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EFFECTIVENESS OF APPLYING SOLAR ENERGY IN THE AQUAPONIC SYSTEM FOR SAVING ENERGY

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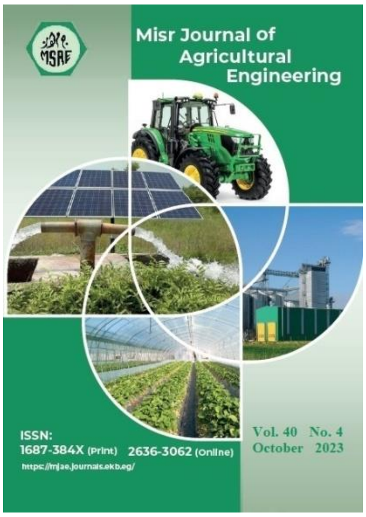

Keywords:
Solar energy; Water; Climate changes; Aquaponic system.

ABSTRACT

Solar energy (pv) is one of the renewable energy sources used to reduce the impact of climate changes and the rise in energy prices. Aquaponic system considered an important turn for food security with water shortage and climate change. The main objective of this study is to apply solar energy in the aquaponic system as a new technology of agriculture for water and energy saving. Design solar photovoltaic system to supply the energy to aquaponic system and evaluate its performance. The results showed that the maximum calculated and measured solar radiation were 789.67 and 856.90 W m^{-2}, Which indicates agreement between the calculated and measured results. Accordingly, the maximum calculated and measured output power of the solar panel were; 252.77 and 233.24 W, respectively. The results indicated that the efficiency of the solar panel ranged from 13.51 to 14.68% during daylight hours. The total value of the electrical energy productivity from PV was 10.49 MJ day^{-1}, with various values throughout the day. The aquaponic system's integrated water and air pumps required a combined 10.32 MJ of specific energy per day, which was generated by the PV system's electrical energy productivity. The results also obtained for lettuce plants indicated that with increasing the flow rate from 0.5 to 1.5 L min^{-1}, dry and fresh weight of shoots, concentration of the nutrient in shoots, lettuce production, and water use efficiency were all increased. Therefore, the study recommends that solar energy can be used to operate the aquaponic system.

1. INTRODUCTION

Solar energy is which considered to be the most effective and economic alternative resource. Solar energy applications are becoming increasingly popular in developing nations like Egypt for diverse systems of supplying electricity and water. One of the key elements affecting the growth of the fish and plants in the aquaponic system is the issue of power outages. To run the air and water pumps, the system needs a constant supply of electricity. A solar-powered aquaponic system is being developed to address this issue. One of the most common methods for applying solar energy is to use photovoltaic cells to power air and water pumps **(Elgeziry, 2022).**

The total daily value of electrical energy output from solar panels can be used to calculate the farm's total specific energy consumption. Solar energy, which is a form of renewable energy, may be used for any agricultural production application and helps to lower the high energy costs **(Omar et al., 2021).**

The daily total electrical productivity from PV for the trial day was reported by **Samak et al. 2022** for the summer, spring, autumn, and winter. The data indicates that throughout the summer, spring, fall, and winter, the irradiance was 7783, 5108, and 3660 W m^{-2}.day, respectively. Throughout the day, the electrical energy productivity from PV varies in value; in the summer, spring, autumn, and winter, the total value was 552, 460, and 330 $Wday^{-1}$. High summer temperatures over 25°C had an impact on the actual efficiency, which went from 13 to 16.6%; however, the temperature had no impact on the efficiency during the spring and winter, thus those changes were not made. The energy consumption for the machine is calculated using PV energy productivity for electrical energy. For periods when PV production is insufficient, the extra electricity over the necessary quantity is stored in the battery.

To provide the energy needed to run the Evaporative Cooling System, a solar cell system was designed and identified as a brand-new, renewable energy source (and as an example of how solar energy is used in agriculture) and essential to supply that energy, in terms of the capacity of the inverter, batteries, and solar cells employed **(Omar et al., 2022).**

The agriculture industry faces several sustainability issues, including water scarcity, contamination of the environment, rising fertilizer costs, population growth, food poverty, and the degradation of fertile soils, can be addressed using an aquaponic system. First and foremost, the capacity to generate large yields with little additional nutrient input, as well as significantly lowering nutrient output and water loss from aquaculture **(Yep and Zheng, 2019).**

According to **Yang and Kim (2020),** aquaponics is a fast-expanding method of growing food that combines aquaculture and hydroponic crop production. This method requires a lot of energy. The aquaponic system is a sustainable one that fully recycles the waste materials that are utilized as plant fertilizers. It is the best technology for food production in resource-constrained and climate change-affected places since it consistently saves water while being more productive than soil-based agriculture. Aquaponics enables extensive and high-quality vegetable production without having any negative effects on the environment due to contamination from either animal wastes or chemical fertilizers in agriculture or aquaculture **(Pantanella, 2018).**

Aquaponics systems are created by combining hydroponics—a technique for growing plants without soil using just water and artificial nutrients—with aquaculture components. In comparison to soil-based agriculture, hydroponic farming uses water and nutrients far more effectively, but its maintenance is more difficult and calls for a different set of inputs, particularly during installation. One of the main benefits of using hydroponics is that it considerably reduces water use, using only 10% compared to more than 80% for soil-based production **(Somerville et al., 2014; Maucieri et al., 2019).**

Aquaponic and hydroponic systems were employed to prevent water from evaporating from the soil, which would otherwise be lost. The main objective of this study is to apply solar energy in the aquaponic system as a new technology of agriculture for water and energy saving. Design and evaluate the performance of solar photovoltaic system to operate the aquaponic and hydroponic system.

2. MATERIALS AND METHODS

2.1 Experimental study

This work was done to study the effectiveness of applying the solar energy in the aquaponic system for saving energy. Utilizing innovative agricultural technologies (Aquaponic system) is the primary goal of this study and renewable energy (solar energy) for energy and water saving. In this study, the performance of the solar energy required to operate the aquaponic and hydroponics system was designed and evaluated. Determine the effect of flow rate (0.5, 1.5 and 2.5 L min^{-1}) the system type (aquaponic and hydroponic systems) on the growth rate of lettuce plants grown in nutrient film technique (NFT) and deep water culture technique (DWC). Each culture type used with three water flow rates (intermittent flow, 4 minutes on and 8 minutes off). A ball valve and a water flow rate sensor were used to regulate the water flow rate. The experiment was carried out in a greenhouse at the Faculty of Agriculture, Shebin El-kom, Agricultural and Bio-Systems Engineering Department, Menoufia University, Egypt between October, and December of 2020. Geographically, the experiment place's latitude angle was 30º 54' North.

