



Study on Agrivoltaic System for Interaction Among Crop Production and Solar Photovoltaic Power Generation

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Abstract: The concept of Agrivoltaics, combining agriculture and solar photovoltaic system, is ideal for populous countries like India as it provides access to eco-friendly power and crop production from the same land. The main objective of this study was to evaluate the performance of solar photovoltaic strings and their suitability for agricultural practices for the green gram crop under North-Gujarat agro-climatic conditions. Eight equal-capacity strings with different geometry were designed to evaluate power generation and crop production beneath the strings. The experiment involved eight strings taken as eight treatments and the traditional system of green gram growing was considered as the ninth treatment. Results revealed that treatment-1 (3.2 m) height string with continuous solar panel pattern) provided the highest gross income from power generation and green gram yield (Rs. 24364.00). In terms of net realization, treatment-4 (1.82 m) string with continuous solar panel pattern) provided the highest net return of Rs. 12417.00, as the capital cost was less for the system. Treatment-5, which involved transparent panels, was found to be better for the photosynthesis process of the green gram crop, as it provided the highest yield under the agrivoltaic system.

Key words: Agrivoltaic system, solar power, photovoltaic (PV), agriculture, green gram crop, solar string, power generation.

Despite large-scale development, solar photovoltaic technology is facing the complex challenge of land use conflict which is crucial for populous countries like India to achieve the promising potential of solar photovoltaic (PV) power plants to reduce reliance on fossil fuels (Adesh *et al.*, 2019). Solar Power Plants are land-intensive and require approximately 1.5 to 2 ha of land to build a 1 MW power generation capacity. If India decides to grow at 9% GDP for the next 20 years, electrical power generation capacity must be increased from 212 GW to 1207 GW by 2031 (Harinarayana and Vasavi, 2014). It demands about 24 mha of free land for placing solar panels. It is anticipated that the solar-based advancement would be made more efficient by positioning PV in a way that is practical for a variety of applications; suggesting that improvements to

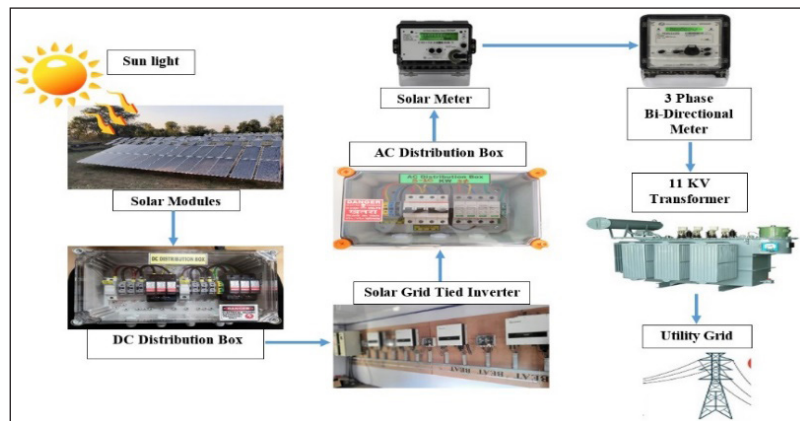


Fig. 1. Flow diagram of solar power plant.

customary practices will be crucial (Denholm and Margolis, 2008).

Agrivoltaic, the co-existence of land for farming and PV, is a creative and progressively emerging way to deal with solar development (Santra *et al.*, 2017; Macknick, 2019). This intentional double use of land is expected to lighten land use contests and support incomes for landowners among different advantages (Mavani *et al.*, 2019). Research on agrivoltaic can be described as simultaneous production of crops and generating electricity from photovoltaic on a same plot of land. Solar photovoltaics can now be transformed from solar sharing to selectively utilizing different wavelengths of light using semi-transparent tinted solar panels. By integrating agrivoltaic into agriculture, farmers can enhance their income, mitigate climate risks, and increase photovoltaic capacity worldwide without compromising agriculture production (Thompson *et al.*, 2020). Agrivoltaic has been accounted for to carry a few favorable advantages to agricultural activity under suitable conditions. The security given by the sun-based overhang

has been noted to create excellent microclimatic conditions (Pandey *et al.*, 2013).

