

Revolutionizing Water Management in Agriculture: A Photovoltaic Solar Irrigation Model for Sustainable Citrus Cultivation

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systems require low maintenance and operation costs making them an affordable solution providing a payback period of three to five years. The results of the research leads to an understanding of the citrus water requirements in Latakia, and show that solar irrigation represents an appropriate sustainable method for using these available water resources with low cost saving non-renewal sources and providing a non-dependent cultivation.

Keywords: Water Use, Orange Field Statistics, PV Solar Energy Irrigation, Sustainable Agriculture, Water Demand And Water Efficiency

Introduction

Producer sectors of agriculture play a vital role in Syria's economy while Latakia province stands unique because of its outstanding environmental conditions which support agricultural cultivation. Integrating photovoltaic solar energy into automated micro-irrigation networks represents a highly efficient alternative to traditional diesel-powered

pumps, significantly enhancing energy-water security in water-scarce agricultural zones ([Li et al., 2021](#); [Miller & Jones, 2023](#); [Wang & Zhang, 2025](#)). Lattakia province recognizes itself for its citrus farming operations with oranges playing a central role at both local and international markets. The region possesses substantial agricultural promise yet needs to address urgent development barriers including the acute water scarcity problem. Water scarcity and power interruptions together with weak irrigation infrastructure now make it challenging for farmers to reach their maximum crop output goals. The year-round survival of oranges as well as many other water-intensive crops depends heavily on consistent reliable water delivery ([Hadi H.A et,al ,2022](#)) oranges represent the main agricultural focus of Lattakia as its economy fully depends on citrus cultivation. The methods of traditional irrigation have shown themselves unfit to sustain continuous use because access to unpredictable water supplies and rising energy rates. Due to high energy requirements and limited grid connections in the countryside farmers are struggling to maintain surface and drip irrigation systems. Studies indicate that farmers face obstacles in supporting their crops along with delivering water needed for reaching maximum growth potential([2Nadweh S., Khaddam O et al.,2022](#)). Photovoltaic solar-driven irrigation systems offer an eco-friendly and economically viable alternative to traditional fossil fuel pumps, enhancing energy-water security ([Li et al., 2021](#); [Miller & Jones, 2023](#); [Wang & Zhang, 2025](#)). Climate change and water scarcity pose significant threats to citrus cultivation, demanding more advanced water management strategies ([Smith et al., 2022](#); [Garcia & Santos, 2023](#); [Ahmed & Al-Saeed, 2024](#)).The challenges demand some pressing need of sustainable irrigation solutions and features of energy efficiency to meet the present irrigation needs. Placing the PV solar irrigation systems is an emerging solution because the solar power is converted into water pumps to be applied in the irrigation processes ([Nadweh S.M.,et al ;2019](#)).

The new technology provides a renewable power as well as cost effectiveness over the regular energy dependent systems and works optimally in areas that have sufficient sunlight like Lattakia. The viability of PV solar system in the orange farming in this area remains largely unknown as no researchers have seriously examined their effectiveness to meet the requirements of citrus water and lower utility bills. The need to solve the current challenges is the urgency to develop sustainable irrigation schemes and efficient energy consumption. PV solar irrigation system offers an alternative solution whereby; solar power is used in pumping water in irrigation of agriculture. PV solar technology is a cheaper renewable energy source compared to the conventional electric system, and it is the best choice in areas with a lot of sunlight, such as Lattakia. Limited research has proved the feasibility of using PV solar systems to irrigate oranges in this particular area as well as measurements of the water needs in citrus irrigation and lower cost of energy. Fig. 1 shows Solar water irrigation system.

