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Enhancing Controlled Environment Agriculture in Desert Ecosystems with AC/DC Hybrid Solar Technology

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ABSTRACT

Controlled Environment Agriculture (CEA) plays a crucial role in promoting sustainable farming practices within the challenging climate of the Arabian Peninsula. Traditional CEAs, however, are confronted with excessive water and electricity consumption due to the region's elevated temperatures and humidity levels. To address these challenges, an innovative project was carried out at the Al Dhaid Research Station, United Arab Emirates, integrating solar-powered cooling and irrigation, closed hydroponic systems, net-house structures, root zone cooling, and ultra-low-energy drippers. The study employed a cooled greenhouse alongside two net houses, one of which was equipped with a solar-powered cooling and irrigation system. Cucumber crops were cultivated within each structure, demonstrating that the combined technologies could prolong production periods despite increasing temperatures, while simultaneously reducing energy consumption by 95% and water usage by 80%, without compromising crop yield. The findings of this study suggest that the implementation of this novel approach holds significant potential for boosting crop productivity and water efficiency in desert agriculture systems.

1. INTRODUCTION

Controlled Environment Agriculture (CEA) serves as a fundamental pillar in desert farming, as it provides protection to crops from harsh conditions and facilitates the management of crop production throughout the year. A primary technical challenge in utilizing conventional greenhouses in desert farming systems lies in maintaining favorable air temperatures and relative humidity levels for plant growth [1]. While greenhouses (GH) perform well in cold or mild climates, the potential for overheating in hot and sunny regions poses a significant obstacle to plant growth in these environments, especially during summer months, without efficient cooling systems [2]. As a result, numerous attempts have been made globally to adapt greenhouses for use in hot and sunny climates [3].

Arid regions are characterized by long, hot summers, intense solar radiation flux, dusty and dry weather conditions, and limited, brackish water resources [4]. These harsh conditions can degrade the optical and mechanical properties of greenhouse covering materials, such as plastic films, and drastically reduce the performance of cooling systems. Commercially available methods for cooling greenhouse interiors in hot summers can be categorized into three main groups: ventilation, evaporative cooling, and heat prevention, such as shading [5].

Although the evaporative cooling system (pad and fan) is widely used, its efficiency is diminished in desert farming systems due to high humidity and temperature levels. One critical issue is the substantial water and energy requirements of the cooling system. Investigations conducted by The International Center for Agricultural Research in the Dry Areas (ICARDA) and national agricultural research systems have found that Protected Agriculture (PA) and associated techniques, such as soilless production systems, have successfully increased yield and water productivity. However, the adoption of greenhouse technology in hot arid areas necessitates overcoming the constraints of cooling systems. Identifying an alternative (even if partial) to the commonly used evaporative cooling method would be beneficial, as these systems consume a large volume of water, often exceeding the amount used for irrigation. In Kuwait, Albaho and Al-Mazidi reported that water consumption for cooling was approximately 2.2 times greater than that for actual production per unit area [6].

In response to the challenges posed by conventional greenhouse cooling, ICARDA and the National Agricultural Research Systems (NARS) have introduced the net-house, which operates for 7-8 months in the Arabian Peninsula. Additionally, ICARDA has supported a Ph.D. study in Oman, demonstrating that the implementation of Root Zone Cooling (RZC) in greenhouses can enhance yield and water productivity. In collaboration with MIT and JANN irrigation, ICARDA has also developed an ultra-low pressure irrigation system employing Ultra-Low Energy Drippers (ULED), which facilitates the dissemination of low-cost, solar-powered drip irrigation solutions [7].

This study aims, for the first time, to combine five technologies: closed soilless production systems, net houses, Ultra-Low Energy Drippers, root zone area cooling, and low-cost solar energy, in order to explore the potential for improving productivity and extending the production period of net houses. The language, structure, and logic of this introduction have been modified to meet the requirements of top academic journals, such as Nature and Science, while preserving the original citation content.

