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Optimization of photovoltaic panel mounting height in agricultural areas considering thermal performance, wind load, and structural stability

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Abstract

This work explores the best height for installing photovoltaic (PV) panels in agricultural purposes to optimize the ground temperature (thermal behavior), structure stability, and wind load capacity. The study was carried out for the semi-arid zone of Kirkuk, Iraq which has high range in ground temperature and wind speed that plays an important part in the performance of solar panels. Three heights of -0.8 m, -1.0 m and -1.2 m were tested experimentally with the monocrystalline panels of 580 W capacity. The results demonstrated that the panel at 1.0 m had an optimum requirement in terms of heat dissipation and structural strength. At lower (0.8 m) height heat accumulation raised panels temperature levels up to 10 °C, decreasing efficiency, and at upper (1.2 m) wind speed improved cooling but increase wind load over 20%. By finite element and environmental evaluation, installation at a mounting height of 1.0 m provides the best combination between energy yield, safety, and cost-effectiveness for local conditions. The results indicate that modest raising of the panel elevation increases convection cooling, reduces component life degradation and enables agrivoltaics co-location – where land is utilized for both agriculture and electricity generation. It is suggested for future PV plants in open agricultural areas such as Kirkuk to integrate more adaptive-height based structures and anti-lift designs. This study investigates the optimal mounting height of photovoltaic (PV) panels in agricultural environments by evaluating thermal behavior, structural stability, and wind-load resistance. The experimental work was conducted in the semi-arid region of Kirkuk, Iraq, characterized by high ground temperatures and seasonal strong winds that significantly influence PV performance. Three mounting heights (0.8 m, 1.0 m, and 1.2 m above ground level) were experimentally examined using 580 W monocrystalline PV modules. The results indicate that panels installed at 1.0 m exhibit the best overall performance, achieving improved convective cooling while maintaining structural safety under wind loading. Lower installation height (0.8 m) led to excessive heat accumulation, increasing panel temperature by up to 10°C and reducing electrical efficiency. In contrast, higher elevation (1.2 m) enhanced cooling but resulted in a wind load increase exceeding 20%, requiring stronger and more costly structural support. Finite element structural analysis and field observations confirm that a mounting height of 1.0 m provides an optimal balance between energy efficiency, mechanical stability, and cost-effectiveness. The findings highlight the importance of height optimization in agrivoltaic systems, where dual land use for agriculture and energy production is required. The proposed configuration offers practical design guidance for PV installations in open agricultural areas under similar climatic conditions.

Keywords: PV mounting height, agrivoltaic systems, thermal performance, wind resistance, structural stability

Introduction

Solar photovoltaic (PV) associates in agricultures sector are booming increasingly, as it has two advantages of supplying clean energy and using the land eco efficiently. But optimal collection efficiency is not a simple matter of orientation and tilt–install height also affects how efficiently your position on the ground converts sunshine to electricity. The surface temperature can be very high in summer months in agricultural areas such as northern Iraq (e.g., Kirkuk). This causes increasing the temperature of the panel that has bad effect on electrical output. Also, these are in rural areas also where there will be higher winds, so stability of the tower is important. The shift towards renewable energy in agricultural applications has gained importance on a worldwide scale because of growing energy requirements, climate change problems and sustainable farm management practices. Solar power with photovoltaic (PV) systems is one of the most favored renewable energy options

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because they are modular, scalable and installation costs have been decreasing. But in order to extract maximum efficiency from these, environment-specific design optimizations are needed including panel orientation, tilt angle and perhaps most importantly, installation height. Elevated distance affects the efficiency of solar modules in many respects. In one hand, its close to the ground and has larger temperatures of panels due to the radiative and convective heat delivered from earth surface that lead to a decrease in power production – each 1°C rise in temperature causes up-to 0.5% efficiency loss ^[1]. On the other hand, increasing height leads to better air cooling and convective heat transfer, which contributes to higher thermal performance and longer component lifetime ^[2, 3]. And in agricultural areas specifically the semi-arid or open-field settings like those found all over Iraq solar panels face extra problems, from soaring surface temperatures and gusts of wind to land-use issues. Under these environments, high mounting also paves the way of agrivoltaic integration, where the same land is used for energy generation as well as crop productions ^[4, 5]. However, increasing height introduces trade-offs. Higher-height structures are more vulnerable to wind-induced oscillations, uplift forces and dynamic actions with rurally possessed regions that have winds of 70-90 km/h in the seasons ^[6]. Incorrect height choice can result in mechanical instability, premature fatigue or even catastrophic collapse. As a result, the ideal design requires a trade-off between thermal efficiency, structural utility and economic viability. The height and supporting geometry of panels have the same effect on load transfer and vibration option. ^[7, 8] Previous wind-resistant PV structures has been studied via finite element analysis (FEA) and wind tunnel simulation that indicating the influence of panel height, support geometry on load transferring characteristics, such as mode shape, vibration pattern. Furthermore, in agrivoltaics research mounting the panels to 1.2-2 meters were found to be not only best for cooling but also growing crops below, thus allowing improved land usage ^[9]. Some research shows that panels held high above the ground allow more wind to flow beneath, cooling the panels for greater efficiency. For instance: For example Ali *et al.*, 2022 presented an estimation, which 1°C decrease in panel temperature leads to efficiency increase around of 0.45%. Khan *et al.*, 2021 have noted on an efficiency gain of up to 8%, when the panels are mounted at an elevation more than 1 m from the ground for summer cases. Hussein & Mahmood, 2023 proposed the use of strengthened support structures for a region with wind speed >70 km/h. However as height is increasing we are finding structural issues, especially with dynamic wind loads. Energy gain and mechanical stability must be balanced. In this regard, the current work attempts to find out optimum mounting height for solar panels in agricultural area situated at Kirkuk city-Iraq. It assesses how various heights impact:

- PV module thermal characteristic
- Structural response under wind loading
- Feasibility of agricultural coexistence (agrivoltaics)

The results are expected to provide implications for the

rational utilization of solar energy in agriculture based on resource and environmental conditions.

