

**INTERNATIONAL JOURNAL OF
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INDUSTRIAL REVOLUTION
(IJIREV)**www.gaexcellence.com/ijirev**IMPACT OF PHOTOVOLTAIC SHADING ON POTATO
(SOLANUM TUBEROSUM) YIELD IN AN AGRIVOLTAIC
SYSTEM: A SIMULATION STUDY IN THE NILE DELTA,
EGYPT**Mohammed Elsayed Samier Madboli Ibrahim ^{1*}, Mohd Rafi Adzman ², Elsayed Madbouly ³¹Faculty of Electrical Engineering and Technology, Universiti Malaysia Perlis, Arau 02600, Malaysia moh-madboli@hotmail.com <https://orcid.org/0009-0008-2309-6531>²Faculty of Electrical Engineering and Technology, Universiti Malaysia Perlis, Arau 02600, Malaysia mohdrafi@unimap.edu.my <https://orcid.org/0000-0002-0347-1698>³The Arab Open University, English Intensive Unit, Academic Coordinator, KSA saidibrahim43@hotmail.com <https://orcid.org/0009-0005-7209-3968>

*Corresponding Author

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Abstract:

The agrivoltaics systems delivers an opportunity to integrate solar PV energy generation with crop production in the same land, with the aim to increase land-use efficiency and to promote energy and agriculture production. However, the solar radiation received by the crops due to PV panel shading can impact the productivity of the crop. Agrivoltaic (AV) systems have been widely studied, but little research has been done concerning the effect of PV shading on potato (*Solanum tuberosum*) production under the climatic conditions of the Nile Delta, Egypt. In order to fill this gap, this study involved the coupling of System Advisor Model (SAM) with AquaCrop to assess the yield productivity of potato in a simulated agrivoltaic system at Kafr El Sheikh. PV performance and ground-level irradiation were estimated using SAM and the simulated irradiance data were fed into AquaCrop for the evaluation of potato growth under PV-shaded conditions. For comparison, an open-field simulation was used. The PV system's capacity factor was 21% and electricity production was about 2.1 GWh/year. Under PV shading, potato dry tuber yield decreased by about 15%, mostly because of reduced biomass accumulation, crop duration and harvest index were almost unaffected. Analysis shows a trade-off between renewable energy production and crop productivity and reveals the need to optimize the PV layout to reduce potato production losses in the Nile Delta.

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Keyword:

Agrivoltaics; Aquacrop; Irradiance Reduction; Nile Delta; Potato; Photovoltaic Shading.



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Introduction

Agrivoltaic systems integrate crop cultivation with solar photovoltaic (PV) energy production on the same land and have gained increasing attention as a strategy to improve land-use efficiency while supporting both renewable energy and food production (Renno & Di Marino, 2026). This approach is particularly relevant in regions with high solar irradiance, where PV generation potential is high but agricultural land remains valuable.

Nile Delta region has great potential for Agrivoltaics applications owing to its high solar resource. PV shading, however, affects the amount and spread of radiation reaching the crops, which may decrease photosynthesis, crop growth and productivity if shading is too heavy (Laub et al., 2022a). Potato (*Solanum tuberosum*) is of particular interest because the development of potato tubers is highly dependent on the photosynthesis of the canopy, and previous research has demonstrated that lower irradiance can impact potato yield, water productivity and tuber production (Witwit et al., 2025)(Ademollo et al., 2026). As integrated assessments of PV performance, ground irradiance, and potato growth under Nile Delta conditions remain limited, simulation provides an efficient alternative to costly and complex field trials.

To address this gap, this study integrates the System Advisor Model (SAM) with AquaCrop to quantify the effects of PV shading on potato productivity in a simulated agrivoltaic system in Kafr El Sheikh, Egypt. SAM is used to estimate PV performance and ground-level irradiance, while AquaCrop is used to compare potato growth and tuber yield under PV-shaded and open-field conditions. The study therefore evaluates the trade-off between electricity generation and crop productivity and provides insight for agrivoltaic system design under the climatic conditions of the Nile Delta.

Literature Review

Agrivoltaic Systems and Land-Use Efficiency

Agrivoltaic systems are designed to combine solar photovoltaic (PV) energy generation and crop cultivation within the same land area. This approach is important because the expansion of large-scale PV systems can increase competition for land, especially in agricultural regions where land is already highly valuable(Asa'a et al., 2024). Instead of separating food production and energy production, agrivoltaics allows both activities to operate together, which can

improve the total productivity of the land when the system is properly designed (Widmer et al., 2024). This makes agrivoltaics a useful option for areas facing pressure from renewable energy development and food security needs.

Although agrivoltaics is often presented as a win-win solution, the actual benefit depends on the trade-off between crop yield and PV energy generation. Some designs may increase electricity output but reduce crop growth due to excessive shading, while other designs may protect crops from heat stress but produce less energy per land area (Pandey et al., 2025). Recent systematic review evidence also shows that agrivoltaic systems can improve water-use efficiency and reduce soil or air temperature but yield reduction may still occur for light-dependent crops under high shading intensity (Ali Abaker Omer et al., 2025). Because of this, each agrivoltaic system needs to be evaluated based on local climate, crop type, and PV layout. This is particularly relevant to the Nile Delta, where high solar irradiance provides strong PV potential, while crop light requirements must still be considered in agrivoltaic design.

Shading and Irradiance Distribution Under PV Panels

Shading in agrivoltaic systems is not uniform, because PV panels block part of the incoming solar radiation at different times of the day. The amount of irradiance reaching the crop area depends on the sun position, panel geometry, row spacing, tilt angle, and whether the light is direct or diffuse. For this reason, the crop area below and between PV rows usually receives a mixed pattern of shaded and unshaded zones rather than one constant level of light. This makes irradiance distribution an important factor to evaluate before connecting crop growth simulation with PV design (Zainali et al., 2023) (Pulido-Mancebo et al., 2022).

PV-induced light reduction is strongly influenced by panel density and ground coverage. Higher PV density increases shaded area and decreases photosynthetically active radiation (PAR), with field measurements showing substantial spatial variation across different PV configurations. This means that even within the same field, crop rows may receive different light conditions depending on their position relative to the panels (Prakash et al., 2023) (Santra et al., 2021).

For crop modelling, irradiance alone may not always be enough because plants respond mainly to the photosynthetically active part of solar radiation. Recent studies suggest that photosynthetic photon flux density or PAR-based analysis gives a more direct representation of light available for crop growth under PV panels. At the same time, PV configuration studies show that different panel arrangements can change both electricity production and the amount of useful light transmitted to the crop area (Yajima et al., 2023) (Ali Khan Niazi & Victoria, 2023). Therefore, evaluating the spatial distribution of irradiance beneath PV arrays is essential for estimating the light available to crops and for linking PV simulation with crop-growth modelling.

Crop Response to Reduced Irradiance

Crop response to reduced irradiance is not always linear, because some crops can tolerate mild shading before yield loss becomes serious. In agrivoltaic systems, lower solar radiation may reduce photosynthesis and biomass production, but the level of impact depends on crop type, shading intensity, and local climate condition. A meta-analysis by Laub et al. (Laub et al., 2022b) reported that many crops can tolerate small reductions in solar radiation, but yield

reduction becomes more obvious as shading increases. Another recent meta-analysis by Tekie et al. (Tekie et al., 2025) also showed that crop yield under shade is affected not only by shading level, but also by environmental stress such as drought and evapotranspiration.