2.2 Aquaponic system setup

Fig.1 show the design of the experimental aquaponic system. The aquaponic system on which the experiment was conducted consists of the following components:

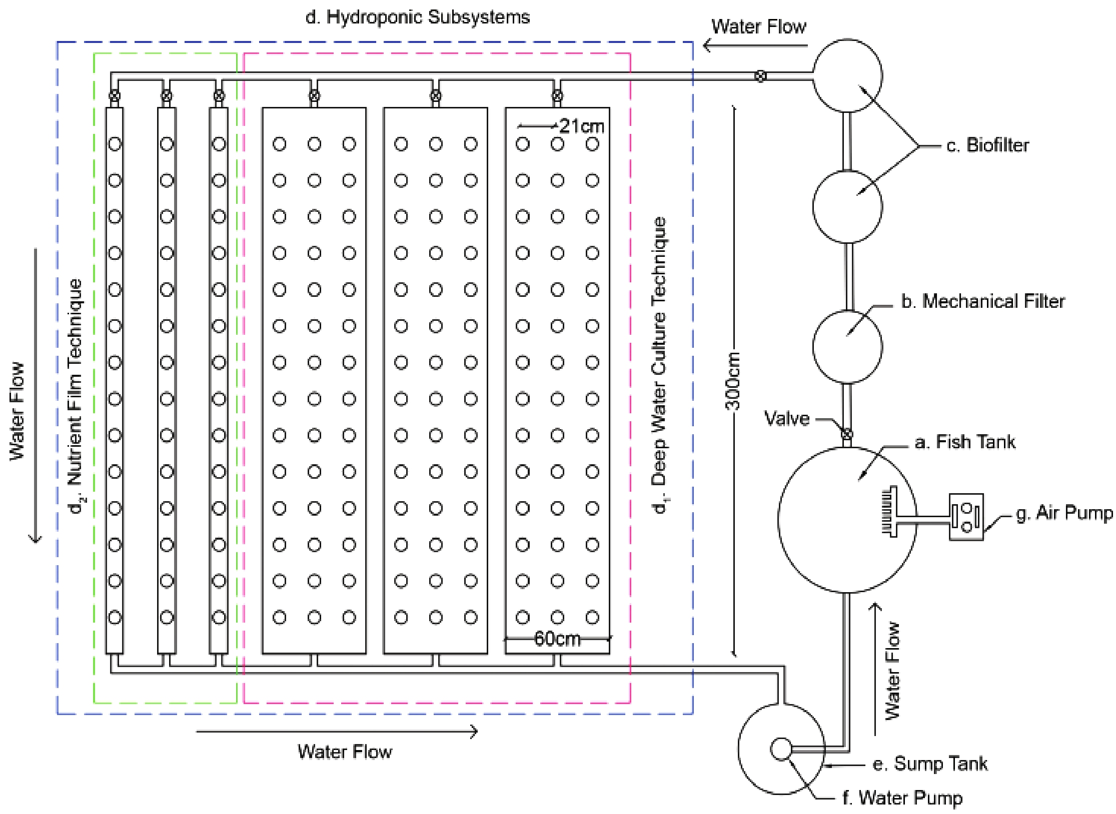

Fig.1: Schematic diagram of the experimental aquaponic system.

a. Fish tank

For the culture of fish, a circular fiberglass tank was employed. The fish tank has dimensions of 70 cm in height and 120 cm in diameter. Tank is provided with a particle trap in the center for water drain waste solids with 3. 81cm, in diameter.

b. Mechanical filter

The fish tank's mechanical filter is utilized to remove suspended and settleable particles. The mechanical filter is made of polyethylene (PE) with dimensions of 95cm height and 58 cm diameter.

c. Biofilter

The biofilter has media on which nitrifying bacteria can grow and turn ammonia into nitrate. It comprises of two circular polyethylene tanks, each measuring 60 cm in diameter and 90 cm in height, one of which is filled with gravel and the other with drip irrigation hoses. Each tank's medium had a height of 60 cm.

d. Hydroponic subsystems

The portion of the system where plants are grown by absorbing excess nutrients from the effluent water. The plants are grown in two hydroponic systems deep water culture technique and nutrient film technique.

d_1 - Deep water culture technique (DWC)

Three rectangular fiberglass troughs were utilized to cultivate lettuce plants. To support the plants, foam boards were placed on top of the troughs. Each foam board had dimensions of 120 cm in length, 60 cm in breadth, and 5 cm in thickness. Plants will be positioned in the 5 cm diameter, 21 cm apart holes that were bored in the foam boards. The water utilized in each trough was 20 cm deep, and the plant spacing was 21 cm. Three air stones are provided in each trough to maintain the levels of dissolved oxygen. Each trough had the following measurements: 300 cm in length, 60 cm in width, and 30 cm in depth.

d_2- Nutrient film technique (NFT)

Three white polyvinyl chloride (PVC) pipes with perforations on top are used in the nutrient film technique to hold the plants. The pipes are where the roots of the plants grow. To provide fourteen plant-slots per line, the pipes were drilled with 5 cm diameter holes spaced at 21 cm apart. The slope recommended is at a rate of 1% or (1cm/m) of pipe length is needed to make sure the water flows through the whole pipe with ease. The dimensions of each pipe were 10.16 cm diameter and 300 cm length.

e. Sump tank

It is the lowest point in the system and contains the submersible water pump. It is a collecting tank from which water is pumped to the fish tank, and to which water drains from the plant bed. It is a 500-liter circular tank made of polyethylene.

f. Submersible water pump

To return water to the fish tank from the sump tank, a submersible water pump is needed. The specifications of this pump are 250 W in power and 6.5m^3/hr in flow rate.

g. Air Compressor

The air compressor (air pump) is used to inject air into water through air pipes and air stones that lie inside the water tanks, thereby increasing the dissolved oxygen levels in the water. Air stones are located at the end of the air line and serve to diffuse the air into smaller bubbles. The specifications of this air compressor are 35 W in power and 50 m^3/hr in flow rate.

2.3 Hydroponic system setup

The hydroponic system on which the experiment was conducted consists of as shown in Fig 2 hydroponic subsystems, solution tank, water pump, sump tank, and air pump. In a hydroponic system, the nutrient solution is used to feed the plants.

