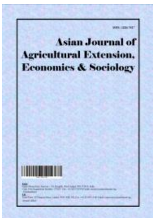

Asian Journal of Agricultural Extension, Economics & Sociology

39(2): 126-140, 2021; Article no.AJAEES.66689
ISSN: 2320-7027

A Comparative Economic Study of Tomato Production by Hydroponics and Conventional Agriculture (With Soil) in Greenhouses: A Case Study in the Nubaria Region

Shady Mohamed Shawky Abdelmawgoud[1*], Hossam Hosney Abdul Aziz[2], Ahmed Abdel Ati Shibl[2] and Mufidah Al-Sayed Qabeel[2]

[1]Department of Agricultural Economics, Faculty of Agriculture, Menoufia University, Egypt.
[2]Agricultural Economy Research Institute, Agricultural Research Center, Egypt.

Authors' contributions

This work was carried out in collaboration among all authors. Author SMSA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors HHAA and AAAS managed the analyses of the study. Author MASQ managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJAEES/2021/v39i230538
Editor(s):
(1) Dr. Golubkina Nadezhda Alexandrovna, Federal Scientific Center of vegetable production, Russia.
Reviewers:
(1) Tiziana Sirangelo, CREA-OFA , Italy.
(2) OFIAELI, Ogochukwu Chioma, Nnamdi Azikiwe University, Nigeria.
(3) Hilario Becerril Hernández, Colegio De Postgraduados, Mexico,
Complete Peer review History: http://www.sdiarticle4.com/review-history/66689

Original Research Article

Received 27 January 2021
Accepted 01 April 2021
Published 09 April 2021

ABSTRACT

One of the most important challenges and obstacles faced by tomato farmers in the new lands is the scarcity of productive resources and their high cost, especially the suppliers of fresh water and arable land, which negatively affects the net yield. Therefore, this research paper aims to make a comparison between tomato production using traditional greenhouses (with soil) and using Hydroponics technology in the new lands with the research sample, aiming to measure the effect of using hydroponics in agricultural greenhouses on the most important indicators of economic returns, by studying and analyzing the cost components of the two production types and studying the most important productive, economic and financial indicators.

**Corresponding author: E-mail: shady.mohamed32@agr.menofia.edu.eg;*

Keywords: Tomato; hydroponic; greenhouse; agriculture.

1. INTRODUCTION

The tomato crop is considered one of the strategic vegetable crops in the Egyptian agricultural sector, which are cultivated in open lands, and protected crops in greenhouses, whether traditional or cultivation without soil, as tomatoes are the most important vegetable crops cultivated in hydroponics[1] [1,2] systems in Egypt, and The average annual area of tomato crop cultivation in the exposed land in the three lugs was about 417.29 thousand acres, With a total production of about 6.94 million tons, the average area of tomatoes grown in traditional agricultural greenhouses was about 1.29 million m^2 with a total production estimated at 17.95 thousand tons, Most of this production is concentrated in the new lands, with an estimated 9.09 thousand tons, accounting for about 50.64% of the total production of tomatoes in agricultural areas at the level of the Republic. Nubariya is one of the most important areas of tomato production using greenhouses in the new lands, as the total number of greenhouses reached about 469, with an area estimated at 234.6 thousand m^2 with a total production estimated at 5.47 thousand tons, representing about 33%, 46.6% and 60.2% respectively of the total number of greenhouses in the new lands, during the period (2016-2018) [2].

It can be said that hydroponic systems are one of the innovative agricultural methods that do not need soil to carry out agricultural processes, as hydroponics depends on water completely to provide the nutritional needs of plants which are necessary for its growth, as vegetables are grown with this technique inside greenhouses and plastic during the winter months, especially tomatoes, as it is considered the most important and widespread vegetable Hydroponics varies between six different techniques [3]: Nutrient Film Technique, Raft Technique, Ebb & Flow Technique, Drip Technique, Aeroponic Technique, Wick Technique, and there are many other systems that are either derived or combined with these six basic methods [4,5]. It can be said that the most common method of hydroponics in Egypt is the cultivation of plants inside the pipes, As shown in Fig. 1, it depends on providing two main basins, one of which is used for feeding, where nutrients are added to the water, and the second is used for emptying the water where it receives the water coming out of the pipes after feeding the plants, and There are holes in these pipes for placing seedlings using pots with holes to allow the water to penetrate, and this system is applied inside the plastic greenhouses.

2. RESEARCH PROBLEM

research problem lies in the challenges and obstacles faced by tomato farmers in the new lands such as the scarcity of production resources and their high cost [6], especially fresh water and fertile arable lands, which negatively affects the net revenue of these farms, These areas are characterized by land that is not directly arable without being reclaimed or with low fertility lands, In addition to the lack of arable fresh water resources, as well as the high cost of obtaining a stable and arable water source, This is in light of Egypt's recent problems with the lack of water available for agriculture, which is a burden on tomato farmers and the low economic revenue of these traditional crops., so the research problem lies in an important question that revolves around the extent to which hydroponics can overcome these productive problems, and its effects on the net economic return.

3. GOALS OF THE RESEARCH

The research aims to compare tomato production in traditional greenhouses (with soil) and using hydroponics technology in new lands, in order to measure the effect of using hydroponics in greenhouses on the most important indicators of economic returns for the production of the research crop, through the following sub-objectives: -

- Measuring and analyzing the cost [7] items of tomato production in greenhouses with the two production types (soil cultivation and hydroponics) with the research sample.

---

[1] - The term Hydroponics originates from the Greek language, with the word "hydro" meaning water, and the word "ponics" meaning work.

[2] - Collected and calculated from data, Ministry of Agriculture and Land Reclamation, Central Department of Agricultural Economics, Agricultural Statistics Bulletin, consecutive numbers.

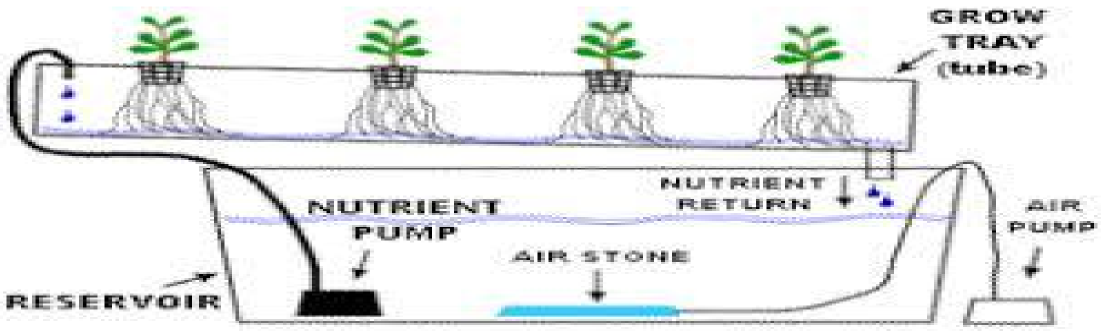

Fig. 1. Cultivation of plants inside the pipes

- Estimating the effect of using hydroponic systems on the most important productive, economic [8,9] and financial indicators of tomato production in greenhouses.
- Determine the optimal production level, and the optimal combinations of production elements, and identify the most influential factors on tomato production, according to the two types of production under study.