Potato plants absorb light for photosynthesis within the 400–700 nm range, and their photosynthetic response increases with irradiance until it reaches a saturation level (Mølmann & Johansen, 2026). When light is reduced, potato plants may show shade-avoidance responses, such as changes in plant architecture and resource allocation, which can later influence tuber formation and yield. Gómez-Ocampo et al. (Gómez-Ocampo et al., 2023) found that simulated shade caused physiological and transcriptomic changes in potato, and the study also reported reduction in tuber yield after shade treatment.

Previous potato shading studies show that moderate shade may still be tolerated, but heavy shade can reduce tuber yield clearly. Schulz et al. (Schulz et al., 2019) found that potato could cope with reduced irradiance up to about 26%, but 50% shading caused strong reductions in tuber number, tuber mass, and dry matter yield. More recently, Colauzzi et al. (Colauzzi et al., 2026) reported from a four-year agrivoltaic potato case study that yield response depends strongly on shading intensity and timing, with some PV tracking conditions giving only limited yield penalties. This means that potato can be suitable for agrivoltaic systems, but the shading condition still needs to be controlled properly.

Simulation Tools for Agrivoltaic Assessment

Simulation tools are useful in agrivoltaic studies because the interaction between PV shading and crop growth is difficult to measure with one simple field observation. Modelling is useful for estimating the irradiance at the crop level, as it is a space-time varying light environment below PV panels. The potential for combining PV light distribution of crops and a crop growth model for better yield prediction is the integration of dynamic shading, canopy development and local microclimate (Moretta et al., 2025). Another reason why ground-irradiance modelling is important is that the pattern of irradiance is influenced by direct and diffuse radiation, the position of the sun and geometry of the system (Kurumundayil et al., 2025).

The PV layout is modeled in SAM, and the field-level irradiance is estimated, as well as the expected PV output from the module and inverter performance. It is appropriate for this study due to its PV model which enables the performance of the system to be evaluated based on weather data, array geometry, module parameters, and inverter data. In addition, SAM's flat-plate PV model has been validated against measured production data from several real PV systems, which supports its use as a practical simulation tool for estimating PV performance before field installation (Freeman et al., 2013)(Roberts et al., 2017).

AquaCrop is used for the crop part of the assessment because it links crop development, biomass, and yield with climate, soil water, and management inputs. This makes it suitable for estimating how potato yield may change when the available radiation is reduced under PV shading. Recent potato modelling work described AquaCrop as a water-driven, process-based model that simulates biomass and yield, and it has been used for potato planning and scenario analysis under different field and irrigation conditions(Rai et al., 2025). Other recent AquaCrop validation work also explains that the model uses daily climate data, crop parameters, soil information, and management files to estimate biomass and harvestable yield through canopy growth, transpiration, and harvest index processes (Zhou et al., 2024)

Although both SAM and AquaCrop have been widely applied in their respective fields, limited work has linked PV-derived ground irradiance directly with potato growth simulation under Nile Delta conditions. Integrating the two models therefore provides a practical framework for assessing the trade-off between PV energy generation and crop productivity.

Methodology

Study Area

The study focuses on a simulated agrivoltaic field located in Kafr El Sheikh Governorate, northern Nile Delta, Egypt. The region consists of flat agricultural land suitable for both PV installation and crop production. The simulation considers a 1-hectare plot with 50% PV coverage and potato (*Solanum tuberosum*) cultivated under partial shading.

Global Solar Atlas data indicate annual GHI, DNI, and DIF values of approximately 2023, 1942, and 763 kWh/m², respectively. The reported optimum PV tilt is about 26° confirming the strong solar potential of Kafr El Sheikh for agrivoltaic applications.



Figure 1: Satellite Location Map Of The Study Site In Kafr El Sheikh Governorate.
Source: ((Global Solar Atlas, 2026))

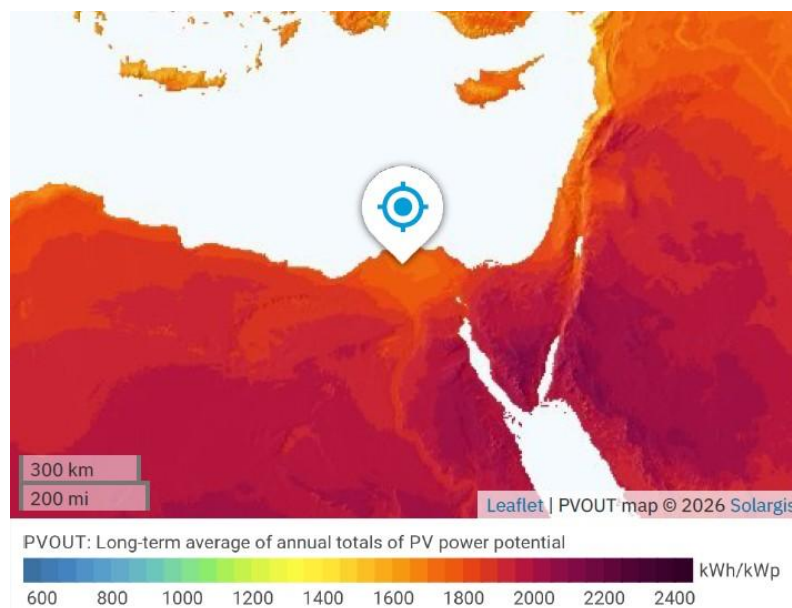


Figure 2: Annual PV Power Potential And Irradiance Data From Global Solar Atlas.

Source: ((Global Solar Atlas, 2026))

The semi-arid climate, with low rainfall and an average temperature of 21.3°C, supports both PV generation and potato cultivation. The region's loamy-sandy soil provides suitable drainage and moisture retention, while its high irradiance and flat terrain make it appropriate for agrivoltaic simulation.

Crop Selection

Potato (*Solanum tuberosum*) was selected to evaluate crop response to PV shading because its productivity is sensitive to light availability and shading distribution. Agrivoltaic studies have shown that shading can affect potato yield, water productivity, and nutrient responses (Witwit et al., 2025). while yield also depends on PV array configuration, shading pattern, and the timing of light reduction (Colauzzi et al., 2026).

The yield of potato tubers is closely related to the amount of photosynthesis in the canopy, which is the source of assimilates for biomass accumulation and tuber bulking. Thus, light conditions affect potato growth, gas exchange, yield and quality, and photosynthetic performance and water-use efficiency are closely related to potato productivity (Pannico et al., 2025) (Dahal et al., 2023)..

Potato is simulated in AquaCrop through crop canopy cover development, rooting depth, biomass development, harvest index and yield response to water availability. This is appropriate because AquaCrop has been recently calibrated and validated for potato yield and crop water productivity under different irrigation scenarios (Rai et al., 2025). In semi-arid conditions, AquaCrop has also been parameterized for potato growth modelling and showed reasonable performance for simulating soil water content, evapotranspiration, tuber dry yield, and water productivity (Ahmadi et al., 2022).

In this study, potato is therefore used as the representative crop to evaluate the agricultural side of the agrivoltaic system. The main crop outputs considered from AquaCrop are canopy development, biomass, tuber yield, water productivity, and percentage yield reduction compared with the open-field reference condition. These indicators are suitable because previous AquaCrop studies on potato have used canopy cover, biomass, yield, and water-use indicators to evaluate model performance under water-limited or climate-sensitive conditions (Wale et al., 2022)(Puma-Cahua et al., 2023).