2. TECHNIQUES OF CONTROLLED ENVIRONMENT AGRICULTURE

2.1 Net-house using insect-proof net

Considering the average monthly temperature in the region, the production of high-value cash crops such as tomato & cucumber could be successfully adopted with protected houses covered only with insect-proof nets (net-house) for at least 7-8 months/year. The net house would protect the crops from harsh environment and pests and diseases while providing excellent ventilation. Creating a physical barrier using nets and screens helps hinder insect pests entering the production environment and reduces the need for agrochemical [8].

To address the challenges facing greenhouse cooling, ICARDA and NARS began to study the production under the net house in 2004, the first study in Oman. However, some activities were carried out in the late 90s in Qatar. The net-houses were introduced to the region in 2008 while NARS in United Arab Emirates subsidized 50% of the establishment cost. Different studies confirm that the net house yield (kg/m^2) is the same as a cooled greenhouse during winter.

In Qatar, a noncooled greenhouse covered with insect-proof nets performed equally well as the polycarbonate-covered and cooled greenhouse in the winter season at the research station. The difference in productivity for cucumber of 10.4 kg/m^2 in the cooled greenhouse and 9.9 kg/m^2 in net noncooled covered greenhouses was not statistically significant [9]. The Net-house provides good protection and excellent ventilation for plants grown in areas with mild winters, such as in Qatar [10].

In United Arab Emirates, production records from September to December 2012 were collected from fourteen growers to compare the cucumber production in cooled greenhouses and net houses at the farm level. Growers were selected randomly by extension agents. The hydroponics production system was adopted in all fourteen farms. The results showed no significant difference in yield between the net house and cooled GH In contrast, the net hose saved a considerable amount of water and electricity for the cooling system [11].

2.2 Root Zone Cooling (RZC)

Several studies show the importance of the root zone temperature in vegetable production inside the greenhouses in the hot and tropical region [12-14]. The air temperature inside the greenhouse tends to be very high during the daytime. The root zone cooling system has been used as an energy-efficient cooling system for GH to overcome this problem [15].

One of the characteristics of hydroponic cultivation is its ability to control the temperature of the nutrient solution around the root system. During the midday period, in the hot summers, the root-zone temperature of hydroponic systems often exceeds 30ºC. The root-zone temperature can often reach 35ºC when the air temperature is 38ºC. This was strongly found to suppress the plant growth process and reduce uptake of water and nutrients [16, 17]. Given the above, it seems the root area zone temperature has a crucial impact on plant nutrient uptake. While the air temperature is one of the most critical environmental elements for the altering secondary metabolism in the plants for production [18, 19], the temperature at the root zone also influences the growth and chemical composition of many plants [20].

2.3 Ultra-Low-Energy Drip irrigation

The Ultra-Low-Energy Drip Irrigation is designed, and field validated ultra-low pressure drip irrigation systems. The new emitters studied through ICARDA-MIT research activities and would cut pumping energy by 80% (for electric or diesel pumps), enable drip systems to run on low-pressure supplies, and facilitate the dissemination of low-cost solar-powered drip irrigation solutions [7].

2.4 AC/DC hybrid solar energy

The AC/DC hybrid solar energy system combines On-Grid and Off-Grid based solar energy systems [21]. It comes with the advantage of on-Grid energy when the solar panel operates is not at its peak or the system requires extra energy to run. The On-grid AC/DC solar chiller used for water cooling in this study was designed mainly to work during the daytime using DC power.

The system can use solar power and Grid, where solar power is prioritized for the compressor and motor. When the solar power is insufficient, the dual PV MPPT tracking system automatically runs by grid power (AC), uninterrupted supply power for composure. This system works perfectly for RZC systems as the irrigation stops at night, and water cooling is not required. As a result, the cost of the establishment was reduced significantly.

3. MATERIALS AND METHOD

3.1 Setting up the experiment

This study aimed to combine the five technologies i.e., closed soilless production system, net house, ultra-low energy irrigation system, root zone cooling, and low-cost solar energy, to investigate the possibility of improving productivity and extend the production period of the net house.