Arrangements of solar panels at appropriate height can ensure easy movement of tractors and farm machinery. Different orientations of solar panels may allow enough solar radiation to satisfy the photosynthesis requirements of the crop grown beneath the solar system. Partial shading due to solar energy may benefit crops in those areas already receiving surplus solar radiation. The agrivoltaic may benefit agriculture by improving water use efficiency and increasing productivity by minimizing evaporation loss due to the partial-greenhouse effect. Overall, agrivoltaic frameworks have been exhibited as a monetarily beneficial utilization of farming areas, fit for defeating the predominant detachment of food and energy creation and possibly increment land efficiency by 35 to 73% (Dupraz *et al.*, 2011).

The main objective of this study is to evaluate the performance of agrivoltaic systems with different geometry of solar photovoltaic strings and their suitability for agricultural practices and crop parameters. The study aimed

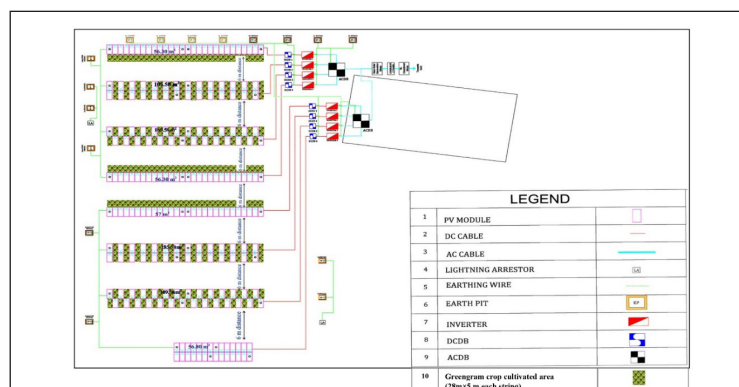


Fig. 2. Schematic diagram of agrivoltaic solar power plant.

Table 1. Design criteria for the solar strings used in the agrivoltaic system

String no.	Treatments	String design	Type of solar module	String height above ground	Capacity
1.	T1	Single frame continuous string	330 Wp Si-Polycrystalline (Opaque)	The lower end of the module at 3.2 m	9.24 kWp
2.	T2	Double frame equal space string (Equal space between solar modules)	330 Wp Si-Polycrystalline (Opaque)	The lower end of the module at 3.2 m	9.24 kWp
3.	T3	Double frame equal space string (Chessboard pattern)	330 Wp Si-Polycrystalline (Opaque)	The lower end of the module at 3.2 m	9.24 kWp
4.	T4	Single frame continuous string	330 Wp Si-Polycrystalline (Opaque)	The lower end of the module at 1.82 m	9.24 kWp
5.	T5	Single frame continuous string	330 Wp Si-Polycrystalline (Transparent)	The lower end of the module at 1.82 m	9.24 kWp
6.	T6	Double frame equal space string (Equal space between solar modules)	330 Wp Si-Polycrystalline (Opaque)	The lower end of the module at 1.82 m	9.24 kWp
7.	T7	Double frame equal space string (Chessboard pattern)	330 Wp Si-Polycrystalline (Opaque)	The lower end of the module at 1.82 m	9.24 kWp
8.	T8	Double-frame Conventional solar power plant	330 Wp Si-Polycrystalline (Opaque)	The lower end of the module at 0.91 m	9.24 kWp
	T9	The traditional method of cultivating green gram in open fields (control).			

to identify compatible solar string patterns for the green gram crop under north-Gujarat agro-climatic conditions of India. The latitude and longitude of the location are 22.309425° north and 72.136230° east, respectively. Being located on the tropic of cancer, the state is endowed with abundant clear solar radiation for more than 300 days a year.

The agrivoltaic system was established in the one-acre agricultural plot near the College of Renewable Energy and Environmental Engineering (CREEE), Sardarkrushinagar Dantiwada Agricultural University (SDAU), Sardarkrushinagar campus.

Materials and Methods

Agrivoltaic solar PV-GRID system

The site was chosen for a 73.92 kW solar power plant divided into eight strings of 9.24

kW capacity, with 28 solar modules in each string. Figures 1 and 2 depict the flow and schematic diagram of the agrivoltaic solar power plant.

Each of the eight strings has a unique design to evaluate their synergy with green gram crops grown underneath. There are eight inverters allocated to assess the power generation potential of each string.

Design of agrivoltaic solar power plant

Table 1 provides design criteria for each string of the agrivoltaic system. Test plots of 28 × 05 m were created for cultivating green gram, with eight plots beneath the eight solar strings and one open field plot as a control. The distance between rows of green gram crops was 45 cm.