4. METHODOLOGY AND DATA SOURCES

To achieve its goals, research depends on the descriptive and quantitative analysis method, and many analytical tools and statistical methods were used in estimating and measuring, such as percentages and arithmetic averages, and some criteria and indicators of economic returns, and the t-Test: for two samples that are not equal in variance, in addition to Using the logarithmic form Cub Douglass [10,11] function in estimating the productive functions, and (t - f) tests to estimate the significance of the regression coefficients for the parameters used in the measurement, and the function took the following mathematical form:

$$\ln Y_i = \alpha + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + ... + \beta_n \ln X_{ni}$$

As for the data sources, two data sources were used, the first of which is: secondary data published and unpublished in institutions related to the research topic, such as the economic affairs sector of the Ministry of Agriculture and Land Reclamation and others, studies and research related to the research topic, and the second: the primary data through a field questionnaire for the research sample [12]. Data were collected through personal interviews with some producers of tomato crops using traditional and hydroponic methods in greenhouses in the Nubaria region.

5. THE RESEARCH SAMPLE

The research sample was selected from the Nubaria region, as it is considered the most important areas of tomato production in greenhouses in the new lands, with an average production of about 5.47 thousand tons, representing about 60% of the counterpart in the new lands during the period (2016-2018), As for the number of greenhouses producing tomatoes that operate with hydroponic systems, no statistics have been issued by any official authority in Egypt yet, but through observation and the personal effort of researchers based on the research, it can be said that Nubaria is the most productive areas of the republic using hydroponic systems, As hydroponics spread in several regions, namely: Al Bustan, West Nubaria, South Tahrir, Al Nahda, Mariout, and bangar elsokar, so it represents the spatial scale for regarding sampling and collecting primary data hydroponics (greenhouses without soil).

Therefore, the sample was selected using the purposive sampling (deliberate sampling)[3]. The size of the research sample was estimated at about 25 views of hydroponics, in addition to a sample for comparison estimated at about 25 observations of farmers who did not apply this technique. and it was taken into consideration when selecting the comparison sample that the traditional greenhouses are close to each other as possible and that the greenhouse areas and agricultural transactions are close. Based on this, the total sample size is estimated at about 50

[3]- The deliberate sample is resorted to in cases where the researcher does not have any options in determining the constituent elements of the research community, and the researcher depends on his selection on his experience and ability to form the sample that he thinks is the most appropriate for the study he conducts, Under deliberate sampling the selection of items is made by choice and It is useful for a small population and its vary between the quota sample, hypothesis, stereotype, chance, and numerical. This research was based on the numerical sample.

observations[4] in addition to about 10% of the sample size chosen as a reserve to face some field problems that impede obtaining the necessary data. Research preview was done in the agricultural season of the year 2019/2020.

6. RESEARCH RESULTS AND DISCUSSION

6.1 Study and Analysis of the Production Costs of Tomatoes in Greenhouses with Two Production Types (Hydroponics and Soil Cultivation) with the Research Sample

6.1.1 Study of tomato production costs in hydroponic greenhouses

6.1.1.1 Investment costs

The construction costs of tomato production in hydroponics greenhouse [13] are estimated at 145.91 thousand pounds/ Hydroponic greenhouse, as shown by Table 1, and by estimating depreciation premiums [14,15] for the items of those costs, the total premiums amounted to about 36.28 thousand pounds/Hydroponic greenhouse, and the annual rent for the greenhouse was estimated at 1598.8 pounds/ Hydroponic greenhouse. The costs of Iron arches come in the first rank as the highest construction costs items, then PVC [(5)] pipes in second rank, then heating devices, followed by black polyethylene plastic, fixed labor, plastic pots, decanters, and a Hydroponic greenhouse engineer, with an estimated value of about 26.419, 22.497, 19.22, 8.73, 6.04, 5.96, 4.9, 4.9, 4.21 thousand pounds / Hydroponic greenhouse, representing about 18.11%, 15.42%, 13.17%, 5.98%, 4.14%, 4.08%, 3.36%, 3.36% and 2.88% respectively of the total construction costs. That is, these nine items combined represent about 70.5% of the total fixed asset costs.

While it comes in the ranks from ten to twenty-seventh, respectively Each of Water lifting motor, Pest Control Motor, Feeding and emptying basins, Ventilation devices, Irrigation network filter, Timer to set irrigation dates, Hoses 18 ml polyethylene, Supplies and column pumping and feeding, Water pump, Air pump, Polyethylene thin hoses for irrigation, Sensitive balance, Ph. meter .ppm, Metal wire, Air motor hoses, Compressed foam panels as cover for basins, Plastic trays for germination of seedlings and Electrical wires and power connectors

6.1.2 Operational costs [16]

The results indicated that the average variable costs of tomato in the hydroponic greenhouses of the research sample amounted to about 69.143 thousand pounds / Hydroponic greenhouse, which represents about 64.6% of the total costs which were estimated at 107.025 thousand pounds / Hydroponic greenhouse, as shown in Table 2.

Seedlings costs come in the first rank as the highest items of variable production costs, estimated at about 23.35 thousand pounds / Hydroponic greenhouse, and they represent about 33.78% and 21.8% of the variable and total costs, respectively, followed by packaging and marketing packages in second rank with about 19.58 thousand pounds / Hydroponic greenhouse representing About 28.3%, 18.3%, respectively, of the variable and total costs. Then comes the nutrient solution, human labor, water for irrigation and nutrition, and pesticides, in ranks from the third to the sixth, respectively, by 6.06, 5.65, 5.5, and 2.19 thousand pounds / Hydroponic greenhouse representing 8.77%, 8.17%, 8.03% and 3.16% respectively of Variable costs, and about 5.66%, 5.28%, 5.19% and 2.04% of the total costs, this means that those five items together represent about 90.2%, 58.29% of the total variable and total costs

While the fuel, growth stimulants, growth media (vermiculite and hydro ton soils), Administrative and petty expenses, sulfuric acid as a pH regulator, Automated spraying motor, in the ranks from the seventh to the twelfth, respectively.