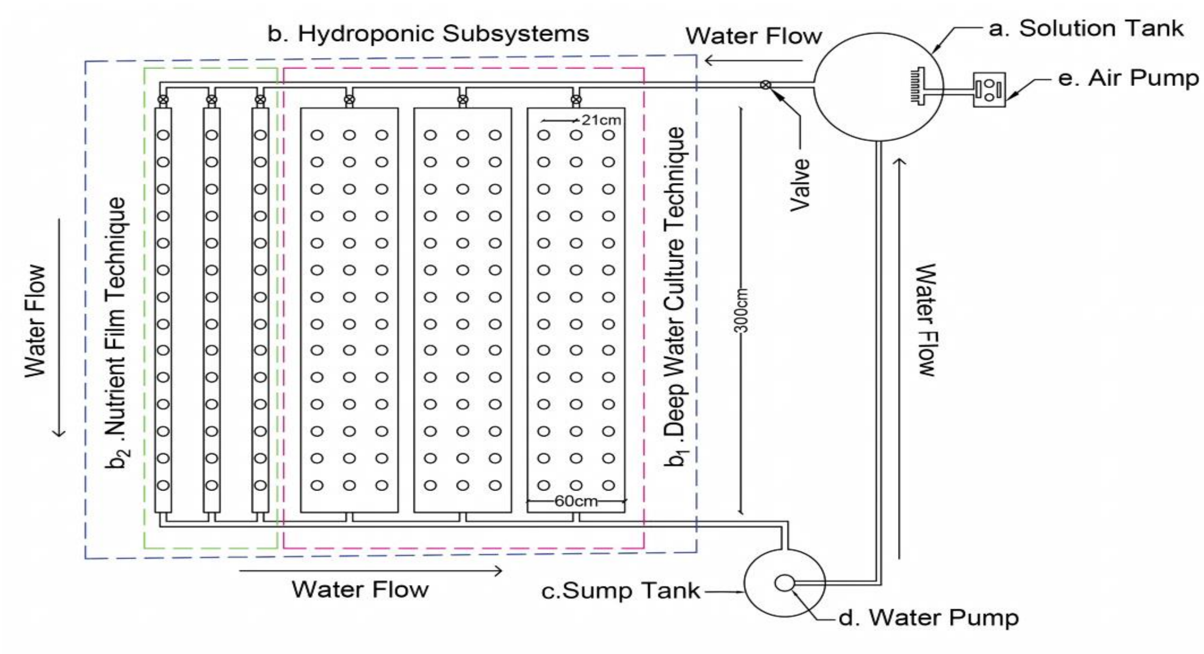

Fig. 2: Schematic diagram of the experimental hydroponic system.

2.4 Water flow dynamics in aquaponic system

In this system the plants were fed using the aquaculture wastewater. The water flows by gravity from the fish tank into the mechanical filter that removes or captures solid wastes and then passes through a biofilter that oxidizes ammonia to nitrate by nitrifying bacteria. The water then moves through plant growth troughs where plants absorb nutrients from it and finally the water returns purified to the fish tank by water pump as shown in **Fig. 3.**

Fig.3: A photograph of aquaponic system.

Table (1): shows the input parameters of the aquaponic used in the experiment.

Date of start	21/10/2020
Date of end	2/12/2020
Duration of culture (days)	42
Fish type	Nile Tilapia
Number of fish	168
Initial average weight of individual fish (g)	20.10
finial average weight of individual fish (g)	52.23
Plant type	Lettuce
Number of plant	168

2.5 Solar energy system design

2.5.1 Estimation of the electrical energy demand for system

The total electrical energy consumed to operate the system was calculated by the following equation according to **Abu-Aligah (2011); Bhatt and Verma (2014)**:

$$\mathbf{E = P_w\,.t_w + P_a\,.t_a} \qquad \textbf{(1)}$$

where:

E= the total electrical energy consumed per day (W h day^{-1}).

P_w= the submersible water pump power (W).

t_w= the submersible water pump hours of operation per day (h day^{-1}).

P_a= the air pump power (W).

t_w= The air pump hours of operation per day (h day^{-1}).

2.5.2 Determine the number of solar panels

The number of solar panels was calculated by the following equation according to **Diantari and Pujotomo (2016)**:

$$\textbf{Number of solar panels} = \frac{E}{P_1} = \frac{\mathrm{E}}{\mathrm{SR_1 \times \mu_{Panel} \times A_{panel}}} \qquad \textbf{(2)}$$

where:

E= the total electrical energy consumed per day (W.h day^{-1}).

P_1= the power output calculated (W. h day^{-1}).

SR_1= the calculated daily solar radiation (W.h m^{-2}.day^{-1}).

μ_{Panel}= the solar panel efficiency (%).

A_{panel} = the solar panel area (m^2).

2.5.3 Solar radiation

The values of solar radiation were determined during each day of the study. The design is made on the least day of daily solar radiation during the study period which is the last day of the experiment. The daily solar radiation was calculated according to **Taha (2010)**.

2.5.4 Determine the solar charge regulator

The solar charge regulator was calculated according to **Bhatt and Verma (2014)**, as follows:

$$\textbf{Solar charge regulator (A)} = \textbf{Number of Solar Panels} \times \textbf{Isc} \qquad \textbf{(3)}$$

where:

Isc = short circuit current (A).

2.5.5 Determine the number of batteries

The require number of batteries can be calculated by using the following equation according to **Shivrath et al. (2012); Bhatt and Verma (2014):**

$$\textbf{The number of batteries} = \frac{E \times N}{V_b \times DOD \times C_b} \quad \textbf{(4)}$$

where:

N= days of autonomy (day).
V_b= battery voltage (V).
DOD= depth of discharge (%).
C_b= the battery capacity (A.h).

2.5.6 Determine of capacity inverter

The capacity inverter was calculated according to **Diantari and Pujotomo (2016)**, as follows:

$$\textbf{Capacity inverter (W)} = \textbf{pumps power(W)} \times \textbf{Power Factor} \quad \textbf{(5)}$$

2.6 General description of proposed photovoltaic system

The photovoltaic system on which the experiment was conducted consists of the following components: Solar panels module, consists of two panels each one 320 W, model STP320 polycrystalline and installed with tilt angle 30º from the horizontal and positioned in south direction. The solar photovoltaic module was installed on a rigid and fixed mineral structure on the roof and is about two meters high facing the sun. The specifications of solar panel are presented in Table 2**.** The capacity of the solar charge regulator used is 20A with 12/24 V and maximum power point tracking (MPPT) type. The capacity of the inverter used is 600 W. The capacity of the battery used is (12 volts, 100 Amp.hr) and number of four batteries, it was connected with charge regulator.

Table 2: Solar panel specifications.