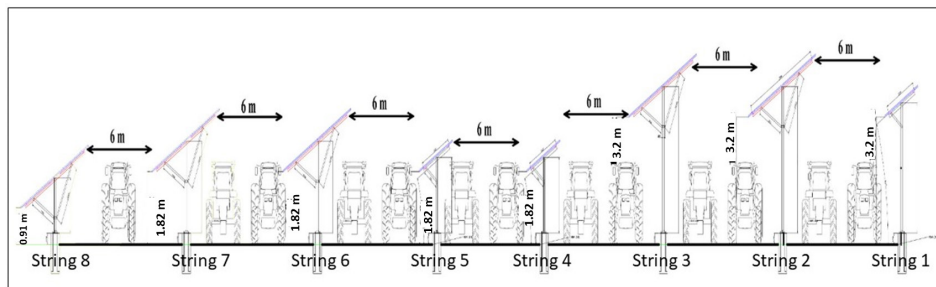


Fig. 3. Schematic diagram of agrivoltaic farm.

Figure 3 shows the flow schematic diagram of the agrivoltaic farm, depicting a tractor in operation.

Selection criteria of the crop for the study

India produces 25% of the world's pulses, with green gram (*Vigna radiata*) accounting for 11% of the total pulse production on 3.7 mha and yielding 1.72 mt (Milosavljevic *et al.*, 2015). Green gram is a high-protein, high-fibre legume crop. Flower drops and delayed grain filling are common issues if the crop is exposed to intense radiation and high temperature during the reproductive stage (Pandey *et al.*, 2013). The green gram is a low-height crop, which is suitable to cultivate under solar PV panels. Summer green gramme is planted at the beginning of February with the seed rate of 17.5 to 20 kg ha⁻¹ with 45 cm spacing between rows. Before planting, the soil is levelled to a medium tilth. Tractor-drawn seed cum fertilizer drill is primarily used for sowing and fertigation of the green gram seed.

Analyzing the Performance of a Solar Power Plant (PV System)

Data from the SCADA system were utilized to evaluate grid-connected solar power plants' performance.

String yield

This is analogous to when the PV power plant must operate with the nominal solar generator power P_O in order to generate string DC energy E_S . It measures in kWh kWp⁻¹.

$$Y_S = \frac{E_S}{P_O} \quad (\text{Adeh et al., 2019}) \quad \dots (1)$$

where,

String energy output per day $E_S = I_{dc} \times V_{dc} \times t$ (kWh); I_{dc} = DC (A); V_{dc} = DC voltage (V); t = Time (h); P_O = Nominal Power at STC; Reference Yield (Y_R)

To get the reference yield, the entire in-plane irradiation H_t is divided by the PV's reference irradiance G_i . Its units are h/d.

$$Y_R = \frac{H_t}{G_i} \quad (\text{Adeh et al., 2019}) \quad \dots (2)$$

where,

H_t = Total Horizontal irradiance on array; plane ($W m^{-2}$); G_i = Global irradiance at STC ($W m^{-2}$)

Final Yield

Under standard test conditions (STC) of 1000 $W m^{-2}$ solar irradiation and 25°C cell temperature, the ultimate yield is computed by dividing the system's yearly, monthly, or daily net AC energy output by the installed PV array's peak power.

$$Y_F = \frac{E_{PV}}{P_{max} G_i} \quad (\text{Adeh et al., 2019}) \quad \dots (3)$$

where,

E_{PV} = Total AC energy output from the inverter generated by the PV power system; P_{max} = Maximum power at standard test condition; G_i = Global irradiance at STC ($W m^{-2}$)

Performance Ratio

Divide the final yield by the reference yield to get the performance ratio. The performance ratio compares the plant output to the plant's output, given the irradiation, panel temperature, grid presence, aperture region size, nominal output power, and temperature correction variables.

$$PR = \frac{Y_F}{Y_R} \quad (\text{Adeh et al., 2019}) \quad \dots (4)$$

where,

Y_F = Final Yield; Y_R = Reference Yield

Capacity Utilization Factor

It is defined as the plant's actual output divided by its theoretical maximum production.

$$CUF = \frac{\text{Energy measured (kW h)}}{365 \times 24 \times \text{Installed capacity of the plant}} \quad \dots (5)$$

Inverter Efficiency

The ratio of DC power generated by PV array system to AC power generated by inverter is inverter efficiency, also known as conversion efficiency. Immediate inverter efficiency is calculated using the following equation:

$$\eta = \frac{P_{AC}}{P_{DC}} \quad (\text{Adeh et al., 2019}) \quad \dots (6)$$

System Efficiency

The instantaneous daily system efficiency is calculated by multiplying the PV module efficiency by the inverter efficiency.

$$\eta_{\text{Sys}} = \frac{\eta_{\text{PV}}}{\eta_{\text{inv}}} \quad \dots (7)$$

Power output or energy fed to a utility grid

The power generated by the PV system is the measured power across the inverter output terminals every minute. It is defined as the total monthly alternating current power generated and the daily monitored alternating current power output.