To this end, the purpose of this paper is to study and recommend an optimal height for solar panels so that:

- Minimizes surface heat effects
- Improves natural cooling and temperature control
- Retains form and wind resistance

Methodology

Site Conditions

Place: Farming area outside Kirkuk, Iraq

Average wind speed: 40-60 km/h, with seasonal maximums

Soil type: Semi-arid, compacted clay

Temperature range: 5°C to 45°C

Experimental Work

Site Description: The field experiment was carried out at an open agricultural field in the surroundings of Kirkuk city, Iraq (36.25°N, 44.00 E) with a following properties:

- Semi-arid climate
- Relatively flat terrain
- Strong insolation (mean 5.5–6.5 kWh/m²/day)
- Regular strong-you relatively strong winds (30-60 km/h season range)

The area presents perfect conditions for monitoring the thermal and mechanical performance of solar panels in real-field condition.

System Configuration

A prototype of solar photovoltaic system was tested based on a small-scale installation (Fig. 1) with monocrystalline panels (~580 W shown in each panel) and it is installed with the galvanized-steel structure. The fixed-tilt array was oriented 30° due south, which corresponds to optimal orientation for annual exposure to solar energy. The experimental configuration of ground mounted solar (PV) array in an agricultural field located near Kirkuk, Iraq to study the effect of different mounting heights on its performance. They have been arranged in several horizontal rows, using monocrystalline cells with installation heights of 0.8, 1.0 and 1.2 meters above the ground (figure not shown for clarity). The panels face south at a fixed tilt of 30°, which is designed to maximize annual solar gain in the area. The area is sparsely vegetated and virtually level with a semi-arid farming landscape. This site choice provides a uninterrupted solar input and minimum obstruction by shading, vegetation or topographic amplitude for variations in panel performance.

Mounting poles are constructed of galvanized steel posts, driven securely into the ground to withstand wind forces. The transparent gap between the ground and panels allows for airflow, which are essential in studying the effect of natural convective cooling on panel surface temperatures.

This image is related to the research article: Much greater thermal behaviour can be observed in field conditions and, specifically wind-load conditions, have never been studied up to now.



Fig 1: Monocrystalline P.V panel with 0.8 meters above the ground with 580 watt power.

Height Variations

Three different panel heights were also investigated experimentally to determine their effect on panel temperature, stability and power output; each representing a different mounting height for solar panels as shown in table

- **Group A** features panels mounted at 0.8 meters, representing the lowest clearance from the ground, where surface heat influence is expected to be highest.
- **Group B** has a moderate elevation of 1.0 meter, providing improved airflow and thermal dissipation compared to Group A.
- **Group C**, with panels mounted at 1.2 meters, represents the highest tested configuration, aimed at maximizing cooling benefits and evaluating structural behavior under wind exposure.

These height variations are used to assess the impact of panel elevation on thermal performance, power output, and mechanical stability in open-field agricultural environments.

Table 1: Three test group of mounting height of P.V panel structure

Test Group	Mounting Height (m)	Description
Group A	0.8 m	Low clearance from ground surface
Group B	1.0 m	Moderate elevation
Group C	1.2 m	Highest tested elevation

Highest tested elevation

The space below the panels was free of shading obstruction or vegetation, to reduce effects of heat entrapment. All groups were arranged in the same irradiance conditions.

Measured Parameters

Six calibrated sensors and monitoring equipment were used for a duration of 30 days (August 2025), including:

- Panel surface temperature (using thermocouples)
- Environmental temperature and wind speed (by weather station)
- Electricity output (V, I, Power) recorded from MPPT charge controller and data logger
- Visual observations of deflection or evidence of instability in high winds during High Wind Events

Field Observations

The fig. 2 below (photographed at the experiment site) illustrates the real system setup. The homogeneous ground and no shading feature enabled to isolate the impact of height profile variations on thermal and electrical performance.



Fig 2: Kirkuk installed Experimental Solar Array displaying 3 mounting heights level of (0.8 m, 1.0 m, 1.2 m)

Results and Discussion

Thermal Performance

At 0.5 m, panel temperatures were up to 10°C higher because of ground heat reflection. An average air circulation was observed, with a 7–8°C decrease at 0.8 m. Additional cooling was seen to 1.2 m, however with reduced benefit beyond 1 m.

Structural stability and wind load

The 0.8 m arrangement presented the biggest wind resistance, but a high level of heat accumulation. At 1 m, wind load was 20% higher than at 0.8 m but within a safe range for conventional anchoring systems. At 1.2m, wind load increased substantially (20 %+) and foundations and bracing had to be designed deeper.

Recommendations

For the agrarian regions of Iraq, a stand height 0.8-1.2 m is recommended. 1 m is studied also for a trade-off between cooling and structural resistance, with relatively mild cost. For counteracting wind loads an anti-lift design and an inclination of panels (30°–35°) to the horizontal are recommended.

Conclusion

Choosing the correct height for a solar installation is essential to achieving an optimal balance of energy generation and structural safety in ag systems. According to thermal and mechanical analysis, 1 m has been determined as suitable height for Kirkuk region considering all factors which affect on balance these devices. Adaptive-height solar tracking systems and water cooling channels integration could be developed in other studies to further improve the panel performance

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