PV System Design in SAM

The photovoltaic (PV) system for this study is modeled in the System Advisor Model (SAM) to simulate both the energy output and ground-level irradiance in the agrivoltaic field. The system consists of a single array with one subarray activated, as shown in the DC sizing configuration (see Figure 3). The subarray includes 2,001 modules, arranged with 23 modules per string and 87 strings in parallel producing a maximum DC voltage of 1,161.5 V.

DC Sizing and Configuration

To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a system with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.

Electrical Configuration	Subarray 1	Subarray 2	Subarray 3	Subarray 4
	(always enabled)	☐ Enable	☐ Enable	☐ Enable
Modules per string in subarray	23			
Strings in parallel in subarray	87			
Number of modules in subarray	2,001			
String Voc at reference conditions (V)	1,161.5			
String Vmp at reference conditions (V)	979.8			

Figure 3: Screenshot Of The DC Sizing And Configuration In SAM Showing Module Number, Strings, And Voltage Settings.

Source: SAM Simulation

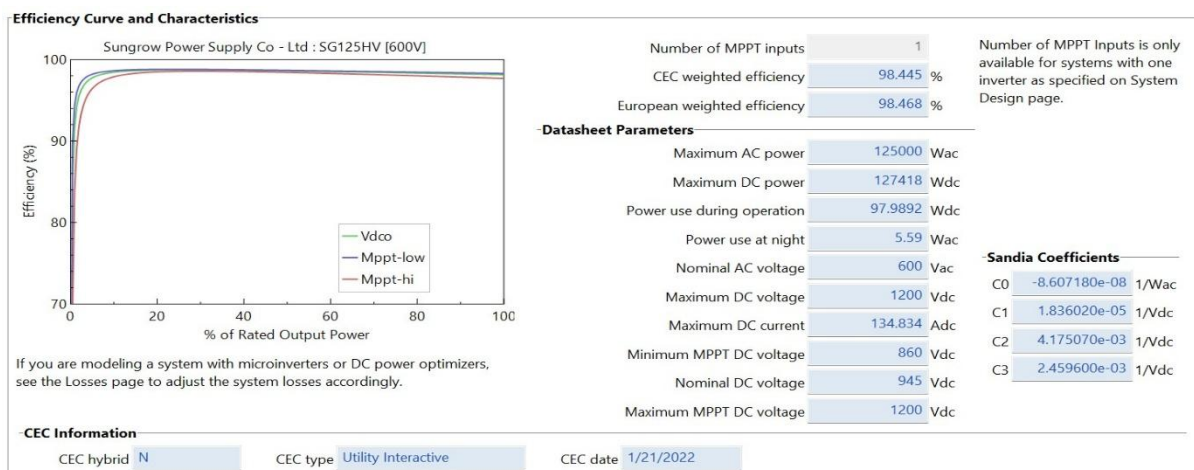


Figure 4: Screenshot Showing Inverter Efficiency And Datasheet Parameters In SAM.

Source: SAM Simulation

The selected Sungrow SG125HV [600V] inverter has a nominal AC power of 125 kW, a maximum DC voltage of 1,200 V, and a CEC-weighted efficiency of 98.445% (Figure 4), providing high conversion efficiency for the simulated PV system.

The LONGi LR5-72HPH-570M monocrystalline module has a nominal efficiency of 22.91%, a maximum power of 570.414 W, and a ground clearance of 1.7 m. The array is configured at a fixed 26° tilt and 180° azimuth with a ground coverage ratio of 0.5, corresponding to 50% PV coverage (Figure 5).

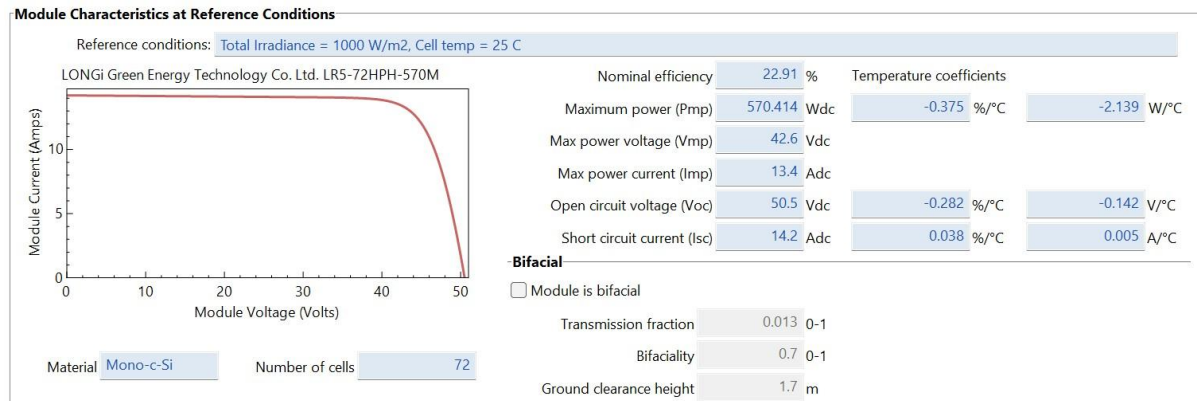


Figure 5: Screenshot Showing Module Characteristics And Fixed Tilt Configuration In SAM.

Source: SAM Simulation

Weather data for Kafr El Sheikh were obtained from the SAM Solar Resource Library at 31.13°N, 30.94°E and 6 m elevation (Figure 6), providing location-specific irradiance, temperature, and solar-angle inputs for the PV shading simulation.

Solar Resource Library							
The Solar Resource library is a list of weather files on your computer. Choose a file from the library and verify the weather data information below.							
The default library comes with only a few weather files to help you get started. Use the download tools below to build a library of locations you frequently model. Once you build your library, it is available for all of your work in SAM.							
Filter:		Name					
Name	Latitude	Longitude	Time zone	Elevation	Station ID	Source	
phoenix_az_33.450495_-111.983688_psmv3_60_tmy...	33.45	-111.98	-7	358	78208	NSRDB	
tucson_az_32.116521_-110.933042_psmv3_60_tmy	32.13	-110.94	-7	773	67345	NSRDB	
32.90°_e_24.09°_n_38.8904_-77.032_nsrdb-GOES-a...	38.89	-77.02	-5	22	1145370	NSRDB	
aswan_24.0901_32.8986_nsrdb-msg-v1-0-0-tmy_60...	24.09	32.9	2	112	1804403	NSRDB	
kafr el sheikh_31.13_30.94_tdy-2022	31.13	30.94	0	6	1704987	NSRDB	

Figure 6: Screenshot of the weather file selection in SAM for Kafr El Sheikh.

Source: SAM Simulation

This PV configuration provides realistic irradiance data for the crop simulation stage in AquaCrop, allowing the study to quantify the impact of partial shading on potato yield while simultaneously estimating PV energy generation.

Ground Irradiance Analysis

Ground-level irradiance between PV rows was obtained from SAM using hourly spatial data that account for panel layout, tilt, and shading. These values were averaged across ground positions to estimate canopy-level irradiance for the crop simulation (Figure 7).