Measuring the effectiveness of farming operations

(i) Effective field capacity

A 45 HP tractor was used to monitor the tractive parameters in the study. Effective field capacity measures actual productivity in terms of area covered per hour. The time taken for actual work and time lost for other activities such as turning and adjustment was considered in calculating effective field capacity. It was calculated as follows:

$$\text{EFC} = \frac{A}{(T_P + T_N)} \quad \dots (8)$$

where,

EFC = Effective field capacity, ha hr⁻¹; A = Area covered, ha; T_P = Productive time, hr; T_N = Non-productive time, hr

(ii) Fuel consumption

Fuel efficiency was calculated based on the quantity of fuel required for a tractor-machine system to cover an area of one hectare.

$$\text{FE} = \frac{\text{Fuel Consumed (L)}}{A \text{ (ha)}} \quad \dots (9)$$

where,

FE = Fuel efficiency, Lha⁻¹; A = Area covered, ha

(iii) Plant height

Plant height is based on various conditions such as soil resistivity, moisture content, soil temperature, sunshine, etc. The height of the plants is measured from the ground surface to the tip of the main axis at intervals of 10, 35, and 60 days after sowing.

(iv) Seed Yield

Fully matured pods were manually plucked randomly from each replication plot from one

square meter area. The plucked pods were sun-dried; seed and stover were separated and weighed in grams on electronics balance.

$$\text{Seed Yield (kg m}^{-2}\text{)} = \frac{W}{A} \times 100 \quad \dots (10)$$

where,

W = weight of green gram seed, kg; A = plot area, m²

(v) Crop harvest index

Crop harvesting index helps to calculate the difference between potential and actual yield. It's the proportion between grain yield and plant yield. It serves as an efficiency indicator for each crop. And it varies depending on the crop. Under the research of agrivoltaic systems, the crop harvesting index was calculated as:

$$\text{Crop harvest index} = \frac{\text{Total yield of greengram seed (kg)}}{(\text{Total weight of Stover} + \text{greengram seed in kg})} \quad \dots (11)$$

(vi) Land equivalent ratio of agrivoltaic system

Land utilization is maximized by combining solar panels and food crops on the same plot of land. The land equivalent ratio (LER) is applied to this new idea to quantify land production and compare the agrivoltaic system by separating solar farms and agriculture (Thompson *et al.*, 2020). It is defined as follows:

$$\text{LER} = \frac{\text{Electricity Generation}_{(\text{AV System})}}{\text{Electricity Generation}_{(\text{Sole})}} + \frac{\text{Crop Yield}_{(\text{AV System})}}{\text{Crop Yield}_{(\text{Sole})}} \quad (\text{Santra et al., 2017}) \quad \dots (12)$$

where,

AV stands for agrivoltaic; Sole stands for open PV farm and open field farming

- PV installation capacity in the agrivoltaic system is 9.24 kW per 140 m²
- PV installation capacity in the sole solar PV power plant is 9.24 kW per 140 m²

(vii) Economics Analysis

The cost of green gram cultivation under different strings of the agrivoltaic system and open field was analyzed. The capital cost of the solar power plant, depreciation interest, etc., are considered. The solar power plant receives credits as per average power purchase cost (APPC) from the state DISCOM for the sale of power at the prevailing rate of 3.5 Rs. kWh⁻¹.