6.2 Studying of Items of Tomato Production Costs in Traditional Greenhouses (in soil)

6.2.1 Investment costs

Looking at Table 3, it becomes clear that the total value of the construction costs for producing tomatoes in traditional greenhouses (in soil) with

[4] - *Each greenhouse represents an area (40 m x 9 m) with a total area 360 m^2 for a greenhouse, whether for hydroponic or traditional farming.*

[5] - *Polyvinyl Chloride (PVC or Vinyl) is an economical and versatile thermoplastic polymer widely used in building and construction industry to produce door and window profiles, pipes (drinking and wastewater), wire and cable insulation, medical devices, etc. It is the world's third largest thermoplastic material by volume after polyethylene and polypropylene, https://omnexus.specialchem.com/selection-guide/polyvinyl-chloride-pvc-plastic.*

Table 1. The Items of Investment Costs (Construction) In the Research Sample for Producing Tomatoes by Hydroponics

Statement / Items	Operating life (years)	Costs Pound / Hydroponic greenhouse	The ratio of the element's cost to the total construction costs	Depreciation Premium Pound / year	% of the Premiums from the total depreciation Premiums
Iron arches	11.56	26418.56	18.11	2330.3	6.42
Planting tubes (PVC) 4-6 inches	7.52	22497.5	15.42	3005	8.28
Heating devices	6.56	19221	13.17	2947.6	8.12
Plastic cover for the greenhouse	5	8732.4	5.98	1781.5	4.91
Polyethylene 16-18 micron for basin lining	2.44	6040	4.14	2575.7	7.10
Fixed labor	1	5957.1	4.08	5957.1	16.42
Plastic pots (cups) for planting	3.2	4900.89	3.36	1551.7	4.28
20-liter jugs	10.6	4900	3.36	464.48	1.28
Greenhouse engineer	1	4205	2.88	4205	11.59
Water lifting motor	10	4182.81	2.87	420.4	1.16
Pest Control Motor	10.64	3685.95	2.53	350.7	0.97
Feeding and emptying basins	10.69	3684.76	2.53	346.3	0.95
Ventilation devices	4.84	3320	2.28	697.06	1.92
Irrigation network filter	3.28	3085.04	2.11	956.69	2.64
Timer to set irrigation dates	6.88	2938.4	2.01	429.41	1.18
Hoses 18 ml polyethylene	3.2	2755	1.89	880.15	2.43
Supplies and column pumping and feeding	4.6	2729.5	1.87	599.81	1.65
Water pump	4.6	2457.61	1.68	540.91	1.49
Air pump	4.76	2074.02	1.42	440.44	1.21
Polyethylene thin hoses for irrigation	2.56	1929	1.32	791.22	2.18
Sensitive balance	10.04	1893.75	1.30	189.16	0.52
Ph. meter. ppm	4.52	1507.62	1.03	338.16	0.93
Metal wires	4.16	1280.95	0.88	318.73	0.88
Air motor hoses	2.28	1215.78	0.83	552.54	1.52
Compressed foam panels as cover for basins	1.24	1017	0.70	894.96	2.47
Plastic trays for germination of seedlings	2.68	442.5	0.30	171.23	0.47
Electrical wires and power connectors	4.76	367.86	0.25	77.82	0.21
Other expenses (*)	1	2468.95	1.69	2469	6.80
Total costs of fixed assets	-	145908.95	100	-	-
Total Depreciation Premium	-	-	-	36283.04	100
Rent	1598.81	-	-	-	-
Total fixed costs	37881.85	-	-	-	-

- *Source: Collected and considered from study sample data for the season of 2019/2020.*
- *(*)Other expenses are greenhouse Installation and establishment costs and petty cash during construction.*
- *The area of the greenhouse is nearly 360 M^2.*

the research sample is about 79.125 thousand pounds / greenhouse, and by estimating the annual premiums for the items of those costs, it is revealed that the total annual depreciation installments were estimated at 16.547 thousand pounds / greenhouse, And the annual rent for the greenhouse was about 1297.78 EGP / greenhouse.

It was found that the costs of the iron arches come in the first rank as the highest items of construction costs, then the heating devices in the second rank, then the plastic cover for the greenhouse, followed by the Water lift motor, the Pest Control Motor, with an estimated value of about 26.908, 18.99, 8.73, 4.16, 3.67 thousand pounds /greenhouse, representing about 34.01%, 24%, 11.03%, 5.25%, and 4.66% of the total construction costs, respectively, meaning that these five items together represent about 78.95% of the total fixed asset costs, while the irrigation network filter comes. Ventilation devices, fixed labor, fertilizer, main irrigation pipes, metal wires, and irrigation hoses, in the sixth to twelfth ranks, respectively, represent about 21.05% of total fixed asset costs.

Heating devices come first as the highest annual depreciation premium, then fixed labor in second rank, then the plastic cover for the greenhouse, then the irrigation network filter and ventilation devices, with an estimated value of 2.88, 2.51, 2.46, 1.94, 9.89, 0.649 thousand pounds / greenhouse, Representing about 17.4%, 15.2%, 14.88%, 11.7%, 5.98% and 3.9% of the total annual depreciation installments, respectively. Consequently, the six items combined represent about 69.1% of the total depreciation installments, while the Water lift motor, then the irrigation hoses, followed by the main irrigation pipes, metal wires, the Pest Control Motor, and the fertilizer, are ranked from seventh to twelfth respectively and represent About 31.9 of the total depreciation installments.

6.2.2 Operational costs

Results of Table 4 Indicate that the average variable production costs for producing tomatoes in traditional greenhouses amounted to about 33,451 thousand pounds / greenhouse, representing about 65.21% of the average total costs, which amounted to about 51,296 thousand pounds / greenhouse.