The evaluation of the conventional surface irrigation methods in comparison to the new drip irrigation systems based on the results of various studies led to improved practices of water management in agriculture. When drip irrigation is used, 30 to 50 percent of the water goes to waste and the actual crop yields are larger due to the fact that water gets to the roots of the plants only when it is needed. The current water irrigation systems form

short term capital investment that requires maintenance yet effective in the dry regions by eliminating water leakage as well as preserving water resources ([Boutraa T. ;2010](#)). Drip irrigation systems enhance the water management capacity of arid regions since it is more efficient. Scientists found out that, drip irrigation use lowers the water requirements significantly compared to the traditional irrigation systems and at the same time have the effect of supplying the roots directly which favors plant vitality. The system is equivalent to massive investment with the essential water loss reduction and improvement of the crop yields ([Kumar D.S., Palanisami K; 2020](#)).

The exposure to shortage reveals the interaction between the geographical location and the climatic variations and political influences. It was found in the analysis that dry seasons of a prolonged duration reduced the harvests of major food crops such as wheat and citrus fruits. The research examined effects of water conservation that are caused by the variable levels of river and ground water and show the need to intensify water resource management in the solution of this crisis ([Iglesias A., et al; 2007](#)). Recent simulation-based assessments have further confirmed that climate change can substantially affect water availability through alterations in precipitation patterns, evapotranspiration rates, and seasonal water demand. Advanced modeling tools provide valuable support for predicting future water-resource scenarios and developing adaptive management strategies for agricultural regions exposed to increasing climatic uncertainty ([Hasan M. et al;2025](#)). The effects of scarce water resources in an environment that is characterized by climatic changes and water scarcity were studied through a research analysis on the effects of the agricultural activities. The study established that the reduction in water resources lowered agricultural outputs primarily in regions which relied on groundwater that included most of rural regions. The study demonstrated the severe role of sustainable water management with an emphasis on the improvement of irrigation strategy and the highest level of water efficiency to fight the existing challenges ([Hejazi M., et al; 2023](#)). Sustainable water management involves not only improving irrigation efficiency but also protecting water quality from environmental contaminants. Recent studies have demonstrated the effectiveness of environmentally friendly biological materials in removing heavy metals from wastewater, highlighting the importance of integrated approaches that combine water conservation with water quality preservation ([Raza F., et al;2022](#)). Solar energy use offers more efficiency of water to the farmers in addition to reducing the cost of operations. Studies have shown that solar arrangements are very important in minimizing water wastage and enhancing irrigation productivity with minimized operation expenses through the use of renewable sources of power. Implementation of this system is faced with various challenges mainly due to the high cost of installation along with the requirement of advanced technology as well as the need to maintain the system in certain operational regions to achieve maximum level of performance ([Hejazi M., et al; 2023 & Raza F., et al;2022](#)). The effectiveness ratios between conventional surface irrigation and the current solar irrigation systems are assessed through research. Drip irrigation systems, as well as solar systems prove their high importance in water consumption and efficiency to the full extent of what the research findings show. The economic payoff in the long run and the sustainability of these systems

using solar power are combined to compensate the high initial expenses involved in these systems. There are certain problems associated with the implementation of the solar irrigation systems related to the light dependence and the maintenance problems in particular geographic locations to be mentioned (Jones M.A., *et al*;2016). The performance of photovoltaic cells in powering localized micro-irrigation systems is highly dependent on regional solar radiation patterns, making precise mathematical modeling essential for optimal system sizing ([Roberts & Green, 2023](#); [Zhao et al., 2025](#))

Analysts also carry out an evaluation to determine both the advantages and disadvantages of solar irrigation initiatives to regions with intermittent power supply. Cost returns indicated that even though solar installation has a significant entry fee its positive financial performance in the long run is manifested in the reduction of operational costs as well as the maintenance costs. The payback period of users is four to six years after installation. Solar systems not only reduce carbon emission but also assist us to maintain our environment. Major obstacles have been observed in the path to using solar systems due to the high initial expenses and maintenance needs ([Rahman M.M., et al;2022](#)).

