed to the independent variables included in the model.

The estimated function demonstrates a positive and statistically significant impact from the following independent factors: (X1) mechanical work hours, (X2) municipal fertilizer quantity (m^3/feddan), (X3) seed quantity (kg/feddan), (X4) irrigation water quantity (m^3/feddan), and (X8) nutrient quantity (liters). Specifically, a 1% increase in these factors results in increases in sesame production of approximately 0.563%, 0.769%, 0.274%, 0.323%, and 0.252%, respectively, assuming all other factors remain constant. The overall elasticity of the model is about 2.181, indicating increasing returns to scale, meaning that a 1% increase in the aforementioned production inputs leads to a 2.181% increase in sesame production.

$$LogYI = -1.558 + 0.563 Logx_1 + 0.769 Logx_2 + 0.274 Logx_3 + 0.323 Logx_4 + 0.252 Logx_8 \quad \ldots\ldots(2)$$

$$^{**}(2.9) \quad ^{**}(4.8) \quad ^{**}(3.6) \quad ^{**}(4.25) \quad ^{**}(3.41)$$

$$R^2 = 0.91 \qquad F = 86.8^{**}$$

- **Statistical Estimation of the Production Function for Sesame Crop Using Modern (Spraying) Irrigation Systems**

The estimation of the sesame production function indicates statistical significance, as evidenced by an F-value of approximately 78.7, confirming the overall significance of the model at a 0.01 probability level. The coefficient of determination (R^2) shows that about 86% of the variations in production quantity can be attributed to the independent variables included in the model.

The estimated function reveals a positive and statistically significant effect from the following independent factors: (X1) automated work hours, (X2) municipal fertilizer quantity

(m^3/feddan), (X3) seed quantity (kg/feddan), and (X8) nutrient quantity (liters). Specifically, a 1% increase in these factors results in increases in sesame production of approximately 0.396%, 0.674%, 0.374%, and 0.251%, respectively, assuming all other factors remain constant. The overall elasticity of the model is about 1.695, indicating increasing returns to scale, meaning that a 1% increase in the mentioned production inputs leads to a 1.695% increase in sesame production.

The estimated production function can be represented as:

$$LogYI=-1.214 +0.396Logx_1+0.674Logx_2+0.374Logx_3 +0.251Logx_8 \quad \text{.....(3)}$$

$$^{**}(3.15) \quad ^{**}(5.1) \quad ^{**}(4.11) \quad ^{**}(2.95)$$

$$R^2 = 0.86 \quad F = 78.7^{**}$$

Statistical Estimation of Cost Functions for Sesame Crop Based on Modern Irrigation Systems:

This section focuses on estimating cost functions by analyzing the relationship between total costs and production quantity for the study sample, revealing that the quadratic form is the most suitable statistical model.

- **Cost Function Estimation for Sesame Crop Using Flood Irrigation Systems**

The cost function estimation for sesame indicates a statistically confirmed direct relationship between total costs and sesame production. The results establish statistical significance, with an F-value of approximately 64.8, confirming the overall significance of the model at the 0.01 probability level. The coefficient of determination (R^2) suggests that around 74% of the variations in total costs are due to changes in production. To find the optimal size that minimizes costs, average costs were equated with marginal costs, estimated at approximately 696 kg/feddan, while average production was about 570 kg/feddan. This indicates that actual sesame production falls short of the optimal production volume by approximately 126 kg/feddan. Ten producers achieved this size, but no producer reached the maximum profit level of about 1,200 kg/feddan. The cost elasticity was calculated at approximately 0.511, indicating that production is in the first, uneconomic stage.

$$TC = 1396.2 - 485X_1 + 235X_2$$

$$R^2 = 0.74 \quad F = 64.8^{**}$$

- **Cost Function Estimation for Sesame Crop Using Drip Irrigation Systems:**

The cost function estimation for sesame shows a statistically confirmed positive relationship between total costs and production. The results indicate statistical significance, with an F-value of approximately 87.8, confirming the overall significance of the model at the 0.01 probability level. The coefficient of determination (R^2) shows that about 92% of the variations in total costs are due to changes in production. The optimal size for minimizing costs was estimated at approximately 1,006 tons/feddan, while average production was about 735 kg/feddan, indicating that actual sesame production is less than the optimal volume by approximately 271 kg/feddan. Eight producers achieved this size, but no producer reached the maximum profit level of about 2.300 tons/feddan. The cost elasticity was calculated at approximately 0.332, indicating that production is in the first, uneconomic stage.