Origin of manufacture	China
Model	STP 320
Max.Power(p_{max})	320 W
Voltage at p_{max} (V_{mp})	37.1 V
Current at p_{max} (I_{mp})	8.63 A
Open Circuit Voltage (V_{oc})	45.6 V
Short Circuit Current (I_{sc})	9.14 A
Panel Dimension	1956 X 992 X 40 mm
Weight	25.8 kg
Solar Cell Efficiency	16.5 %

The standard test condition of 25° C cell temperature, 1.5 Air mass ratio (AM) and 1000 W/m^2 solar radiation.

Table (3) shows the value of calculated average total solar radiation, it was 4898.72 W.h m^{-2} day^{-1} and electrical energy consumed in the aquaponic system was 2840 W.h day^{-1}. It also shows that the design values of the solar energy system components as presented in Table (3).

Table (3): Calculations of the solar energy used in the operation of an aquaponic system.

Type pump	**Pumps power**	**Time of operation**	**Electrical energy consumed**	**Calculated daily solar radiation**	**Number of solar panels**	**Solar charge regulator**	**Number of batteries**	**Capacity inverter**
Water pump	250 W	8 h	2840 W.h day^{-1}	4898.72 W.h m^{-2} day^{-1}	1.81 ≅ 2	20 A	3.94 ≅ 4	600W
Air pump	35 W	24 h						

2.7 Measurements

2.7.1 Energy measurements

Measurements such as: Air temperature, solar radiation, output voltage and current from 7 am to 5 pm for three days were performed to assess the performance of the proposal PV system. Air temperature was measured by air temperature sensor, solar radiation was measured by aTES 1333 solar power meter and output voltage and current was measured by digital multimeter.

2.7.2 Solar panel efficiency

Efficiency of PV panel is the measure of ability the PV to production of electrical energy from sunlight. The efficiency of the solar panel is calculated using the following formula according to **Okasha (2016) and Sharma et al. (2020)**:

$$\mu_{panel} = \frac{P_{out} \text{ or } P_2}{P_{in}} = \frac{V_{oc} \times I_{sc} \times FF}{SR_2 \times A_{panel}} \times 100 \qquad \textbf{(6)}$$

where:

μ_{panel}= the solar panel efficiency measured (%).

P_{out} =the output power measured of the panel (W).

P_{in}= the solar power input measured of the panel (W).

V_{oc} =open circuit voltage (V).

I_{sc} = short circuit current (A).

SR_2= measured solar radiation (W m^{-2}).

A_{panel} = the solar panel area (m^2).

FF= factor equals about 0.67 according to **Okasha (2016)**.

2.7.3 Plant sampling and measurements

Dry and fresh weight of shoots was measured at the end of the workout. After fresh weight measurement plants were dried in an oven at 70 °C for 48 hours until a constant weight was reached in a hot air oven.

2.7.4 Water use efficiency

The water use efficiency was determined by the following formula according to **Djidonou et al. (2013)**:

$$\mathbf{WUE} = \frac{CY}{CWU} \qquad \textbf{(7)}$$

where:

WUE= the water use efficiency (Kg m^{-3}).

CY= the crop yield (plant m^{-3}).

CWU= the crop water uptake (m^3 $plant^{-1}$).

2.8 Statistical analysis

The obtained data were analyzed using the Statistical Package for the Social Sciences (SPSS) program; version 26 in which two ways ANOVA are used.

3. RESULTS AND DISCUSSION

3.1. Solar energy

Evaluate the solar energy system designed to supply the energy needed to operate the aquaponic system by comparing the calculated and measured output power from the solar panel.

3.1.1 Evaluation of Solar radiation and solar panel output power

Fig. 4 represent the calculated and measured output power (P_1 and P_2) from the solar panel based on the calculated and measured ambient air temperature and solar radiation (SR_1 and SR_2) at different times of the day. The experimental results showed that output power values from the solar panel changes by increase and decrease together affected by both solar radiation and the temperature of the surrounding air. It gradually increased with increasing solar radiation and the maximum value was at 12.00 pm.

The results showed that the calculated and measured solar radiation increased from 52.80 to 789.67 and 57.40 to 856.90 w m^{-2}, between 7.00 am to 12.00 pm respectively. Accordingly, the calculated and measured output power of the solar panel increased from 16.90 to 252.77 and 15.20 to 233.24 W, respectively. Whereas the calculated and measured output power from the solar panel decreased from 252.77 to 16.90 and 233.24 to 16.70 w, respectively, with the calculated and measured solar radiation decreased from 789.67 to 52.80 and 856.90 to 61.45 w m^{-2}, respectively with the increase in time from 12.00 to 17.00 pm.

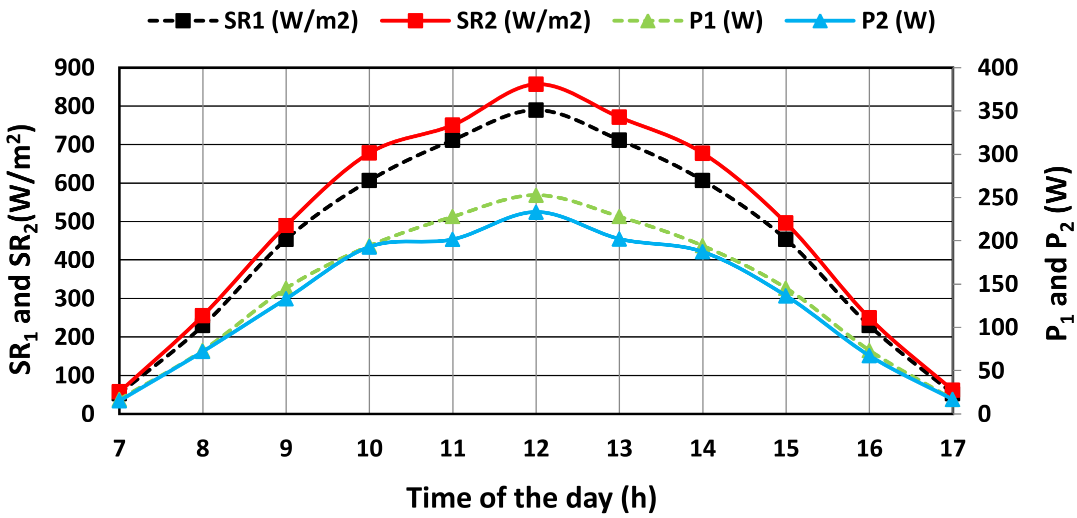

Fig. 4: The calculated and measured power output from the solar panel based on the calculated and measured solar radiation at different times of the day.

3.1.2 Performance of solar panel

The solar panel's output power is influenced by insolation and the number of hours of sunshine that are available in a certain place each day. Input solar radiation and output power of the solar panel was measured every hour. The short circuit current and short circuit voltage of the solar panel was measured by using digital multimeter and solar radiation was measured by using solar power meter. Measurements were made to assess how well solar panels and photovoltaic systems functioned under various performance-affecting situations.