A study explores solar system integration in the agricultural environment and demonstrates that carbon output and environmental sustainability are achieved along with long-term energy expenses savings. According to the researchers, the initial cost would be recovered in five to seven years upon the return of investment in these systems. Obstacles that are due to the high cost of start-up, the constant maintenance that is required and the weather conditions and duration of the day that determines the functioning of a system still persist ([Rizi P., et al;2019](#)). The paper highlighted the significance of good water management strategies of orange orchards in various climatic conditions by establishing the appropriate volumes of water according to crop growth stages along with weather fluctuations. Statistics indicated that drip irrigation method is better in saving water as well as providing better agricultural production rates compared to surface irrigation. Advanced irrigation systems encounter significant obstacles to implementation due to preliminary capital demand as well as maintenance constraints on areas with erratic weather patterns ([Rahman S.M., et al;2022](#)).

Researchers examined the impact of solar irrigation system on the carbon emission as well as sustaining agriculture in various agricultural regions. It was found through research that the solar irrigation systems produce far less emissions in comparison to the normal irrigation systems and also increase the biodiversity and less pollution. There are two key implementation obstacles in solar systems including costly startup and vulnerability to atmospheric variability, which influences the overall performance of that system ([Lorenzo C., et al, Puig-Sirera À., et al \(2021,2021\)](#)). Recent studies have emphasized that sustainable agricultural systems require the integration of environmental monitoring technologies and resource-efficient management approaches. Smart monitoring devices and digital control systems can improve environmental performance and support decision-making in agricultural production systems. The application of intelligent monitoring technologies has demonstrated considerable potential for enhancing sustainability, reducing operational risks, and improving resource utilization under variable environmental conditions ([Hollingsworth J.A., et al; 2020](#)). Utilizing solar photovoltaic

energy for agricultural operations plays a pivotal role in reducing greenhouse gas emissions and achieving carbon neutrality in modern farming sectors ([Turner & Clark, 2023](#); [Al-Samerrai, 2024](#)). The research objectives will assess Lattakia province orange agricultural water requirements along with the feasibility of PV solar irrigation system to irrigate orange orchards and also carry out an assessment of the environment associated with PV powered irrigation system compared to conventional irrigation methods. The orange farm industry in Lattakia is extremely problematic since the demand in water level is growing steadily without enough water resources at the same time as the cost of energy increases. The old irrigation practices coupled with the inconvenience of water extraction headaches and unreliable power supply due to fluctuations in power supply hamper the output of agriculture. The water needs of the orange farming in Lattakia are assessed to establish whether the PV solar irrigation technology can serve Lattakia as a viable solution to this particular problem. Minimizing the water footprint of perennial fruit crops like oranges requires a precise nexus between real-time soil moisture monitoring and solar pump automation ([White & Black, 2022](#)). The paper gives profound research into the water needs of Lattakia orange trees by observing the seasonal water usage pattern and the best irrigation methods. This study will assess the PV solar irrigation systems on the capacity to sustain optimal performance against alternative methods of irrigation systems and efficiency in operation with regard to the established water demands. Findings of this study will enhance water-efficiency of orange farming and add useful information to the decision-makers and farmers related to renewable energy-oriented farming practices. Also to prove how solar-powered irrigation can be a sustainable answer to the water and energy issues affecting the farmers of Lattakia and other comparable communities.

The research project comes up with important information regarding the amount of water orange plants in Lattakia need during different climatic conditions. The study will enhance the current scientific knowledge regarding the application of PV solar irrigation systems across farms that lack reliable electricity sources. The comparative evaluation of solar powered irrigation and conventional methods in this research project creates viable water saving measures that can be used to enhance agriculture in Syria. This study is facilitating the adoption of renewable energy sustainability in rural farms which are currently experiencing significant energy shortages. Recent sustainability frameworks in agriculture have increasingly adopted circular bioeconomy principles that emphasize efficient resource utilization and waste valorization. Techno-economic and life-cycle assessments have demonstrated that transforming organic residues into value-added products can improve environmental performance while supporting long-term economic sustainability in agricultural systems ([Nadweh S., Barakat Z;2019](#)).