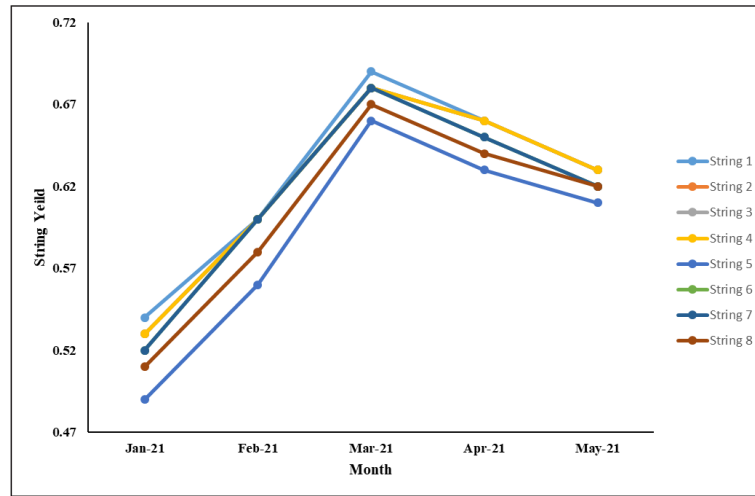


Fig. 4. Month-wise average string yield of agrivoltaic system

Benefit Cost Ratio (B: C Ratio) of agrivoltaic system

In capital budgeting, the Benefit Cost Ratio (BCR) is often used to estimate the total value of money spent on a new project. BCR is determined by dividing the project's proposed total cash benefit by the project's proposed total cash cost. Benefit: Cost Ratio for each treatment was calculated based on following formula:

$$\text{Benefit: Cost Ratio} = \frac{\text{gross return}}{\text{cost of cultivation}} \quad \dots(13)$$

Results and Discussion

The section analyzed the performance of agrivoltaic systems with various solar photovoltaic string geometries and their applicability to crop production.

Performance Analysis of the solar strings in an agrivoltaic system

String yield

Figure 4 shows the monthly average yield from highest to lowest: March, April, May, February, and January. String-1 had the highest yield, followed by strings 2, 3, 4, 6, 7, 8, and 5. However, the yields of the first four strings and string numbers 6 and 7, where solar panels are mounted at height, did not differ significantly.

The difference in string yield was found due to variation in DC cable length up to the inverter. String 5 had the lowest performance due to lower power generation efficiency, while string 8 had a lower yield due to higher dust formation and shading from farming practices and labor movement. (Milosavljevic *et al.*, 2015).

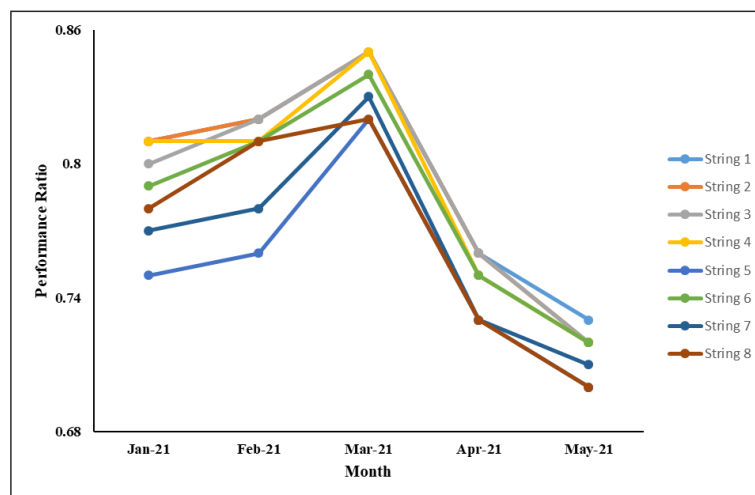


Fig. 5. Performance ratio of each string in an agrivoltaic system, organized by month.

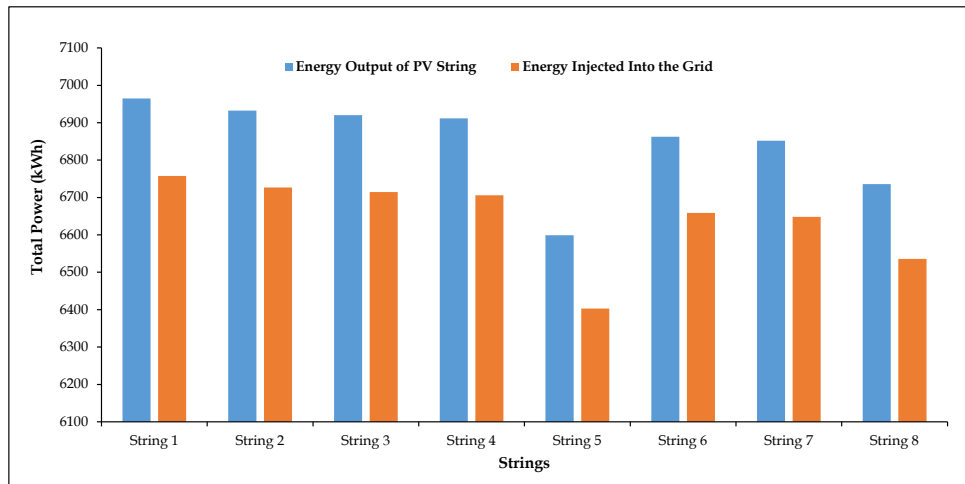


Fig. 6. String-wise DC and AC power generation.