The effect of solar radiation on the solar panel output power and solar panel efficiency at different times of the day are presented in Table (٤) and Fig. 5. It was observed that the solar radiation and ambient air temperature were increasing from 7:00 am to come at the maximum point at 12:00 pm then it reduces to the minimum at 17:00 pm.

The experimental results showed that solar panel output power (P_2) was increased from 7.83 to 120.23 W m^{-2} with increasing the solar radiation (SR_2) from 57.40 to 856.90 W m^{-2} and ambient air temperature from 14.20 to 24.10 ^{o}C and decreased from 120.23 to 8.61 w m^{-2} with decreasing the solar radiation from 856.90 to 61.45 W m^{-2} and ambient air temperature from 24.10 to 15.07 ^{o}C.

The highest value of solar panel efficiency was 14.68 % obtained at a solar radiation of 678.09 W m^{-2} and ambient air temperature of 21.87 ^{o}C. Whereas the lowest value of solar panel efficiency was 13.51 % occurred at a solar radiation of 771.00 W m^{-2} and ambient air temperature of 23.50 ^{o}C. The decrease in efficiency is due at some points because it is affected by solar radiation and temperature. The maximum solar panel efficiency available from the PV panel is 1000 W m^{-2} solar radiation and at a temperature of 25^{o}C **(Abu-Aligah, 2011).**

Table (4): Solar radiation, ambient air temperature, solar panel output power and actual solar panel efficiency at different times of the day.

Time of the day (h)	T_{air} (^{o}C)	SR_2 (W m^{-2})	P_2 (W m^{-2})	μ_{panel} (%)
7	14.80	57.40	7.83	13.65
8	15.10	255.49	37.16	14.54
9	16.20	489.85	68.58	14.00
10	21.87	678.09	99.51	14.68
11	22.93	750.63	103.95	13.85
12	24.10	856.90	120.23	14.03
13	23.50	771.00	104.19	13.51
14	22.90	677.60	96.52	14.24
15	21.87	496.00	70.31	14.17
16	15.70	249.33	34.65	13.90
17	15.07	61.45	8.61	14.01

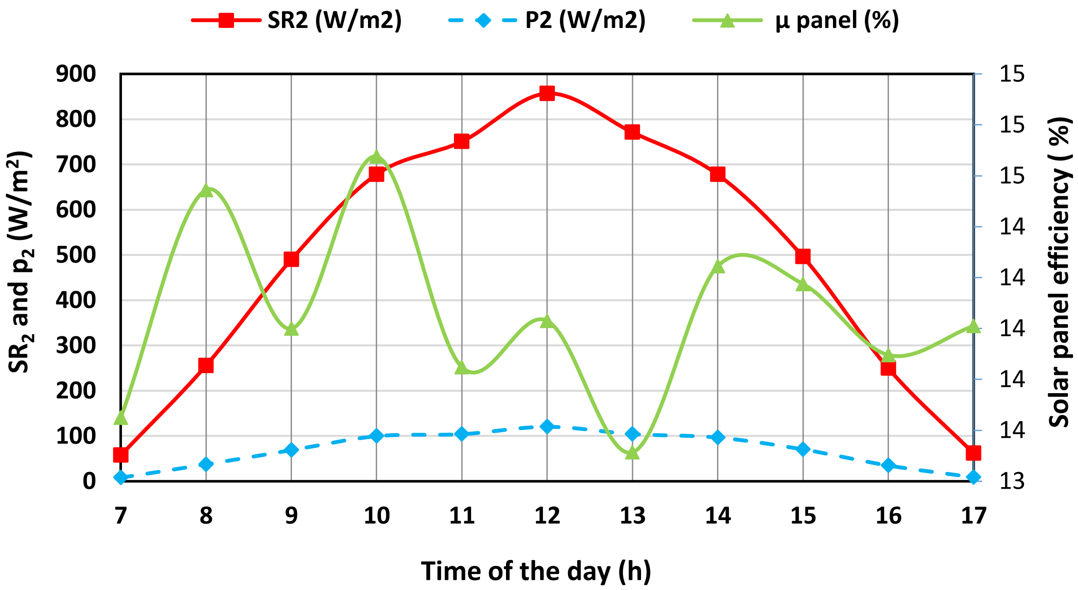

Fig. 5: Solar radiation, solar panel output power and solar panel efficiency at different times of the day.

3.1.3 Electrical output from PV and energy use in aquaponic systems

The power required to operate the aquaponic system was calculated according to equation (1). It was found 2840 W.h day^{-1}. The energy consumption for the system obtained from electrical energy productivity from PV.

Table (5) shows the experimental day's daily average PV electrical output during the winter. The data indicates that during the winter, the irradiance was 5343.74 W m^{-2}day. The total value of the electrical energy productivity from PV in the winter was 2915.98 Wday^{-1}, with variable values throughout the day. This outcome concurs with **Ruiz et al., (2020**). The actual efficiency changed between 13.51 to 14.68 %, affected by change in solar irradiance during the day periods. The total value of the electrical energy productivity from PV was 10.49 MJ day^{-1}, with various values throughout the day. **Ruiz et al., 2020** concur with this result. The aquaponic system's integrated air pump and water pump had a combined specific energy consumption of 10.32 MJ per day, which was derived from PV energy productivity. Excess electricity over what was needed was stored in a battery to be used when PV energy output was low. The designed module was able to operate an aquaponic system with an overflow of 0.17 MJ day^{-1}.

Table (5): The electrical output from PV, the hourly solar irradiation, and the energy consumption of the system.

Time (h)	Solar energy, (W m^{-2})	Solar energy (MJ m^{-2})	Solar panel efficiency (%)	Electrical productivity from PV system (MJ day^{-1})	Energy consumption of aquaponic system (MJ day^{-1})
1	-	-	-	-	0.43
2	-	-	-	-	0.43
3	-	-	-	-	0.43
4	-	-	-	-	0.43
5	-	-	-	-	0.43
6	-	-	-	-	0.43
7	57.40	0.21	13.65	0.11	0.43
8	255.49	0.92	14.54	0.52	0.43
9	489.85	1.76	14.00	0.96	0.43
10	678.09	2.44	14.68	1.39	0.43
11	750.63	2.7	13.85	1.45	0.43
12	856.90	3.08	14.03	1.68	0.43
13	771.00	2.76	13.51	1.45	0.43
14	677.60	2.44	14.24	1.35	0.43
15	496.00	1.76	14.17	0.97	0.43
16	249.33	0.9	13.90	0.49	0.43
17	61.45	0.22	14.01	0.12	0.43
18	-	-	-	-	0.43
19	-	-	-	-	0.43
20	-	-	-	-	0.43
21	-	-	-	-	0.43
22	-	-	-	-	0.43
23	-	-	-	-	0.43
24	-	-	-	-	0.43
Total Energy	**5343.74**	**19.19**		**10.49**	**10.32**

Note: (-) mean no solar radiation.