To do so, three (3) greenhouse structures in the Al-Dhaid research station, Ministry of Climate Change and Environment (MOCCAE), United Arab Emirates, were selected. Two of the structures were covered with insect-proof net (net-house) and the third one with polycarbonate and pad and fan cooling system. All three greenhouses had the same size (8×30m) and five growing canals.

The five technologies package installed on the experimental net-house. To compare the yield, production period, and conduct cost benefit analysis two other structures, one net-house and one cooled GH (conventional practices), used as control unit.

The irrigation schedule in all three greenhouses has been controlled by an automatic start/stop device operating from 6 am to 5 pm and 5 min per hour. Irrigation in the net-house with RZC powered 100% by solar energy using small DC pump

24volt (0.6hp or 450watt) one solar panel 300 watt and two batteries 20Ah. The ULED has been used; therefore, pump size was reduced significantly (from 2hp in the other two structures to 0.6hp). As a result, the establishment cost for solar systems is reduced by more than three folds.

Similar irrigation tanks ($3m^3$) were located outside each structure under a net green shade. All structures were equipped with double door entrance and closed hydroponics systems (irrigation water recirculated) with five growing canals—the Cucumber crop planted in polystyrene pots filled with perlite. The required nutritional elements were added to the solution using liquid fertilizer. The PH and EC were maintained at 6-6.5 and 2500-3000 ppm throughout the production period.

The cucumber plants were transplanted on 24 March 2021 into all three structures. Based on greenhouse size (240 m^2), a total of 700 cucumber seeds (f1 hybrid) were planted in each greenhouse. The grower standard practice for the net house in the region is to stop production by the end of May [10] due to hot weather. For many crops including cucumber, the best periods of production in the UAE are between October and May, when the weather is cooler. During the hotter months (June to September), temperatures can be extremely high, which can cause stress to plants, within a controlled environment like a net-house. Therefore, some farmers might choose to grow heat-tolerant crops or stop production during these months. However, to monitor the effect of RZC on cucumber production in hot seasons, cucumber seedlings were planted at the end of March.

The irrigation water in the experimental net houses remained constant at 25 degrees. A water tank chiller with a 1580Watt AC/DC solar hybrid system has been used for water cooling inside the irrigation tank. The RZC system was powered by a hybrid solar system, including five (5) panels of 300watt each. On the startup time or when the panels did not generate enough energy, the system automatically switched to grid and back again on solar when there was enough energy from the panels. As a result, batteries were removed, and the number of required panels was reduced from 12 to 5 panels, reducing the establishment cost. The solar system generated 85% of required energy.

3.2 Study design

Previous studies show some difference in the relative humidity and temperature along the length and width of the net house. through the net house width and length respectively. The relative Teitel in 2001 show 12% and 10% relative difference in the temperature variation humidity variations (max-min) were 25% in the vertical direction and 30% in the horizontal direction [22].

The variations in air humidity, temperature, and other factors such as the distance to the water pump, RZC system, entrance, and cooling pad (in cooled GH) can significantly impact plant growth and yield. To address this issue and ensure the reliability of the t-test, we divided each of the structures into seven sections based on their length.

In a two-sample t-test, a minimum of two degrees of freedom (df) is required, with one for each sample. The degrees of freedom (df) are determined by the sample size of the groups being compared. However, in practical terms, much larger sample sizes are necessary to ensure the validity of the t-test. A larger sample size allows for more accurate estimation of the population parameters, thereby enhancing the reliability of the results. Each section had 70 pots and 140 plants. The space between each section was about 1m. The production records of each section were collected separately and used as different samples to compare each structure's average yield and water productivity using independent samples t-test. Mokhtari Sataiy et al. [23] also used a similar design with t-test for comparing experimental and control greenhouses in 2021.

3.3 Data collection

In addition to maintaining production records and logs of agricultural inputs utilization, water and electricity meters were installed across all three structures to monitor the consumption of irrigation and cooling water, as well as electricity. Specifically, a 1-inch multi-jet analog water meter was installed in each structure upstream of the irrigation tank, enabling precise measurement of the system's water consumption. For the Pad and Fan system, a separate, identical water meter was fitted. These meters possess a four decimal digit reading capability.