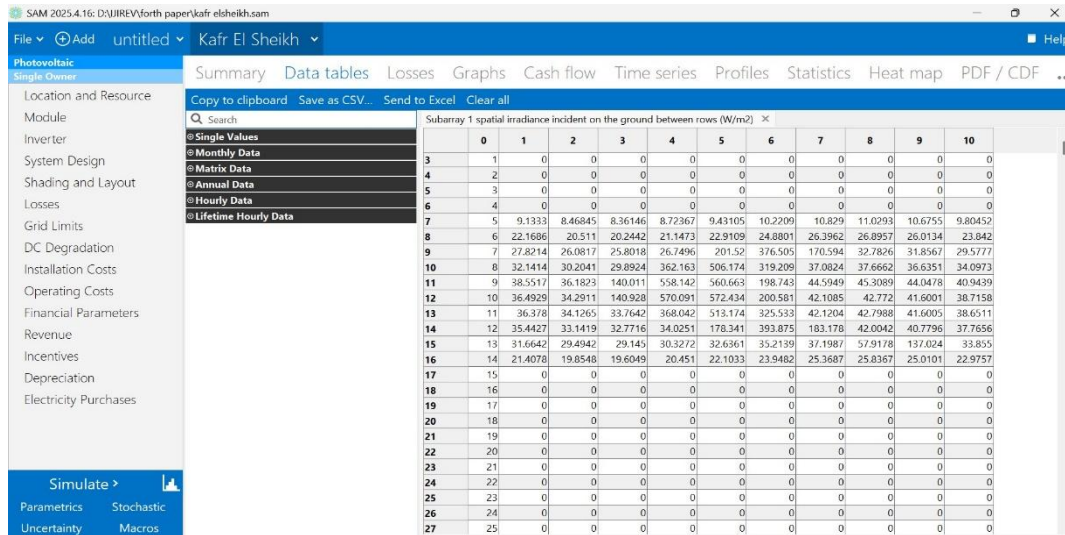


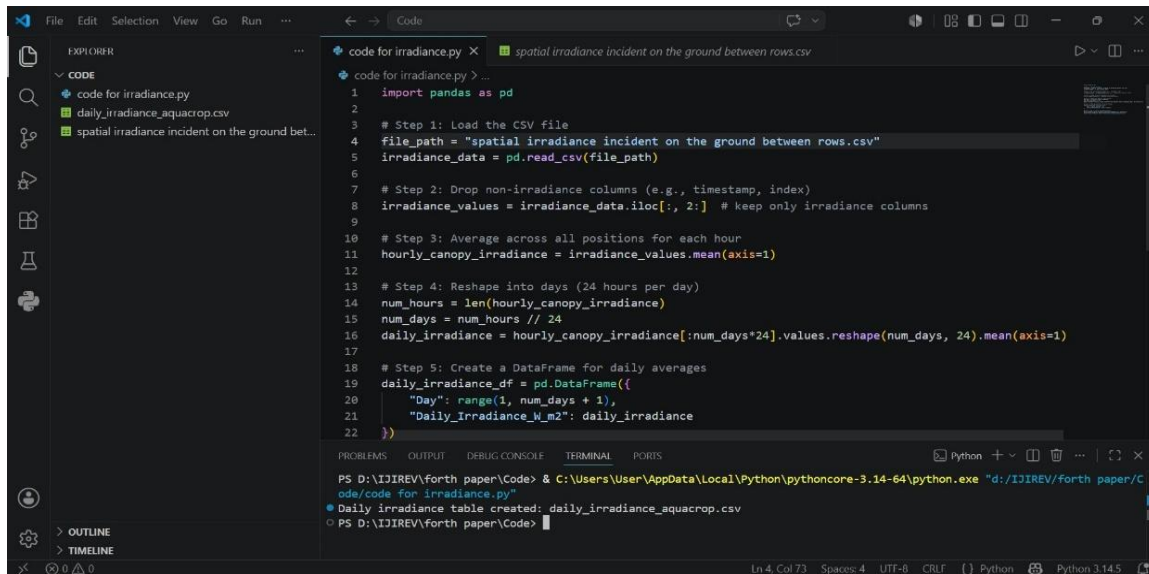
Figure 7: Spatial Irradiance Values On The Ground Between Rows (W/m²).

Source: SAM Simulation

The hourly irradiance for each position between PV rows is first averaged to represent the typical light exposure for that hour. These hourly values are then grouped into daily values, and the daily average irradiance I_{daily} is calculated using the formula:

$$I_{daily} = \frac{1}{24} \sum_{h=1}^{24} I_{hourly,h}$$

where $I_{hourly,h}$ The hourly irradiance data were averaged to obtain daily values used as the PAR input for AquaCrop. Python was used to automate the processing of the full-year SAM dataset by averaging irradiance across ground positions, grouping the hourly values into daily sequences, and exporting the resulting daily dataset as a CSV file for AquaCrop (Figure 8).



```

1  import pandas as pd
2
3  # Step 1: Load the CSV file
4  file_path = "spatial irradiance incident on the ground between rows.csv"
5  irradiance_data = pd.read_csv(file_path)
6
7  # Step 2: Drop non-irradiance columns (e.g., timestamp, index)
8  irradiance_values = irradiance_data.iloc[:, 2:] # keep only irradiance columns
9
10 # Step 3: Average across all positions for each hour
11 hourly_canopy_irradiance = irradiance_values.mean(axis=1)
12
13 # Step 4: Reshape into days (24 hours per day)
14 num_hours = len(hourly_canopy_irradiance)
15 num_days = num_hours // 24
16 daily_irradiance = hourly_canopy_irradiance[:num_days*24].values.reshape(num_days, 24).mean(axis=1)
17
18 # Step 5: Create a DataFrame for daily averages
19 daily_irradiance_df = pd.DataFrame({
20     "Day": range(1, num_days + 1),
21     "Daily_Irradiance_W_m2": daily_irradiance
22 })

```

PS D:\IJIREV\forth paper\Code> & C:\Users\User\AppData\Local\Python\pythoncore-3.14-64\python.exe "d:/IJIREV/forth paper/C
ode/code for irradiance.py"
Daily irradiance table created: daily_irradiance_aquacrop.csv
PS D:\IJIREV\forth paper\Code>

Figure 8: Python script used to calculate daily average irradiance from SAM outputs.

Source: Python coding

Pseudo-code for processing hourly irradiance to daily AquaCrop input:

- # Step 1: Load hourly spatial irradiance CSV exported from SAM
- # Step 2: Remove non-irradiance columns (timestamps, indices)
- # Step 3: Average irradiance values across all ground positions for each hour
- # Step 4: Group hourly canopy-level values into 24-hour sequences for each day
- # Step 5: Calculate daily average irradiance by summing 24 hourly values and dividing by 24
- # Step 6: Export the daily average irradiance table as CSV for AquaCrop input

This approach ensures that the irradiance values used in AquaCrop reflect both shading effects and local daily light variability, providing realistic inputs for simulating crop performance under the agrivoltaic system.

Potato Growth Simulation under Open-Field Conditions

The open-field AquaCrop simulation incorporated local climate, soil, crop, and irrigation conditions to establish an unshaded baseline for comparison with the PV-shaded scenario. Daily temperature, precipitation, evapotranspiration, and relative humidity data were obtained from NASA POWER for Kafr El-Sheikh. The potato growing season was set from 1 August to 29 November (121 days), with temperature and growing degree-day thresholds used to define heat and cold stress limits in AquaCrop