3.2 Fresh and dry weight of the lettuce shoots

The effect of all treatments in this study on the fresh and dry weight of shoots production of lettuce plants grown in deep water culture technique and nutrient film technique at the end of growing period are presented in Table (6 and 7). The results showed that the fresh and dry weight of shoots were higher in hydroponic system compared to aquaponic system. The higher water temperature, water pH and lower dissolved oxygen in aquaponic system possibly one of the factors behind the decreased plant development. These results agreed with **Yang and Kim (2020b).**

Shoots' fresh weight was significantly influenced by flow rate (F), but not by system or by interactions between treatments (S and F). The results indicate that the fresh weight of shoots was 176.97, 217.19 and 170.18 g plant^{-1} in deep water culture technique and 199.03, 230.63 and 176.27 g plant^{-1} in nutrient film technique for 0.5, 1.5 and 2.5 L min^{-1} flow rate, respectively with aquaponic system. While in the case of hydroponic system, the fresh weight of shoot was 196.56, 233.44 and 189.78 g plant^{-1} in deep water culture technique and 217.56, 237.89 and 203.67 g plant^{-1} in nutrient film technique for 0.5, 1.5 and 2.5 L min^{-1} flow rate, respectively.

The dry weight of shoots was significantly affected by system and flow rate but not significantly affected by interactions between treatments with deep water culture technique. While in the case nutrient film technique, the dry weight of shoots was significantly affected by flow rate but not significantly difference system and interactions between by system and flow rate.

The results also indicate that the dry weight of shoots was 20.18, 22.43and 18.32 g plant^{-1} in deep water culture technique and 21.35, 23.64 and 19.52 g/plant in nutrient film technique for 0.5, 1.5 and 2.5 L min^{-1} flow rate, respectively with aquaponic system. While in the case of hydroponic system, the dry weight of shoots was 21.41, 24.20 and 21.34 g plant^{-1} in deep water culture technique and 22.58, 24.95 and 21.37 g/plant in nutrient film technique for 0.5, 1.5 and 2.5 L min^{-1} flow rate, respectively.

In deep water culture technique, the average values of fresh and dry weight of shoots were 188.11 and 20.31; 206.59 and 22.32 g plant^{-1} with aquaponic and hydroponic system, respectively. While, in the case of nutrient film technique results show that the average values of fresh and dry weight of shoots were 201.98 and 21.5; 219.71 and 22.97 g plant^{-1} with aquaponic and hydroponic system, respectively.

The fresh and dry weight of shoots was increased with increasing the flow rate from 0.5 to 1.5 L min^{-1} may be due to increasing in nutrients consumption rate. The fresh and dry weight of shoots were decreased with increasing the water flow rate from 1.5 to 2.5 L min^{-1}. That may be due to decrease nutrient uptake time and higher flow rates causes high stress on the roots causing root crushing which decrease the nutrients consumption. These results agreed with **Ali (2016)** found that the fresh and dry weight of shoots increased with increasing the flow rate at 1 to 1.5 L h^{-1} and decreased with increasing the water flow rate from 1.5 to 2 L h^{-1}.

The best treatment was found at the highest value of fresh and dry weight of the shoots with the flow rate 1.5 L min^{-1}. These results agreed with those obtained by **Khater (2006) and Genuncio et al. (2012); Yang and Kim (2020).**

Table (6): Fresh weight of lettuce shoots at the end of the growing period.

Flow rate (L min^{-1})	Fresh weight of shoots (g plant^{-1})			
	DWC		NFT	
	Aquaponic	Hydroponic	Aquaponic	Hydroponic
0.5	176.97	196.56	199.03	217.56
1.5	217.19	233.44	230.63	237.89
2.5	170.18	189.78	176.27	203.67
Mean	188.11	206.59	201.98	219.71
Treatments	**ANOVA**			
System (S)	**2.590^{ns}**		**2.592^{ns}**	
Flow rate (F)	**6.049****		**5.445****	
S×F	**0.009^{ns}**		**0.280^{ns}**	

Table (7): Dry weight of lettuce shoots at the end of` the growing period.

Flow rate (L min^{-1})	Dry weight of shoots (g plant^{-1})			
	DWC		NFT	
	Aquaponic	Hydroponic	Aquaponic	Hydroponic
0.5	20.18	21.41	21.35	22.58
1.5	22.43	24.20	23.64	24.95
2.5	18.32	21.34	19.52	21.37
Mean	20.31	22.32	21.50	22.97
Treatments	**ANOVA**			
System (S)	**9.284****		**3.487^{ns}**	
Flow rate (F)	**9.950****		**8.168****	
S× F	**0.651^{ns}**		**0.060^{ns}**	

Note: ns, ** mean no significant and significant at $P \leq 0.01$ respectively.

3.3 Water use efficiency

Water use efficiency (WUE) is the primary measure of how effectively irrigation water is used. The ratio of crop yield (kg plant^{-1}) to crop water intake (m^3 plant^{-1}) is represented by this measure. The WUE for all treatments at the end of the study is shown in Fig. 6. The results demonstrated that the WUE was significantly affected by system (S), flow rate (F) and interactions between treatments (S×F).

The results showed that the WUE was 38.81, 45.81 and 37.44 kg m^{-3} in DWC and 42.09, 48.00 and 38.33 kg m^{-3} in NFT for 0.5, 1.5 and 2.5 L min^{-1} flow rate, respectively with an aquaponic system. While the WUE was 62.29, 70.67 and 60.22 kg m^{-3} in DWC and 66.37, 71.16 and 63.05 kg m^{-3} in NFT for 0.5, 1.5 and 2.5 L min^{-1} flow rate, respectively with a hydroponic system.

In DWC, the maximum value of WUE was (45.81 and 70.67 kg m^{-3}) with aquaponic and hydroponic system, respectively at a flow rate of 1.5 L min^{-1}. While the lowest value of WUE was (37.44 and 60.22 kg m^{-3}) with aquaponic and hydroponic system, respectively at a flow rate of 2.5 L min^{-1}. Whereas, in the case of NFT, the maximum value of WUE was (48.00 and 71.16 kg m^{-3}) with aquaponic and hydroponic system, respectively at a flow rate of 1.5 L min^{-1}. While the lowest value of WUE was (38.33 and 63.05 kg m^{-3}) with aquaponic and hydroponic system, respectively at a flow rate of 2.5 L min^{-1}.