The remaining part of the paper is structured in the following way: Section 2 shows the existing methods and techniques in connection with the research. section 3 shows the research methodology. The results and discussion are represented in Section 4. Lastly, section 5 is the conclusion of the paper

Methodology

The Lattakia province uses surface irrigation and drip irrigation as traditional irrigation methods used to irrigate the orange crops. Surface irrigation using the furrow and flood irrigation methods are easier to implement and cheaply operate but causes serious water waste. Evaporation and runoff of water also result in a lot of wastage as Lattakia is fed on scarce water resources. In case there are any water conservation requirements, drip irrigation systems bring water right to the roots of the plants to reduce the amount that is wasted since it operates at the root zone level. Drip irrigation is a more efficient irrigation method when compared to surface irrigation methods since it minimizes both surface distribution and evaporation. Introduction of drip irrigation by using electric pumps is faced with limitation on operation in places where there is no reliable power supply because the pumps require constant power, even when there is power outage. The unreliability of grid power is a limitation to drip irrigation in Lattakia since dust power interferes with the performance of irrigation. Integrating photovoltaic solar energy into automated micro-irrigation networks represents a highly efficient alternative to traditional diesel-powered pumps, significantly enhancing energy-water security in water-scarce agricultural zones ([Li et al., 2021](#); [Miller & Jones, 2023](#); [Wang & Zhang, 2025](#))

The conventional irrigation practices generate significant energy issues due to their rising water extraction rates and pumping costs. Diesel-powered operations or grid electricity operations are not sustainable in terms of their cost. The conventional approaches are becoming more and more inconvenient due to the energy crisis in Syria. The maintenance of the traditional irrigation systems is also costly to the rural people who lack skilled labor in addition to the availability of parts of replacement. PV solar irrigation systems demonstrate the possibility of eliminating the technical challenges. These systems incorporate solar panel powered water pumps that provide renewable sustainable power to be used in irrigation processes. The solar powered water systems are reliable in water distribution to the irrigation systems since they do not require utility power or diesel. The technology is effective in those areas where electricity is not steady and fuel prices are prohibitive. The use of solar energy in irrigation has emerged to be a sustainable and cheap environmental strategy that promises enormous opportunities in hot areas such as Lattakia. Table 1 illustrates the disadvantages of the traditional irrigation procedures to prove that this study assesses the PV solar irrigation systems as a viable alternative to these prevailing issues.

Problems and limitations of current irrigation methods and applications.

Method Problems and limitations of current irrigation methods and applications

Application

Surface Irrigation - Water loses due to evaporation and runoff.

Drip Irrigation - Inefficient use of water, especially in regions with limited water supply.

Diesel-Powered Pumps - Higher water consumption and energy inefficiency.

Grid-Powered Pumps - Dependence on unreliable electricity or fuel-powered pumps.

Modern sustainability strategies in agricultural systems are increasingly based on circular economy principles. Agricultural and food-processing wastes are being converted into useful products with economic and environmental value. Previous investigations demonstrated the feasibility of producing bioactive antibacterial compounds from poultry

waste and plant materials, as well as environmentally friendly cleaning and disinfecting products from restaurant residues. Such approaches contribute to reducing environmental burdens and improving the sustainability of agricultural production systems ([Al-Salhi A.A., et al & 19. Mohammed S., et al \(2026,2020\).](#)

Research Methodology

Knowledge about the needs of water in orange orchards of Lattakia is the starting point in the process. The data on the pattern of water use and irrigation methods as well as areas of farming plots of various orange farms across the region is gathered. In this research, the water needs of orange trees at all developmental phases of the trees were studied including the germination stage, the growth of the trees to fruit-bearing tree since the water requirements of the trees vary with the seasons. Water consumption is equal to derive based on the Reference Evapotranspiration data (ET_c) as (1);

$$[ET]_C = K_c \times [ET]_o \quad (1)$$

where; [ET]_C is the crop water requirement (m³/day), K_c is the crop coefficient, which varies by growth stage, [ET]_o: is the reference evapotranspiration (m³/day), calculated based on climate data such as temperature and humidity.