The costs of seedlings come in the first rank as the highest item of variable production costs, as it is estimated at about 10.324 thousand pounds / greenhouse and represents about 30.86% and 20.13% of the variable and total costs respectively, followed by packaging and marketing packages in the second rank with about 9.265 thousand pounds / greenhouse representing About 27.70% and 18.06%,

Table 2. The items of the operating costs in the research sample for producing tomatoes by hydroponics

Statement / Items	Costs (pound)	% Of variable costs	% Of total costs
Seedlings	23353.81	33.78	21.82
Packaging and marketing packages	**19580.4**	28.32	18.30
Nutrient solution (6)	**6060.53**	8.77	5.66
Human labor	5651.08	8.17	5.28
Water for irrigation and feeding	**5550**	8.03	5.19
Pesticides	2185.5	3.16	2.04
Fuel	**2002.27**	2.90	1.87
Growth stimulants	1570.91	2.27	1.47
growth media (vermiculite and hydro ton soil) (7)	**1470.2**	2.13	1.37
Administrative and petty expenses	**1239.46**	1.79	1.16
Sulfuric acid as a pH regulator	**307.07**	0.44	0.29
Automated spraying motor	**171.6**	0.25	0.16
Total variable costs	**69142.82**	100	64.60
Total fixed costs	**37881.85**	**-**	35.40
Total costs	**107024.67**	**-**	100

Source: Collected and calculated from the study sample data for the 2019/2020 season.

- *The area of the greenhouse is nearly 360 M^2.*

[6]- *Hydroponics depends mainly on providing the needs of plants with nutrients and some elements such as nitrogen, potassium, and phosphorus by adding them to water in the form of nutrient solutions.*

[7] *-Hydroton is a growing medium composed of expanded clay pebbles. and vermiculite is the natural mineral is used in many sectors, from the building industry to gardening. It's the common name for hydrated laminar magnesium-aluminum-iron silicate.*

Table 3. The Items of Investment Costs (Construction) In the Research Sample for Producing Tomatoes in traditional greenhouses (in soil), by the research sample

Statement / Items	Operating life (years)	Costs Pound / Hydroponic greenhouse	The ratio of the element's cost to the total construction costs	Depreciation Premium (Pound / year)	% of the Premiums from the total depreciation Premiums
Iron arches	11.21	26908.33	34.01	2461.87	14.88
Heating devices	6.64	18993.4	24.00	2882.32	17.42
Plastic cover for the greenhouse	4.56	8730	11.03	1937.93	11.71
Water lifting motor	9.88	4156.36	5.25	422.49	2.55
Pest Control Motor	10.64	3685.95	4.66	350.7	2.12
Irrigation network filter	3.28	3190.55	4.03	988.94	5.98
Ventilation devices	4.56	2925.51	3.70	649.43	3.92
Fixed labor	1	2511.68	3.17	2511.68	15.18
Fertilizer	6.6	1521.43	1.92	231.89	1.40
Main irrigation pipes	4.96	1351.67	1.71	394.83	2.39
Metal wire	3.4	1208.93	1.53	361.61	2.19
Irrigation hoses	2.52	1002.08	1.27	414.13	2.50
Other expenses	1	2939.299	3.71	2939.29	17.76
Total costs of fixed assets	-	79125.18	100	-	-
Total Depreciation Premium	-	-	-	16547	100
Annual rent	1297.78				
Total fixed costs	17844.89				

- *Source: Collected and considered from study sample data for the season of 2019/2020.*
- *(*)Other expenses are greenhouse Installation and establishment costs and petty cash during construction.*
- *The area of the greenhouse is nearly 360 M^2.*

respectively, of the variable and total costs, Then human labor, fuel, and pesticides came in the ranks from the third to the fifth, respectively, with an average of about 8773, 2002.27, 1430.7 pounds / greenhouse, and each of them represented about 26.23%, 5.99% and 4.28%, respectively, of the average variable costs , And about 17.10%, 3.90%, and 2.79% of the total costs, respectively, meaning that these five items together represent about 95.06%, 61.98% of the variable and total costs, While potassium sulfate, automatic irrigation, foliar compost, automatic tractor work, Automated work with a spray motor, ammonium nitrate, superphosphate, and magnesium sulfate are ranked from sixth to thirteenth, respectively.

From the above, it can be said that the construction costs of producing tomatoes in hydroponic greenhouses are greater than in the case of traditional greenhouses, this was reflected positively on the value of the depreciation installment and the rental value of the greenhouse and also fixed costs, this is due to the multiplicity of fixed assets items and the high costs of some of them, such as PVC pipes and polyethylene used for lining basins, and others. It is due to the difference in the technical nature between the two production types., The operating costs have also surpassed in Hydroponics compared to its traditional counterpart, which can be attributed to the high costs of operational components, especially the nutrient solution, and growth stimulants.

Table 4. The items of the operating costs in the research sample for producing tomatoes in traditional greenhouses (in soil)

Statement / Items	Costs (pound)	% Of variable costs	% of total costs
Seedlings	10324.48	30.86	20.13
Packaging and marketing packages	9264.9	27.70	18.06
Human labor	8773.02	26.23	17.10
Fuel	2002.27	5.99	3.90
Pesticides	1430.71	4.28	2.79
Potassium sulfate	439.79	1.31	0.86
automatic irrigation	390.44	1.17	0.76
Foliar compost	320.17	0.96	0.62
automatic tractor work	216.38	0.65	0.42
Automated work with a spray motor	163.83	0.49	0.32
Ammonium nitrate	66.78	0.20	0.13
Superphosphate	46.76	0.14	0.09
Magnesium sulfate	11.99	0.04	0.02
Total variable costs	33451.52	100	65.21
Total fixed costs	17844.89	-	34.79
Total of total costs	51296.41	-	100.00

Source: Collected and calculated from the study sample data for the 2019/2020 season.

- *The area of the greenhouse is nearly 360 M^2.*

Table 5. The most important productive and economic indicators of tomato production in traditional and hydroponic greenhouses in the research sample

Indicator / Type of cultivation	Production mode: Hydroponic	Production mode: Traditional	Mean differences	% For differences (*)	(t) Computed	Significant
Average production (kg)	28254.5	12488.1	15766.4	126.3	98.86	Significant
Sale price (pounds / kg)	5.11	4.82	0.29	6.0	5.96	Significant
Total revenue (EGP)	144235.8	60192.4	84043.4	139.6	76.37	Significant
Total costs (EGP)	107024.7	51296.4	55728.3	108.6	47.34	Significant
Net revenue (EGP)	37211.2	8896	28315.1	318.3	22.22	Significant
Revenue / Cost Ratio (EGP)	1.35	1.17	0.18	15.4	9.59	Significant
Return on the invested pound	0.35	0.17	0.18	105.9	9.59	Significant
Production cost per kg (EGP)	3.79	4.11	(0.32)	(7.8)	9.98	Significant

Source: collected and calculated from the study sample data for the 2019/2020 season.
where