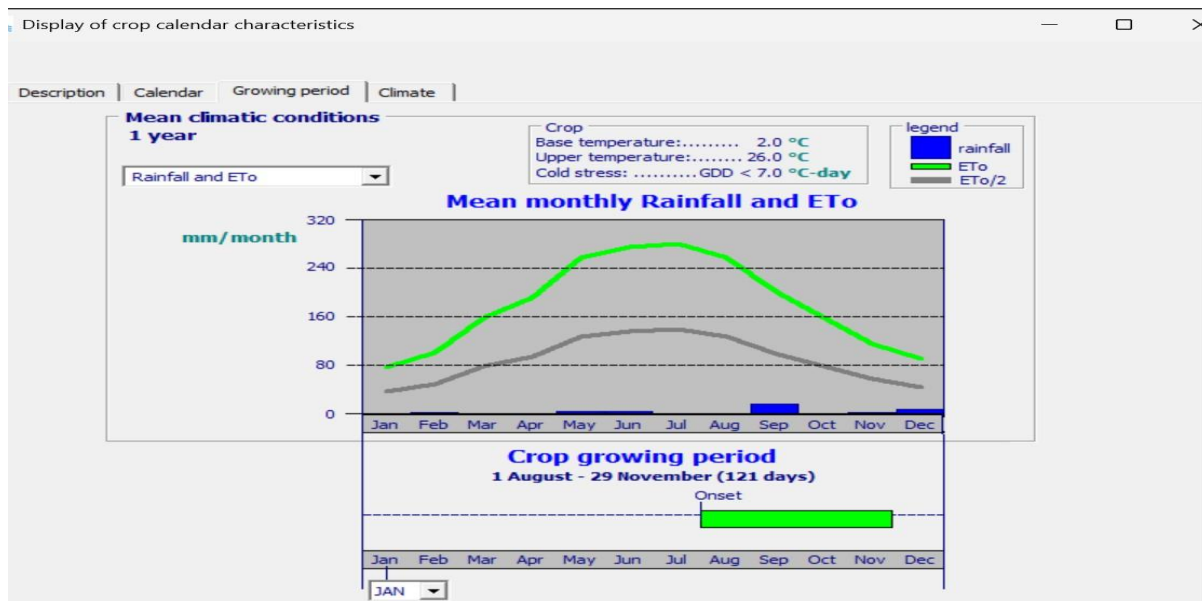


Figure 9: Crop Calendar And Mean Monthly Climatic Conditions Used For Simulation.

Source: Aquacrop simulation

The soil profile was defined using measured field properties, with initial soil water content specified at 0.3 m and 0.9 m depths. Salinity was assumed negligible, with zero electrical conductivity applied throughout the soil profile.

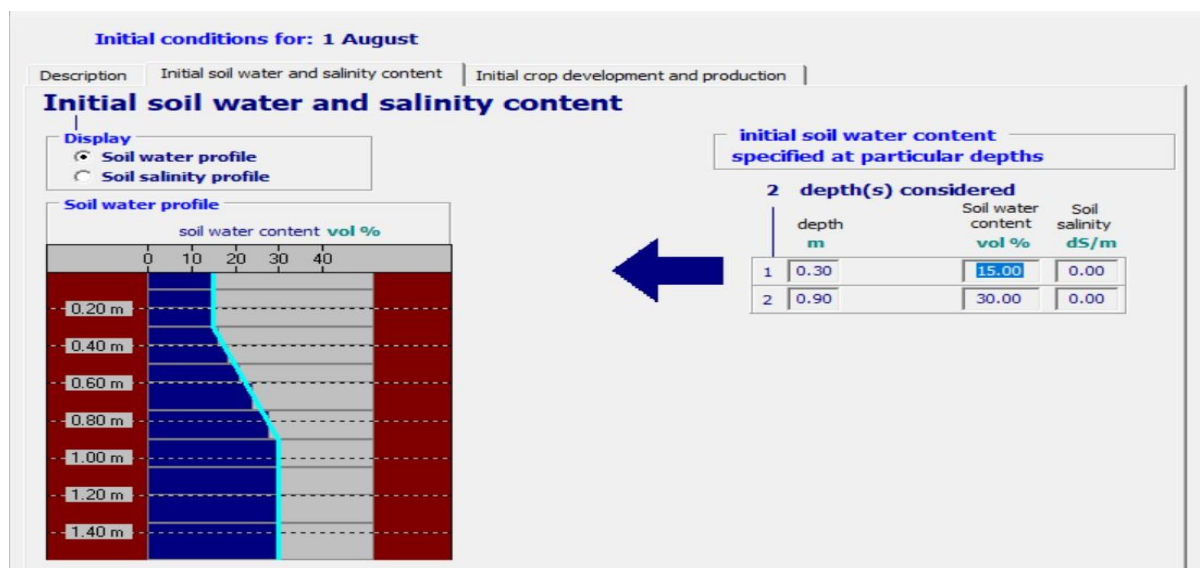


Figure 10: Soil Water And Salinity used For Simulation.

Source: Aquacrop simulation

Soil hydraulic properties, including total available water, field capacity, permanent wilting point, and hydraulic conductivity, were defined based on the measured characteristics of the site's silty clay loam soil.

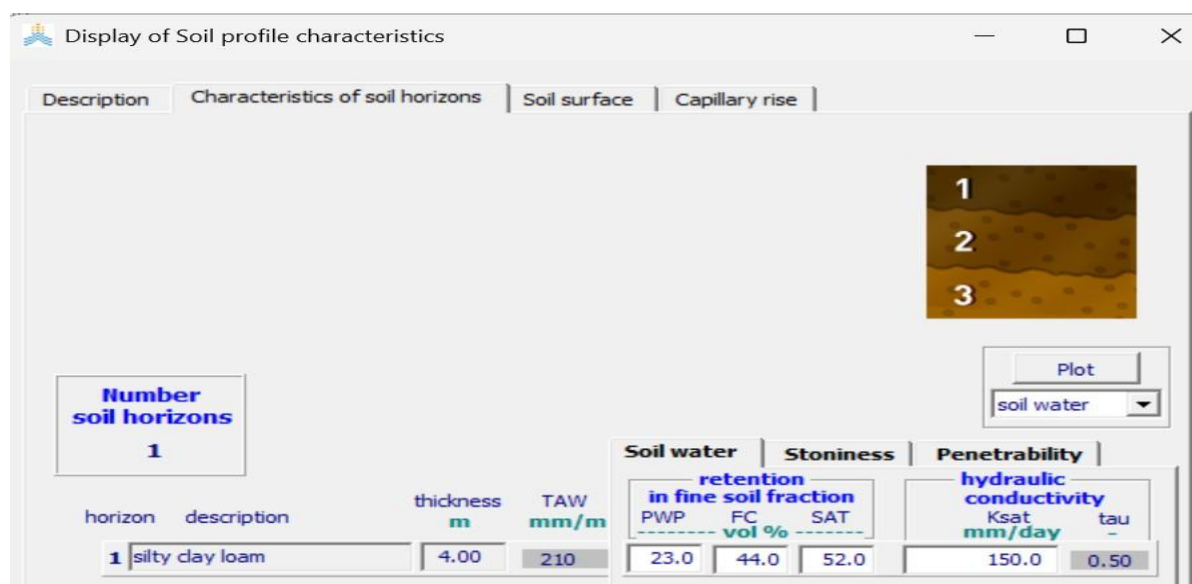


Figure 11: Soil Properties used For Simulation.

Source: Aquacrop simulation

Irrigation was managed through a weekly irrigation schedule, where water was applied to maintain the root zone near field capacity. The depletion threshold was set at 40% of total available water, and the irrigation depth returned soil moisture to field capacity.