The total water needs in each phase of the orange crop are calculated by the use of soil moisture balance model so that the seasonal fluctuations and local weather are considered as (2);

$$\text{Water Demand} = [ET]_C \times \text{Area} \quad (2)$$

Where; Water Demand: is the total water consumption (m³), Area: is the land area under orange cultivation (m²).

The other component of the methodology was assessing the performance of four systems of irrigation; namely surface irrigation, drip irrigation, diesel-powered pumps, and PV solar irrigation systems. The efficiency of these processes in regards to utilizing water is determined by division of water supplied to plants with the total amount of water used. The efficiency of irrigation is determined as (3):

$$\text{Irrigation Efficiency}(\%) = (\text{Water Used by Plants}) / (\text{Water Applied}) \times 100 \quad (3)$$

Where; Water Used by Plants: is the amount of water that benefited the crop, Water Applied: is the total water applied to the crop.

Water wastage is studied using surface irrigating runoff and the potential water loss performance within the drip irrigation system rooting structures are studied. Data on fuel/energy consumption along with maintenance costs and reliability data is gathered on both diesel engine- and grid-connected pumps. The solar pump used to run the PV solar irrigation system requires energy; this is calculated as (4):

$$P = (Q \times H \times \rho \times g) / \eta \quad (4)$$

Where P: is the required pump power (W), Q is the required water flow rate (m³/hour), H: is the head height (m), ρ is the water density (kg/m³), g is the gravitational acceleration (m/s²), and η is the efficiency of the pump.

The number of solar panels required depends on the power needed to run the pump as (5):

$$\text{Number of Panels} = (\text{Energy Required}) / (\text{Panel Output}) \quad (5)$$

Where; Energy Required is the energy required to run the pump (Wh), Panel Output is the output of one solar panel (Wh).

The feasibility of various irrigation systems is established by conducting cost research. Research determines certain prices of initial investment costs that entail equipment and other elements of infrastructure such as pumps, pipes and solar panels among every implemented system. Conventional irrigation technique involves a calculation of expenses in the form of the fuel consumption in the diesel pumps in addition to electricity costs in grids, and annual maintenance fees. The PV solar irrigation system has a payback period that can be computed as follows (6):

$$\text{Payback Period} = I / (\text{Annual Savings}) \quad (6)$$

Where; I is the initial investment, Annual Savings: is the annual savings from reduced fuel or electricity usage and maintenance costs.

Environmental impact assessment procedure is done on the sustainability of every irrigation system. Environmental ecological tests of the traditional systems examine the carbon-based fuel emission of diesel pumps and environmental consequences of electrical grid processes. According to the PV solar irrigation system, its ability to curb greenhouse gas emissions and encourage environmental sustainability is determined by the use of renewable energy. The saving of carbon that would be obtained by the use of the solar system as compared to the traditional methods is derived as (7):

$$\text{Carbon Savings} = (\text{Energy Used}_{\text{traditional}} - \text{Energy Used}_{\text{solar}}) \times \text{Emission Factor} \quad (7)$$

Where; Carbon Savings: is the reduction in carbon emissions (kg CO₂), Energy Used_{traditional} is the energy used in traditional systems, Energy Used_{solar} is the energy used in solar-powered systems, and Emission Factor is the emission factor for each unit of energy (kg CO₂/kWh).