1. *The ratio of total revenue to costs = total revenue / total costs.*
2. *Return on invested pound = The net revenue / total costs.*
3. *Kg production cost = total / average production costs.*
4. *(*) The differences in the averages are attributable to the values of the traditional production pattern.*
5. *The numbers in parentheses are negative.*

7. THE IMPACT OF USING HYDROPONIC SYSTEM ON SOME PRODUCTIVE, ECONOMIC AND FINANCIAL INDICATORS OF TOMATO PRODUCTION IN AGRICULTURAL GREENHOUSES

To study and interpret the effect of Hydroponics technology on some productive, economic and financial indicators of tomato yield by the research sample, the t-Test was conducted, so that it can be identified whether there is a statistically significant difference in the arithmetic mean of those indicators between users and non-users of hydroponic systems, as shown in the Table (5), (6) As following

Table 6. The most important financial indicators for tomato production in hydroponic and traditional greenhouses in the research sample

Type of cultivation / Indicator	Production mode		Mean differences	% of differences (*)	(t) Calculated	Significant
	Hydroponics	Traditional				
Break-even production value (pound)	**55205.8**	**37394.2**	17811.6	**47.6**	**13.35**	Significant
Break-even production Volume (kg)	**7425.4**	**3709.9**	3715.5	**100.2**	**47.59**	Significant
Payback period (years)	**1.01**	**1.32**	(0.31)	(**23.5**)	**16.42**	Significant
Rate of return on investment**(%)**	**25.53**	**11.32**	14.21	**125.5**	**12.33**	Significant
Net Profit to Total Revenue	**25.8**	**14.61**	11.16	**76.4**	**9.53**	Significant
Total asset turnover	**0.99**	**0.76**	0.23	**30.3**	**17.26**	Significant
Productive safety limit **(%)**	**73.7**	**70.28**	3.44	**4.9**	**7.4**	Significant

Source: collected and calculated from the study sample data for the 2019/2020 season.
Where:

1. *Break-Even Production Value = Total Construction Costs / (Average Selling Price Per Kilo - Average Variable Costs Per Kilo).*
2. *Average Variable Costs Per Kilogram of Tomatoes with Conventional Production = 2.68 (Pound), Hydroponic = 2.44 (Pound).*
3. *Break-Even Production Volume = Total Construction Costs / Average Selling Price Per Kg.*
4. *Payback Period = Total Construction Costs / Total return.*
5. *Rate of Return on Investment (%) = Net return / Total Construction Costs.*
6. *Net Profit to Total return (%) = Net return / Total return.*
7. *Total Asset Turnover = Total return / Total Construction Costs.*
8. *Production Safety Limit (%) = ((Actual Production Volume - Breakeven Production Volume) / Actual Production Volume) * 100.*
9. *(*) The Differences in The Averages Are Attributable to The Values of The Traditional Production Pattern.*
10. *The Numbers in Parentheses Are Negative.*

7.1 The Most Important Productive and Economic Indicators

It was found that the average production in greenhouses using hydroponic technology and traditional technology was about 28.26 and 12.49 tons / greenhouse, respectively, with a difference of about 15.76 tons more than productivity of the traditional greenhouses, this increase has been statistically proven significant, and the increase in productivity may be due to the precise control of plant nutrition, Which helped to increase the efficiency of the use of nutrients, And improve nutrition operations, irrigation and ventilation roots, as well as the complete sterilization of agricultural environment [8] , The average farm price reached 5.11 and 4.82 EGP / kg for hydroponic and conventional greenhouses respectively.

As for the revenue from greenhouses that use hydroponic technology and traditional technology, it was found that it amounted to about 144.24 and 60.19 thousand pounds / greenhouse, respectively, which was positively reflected on the net revenue average, where it reached about 37.21, 8.89 a thousand pounds / a greenhouse respectively in spite of rising of the total productive costs of the hydroponic greenhouses, these differences were statistically proved significant.

As for the revenue to costs as a measure of economic efficiency, it was found that it was 1.35% and 1.17% in hydroponic and traditional greenhouses, respectively, meaning That is, every one pound in costs gives a return of about 0.35 and 0.17, respectively, which confirms that there is an efficiency of hydroponic greenhouses. Hence, greenhouses that use hydroponic technology are more efficient in their production

8 - That is, the possibility of a pathological infection of plants is a small possibility, but in the event of a truly pathological infection, it is transmitted to all plants compared to the traditional production pattern, and here comes the importance of relying on trained labor, unlike the traditional production pattern.

than traditional greenhouses, due to their superiority in both the net revenue and the return on the invested pound.

7.2 The Most Important Financial Indicators

By studying and analyzing the break-even point and the safety limit for tomato production in hydroponic and traditional greenhouses with the research sample, it was found that the value of the equivalent production is estimated at 55.21 and 37.39 thousand pounds, respectively, for both hydroponics and traditional greenhouses, as shown in Table 6 and the production safety limit were estimated at 73.72%. 70.28%, respectively, this means that the project remains profitable even if production decreased by 73.72% and 70.28%, respectively, and then a decrease in production from that percentage means losses.

It was found that the total assets turnover rate for both the hydroponic and traditional greenhouses that produce tomatoes in the research sample was about 0.99 and 0.76 times, respectively, which reflects the management's efficiency in using the fixed assets available in both production types, and the net profit ratio to the total revenue for each of the two Production types was estimated. At 25.77% and 14.61% respectively, meaning that the greenhouse projects for hydroponics are economically rewarding compared to their traditional counterparts.

While the rate of return on investment in the two production types of hydroponic and traditional greenhouses was estimated at 25.53 and 11.32%, and the payback period for each of them was about 1.01 and 1.32 years each, respectively, and then the investment preference in producing tomatoes with hydroponic greenhouses compared to their traditional counterparts.

In other words, the hydroponic systems have a positive effect on the productive, economic and financial indicators assessed by the research, as all of these indicator’s averages outperformed for the production of tomatoes in hydroponic greenhouses compared to their traditional counterparts, these differences among the averages were statistically significant and they were sufficient enough to overcome the overall high costs of the hydroponic farming.

8. SENSITIVITY ANALYSIS FOR TOMATO PRODUCTION IN HYDROPONIC [17] AND TRADITIONAL GREENHOUSES WITH THE RESEARCH SAMPLE

This part of the research is concerned with studying the extent of the response or sensitivity [18] of the project under study to the change in the factors that affect its profitability, by re-conducting the evaluation under the assumptions of changing returns and costs assuming changes in circumstances.