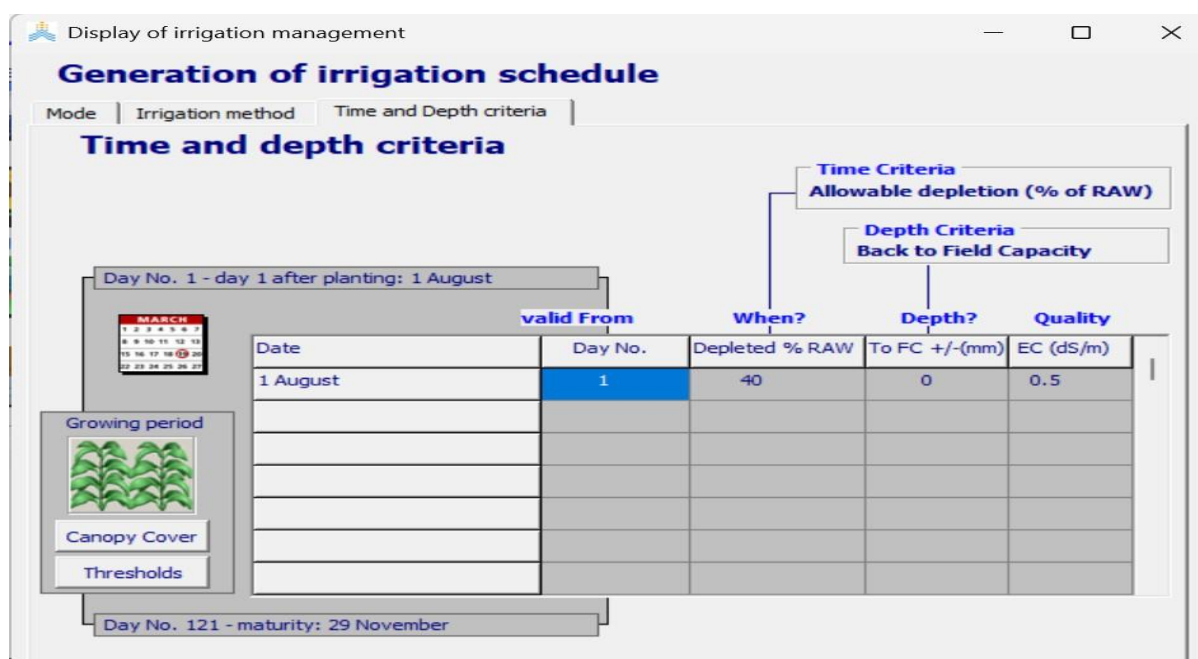


Figure 12: Irrigation Schedule Used For Simulation.

Source: Aquacrop simulation

Crop-specific growth coefficients, canopy development, root expansion, evaporation, water-depletion, and senescence parameters were configured to represent potato growth under optimal conditions. Soil-water processes, including capillary rise and curve-number adjustment, were also enabled.

Environment, Crop and Simulation files | Program settings

Program settings - Crop	
4	Evaporation decline factor for Stage II
1.10	Ke(x) : Soil evaporation coefficient for fully wet and non-shaded soil surface
5 %	Threshold for green CC below which HI no longer increase
70 % of Zn	Starting depth of root zone expansion curve
5.00 cm/day	Maximum allowable root zone expansion (fixed at 5 cm/day)
-6	Shape factor for effect of water stress on root zone expansion
20 % TAW	Required soil water content in top soil for germination
1.0	Adjustment factor for the FAO-adjustment by ETo of the soil water depletion thresholds (p)
3 days	Number of days at which the deficient aeration conditions in the root zone are fully effective
1.00	Exponent of senescence factor adjusting the drop in photosynthetic activity of a crop losing its green canopy
12 %	Decrease of p(senescence) once early canopy senescence is triggered
10 cm	Thickness top soil in which soil water depletion has to be determined
Program settings - Field Management	
30 cm	Depth of soil profile from which water can be extracted by soil evaporation
Program settings - Soil	
0.30 m	Considered depth of soil profile for calculation of mean soil water content for CN adjustment
yes	Adjustment CN to Antecedent Moisture Class
20 %	Salt diffusion factor (capacity for salt diffusion in micro pores)
100 g/liter	Salt solubility
16	Shape factor for effect of soil water content gradient on capillary rise
Program settings - Climate (Air temperature)	
12.0 °C	Default minimum temperature if no temperature file is specified
28.0 °C	Default maximum temperature if no temperature file is specified
3	Method number for the calculation of growing degree days
Program settings - Climate (10-day/monthly Rainfall)	
USDA	Method for estimating effective rainfall
70 %	Effective rainfall (when Method is fixed percentage)
2	Number of showers in 10-day period
5	n-th root (for estimating reduction in soil evaporation)

Figure 13: Specific Simulation Parameters Used For Simulation.

Source: Aquacrop simulation

Potato Growth Simulation under PV-Shaded Conditions

The PV-shaded AquaCrop simulation used the same crop, soil, irrigation, and management settings as the open-field baseline, with only the irradiance input changed. Open-field irradiance was replaced with daily ground-level irradiance derived from SAM and processed in Python. The shaded and baseline simulations were then compared in terms of canopy development, biomass, tuber yield, water productivity, and yield reduction.

Results

PV Simulation Results

In the first simulation year, the PV system generated 2,184,179 kWh of net DC electricity and delivered 2,103,175 kWh of net AC electricity, with a 21.0% capacity factor and a performance ratio of 0.79. Energy production was higher from March to October, peaking in summer, and lower during the winter months.

Detailed Photovoltaic
Single Owner

1.1 DC MW Nameplate
\$0.78/W Installed Cost

31.13, 30.94
UTC +0

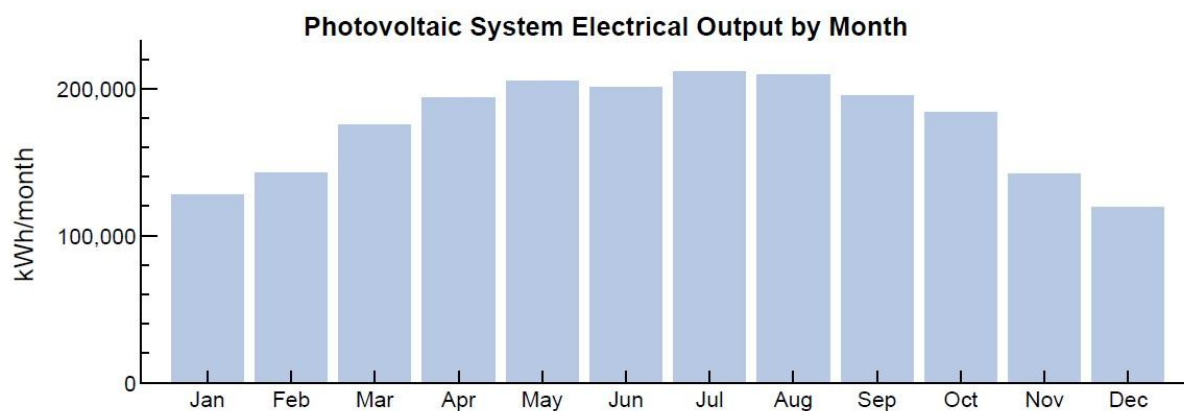


Figure 14: Monthly System Electrical Output By Month.

Source: SAM simulation

PV output losses were mainly associated with soiling, module mismatch, wiring, and inverter inefficiencies. System-level shading loss was 1.769%, compared with a 5% soiling loss. Despite the relatively small electrical shading loss, PV modules still reduced ground-level irradiance, providing the shaded input used in the AquaCrop simulation.