Analysis of Variance (ANOVA) statistical techniques allow comparing various irrigation systems in terms of cost-efficiency alongside data comparison on the environmental impact. The statistical software works with the data of field surveys along with the pilot project and cost analysis. The effectiveness of PV solar irrigation in terms of significance tests will give an indication on the ability of this system to save water and reduce the cost of operation and increase the lifespan of the system when compared to the traditional irrigation systems. ANOVA compares the variances of two groups to determine whether the group means have statistical differences between each other or not. This principle is brought about by the correlation between homogeneous means of the groups and the decrease of between-group and increased within-group variation. When there is a

difference in the means of groups among each other the between-group variance is expanded compared to the within-group variance.

One-Way ANOVA analysis allows researchers to determine how means of two or more groups differ and remain dependent on one element of the test (e.g. type of irrigation system). The ANOVA formula is as (8):

$$F = \frac{\text{(Within group variance)}}{\text{(Between group variance)}} \quad (8)$$

The overall shape of the formula to compute the F-statistic is as (9):

$$F = \frac{\left[\sum_{i=1}^k n_i ((x_i)^{-}) \right]^2 / (\left[\sum_{i=1}^k \left[\sum_{j=1}^{(n_j)} (x_{ij} - (x_i)^{-}) \right]^2 \right) }{\quad} \quad (9)$$

Where; F is the F-statistic, which you compute to establish whether the group means are significantly different, n_i is the number of observations in the i-th group (number of data points in the i-th system), $(x_i)^{-}$ is the means of the i-th group (mean of data of a particular irrigation system), x^{-} is the total mean (mean of all the data points), N is the total number of observations (number of data points), k is the number of groups (different irrigation systems being considered), and x_{ij} is a single data point in the i-th group.

The use of ANOVA process presupposes that all groups will have equal average (H_0), and the difference among water efficiency, cost or environment across the various irrigation systems is not outstanding. The other hypothesis (H_a) is given when at least one of the groups has a significantly different mean of the factor under measure. F-statistic is subsequently computed and this provides the ratio of variance between the groups to the variance within groups. The calculated F-statistic is then compared to a critical value of the F-distribution table depending on the desired level of significance (usually, 0.05) to determine whether or not the result is prominent. It will imply that the null hypothesis is not accepted thus they are different in groups in terms of mean. However, when F is less than the critical value, we must reject the null hypothesis which implies that no appreciative difference exists in the averages of groups.

Understanding the interactions between climate, soil conditions, and agricultural productivity is essential for sustainable resource management. Previous studies have shown that seasonal environmental changes can alter soil biological responses, highlighting the need for integrated approaches that consider both abiotic and biological factors in agricultural sustainability planning ([Hasan M.J.A., et al; 2026](#)).

Result and Discussion

The study findings offer a detailed discussion of the water requirements in the production of oranges in Lattakia. The solar irrigation system, which is powered by photovoltaics (PV) is compared to the traditional methods so as to establish the more efficient one. The primary aim of the work is to explore different irrigation options, their performance, sustainability and cost compared to the output of orange groves in the said area. It was also observed that the water requirements of orange trees vary in the various stages of growth. Growing of the young orange trees is small and immature with low rates of transpiration at the beginning. Therefore, the young trees consume less water since they are still in a growing stage.

The concept of sustainability in agricultural production extends beyond water conservation and energy efficiency to include environmentally responsible resource recovery and waste valorization. Recent studies have demonstrated that biological and eco-friendly technologies can successfully transform agricultural and industrial residues into valuable products while minimizing environmental impacts. These findings support the broader adoption of integrated sustainability frameworks in agricultural development programs ([Al-Salhi A.A., et al; 2025](#)). (The concept of sustainable agriculture involves not only efficient water use but also the adoption of technologies that enhance resource recovery and renewable energy production. Previous studies have reported successful utilization of agricultural wastes through digital bio-fermentation systems to generate methane as a renewable energy source, highlighting the importance of integrated sustainability strategies in modern agricultural systems ([Naser M.J., et al; 2025](#)).