To measure electricity usage, three analog current electricity meters, each rated for single-phase alternating current at 10(40)-amp 230V 50Hz, were installed in each of the structures. Internal conditions such as humidity and temperature extremes were recorded daily using a digital greenhouse humidity and thermometer device with max-min recording functionality. Statistical analyses were carried out using Microsoft Excel.

4. RESULTS

4.1 Yield and water productivity

The cucumber plants were transplanted on 24 March 2021 into all three structures. The cooled greenhouse and net-house with RZC were in production until 13 June (12 weeks).

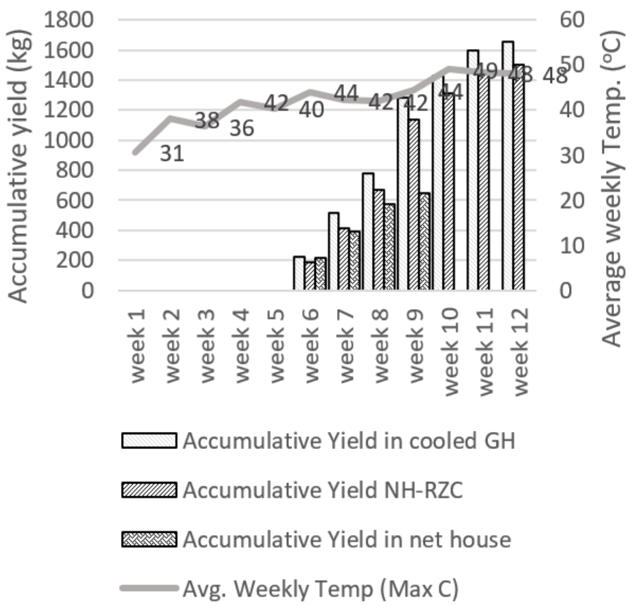

Figure 1. Accumulative cucumber production in net house with RZC (NH-RZC) and conventional pad and fan system (Cooled GH) from 24th March to 13th June 2021

The Net-house without RZC, as expected, stopped production on 28 May when the average air temperature passed 44°C. As mentioned before, the standard practice for the net house in the region is to stop production by the end of March. However, the net house with RZC remained in production, the same as the cooled greenhouse, until mid-June, when the average weekly temperature reaches a peak of 48°C. Figure 1 shows the accumulative yield (total production) of the three structures and the average weekly temperature recorded.

The average cucumber production in the cooled greenhouse (GH) and Net-house with RZC (NH-RZC) was 6.95 kg/m^2 and 6.32kg/m^2, respectively. The Net-house without RZC only produces 2.71 kg/m^2 during this production period. This figure was expected for the net-house without RZC as this was out the growing season production and just as a control unit. Table 1 presents the total cucumber yield (kg/m^2) and each section for both NH-RZC and cooled GH.

The assumption made for independent t-test includes: The measurement scale used for the collected data operates on a continuous basis. When dividing each structure into seven sections, the data sampling becomes representative of the entire population, with data independently collected from each section. Both structures yielded data displaying a normal distribution. According to the Shapiro-Wilk test, neither the Cooled-GH (*W(7)=0.89, p=0.321*) nor the NH-RZC (*W(7)=0.91, p=0.486*) exhibited a significant deviation from normality.

The f-test shows no difference in variance between the two groups. The independent two-tail t-test for equal variance proved no significant yield between cooled-GH and NH-RZC (Table 2). The cooled-GH consumed about 6950 kWh electricity during the production period, while the NH-RZC consumed 300 kWh.