8.1 Sensitivity Analysis For Hydroponic Tomato Production

By studying the extent of the response of the net returns to the changes that occurred mutually in revenues and costs, as shown in Table (7), As follows:

- When revenues decrease by 10%, 20% and 50%, the net return drops from about 37.2 thousand pounds to about 22.78, 8.36 and -34.91 thousand pounds, respectively. While the revenues increased by 10%, 20% and 50%, the net return rose from about 37.2 thousand pounds to about 51.63, 66.06 and 20.93 thousand pounds, respectively, assuming the total costs are constant.
- As for the increase in costs by 10%, 20% and 50%, the net return decreased from about 37.2 thousand pounds to about 26.51, 15.81 and 16.30 thousand pounds, respectively, while in the case of a decrease in costs by 10%, 20% and 50 %, The net revenue increased from about 37.2 thousand pounds to about 47.91, 58.62 and 90.72 thousand pounds, respectively, when the revenues are fixed.

8.2 Sensitivity Analysis for Tomato Production in Traditional Greenhouses (With Soil)

Results in Table (8) indicate the following:

- That in the case of a decrease in revenues by 10%, 20% and 50%, the net return decreases from about 8,896 thousand pounds to about 2.88, -3.14 and -21.20 thousand pounds, respectively, while the profit increases from about 8,896 thousand

Table 7. Results of sensitivity analysis for tomato production in hydroponic greenhouses

The change	Cost constancy	% 10 +	%20+	%50+	%10-	%20-	%50-
Revenue constancy	37211.2	26508.7	15806.2	(16301.4)	47913.7	58616.2	90723.7
%10+	51634.7	40932.2	30229.7	(1877.9)	62337.2	73039.7	105147.2
%20+	66058.3	55355.8	44653.3	12545.8	76760.8	87463.3	119570.8
%50+	109328.9	98626.4	87923.9	55816.4	120031.4	130733.9	162841.4
%10-	22787.7	12085.2	1382.7	(30724.9)	33490.2	44192.7	76300.2
%20-	8364.1	(2338.5)	(13041.0)	(45148.5)	19066.6	29769.1	61876.6
%50-	(34906.6)	(45609.1)	(56311.6)	(88419.1)	(24204.1)	(13501.6)	18606.0

Source: collected and calculated from the study sample data for the 2019/2020 season.

Where

- *The numbers in parentheses are negative.*
- *By studying the increase in revenues by 10%, with the decrease in costs by the same percentage, the net return increased from about 37.2 thousand pounds to about 62.34 thousand pounds, while it decreased to about 12.09 thousand pounds in the case of an increase in costs by 10% with the decrease in revenues by the same percentage.*
- *- In the case of an increase in revenues and a decrease in costs together by 20%, the profit increased from about 37.2 thousand pounds to about 87.46 thousand pounds, while in the case of a decrease in revenues and an increase in costs together by 20%, the net return drops to about -2.34 thousand pounds..*
- *In the case of a 50% increase in revenues and a decrease in costs by the same percentage, the net return rises from about 37.2 thousand pounds to 162.84 thousand pounds, while the net return decreases to about -88.42 thousand pounds, in the case of a 50% increase in costs and a 50% decrease in revenues.*
- *From the foregoing, it appears that profits were more sensitive to lower revenues compared to increasing it, as well as to increasing costs compared to its decrease.*

Table 8. Results of sensitivity analysis for tomato production in traditional greenhouses (with soil)

Change	Cost stability	%10+	%20+	%50+	%10-	%20-	%50-
Revenue constancy	8896	3766.37	(1363.27)	(16752.2)	14025.65	19155.29	34544.22
%10+	14915.2	9785.57	4655.93	(10733)	20044.85	25174.49	40563.42
%20+	20934.4	15804.77	10675.13	(4713.8)	26064.05	31193.69	46582.62
%50+	38992.2	33862.57	28732.93	13344	44121.85	49251.49	64640.42
%10-	2876.8	(2252.83)	(7382.47)	(22771.4)	8006.45	13136.09	28525.02
%20-	(3142.39)	(8272)	(13401.67)	(28790.6)	1987.25	7116.89	22505.82
%50-	(21200.19)	(26329.8)	(31459.47)	(46848.4)	(16070.55)	(10940.9)	4448.02

Source: collected and calculated from the study sample data for the 2019/2020 season.

Where

- *The numbers in parentheses are negative.*
- *When the costs increased by 10%, 20% and 50%, the profit decreased from about 8,896 thousand pounds to about 3.77, -1.36 and -16.75 thousand pounds, respectively. Whereas when costs decrease by 10%, 20% and 50%, the profit rises from about 8,896 thousand pounds to about 14.03, 19.16, 34.54 thousand pounds, respectively, assuming that the revenues are constant.*
- *As for the case of increasing revenues and decreasing costs together by 10%, the profit increased from about 8,896 thousand pounds to about 20.04 thousand pounds, while the profit decreased to about -2.25 thousand pounds in the event of a decrease in revenues and an increase in costs by 10% together.*
- *While in the case of a 20% increase in revenues and a decrease in costs by the same percentage, the profit rose from about 8,896 thousand pounds to about 31.19 thousand pounds, while the profit decreased to about -13.40 thousand pounds in the case of a 20% increase in costs and a 20% decrease in revenues.*
- *By studying the decrease in revenues by 50%, and the increase in costs by the same percentage, the net revenue decreased from about 8,896 thousand pounds to about -46.85 thousand pounds, while the profit rose to about 64.64 thousand pounds in the case of a 50% decrease in costs and an increase in revenues by the same percentage.*
- *This means that the net return is sensitive and responsive to increasing costs compared to decreasing it, as is the case for decreasing revenues compared to increasing it.*

pounds to about 14.92. 20.93 and 38.99 thousand pounds in the case when revenues increased by 10%, 20% and 50% respectively, when total costs were fixed.

9. THE ECONOMIC ANALYSIS OF TOMATO PRODUCTION FUNCTIONS IN HYDROPONIC AND TRADITIONAL GREENHOUSES

The primary purpose of estimating farm production functions is to determine the optimum production level and optimal combinations of each of the productive elements, Where the linear regression model and the double logarithmic regression were estimated by the multiple and stepwise method to determine the most influencing factors on tomato production, and this required estimating the correlation matrix between production and each of the different productive factors of the different farmers of the study sample, To know the relationship between each of these productive elements and production, and based on the results of the estimates, some productive inputs were excluded when estimating the Stepwise regression.