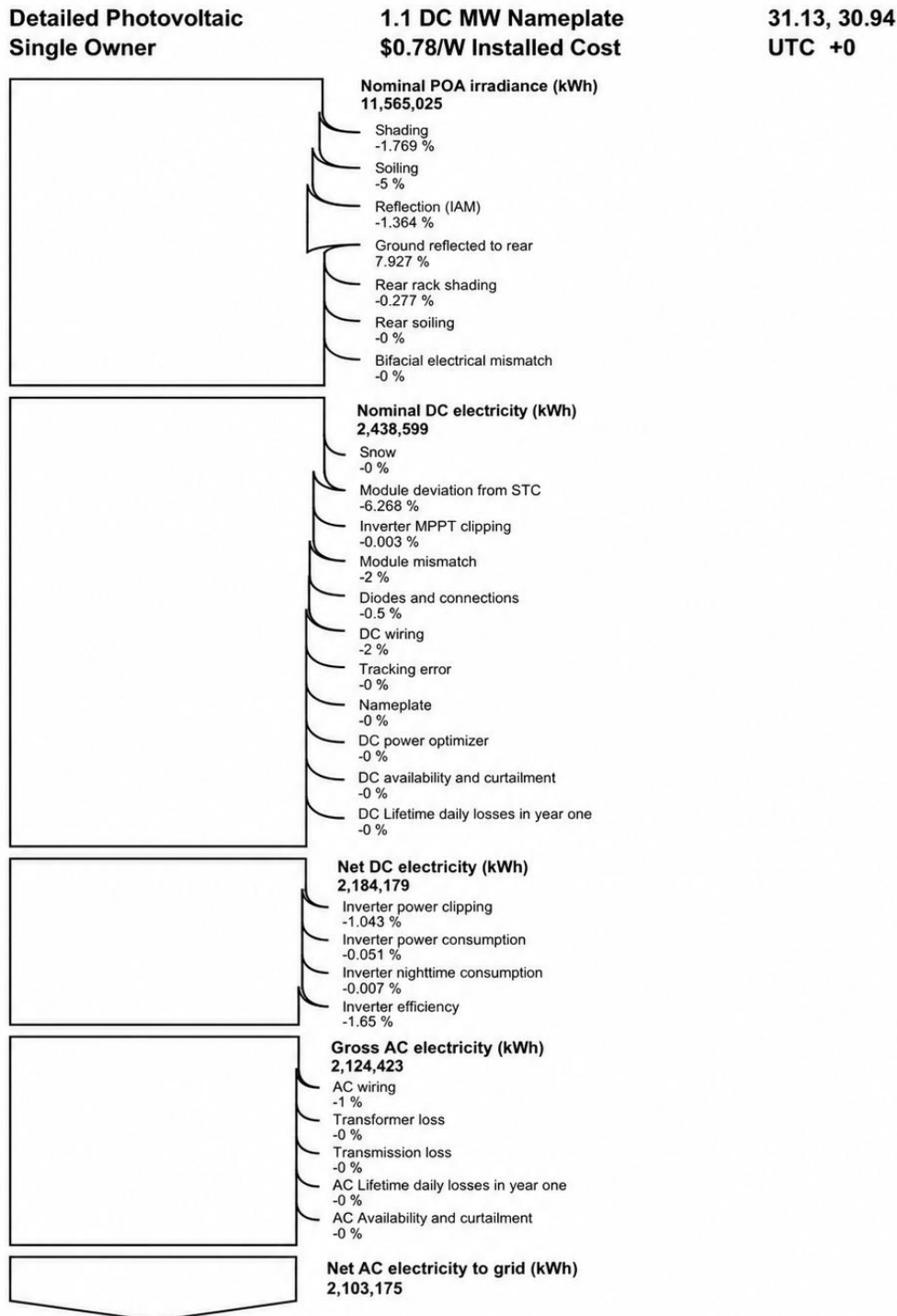


Figure 15: Loss Diagram Of The Simulation.

Source: SAM simulation

Crop Open Field Simulation Results

The open-field AquaCrop simulation ended on 29 November 2025, producing a final dry biomass of 16.149 t/ha and a dry tuber yield of 12.188 t/ha. These values were used as the baseline for comparison with the PV-shaded scenario.

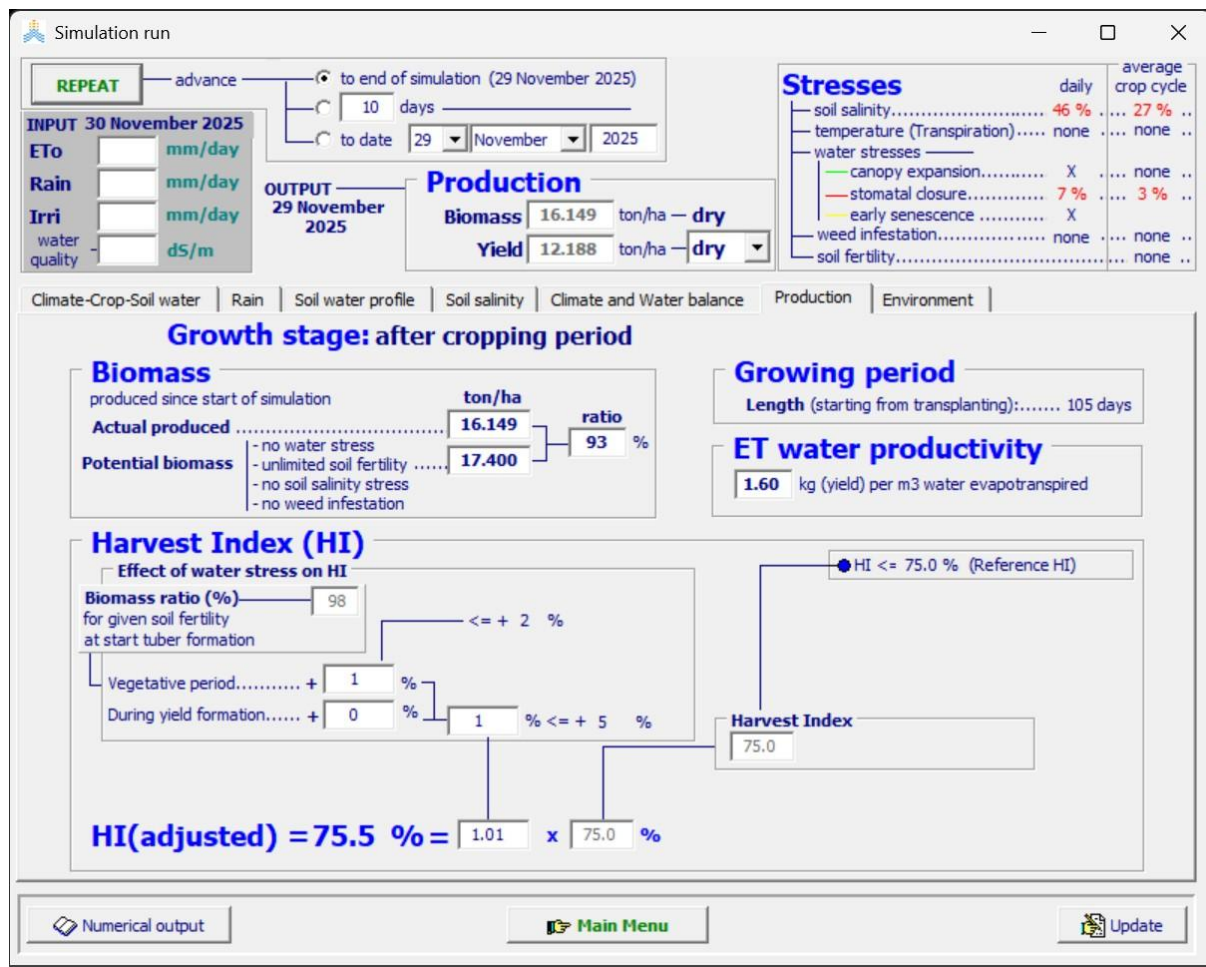


Figure 16: Results Of The Open Field Simulation.