Table 1. Comparison of cucumber yield under NH-RZC and Cooled-GH

	NH-RZC production (kg/m^2)	**Cooled-GH production (kg/m^2)**
Section 1	7.13	6.18
Section 2	6.49	7.24
Section 3	6.14	7.94
Section 4	6.07	7.41
Section 5	5.82	7.24
Section 6	6.46	6.42
Section 7	6.18	6.21
Average	6.32	6.95

Table 2. Independent two-tail t-test shows no significant difference in yield between NH-RZC and cooled-GH

Parameters	**Cooled-GH**	**NH-RZC**
Mean	6.947899	6.322689
Variance	0.463154	0.179555
Observations	7	7
Pooled Variance	0.321354	
Hypothesized Mean Difference	0	
df	12	
t Stat	2.063326	
P(T<=t) one-tail	0.030704	
t Critical one-tail	1.782288	
P(T<=t) two-tail	0.061409	
t Critical two-tail	2.178813	

**t Stat< t Critical two-tail, therefore, accept the H0*

The water productivity in the net house increased significantly, mainly due to saving cooling water. Both structures used about 40m^3 of water for crop irrigation and fertigation with a closed hydroponics production system, while the cooled-GH consumed an extra 176.85m^3 of water for the cooling system. This amount of water is more than the actual water used for crop production by 4.5 times. Considering the total water used, the water productivity of NH-RZC and cooled-GH was 37kg/m^3 and 8kg/m^3, respectively (Figure 2).

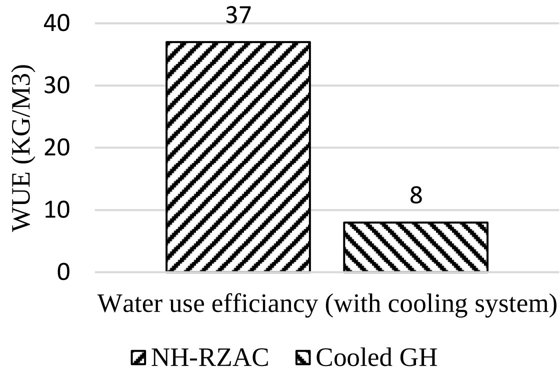

Figure 2. Water Use Efficiency (kg/m^3) in the NH-RZC and Cooled-GH

4.2 Economic analysis

<u>Machinery and depreciation</u>

The machinery costs calculated based on the depreciation of greenhouse structures and covering materials for years 10 years; irrigation system (conventional and solar), cooling system, and RZC system (Table 3).

Table 3. Estimated cost of establishment and equipment

	Establishment cost (AED)		**Economic life (year)**	**Annual cost (AED)**	
	cooled GH	NH-RZC		cooled GH	NH-RZC
Greenhouse structure	40000	25000	10	4000	2500
Irrigation system	2930	2015	5	586	403
Root zone cooling	0	7000	5	0	1400
cooling system	10000	0	5	2000	0
Hydroponics system	3000	3000	5	600	600
Total	55930	37015		7186	4903
Cost per season (4 seasons for cooled GH and 3 seasons for the net house)				1797	1634

All figures in United Arab Emirates Dirham (AED)

Greenhouse and net house structures, covering materials and cooling system (pad and fan) estimated costs are based on average market price collected from the local market. The depreciation cost is calculated per season. However, for cooled GH four and NH-RZC, three crops per year have been considered. The main difference is the structure and covering materials, which is about 38% lower for the net house.

Partial budget analysis

A partial budget helps evaluate the economic effect of new technology or innovations [24]. Table 4 shows the cost of production breakdown, total revenue, and net return of both Cooled-GH and NH-RZC for one crop, which is about 12 weeks. These data indicate that utilizing net house with RZC powered by solar energy reduced the total cost of production by 27% and increased net income by about 14% compared to the conventional cooled greenhouse. The main saving in cost of production was on energy, machinery (including depreciation), and water.