In DWC, the mean WUE was 40.69 and 64.40 kg m^{-3} with aquaponic and hydroponic system, respectively. Whereas, in the case of NFT the mean WUE was 42.81 and 66.86 kg m^{-3} with aquaponic and hydroponic system, respectively.

The WUE was higher in hydroponic system compared to aquaponic system. The WUE increased when the flow rate was increased from 0.5 to 1.5 L min^{-1} and dropped when the flow rate was increased from 1.5 to 2.5 L min^{-1}. These results agreed with **Ali (2016)**. He discovered that the WUE increased when the flow rate was raised from 1 to 1.5 L h^{-1} and dropped as the flow rate was raised from 1.5 to 2 L h^{-1}.

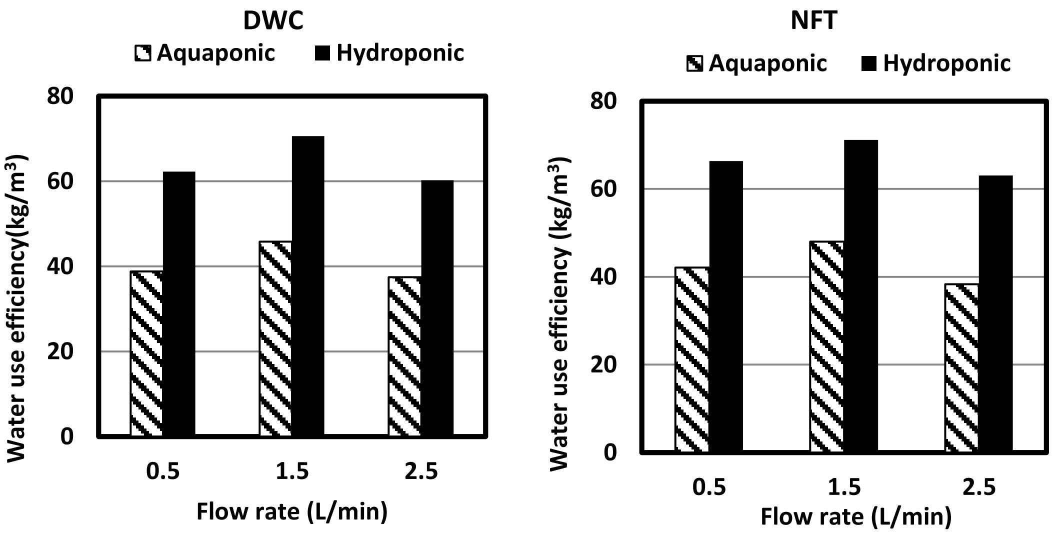

Fig. 6: Variation in WUE for lettuce plants grown in DWC and NFT at the end of the study for all treatments.

4. CONCLUSIONS

The major goal of this study is to use innovative agricultural technology (such as the aquaponic system) and renewable energy sources (such as solar energy) to conserve water and energy. From October to December of 2020, the experiment was carried out in a greenhouse at the Faculty of Agriculture, Shebin El-kom, Menoufia University, To achieve that was studied the effect of flow rate (0.5, 1.5 and 2.5 L min^{-1}) the system type (aquaponic and hydroponic systems) on the following parameters: fresh and dry weight of shoots and roots, nutrient concentrations in shoots and water use efficiency for lettuce plants. **The following points provide a summary of the outcomes attained:**

- The highest value of solar panel efficiency was 14.68 % obtained at a solar radiation of 678.09 Wm^{-2} and ambient air temperature of 21.87 ^oC. Whereas the lowest value of solar panel efficiency was 13.51 % occurred at a solar radiation of 771.00 Wm^{-2} and ambient air temperature of 23.50 ^oC.

- The results showed that the maximum calculated and measured solar radiation were 789.67 and 856.90 Wm^{-2}, Which indicates agreement between the calculated and measured results.
- The maximum calculated and measured output power of the solar panel were 252.77 and 233.24 W, respectively.
- The total value of the electrical energy productivity from PV was 10.49 MJ day ^{1}, with various values throughout the day. The aquaponic system's integrated water and air pumps required a combined 10.32 MJ of specific energy per day, which was generated by the PV system's electrical energy productivity.
- The results also obtained for lettuce plants indicated that with increasing the flow rate from 0.5 to 1.5 L min^{-1}, dry and fresh weight of shoots, concentration of the nutrient in shoots, lettuce production, and water use efficiency were all increased.
- Compared to aquaponic systems, the hydroponic system had a higher water use efficiency. The efficiency of water use increased when the water flow rate was increased from 0.5 to 1.5 L min^{-1} and declined when the water flow rate was increased from 1.5 to 2.5 L min^{-1}.

5. REFERENCES

Abu-Aligah, M. (2011). Design of Photovoltaic Water Pumping System and Compare it with Diesel Powered Pump. Jordan Journal of Mechanical & Industrial Engineering, 5(3), 273 – 280.

Ali, M.M. (2016). Comparison between hydroponic and aeroponic systems for lettuce production. M.Sc. Thesis, in Agricultural Engineering, Faculty of Agriculture, Moshtohor, Benha University, Egypt.

Bhatt, P. and A. Verma (2014). Design and cost analysis of PV System using nano solar cell. International Journal of Scientific and Research Publications, 4(3), 1-7.

Diantari, R. A. and I. Pujotomo (2016). Calculation of electrical energy with solar power plant design. International Seminar on Intelligent Technology and Its Applications (ISITIA) (pp. 443-446).

Djidonou, D., X. Zhao, E.H. Simonne, K.E. Koch and J.E. Erickson (2013). Yield, water and nitrogen use efficiency in field grown grafted tomatoes. Hort. Sci. 48(4), 485–492.

Elgeziry, A. A. (2022). Study the Effect of Some Engineering Factors on the Performance of an Integrated Aquaponic Unit. M.Sc. Thesis, in Agricultural & BioSystems Engineering, Faculty of Agriculture, Shebin El-kom, Menoufia University, Egypt.

Genuncio, G. D. C., M. Gomes, A. C. Ferrari, N. Majerowicz and E. Zonta (2012). Hydroponic lettuce production in different concentrations and flow rates of nutrient solution. Horticultura Brasileira, 30(3), 526-530.

Khater, E.G. (2006). Aquaponics: the integration of fish and vegetable culture in recirculating systems. M.Sc. Thesis, in Agricultural Engineering, Faculty of Agriculture, Moshtohor, Benha University, Egypt.