9.1 The Statistical Estimate of Tomato Production Function with Hydroponic Greenhouses

By studying the relationship between the main output of tomatoes ($\hat{Y}1i$) measured in tons, as a dependent variable, and the productive elements as explanatory variables, represented by: the number of seedlings (x1) measured by unit, the amount of pesticides (x2) measured in liters, and human labor (x3) measured (man / day) The amount of growth stimulants (x4) measured in liters, the automatic work of the spray motor (x5) measured by the hour, the amount of nutrient solution (x6) measured in liters, and the amount of growth media (vermiculite and hydro ton soils) (x7) measured in liters, according to the economic and statistical comparison criteria, the best model to express the productive function is the double logarithmic form, as it is considered the best estimate of the Cub Douglass model.

Hence, equation (1) in Table (9) clarified that the most productive factors affecting tomato production in hydroponic greenhouses are: human labor (x3), the amount of nutrient solution (x6), and the amount of growth media (x7). The relation of production with the two components of human labor, the nutrient solution was inverse, which indicates an excessive use of these two components, while the effect of the amount of growth media was positive, and the total elasticity of the function was estimated at about 0.25, meaning that with an increase of those production elements by 10%, tomato production increased by 2.5%, This means that production takes place in the second stage of the production function Hence it is subject to the relationship of decreasing returns to scale, And tomato farmers, using this production mode, can increase their profits by reducing the quantities used from these productive elements, and adjusted R squared ($\bar{R}^2$) indicates that about 90% of the changes in tomato production are in this production pattern are due to the change in the productive elements included in the function.

The marginal product of human labor (x3), the amount of nutrient solution (x6), and the amount of growth media (x7) were estimated at 0.187, 0.036 and 0.101 tons, respectively, and the marginal product value was about 1030.4, 198.36, 556.51 pounds, while The unit price of those elements was estimated at about 48.27, 55.69, and 11.45 pounds, respectively, as shown in Table 10, and then it can be said that the elements included in the function have achieved economic efficiency that exceeds the value of the marginal product for them than their prices, and that it is possible to increase The quantities used from these elements up to the point at which the value of marginal product equals the market price of the productive component.

9.2 Statistical Estimation of the Function of Tomato Production in Traditional Greenhouses (With Soil)

The study showed that the best models expressing the productive function of tomatoes in traditional greenhouses are the double logarithmic form, The function included the following elements: number of seedlings (x1) measured by number of plants / greenhouse, amount of pesticides (x2) measured in liters, human labor (x3) (man / day), The amount of foliar fertilizer (x4) in liter, the amount of nitrate Aluminum (x5) in effective units, amount of superphosphate fertilizer (x6) in effective units, amount of fertilizer potassium sulfate (x7) in effective units, amount of magnesium sulfate fertilizer (x8) in effective units, automatic tractor work (x9) per hour, automatic irrigation work (x10) Per hour, Automated work with a spray motor (x11) per hour, and the main output of tomato (Y1) measured in ton.

Table 9. Estimation of the production functions of tomato crop in hydroponic and traditional greenhouses with the research sample

Production mode	Estimated equation	elasticity		F computed
Hydroponic	$L\hat{Y}_{1i}$ = 8.836 – 0.071 LX_{3i} – 0.138 LX_{6i} + 0.459 LX_{7i} (31.819)** (-2.379)* (-3.086)** (13.762)**	0.250	0.900	72.770 **
Traditional	$L\hat{Y}_{2i}$ =0 **10.**2+ 0.872 LX_{5i} + **0.862** LX_{6i} – **0.550** LX_{7i} (18.798)** (6.609)** (5.771)** (-3.110)** + 0.102 LX_{10i} + 0.046 LX_{11i} (2.767)** (2.903)*	1.332	0.771	17.183 **

Source: collected and calculated from the study sample data for the 2019/2020 season.
Where:

Hydroponics

- *$\hat{Y}_1i$: Estimated tomato yield per observation i*
- *X_3i: number of workers (man / day) per observation i*
- *X_6i: the amount of the nutrient solution (liter) per observation i*
- *X_7i: Amount of growth media (liters) per observation i*
- *L: logarithm= Ln*
- *i: 1, 2, ……., 25*
- *(*) Significant at: 0.05 level of significance*
- *(**) Significant at: 0.01 level of significance*

traditional (with soil)

- *$\hat{Y}_2i$: Estimated tomato production value per observation i.*
- *X_5i: Ammonia nitrate amount (unit) in observation i*
- *X_6i: Amount of superphosphate (unit) in viewing i.*
- *X_7i: Amount of potassium sulfate (unit) per observation i.*
- *$X_{10}i$: Irrigation hours per view i.*
- *$X_{11}i$: Hours of spray motor per observation i.*
-

Table 10. Estimating the economic efficiency of the inputs of the tomato production functions in the traditional and hydroponic greenhouses by the research sample

	The total amount of product by the function	Variables	logarithmic geometric mean	geometric mean	A. P.)tons)	Elasticity	M.P. (tons)	M.P. Value (EGP)	Item Price (EGP)	Eco. efficiency
Hydroponic	$\hat{Y}L_1$= 3.34 (28.22) ton	X_3	2.374	10.74	2.663	0.071	0.187	1030.4	48.27	(*)
		X_6	4.689	108.74	0.260	0.138	0.036	198.36	55.69	*
		X_7	4.853	128.12	0.220	0.459	0.101	556.51	11.45	*
traditional	$\hat{Y}L_2$ = 2.52 (12.43) ton	X_5	1.569	4.80	2.59	0.872	2.26	10893.2	4.59	*
		X_6	2.291	9.89	1.26	0.862	1.09	5253.8	2.18	*
		X_7	2.852	17.32	0.718	0.550	0.395	1903.9	12.70	*
		X_{10}	1.258	3.52	3.53	0.102	0.360	1735.2	110.64	*
		X_{11}	0.257	1.29	9.64	0.046	0.443	2135.3	122.04	*

Source: collected and calculated from the study sample data for the 2019/2020 season.
Where:

Hydroponics

- *$\hat{Y}_1i$: Estimated tomato yield per observation i*
- *X_3i: number of workers (man / day) per observation i*
- *X_6i: the amount of the nutrient solution (liter) per observation i*
- *X_7i: Amount of growth media (liters) per observation i*
- *L: logarithm In*
- *i: 1, 2, …… ..., 25*
- *A.P.: average product*
- *M.P.: marginal product*

traditional (with soil)

- *$\hat{Y}_2i$: Estimated tomato production value per observation i.*
- *X_5i: Ammonia nitrate amount (unit) in observation i*
- *X_6i: Amount of superphosphate (unit) in viewing i.*
- *X_7i: Amount of potassium sulfate (unit) per observation i.*
- *$X_{10}i$: Irrigation hours per view i.*
- *$X_{11}i$: Hours of spray motor per observation i.*
- *(*) Significant at: 0.05 level of significance*
- *(**) Significant at: 0.01 level of significance*

** There is economic efficiency, but it is still possible to increase this efficiency by using quantities of the element until the value of the marginal product equals the price.*
The price per ton of tomatoes planted with soil = 4820 pounds / ton.
The price per ton of tomatoes in hydroponics = 5510 pounds / ton.