Table 4. Partial budget analysis comparing Cool-GH and NH-RZC powered by solar energy–one crop (20 weeks)

Parameters	Cooled GH (AED)	NH-RZC (AED)
Seeds	180	180
Total fertilizer	225	225
Total pesticides	50	50
Labor	500	500
Energy	302	14
Machinery (including depreciation)	1797	1634
Water	680	126
Total cost	3733	2729
Total revenue	6614	6019
Net return	2881	3290
% Change in NR (Net Returns)	*14%*	
% Change in TC (Total Costs)	*-27%*	

Energy

The cost of electricity is calculated at 4.5 fils/kWh based on agricultural electricity tariff [25]. As mentioned before, the cooled-GH consumed about 6950 kWh electricity during the production period, while the NH-RZC consumed 300 kWh electricity. So, the total costs were 302AED and 14AED respectively. Therefore, it can be estimated that utilizing solar energy saves annually about 4AED/m^2 of greenhouse considering three cropping seasons for cucumber. On the other hand, the average business electricity price worldwide in March 2021 was reported at 0.135US$ or 0.5AED per kWh [26]. Considering the difference between the average international and local prices, it can be estimated that using solar energy for irrigation and RZA saves about 38AED/m^2 of greenhouse. Less electricity means less carbon footprint. The 6650-kWh saving is equivalent to 4.7 metric tons of CO_2 not emitted to the atmosphere. This is equal to a CO_2 generated by a small car run for one year [27].

Water consumption

The Water cost is 3.13 AED/m^3 as agricultural water tariff [25]. The significant water consumption was for the cooled-GH cooling system, which consumed 176.85m^3 of water with a total cost of 553.4AED. The actual water consumption for plant production in each structure was 40m^3, costing 125.2AED. Overall, the NT-RZC saved water costs by more than 5 folds.

5. DISCUSSION

This study combines five proven technologies to develop a new technology package with the accumulative benefit of each targeted technology. These technologies include net house, closed soilless production system, root zone cooling, Ultra-Low-Energy Dripper, and solar system to power irrigation and RZC systems. From the findings of this study, it can be stated that cooling the root zone area increased the cucumber yield, expanded production and water productivity under net-house. The integrated technologies could extend production periods despite rising temperatures, saving 95% energy and 80% water without compromising yield. Cooling the irrigation water at 25°C appears to have a positive impact on plant growth, yield, and production period particularly when air temperatures rise and subsequently increase the water temperature. Several studies indicate that elevated water temperature can induce heat stress in plants, forcing them into survival mode. Symptoms of heat stress may include wilting, reduced levels of dissolved oxygen, flower drop and fruit abortion, as well as slimy roots [28]. This study demonstrates that root zone cooling in hydroponics can significantly enhance cucumber production. This improvement can be attributed to various factors, one of which is the substantial enhancement of plant nutrient uptake. By maintaining lower temperatures in the root zone, plants can optimize their metabolic activity, resulting in improved absorption and utilization of nutrients. Cooler root zone temperatures promote increased enzymatic activity in plants, thereby enhancing the availability of nutrients. Additionally, these lower temperatures contribute to a higher concentration of dissolved oxygen in the root zone, facilitating the absorption of nutrients by the roots. The increased availability of oxygen improves the efficiency of nutrient uptake and fosters the development of healthier roots [29].

This finding is in line with Moon et al. study designed to investigate the effects of root-zone cooling upon cucumber's growth and yield when shoots were exposed to high fluctuating air temperature during the hot season. Cucumber plants were cultivated in a plastic house for three months after transplanting. Cucumber plants were grown in perlite medium, which was cooled by 10°C cold water flowing through a pipe system buried at a depth of 15 cm. The temperature of the cooled root zone was, on average, about 6°C lower than that of the noncooled root zone. The noncooled root-zone mean temperature was measured at 30.9°C and 26.9°C and cooled root-zone at 24.3°C and 20.6°C, at a depth of 5 cm and 15 cm, respectively. The yield in the noncooled root zone decreased more rapidly than that in the cooled root zone as the plants grew. The number of fruits per plant was 15.9 in noncooled and 19.3 in the cooled zone. Thus, root-zone cooling increased cucumber yields even though shoots were exposed to high air temperature. Root-zone cooling also significantly improved root growth [30].

In another study, Wang, and Tachibana in 1996 reported that root growth, leaf expansion rate, leaf water content, photosynthetic activity, and leaf mineral concentrations were reduced more severely by high root-zone temperature. They suggested that, in the case that relative air humidity was low enough to activate leaf transpiration for lowering the temperature of leaves, root-zone cooling could reduce the inhibition by high air temperature [31].