$$TC = 3005.5 - 765X_1 + 185X_2$$

$$R^2 = 0.92 \quad F = 87.8^{**}$$

- **Cost Function Estimation for Sesame Crop Using Spraying Irrigation Systems**

The cost function estimation for sesame indicates a statistically confirmed positive relationship between total costs and production. This is supported by the results, which show statistical significance with an F-value of approximately 78.5, confirming the overall significance of the model at a 0.01 probability level. The coefficient of determination (R^2) is approximately 82%, indicating that 82% of the variations in total costs are due to changes in production. To determine the optimal production size that minimizes costs, average costs were equated with marginal costs, estimated at approximately 837 kg/feddan, while average production was about 624 kg/feddan. This suggests that actual sesame production is below the optimal volume by approximately 213 kg/feddan. Nine producers achieved this optimal size, but no producer reached the maximum profit level of about 1,700 tons/feddan. The cost elasticity was calculated at approximately 0.381, indicating that production is in the first, uneconomic stage.

$$TC = 2512.2 - 691X_1 + 225X_2$$

$$R^2 = 0.82 \quad F = 78.5^{**}$$

Analysis of Variance of Productivity and Economic Indicators for Sesame Crop Based on Modern Irrigation Systems:

This section conducts a variance analysis of productivity and economic indicators based on the application of modern irrigation systems, including surface (flood), drip, and spraying methods. The analysis examines indicators such as per-feddan productivity, total costs, total revenue, and net return.

- **Variance Analysis of Productivity and Economic Indicators for Sesame Crop**

Table No. (4) Presents a comparative analysis of variance for sesame production across the three irrigation methods: flooding, drip, and spraying. The study sample shows average production of approximately 570 kg/feddan for flooding, 735 kg/feddan for drip, and 624 kg/feddan for spraying. The variance analysis indicates statistical significance, with an F-value of approximately 21.28.

The LSD test results confirm a statistically significant difference at the 0.000 level. Specifically, there is a significant difference in the mean production between the second method (drip) compared to both the first (flood) and third (spraying) methods. The average productivity for the first method increased by 165 kg/feddan, and for the third method, it increased by 111 kg/feddan, with these differences being significant at the 0.000 level. Additionally, the average productivity for the third method compared to both the first and second methods showed an increase of 54 kg/feddan, significant at the 0.004 level.

The same table provides a comparative analysis of the variation in sesame production costs across three irrigation methods: flooding, drip, and spraying, within the context of modern irrigation systems. The study sample indicated that the average total costs were approximately 18,482, 18,505, and 18,536 pounds per feddan, respectively. The variance analysis among these methods showed statistical significance, with an F-value of about 11.43. Additionally, the LSD test results confirmed a statistically significant difference at the 0.000 level.

Comparative Analysis of Costs, Revenue, and Net Returns for Sesame Production:

The table presents a comparative analysis of sesame production costs across three irrigation methods: flooding, drip, and spraying, within the context of modern irrigation systems. The study sample revealed average total costs of approximately 18,482, 18,505, and 18,536 pounds per feddan, respectively. The variance analysis indicated statistical significance, with an F-value of about 11.43. The LSD test results confirmed a statistically significant difference at the 0.000 level. Specifically, there is a significant difference in the mean costs for the second method (drip) compared to both the first (flooding) and third (spraying) methods. The average total costs for the first method increased by 1,224.7 pounds/feddan, and for the third method, by 1,151.6 pounds/feddan, with these differences being significant at the 0.000 level. Additionally, when comparing the first method to the second and third methods, the average total costs increased by 1,176.3 pounds/feddan with the third method, significant at the 0.003 level.