Equation No. (2) in Table 9 showed that there is a positive relation between tomato production (Y2) per ton as a dependent variable, and between each of the amount of ammonium nitrate (x5), the amount of superphosphate fertilizer (x6), and the mechanical action of irrigation (x10), The automatic work of the spray motor (x11), and an inverse relation with the amount of potassium sulfate fertilizer (x7) as independent variables, and the total elasticity of the function was about 1.322, meaning that with an increase of the independent factors of the function by 10%, the main output of tomatoes increases by 13.2%, and then The production takes place in the first stage of the production function and is subject to the increasing returns to scale, meaning that tomato farmers with this production pattern can increase their profits by expanding the use of those productive elements. and adjusted R squared ($\bar{R}^2$) indicates that about 77% of the changes in the quantity Production is due to the change in the independent variables combined.

The marginal product of the production elements included in the function is the amount of ammonium nitrate per unit (x5), the amount of superphosphate fertilizer per unit (x6), the amount of fertilizer potassium sulfate per unit (x7), the hourly automatic irrigation work (x10), and the automatic work of the sprinkler motor (x11)), It was estimated at 2.26, 1.09, 0.395, 0.360 and 0.443 tons, respectively, and the value of the marginal product of those elements was about 10893.2, 5253.8, 1903.9, 1735.2, and 2135.3 pounds, respectively, and the unit price of those elements was estimated at 4.59, 2.18, 12.70, 110.64 and 122.04 pounds, respectively, as shown in Table 10.

10. CONCLUSION

Based on the aforementioned results, it can be said that the production of tomatoes in hydroponic greenhouses depends mainly on the nutrient solution, growth stimulants, and growth media, almost completely as a source for plant needs, and thus tomato production in hydroponic greenhouses It differs from traditional greenhouses, in that it relies on fertilization of various kinds and pesticides, and soil as a growth media, and thus the producers of tomatoes in hydroponic greenhouses had the ability to control production factors more efficiently compared to cultivation in traditional greenhouses, Hence, construction and operational costs and the value of the depreciation and rent premium for producing tomatoes in hydroponic greenhouses was superior to its traditional counterparts, but all the averages of the productive, economic and financial indicators estimated by the research, were superior to their traditional counterparts sufficiently to overcome the high total costs of hydroponics, In addition to the economic stage in which production takes place, which was positively reflected in the net return from hydroponics, however, many greenhouses, especially those scattered in desert lands that suffer from a shortage of water and fertile land resources, lack these modern technologies (hydroponics) in the production, the use and distribution of production elements on accurate scientific basis, thus wasting large quantities of production elements and their distribution imbalance, and thus the efficiency of their use decreases.

11. RECOMMENDATIONS

- Supporting and encouraging of tomato producers with traditional greenhouses to shift to the productive mode using hydroponic technology, especially those producers in the new lands of low fertility.
- Necessity of adopting of agricultural guidance to spread this (hydroponic) production pattern among tomato producers in traditional greenhouses, as well as training and qualifying workers on this technology.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Douglas JS. Hydroponics. The Bengal system. Hydroponics. The Bengal System; 1951.
2. Pandey R, Jain V Singh K. Hydroponics agriculture: Its status, scope and limitations. Division of Plant Physiology, Indian Agricultural Research Institute, New Delhi. 2009;20.
3. Sharma N, Acharya S, Kumar K, Singh N, Chaurasia O. Hydroponics as an advanced technique for vegetable production: An overview. Journal of Soil and Water Conservation. 2018;17(4):364-371.
4. Douglas JS. Advanced guide to hydroponics: Pelham Books; 1985.
5. Sardare MD, Admane SV. A review on plant without soil-hydroponics. International Journal of Research in

Engineering and Technology. 2013;2(3): 299-304.

6. Taylor R, Carandang J, Alexander C, Calleja J. Making global cities sustainable: Urban rooftop hydroponics for diversified agriculture in emerging economies. OIDA International Journal of Sustainable Development. 2012;5(7):11-28.
7. Holliman JB, Adrian J, Chappell J. Integration of hydroponic tomato and indoor recirculating aquacultural production systems: an economic analysis; 2008.
8. Malik AM, Mughal K, Mian S, Khan M. Hydroponic tomato production and productivity improvement in Pakistan. Pakistan Journal of Agriculture Research. 2018;31(2):133-144.
9. Quagrainie KK, Flores RMV, Kim HJ, McClain V. Economic analysis of aquaponics and hydroponics production in the US Midwest. Journal of Applied Aquaculture. 2018;30(1):1-14.
10. Meeusen W, van Den Broeck J. Efficiency estimation from Cobb-Douglas production functions with composed error. International Economic Review. 1977;435-444.
11. Zellner A, Kmenta J, Dreze J. Specification and estimation of Cobb-Douglas production function models. Econometrica: Journal of the Econometric Society. 1966; 784-795.
12. Cochran WG. Sampling techniques: John Wiley & Sons; 2007.
13. Jensen MH. Hydroponics. HortScience. 1997;32(6):1018-1021.
14. Ilaslan G, Langhans R, White G. The investment analysis of cea hvdropoxic system growing boston lettuce. Paper presented at the XIVth International Symposium on Horticultural Economics. 2000;536.
15. Rhea AJ, Brooker J, Mundy J, Eastwood DB, Sams CE. An economic analysis of sequential cropping systems in greenhouses in Tennessee: tobacco and tomatoes. Agricultural Experiment Station. University of Tennessee. Knoxville; 2001.
16. Tokunaga K, Tamaru C, Ako H, Leung P. Economics of small-scale commercial aquaponics in Hawai 'i. Journal of the World Aquaculture Society. 2015;46(1): 20-32.
17. Holliman J. An economic analysis of integrating hydroponic tomato production into an indoor recirculating aquacultural production system; 2006.
18. Chaves P, Sutherland R, Laird L. An economic and technical evaluation of integrating hydroponics in a recirculation fish production system. Aquaculture Economics & Management. 1999;3(1): 83-91.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/66689