Maucieri, C., C. Nicoletto, E. Van Os, D. Anseeuw, R. Van Havermaet and R. Junge (2019). Hydroponic technologies. In Aquaponics food production systems. Springer, Cham, (pp. 77-110).

Okasha, A. M. (2016). Performance of a small drip irrigation system powered by solar photovoltaic for corn production. Misr Journal of Agricultural Engineering, 33(4), 1369-1386.

Omar, M.N., A.T. Taha, A.A. Samak, M.H. Keshek, E.M. Gomaa, and S.F. Elsisi (2021). Simulation and validation model of cooling greenhouse by solar energy (P V) integrated with painting its cover and its effect on the cucumber production. Renewable Energy 172 (July 2021) 1154-1173, https://doi.org/10.1016/j.renene.2021.03.092

Omar, M.N, A. A. Samak and S. F. Elsisi (2022). Effect of the solar evaporative cooling and reducing the cover permeability on the production and quality of greenhouse cucumber. Misr Journal of Agricultural Engineering., 39 (3): 425 – 448 DOI: 10.21608/mjae.2022.133228.1071

Pantanella, E. (2018). Aquaponics production, practices and opportunities. In Sustainable Aquaculture. Springer, Cham, (pp. 191-248).

Ruiz J., P. Martínez, H. Sadafi, F.J. Aguilar, P.G. Vicente and M. Lucas (2020). Experimental characterization of a photovoltaic solar-driven cooling system based on an evaporative chimney. Renewable Energy 161 (December 2020) 43 – 54. https://doi.org/10.1016/j.renene.2020.06.111

Samak, A. A, M. N. Omar and S. F. Elsisi (2022). Developing and evaluating a multi nozzle spraying machine powered by solar energy for agricultural smallholdings. Misr Journal of Agricultural Engineering., 39 (3): 353 – 374.

Sharma, R., S. Sharma and S. Tiwari (2020). Design optimization of solar PV water pumping system. Materials Today: Proceedings, 21, 1673-1679.

Shivrath, Y., P. B. Narayana, S. Thirumalasetty and E. L. Narsaiah (2012). Design & integration of wind-solar hybrid energy system for drip irrigation pumping application. International Journal of Modern Engineering Research (IJMER), 2(4), 2947-2950.

Somerville, C., M. Cohen, E. Pantanella, A. Stankus and A. Lovatelli (2014). Small-scale aquaponic food production: integrated fish and plant farming. FAO Fisheries and Aquaculture Technical Paper, (589), I.

Taha, A. T. H. (2010). Estimation of hourly global solar radiation in Egypt using mathematical model. Misr Journal of Agricultural Engineering, 27(4), 2033-2047.

Yang, T. and H. J. Kim (2020). Effects of hydraulic loading rate on spatial and temporal water quality characteristics and crop growth and yield in aquaponic systems. Horticulturae, 6, 9: 1-23.

Yang, T., and H. J. Kim (2020b). Characterizing nutrient composition and concentration in tomato-, basil-, and lettuce-based aquaponic and hydroponic systems. Water, 12(5), 1259:1-32.

Yep, B. and Y. Zheng (2019). Aquaponic trends and challenges – A review. Journal of Cleaner Production, 228, 1586–1599.

فاعلية تطبيق الطاقة الشمسية في تشغيل نظام الأكوابونيك لتوفير الطاقة

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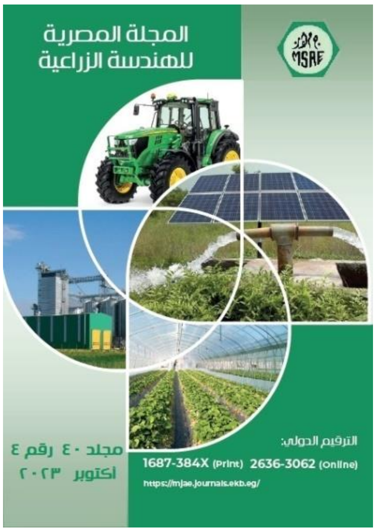
الملخص العربي

الطاقة الشمسية هي أحد مصادر الطاقة المتجددة المستخدمة للحد من تأثير التغيرات المناخية وارتفاع أسعار الطاقة. وفي ضوء التغير المناخي وندرة المياه يلعب نظام الأكوابونيك دورًا مهمًا في تحقيق الأمن الغذائي والتنمية الاقتصادية. الهدف الرئيسي من هذه الدراسة هو تطبيق الطاقة الشمسية في تشغيل نظام الأكوابونيك كتقنية جديدة للزراعة لتوفير المياه والطاقة. تم إجراء هذه التجربة في قسم الهندسة الزراعية والنظم الحيوية، كلية الزراعة، شبين الكوم، جامعة المنوفية خلال عام ٢٠٢٠. وخلال هذه الدراسة تم تصميم نظام الطاقة الشمسية الكهروضوئية لتزويد نظام الأكوابونيك بالطاقة وتقييم أدائه. تم دراسة تأثير معدل التدفق ونوع النظام على الوزن الطازج والجاف للمجموع الخضري وكفاءة استخدام المياه بالنسبة لنباتات الخس. أظهرت النتائج أن الحد الأقصى للإشعاع الشمسي المحسوب والمقاس كان ٧٨٩,٦٧ و٨٥٦,٩٠ واط في المتر المربع، مما يدل على التوافق بين النتائج المحسوبة والمقاسة. وفقًا لذلك، كان الحد الأقصى للطاقة الكهربائية المحسوبة والمقاسة للخلايا الشمسية ٢٥٢,٧٧ و٢٣٣,٢٤ واط في المتر المربع، على التوالي. تراوحت كفاءة الالواح الشمسية من ١٣,٥١ إلى ١٤,٦٨٪ خلال ساعات النهار. قيمة إنتاجية الطاقة الكهربائية من الألواح الشمسية لها قيم مختلفة على مدار اليوم والقيمة الإجمالية كانت ١٠,٤٩ ميجا جول في اليوم. وإجمالي استهلاك الطاقة المحدد لمضخة الهواء ومضخة المياه في نظام الأكوابونيك كان ١٠,٣٢ ميجا جول في اليوم تم الحصول عليها من إنتاجية الالواح الشمسية. كما أشارت النتائج التي تم الحصول عليها لنباتات الخس إلى أنه مع زيادة معدل التدفق من ٠,٥ إلى ١,٥ لتر في الدقيقة زاد الوزن الجاف والطازج للبراعم وإنتاجية الخس وكفاءة استخدام المياه. لذلك يمكن استخدام الطاقة الشمسية في تشغيل نظام الأكوابونيك.



الكلمات المفتاحية:
الطاقة الشمسية؛ المياه؛ التغيرات المناخية؛ نظام الأكوابونيك.