The table also provides a comparative analysis of sesame production revenue across the three irrigation methods. The average total revenue was approximately 40,012, 52,922, and 44,561 pounds per feddan, respectively. The variance analysis among these methods showed statistical significance, with an F-value of approximately 15.7. The LSD test results confirmed a statistically significant difference at the 0.000 level.

Specifically, there is a significant difference in the mean revenue for the second method compared to both the first and third methods. The average total revenue for the first method increased by 9,988.4 pounds/feddan, and for the third method, by 5,439.7 pounds/feddan, with these differences being significant at the 0.000 level. Additionally, for the third method compared to both the first and second methods, the average total revenue increased by 4,548.8 pounds/feddan with the first method, significant at the 0.004 level.

The table further presents a comparative analysis of net returns for sesame production across the three irrigation methods. The average net returns were approximately 21,530, 34,417, and 26,025 pounds per feddan, respectively. The variance analysis indicated statistical significance, with an F-value of approximately 30.5. The LSD test results confirmed a statistically significant difference at the 0.000 level.

Specifically, there is a significant difference in the mean net return for the second method compared to both the first and third methods. The average net return for the first method increased by 11,043 pounds/feddan, and for the third method, by 6,426 pounds/feddan, with these differences being significant at the 0.000 level. Additionally, for the third method compared to both the first and second methods, the average net return increased by 4,614.6 pounds/feddan with the first method, significant at the 0.002 level.

Table No. (4) Results of the analysis of variance and results of the LSD analysis for the least significant differences for per-feddan productivity, total costs, total revenues, and net returns for sesame according to the application of modern irrigation systems 2023.

Analysis of variance for feddan productivity, total costs, total revenue, and net return of the sesame crop according to the application of modern irrigation systems in the study sample						
The statement		**Sum of Squares**	**df**	**Mean Square**	**F**	Sig
Productivity	**Between Groups**	285428.033	2	142714.017	21.281	.000
	Within Groups	382248.950	57	6706.122		
	Total	667676.983	59			
total costs	**Between Groups**	42113640.033	2	21820.017	11.43	.194
	Within Groups	28255487.700	57	513254.170		
	Total	28299117.733	59			
total revenue	**Between Groups**	1000326427.733	2	500163213.867	15.647	.000
	Within Groups	1822039614.000	57	31965607.263		
	Total	2822366041.733	59			
net return	**Between Groups**	1230620656.033	2	615310328.017	30.479	.000
	Within Groups	1150720936.950	57	20188086.613		
	Total	2381341592.983	59			

Results of LSD analysis for the least significant differences in per-feddan productivity, total costs, total revenue, and net yield for sesame according to the application of modern irrigation systems in the study sample						
The statement	**(I) X1 (J) X1**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	95% Confidence Interval	
					Lower Bound	**Lower Bound**
Productivity	2.00 1.00	-165.75000*	25.89618	.000	-217.6062	-113.8938
	3.00	-54.55000*	25.89618	.040	-106.4062	-2.6938
	1.00 2.00	165.75000*	25.89618	.000	113.8938	217.6062
	3.00	111.20000*	25.89618	.000	59.3438	163.0562
	1.00 3.00	54.55000*	25.89618	04.0	2.6938	106.4062
	2.00	-111.20000*	25.89618	.000	-163.0562	-59.3438
total costs	2.00 1.00	24.6900011-	288.53672	.038	-453.0948	702.4748
	3.00	1176.27000*	288.53672	03.0	598.4852	1754.0548
	1.00 2.00	*24.6900021	288.53672	.000	702.47481	453.0948
	3.00	51.58000*11	288.53672	.000	473.79521	1629.3648
	1.00 3.00	-1176.27000*	288.53672	.031	-1754.0548	-598.4852
	2.00	-1051.58000*	288.53672	.025	-1629.3648	-473.7952
total revenu	2.00 1.00	-9988.400*	1787.893	.000	-13568.59	-6408.21
	3.00	-4548.800*	1787.893	.014	-8128.99	-968.61
	1.00 2.00	9988.400*	1787.893	.000	6408.21	13568.59
	3.00	5439.600*	1787.893	.000	1859.41	9019.79
	1.00 3.00	4548.800*	1787.893	40.0	968.61	8128.99
	2.00	-5439.600*	1787.893	46.0	-9019.79	-1859.41
net return	2.00 1.00	-11043.750*	1420.848	.000	-13888.95	-8198.55
	3.00	-4614.550*	1420.848	.002	-7459.75	-1769.35
	1.00 2.00	11043.750*	1420.848	.000	8198.55	13888.95
	3.00	6429.200*	1420.848	.000	3584.00	9274.40
	1.00 3.00	4614.550*	1420.848	.002	1769.35	7459.75
	2.00	-6429.200*	1420.848	.000	-9274.40	-3584.00