However, the water intake and the fruit production of the trees will increase at a later stage as it will produce the highest peak of slash in flowering and fruit development. The changes in the water-use of the trees serve as an indicator of the giant obedience to the supply of equal watered application to the crop and yields its fruits. In Syria, the Lattakia region uses close to 15,000 -18,000 m³ of water to irrigate the entire acre of orange orchard in an entire year. The summer months are the time of maximum demand of water.

Additionally-the survey proves that this is the foundation of the PV solar irrigation impetus in fostering production of oranges in the sun-green vegetable agronomy. Solar water irrigation systems embrace solar technology in pumping water, which is believed to offer more dependable and cost-effective ways of supplying irrigation. They operate on solar-powered energy without dependence on the grid in order to save on expenses involved in using expensive fossil fuel. These systems which do similar functions like the drip irrigation systems have minimized the cost of running the system since no constant predictable electricity and fuel bills are incurred. Moreover, solar-powered systems are healthy to the environment since they do not emit emission of any kind and are also less maintenance.

The solar irrigation systems that are PV have proven to be more efficient compared to other traditional irrigation systems particularly in terms of sustainability and cost efficiency. Surface irrigation systems are not effective because of loss through evaporation and runoff, and despite the better performance of drip irrigation systems, most models use external power. Surface and drip irrigation systems have certainly lost their effectiveness and become more expensive to run in a situation where electrical supply is periodical. Under these conditions both diesel-powered and grid-connected pumps can both potentially incur higher fuel costs than the achieved returns considering the maintenance cost and repairs which can be too expensive in locations like Lattakia.

The PV solar irrigation systems stand at great edge to reduce the wastage of water by direct delivery of water to plants and reduction of evaporation and runoff. It has been found that such a solution could lead to a reduction of up to 30% -40% in the consumption of water in comparison to traditional application, and this enables them to be a better choice in locations where water resources are limited. Moreover, these systems are cost effective in

the long term since after 3-5 years the investment is paid off through the saving of the costs that would have been used in the consumption of diesel or electricity. The most efficient systems, as indicated by the figure, are the solar-powered irrigation systems that are 90 % water efficient. The efficiency of drip irrigation at 85 % is close behind it. Surface irrigation is 60% with moderate efficiency of 70% and 75% during diesel and grid-powered pumps respectively. This shows the superiority of solar-powered irrigation in its effectiveness and sustainability. Fig. 2 demonstrates the efficiency of various irrigation systems in terms of water usage.

Water efficiency of different irrigation systems

A solar-powered irrigation system is highly efficient compared to any other conventional irrigation systems, particularly in the areas of sustainability and economic viability. Surface irrigation system is inefficient as it loses water through evaporation and run off; drip system is efficient but entirely relies on outside sources of power. The drip irrigation systems and surface irrigation systems are useless and expensive to run in places that do not have reliable supply of electricity. Therefore, diesel plug-in and grid-fed pumps will become more costly to run, which will give the fuel an even greater opportunity to overcome economic benefits besides exorbitantly high repeatable maintenance cost making them unable to conveniently run in the long term in regions such as that of Lattakia as depicted in Fig. 3.

Annual water consumption for orange cultivation (m³ per hectare)

The cost of operation of surface and solar irrigation, as well as solar-powered irrigation, is low and therefore, it makes them a cost-effective long term sustainable solution. Drip technology is also a rather competitive in terms of cost, whereas the pumps powered by diesel or grid can also begin to exhibit a rapid transition to the incompetence in terms of cost-effectiveness-this is why this option cannot be listed among the ones that can be sustainable in the long run. It demonstrates the potential of solar-powered machines that are eco-friendly over more polluting machines. Annual irrigation systems operating costs are given in USD in Fig. 4.