The effect of root zone cooling on lettuce and capsicum has also been tested in a tropical greenhouse (structure like a net house) in Singapore. The root zone cooling system-maintained root temperatures between 15 and 25°C while the shoot temperatures ranged from 26 to 42°C. Interestingly, reducing root zone temperatures to 25°C yields 37.7% more than reducing it to 30°C, and 61.4% more than without root zone cooling treatment [32].

Similar results have also been proven in the hydroponic Nutrient Film Technique (NFT) in tropical climate regions of

Brazil for lettuce plants. The plants were tested at root zone temperature around 24-30°C. The test results concluded that cooling the root zone around 26°C was the optimum temperature for lettuce growth in tropical climate regions [33].

A similar result was confirmed in Oman when cucumber crop production was compared with different root zone area temperatures. The results indicated that the crop at root-zone temperatures of 22°C and 25°C showed superior performance in terms of plant height, leaf number/plant, chlorophyll content, leaf area, fruit number/m^2, yield, fresh and dry weight (g) shoot and root with significant differences between the treatments of 28°C and 33°C [34].

This study finding also supports the fusibility of cucumber production under net-house with RZC, where the total net return increased by 14% and cost reduced by 27%. Most of the saving was on the cost of establishment and maintenance, electricity, and water. NH-RZC reduced the cost of water and electricity by 95% and 81%, respectively, compared to the cooled-GH. Considering 4 growing seasons for cooled GH per year and 3 growing seasons for NH-RZC, still, the establishment and depreciation cost per growing season is less by 5% in NH-RZC. These findings are in line with another study in the region were proved that net house significantly reduces the costs for construction, water, and electric energy [35].

Utilizing solar energy for irrigation and root zone cooling system increased the establishment cost but reduced 95% of the energy cost during the production: some adjustments and new technology were utilized to reduce the establishment cost. The RZC system was powered by a hybrid (gride-tied) solar system, including five (5) panels only with no batteries, which significantly reduced production costs. The hybrid solar energy system combines On-Grid and Off-Grid based solar energy systems. It comes with the advantage of solar energy when the solar panel generates enough energy and low-cost grid energy when the solar system would not produce sufficient energy [36]. Batteries have been removed as the hybrid system generates enough energy to start the compressor, and the root zone cooling system was not operational at night.

6. CONCLUSION

The study's findings suggest that combining AC/DC hybrid on-grid solar energy with four other proven technologies can significantly improve cucumber crop yield, water productivity, and production period in net house systems compared to conventional pad and fan greenhouses in desert farming.

These technologies include net house structures, closed soilless production systems, root zone cooling, Ultra-Low-Energy Drippers, and hybrid solar-powered irrigation and RZC systems. By eliminating the pad and fan cooling system, the combined approach reduces energy consumption by up to 95% and water usage by 80%, without negatively affecting yield. The system operates with sensors and an automatic controller for precise climate management, marking a step towards precision climate-smart agriculture technology.

The combination of these techniques supports growers by enhancing productivity, reducing costs, conserving resources, and minimizing the carbon footprint of agricultural production. Net houses create a controlled environment that protects crops from adverse weather and pests, ensuring consistent and high-quality yields. The closed soilless production system allows precise control over nutrients, pH levels, and water availability, optimizing plant growth and production. Root zone cooling enhances nutrient uptake by maintaining lower temperatures, promoting metabolic activity, and improving nutrient absorption and utilization. Ultra-Low-Pressure Drippers enable efficient and precise irrigation, minimizing water waste. Incorporating solar power reduces reliance on fossil fuels, lowers energy costs, and contributes to sustainable agricultural practices.

In summary, the combination of a net house, closed soilless production system, root zone cooling, Ultra-Low-Pressure Dripper, and solar power offers substantial support to growers. These integrated approaches improve productivity, reduce costs, optimize resource utilization, and contribute to environmentally friendly agricultural practices.

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