Source: AquaCrop simulation

The harvest index was also stable under the open-field condition. The reference harvest index was 75.0%, while the adjusted harvest index reached 75.5%, showing only a small positive adjustment during the crop cycle. The stress summary showed no temperature stress, weed infestation, or soil fertility stress. Overall, this open-field result provides the baseline yield and biomass condition before applying the reduced irradiance input for the PV-shaded simulation.

Crop Reduced Irradiance Simulation Results

The reduced irradiance AquaCrop simulation was also completed at the end of the cropping period on 29 November 2025. In this scenario, the crop setup remained the same as the open-field simulation, but the irradiance input in the weather file was reduced to represent the light condition under PV shading. The simulation estimated a final dry biomass of 13.727 ton/ha and a final dry tuber yield of 10.360 ton/ha. Compared with the open-field result, both biomass and yield were reduced by about 15%, showing the direct effect of lower irradiance on potato production.

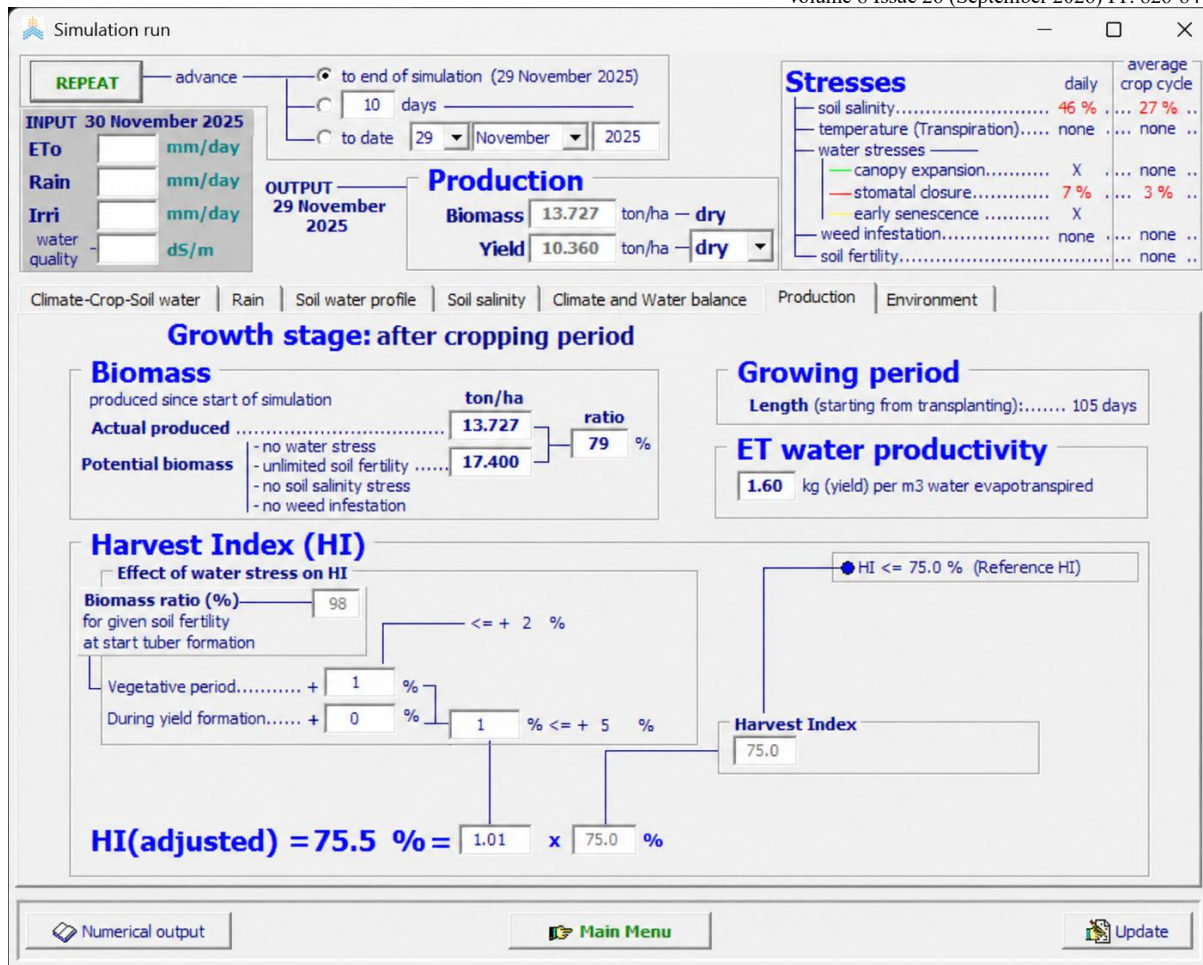


Figure 17: Aquacrop Reduced Irradiance Simulation Output

Source: Aquacrop simulation

The growing period remained 121 days, which means the crop cycle length did not change after applying the reduced irradiance input. The ET water productivity was also shown as 1.60 kg of yield per m³ of water evapotranspired. The harvest index remained nearly unchanged at 75.0% (reference) and 75.5% (adjusted), indicating that reduced irradiance primarily affected biomass accumulation and tuber yield rather than harvest index or other crop growth conditions.

Conclusion

The present study examined the effect of interaction between PVs energy production and potato (*Solanum tuberosum*) productivity in the simulated agrivoltaic system under climatic conditions of Kafr El Sheikh, Nile delta, Egypt. The study combined the System Advisor Model (SAM) with AquaCrop, to create a modelling framework that first predicted PV performance and then used the predicted irradiance conditions in the field to estimate crop responses to PV shading in AquaCrop. The study's integrated approach is an important contribution since the energy and agricultural parts of an agrivoltaic system are directly coupled in the same simulation framework.

The PV system results have high potential for energy generation with an average annual energy generation of 2.1 GWh and capacity factor of 21%. The crop simulation, on the other hand, exhibited a clear response to the decrease in available irradiance. Under PV-shaded conditions,

yield of dry tubers was reduced by around 15% and there was a similar reduction in biomass accumulation. The harvest index, however, did not change significantly, suggesting that the main impact of the PV shading in the simulation was to reduce biomass production, rather than to significantly alter biomass allocation to tubers.

The results show quantitatively the trade-off between the generation of renewable energy and potato productivity in the simulated Nile Delta conditions. It displayed the potential for PV crop production under PV arrays and also highlight the need to manage shading carefully. Thus, agrivoltaic design should not be concerned solely with generating the highest amount of electricity but also include consideration of the solar radiation available to the crop, and its distribution.

By linking SAM with AquaCrop, this study provides a practical way to evaluate PV performance and potato productivity together under Nile Delta conditions. The modelling framework can be useful for early-stage agrivoltaic planning, as different PV configurations can be assessed before field implementation. Future applications of the framework could examine panel spacing, height, tilt angle, ground coverage, and crop-row arrangement to identify configurations that maintain satisfactory energy production while minimizing crop yield losses.

Because the present findings are based on simulation, they should be interpreted as model-based estimates rather than direct field observations. Future work should validate the results using field measurements of ground-level irradiance, crop growth, biomass, and tuber yield under actual agrivoltaic conditions. Further simulations should also examine alternative PV layouts and shading intensities to determine configurations that provide a more favorable balance between electricity generation and agricultural productivity. Such work would strengthen the practical application of agrivoltaic systems in the Nile Delta and other regions with similar climatic conditions.

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