Source: Data from the study sample in Fayoum Governorate for the season. 2023.

Key Problems and Solutions for Sesame Producers Using Modern Irrigation Systems in Fayoum (2023 Agricultural Season):

- **Major Problems Facing Sesame Producers:**

According to the data, the most pressing problems faced by sesame producers in Fayoum for the 2023 agricultural season are as follows:

1. Water Availability: A lack of available irrigation water, coupled with increased evaporation rates for open irrigation, high weed percentages in canals, poor water access at canal ends, irregular irrigation schedules, pollution in canals, and inadequate disinfection and maintenance. Freshwater mixing with wastewater was noted as a significant issue, affecting about 95% of the sample size (approximately 230 producers).
2. High Production Costs: The rising prices of production inputs (fertilizers, seeds, pesticides) and the lack of state-subsidized fertilizer courses necessary for the crops affected about 90% of the sample size.
3. Weak Agricultural Extension: The limited role of agricultural extension services in educating farmers about water usage and modern irrigation systems was a concern for about 86% of the sample.
4. Seed Variety Limitations: The absence of high-yielding, disease-resistant seed varieties affected about 83% of the sample size.
5. Lack of Production Data: Insufficient production and marketing information prior to planting, along with weak contract farming practices between producers, traders, companies, and factories, impacted about 79% of the sample.
6. High Irrigation Costs: The expense associated with flood, drip, and sprinkler irrigation systems affected about 67% of the sample.
7. Production Losses: A high percentage of losses during production and harvesting stages was reported by about 63% of the sample.
8. Financial Constraints: Limited loan sizes and high interest rates for agricultural financing were noted by about 55% of the sample.

Proposed Solutions for Sesame Producers:

The data highlighted the most important proposed solutions for sesame producers in Fayoum for the 2023 agricultural season, arranged in descending order:
1. Increasing Awareness: Enhancing farmers' understanding of optimal irrigation water usage to boost productivity was prioritized by about 94% of the sample.
2. Canal Maintenance: The need to clear obstructions in canals and waterways to ensure proper water access ranked second, affecting about 82% of the sample.
3. Reducing Input Prices: Lowering the costs of production inputs (fertilizers, seeds, pesticides) was deemed essential by about 80% of the sample.
4. Enhancing Agricultural Extension: Activating agricultural extension services to educate producers on modern irrigation methods and developing low-water seed varieties was supported by about 80% of the sample.
5. Providing Data: Ensuring access to production and marketing data before cultivation was ranked fifth, affecting about 76% of the sample.
6. Increasing Oversight: Strengthening state supervision over contracting systems between producers, traders, companies, and factories to protect producers was supported by about 75% of the sample.

Recommendations: The research proposes the following key recommendations:
1. Policy Development: Establish policies and mechanisms to transition to advanced irrigation systems to reduce water usage and enhance productivity across various crops. Implement necessary regulations to facilitate this transition.
2. Farmer Education: Increase awareness among farmers about the benefits of modern irrigation systems through extension agencies and media. Provide material and technical support, training for transitioning from flood to advanced irrigation, and facilitate access to soft, long-term loans for implementing these systems.
3. Specialized Education: Create new specializations in agricultural colleges focused on water management and irrigation network organization to produce skilled professionals.
4. Maintenance of Irrigation Networks: Ensure annual replacement and maintenance of modern irrigation networks with appropriate financial contributions to enhance infrastructure and expand water supply sources to meet growing demands.
5. Development of High-Yield Varieties: Focus on developing high-yielding seed varieties that are resilient to adverse weather conditions and require less water.

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