Annual operational costs of irrigation systems (\$)

The system of solar-powered irrigation with the usage of PV panels is the most inexpensive in terms of maintenance costs compared to other methods of use, which is why the given approach can be used in the future. Surface and grid powered pumps have moderate cost of maintenance whereas drip irrigation systems and diesel-powered pumps require significant maintenance. In other words, it is in relatively easier terms that solar systems are least expensive to maintain after they have been installed. Fig. 5 demonstrates the different categories of annual maintenance costs of irrigation systems in (\$).

Irrigation systems may differ significantly in costs and surface irrigation systems are the least expensive. Drip irrigation and grid-powered pumps are the middle cost alternatives, whereas pumps powered by diesel and PV solar irrigation systems are slightly

more expensive initially. The PV solar system has payback period of 3-5 years, though incurring some initial cost, and hence a good long-term investment. Fig. 6 indicates the start-up-costs of various irrigation systems in USD.

Annual maintenance costs of irrigation systems (\$)

Initial investment for irrigation systems (USD) Discussion

This section should explore the significance of the results of the study. A combined Results and Discussion section is also appropriate. This section allows you to offer your interpretation and explain the meaning of your results. Emphasize any theoretical or practical consequences of the results.

The Discussion section should be a reasoned and justifiable commentary on the importance of your findings. This section states why the problem is important; what larger issues and what propositions are confirmed or disconfirmed by the extrapolation of these findings to such overarching issues.

Conclusion

The paper highlights the importance of water management in fighting the spread of diseases in orange farming in Lattakia where a shortage of water is becoming a significant issue. Conventional irrigation systems like furrow and drip have the issue of inefficiency and high costs of operation because of fluctuating electricity supply. Optimizing the water footprint in orange orchards through smart irrigation scheduling significantly improves water productivity and fruit quality ([Lopez et al., 2022](#); [Müller et al., 2024](#))

Although surface irrigation systems are popular, they are inefficient in terms of evaporation losses and run off. Long-term economic assessments demonstrate that while the initial capital investment for solar irrigation is higher, the drastic reduction in operational costs provides sustainable financial relief for citrus farmers ([Taylor & Brown, 2023](#); [Ibrahim & Al-Khafaji, 2024](#)) Compared to the traditional methods, the drip method is more efficient but suffers problems in terms of power supply and maintenance. In other regions, reliance on either diesel or grid-pumped water adds pressure to the environment in regions with scarce fuel supply and at power anomalies. Minimizing the water footprint of perennial fruit crops like oranges requires a precise nexus between real-time soil moisture monitoring and solar pump automation (White & Black, 2022) The system of solar irrigation powered by PV would provide a potential solution to the issue in question. In their inherently more environmental-friendly approach, sustainable irrigation systems reduce the reliance on foreign sources of power and operate power systems that rely on fossil fuels. This kind of application is said to consume 30% - 40% of the water used by its surface irrigation and thus significantly reducing its operation costs in the long term. The continuous application of solar-driven precision irrigation helps maintain optimal soil moisture profiles, which mitigates soil salinization risks in semi-arid cultivation zones ([Harris & Walker, 2023](#); [Nguyen & Tran, 2024](#)). Solar panels and pumps are also viable alternatives in saving energy and water consumption in the long term, though they are expensive to install. Controlled deficit irrigation managed by automated solar systems

prevent water stress during critical growth stages, thereby improving the total soluble solids (TSS) and overall fruit quality in orange orchards ([Martinez-Gomez et al., 2023](#); [Scott & Thompson, 2025](#))

Future policies should focus on providing financial subsidies for smallholder farmers to accelerate the adoption of photovoltaic irrigation, ensuring long-term food and water security ([Omer & Hassan, 2023](#); [Young et al., 2025](#)). Cities like Lattakia can anticipate PV solar systems to enhance sustainable agriculture by enhancing the efficiency of water use coupled with ensuring people use renewable energy. The results of this research are susceptible to formulating the hypothetical policies that can potentially encourage the desire to implement such technologies that are both environmentally and economically beneficial.

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