(ii) Performance Ratio (PR)

Figure 5 shows that string-1 outperformed the other strings. However, there was no significant difference in performance ratio between the first four strings, and string numbers 6 and 7. DC cable length variations caused minor differences in performance ratios. String 5 had the lowest performance ratio due to its lower power generation efficiency. String 8 had a lower performance ratio due to dust formation and shading by farming practices and labor movement. The performance ratio was highest in March, followed by February, January, April, and May, respectively (Kumar and Sudhakar, 2015).

(iii) String-wise power output of an agrivoltaic system

Figure 6 displays the power generation of different strings during green gram crop cultivation. Results show that 3.2 m and

1.82 m strings generated more power than the conventional 0.91 m string. String-1 produced the highest DC and AC power, while transparent string-5 had the lowest. DC and AC power generation from conventional string-8 were also low compared to other strings.

(iv) Capacity utilization factor (CUF)

Figure 7 shows the capacity utilization factor (CUF) for different strings, with string-1 performing the best consistently. String-5 and conventional string-8 had lower CUF throughout all months. The plant's CUF was 20.44, considered best in the photovoltaic industry and indicative of the system's sustainability (Kumar et al., 2017).

(v) Assessing the effectiveness of solar PV strings in relation to agricultural operations

According to Figure 8, the first three treatments had better effective field capacity, field efficiency, and less fuel consumption

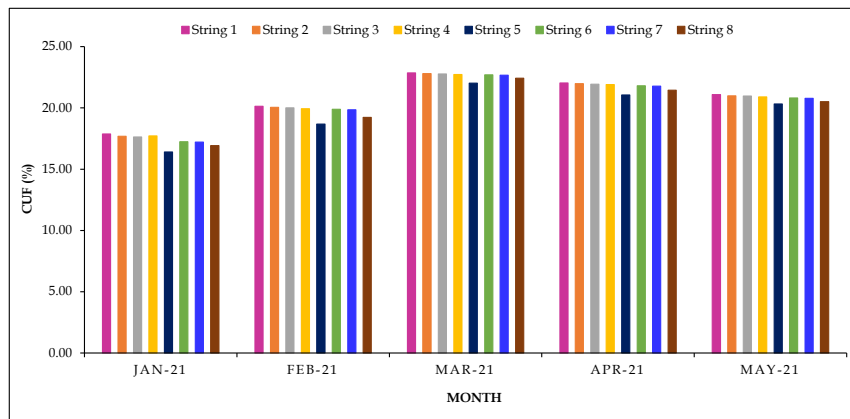


Fig. 7. Monthly average Capacity Utilization Factor of strings.

Table 2. Economics analysis

Parameters	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	T ₈	T ₉
Capital Cost of solar power plant (string wise) (Rs.)	460000	460000	460000	410000	480000	410000	410000	390000	--
Salvage price (Rs.)	46000	46000	46000	41000	48000	41000	41000	39000	--
Total life span of the solar power plant in years	25	25	25	25	25	25	25	25	--
Depreciation (Rs./year)	16560	16560	16560	14760	17280	14760	14760	14040	--
Interest (Rs./year) @ 5%	12560	12560	12560	11275	13200	11275	11275	10725	--
Repair and maintenance (Rs./year) @ 2% of capital cost	9200	9200	9200	8200	9600	8200	8200	7800	--
Total operating cost (Rs./year)	38410	38410	38410	34235	40080	34235	34235	32565	--
Total operating cost (Rs./plot of 140 sq. m) for four months	12803	12803	12803	11411	13360	11411	11411	10855	--
i) Seed	10	10	10	10	10	10	10	10	10
ii) Fertilizer cost	35	35	35	35	35	35	35	35	35
iii) Tractor, fuel, Labor charges (Rs./hr) (soil preparation, weeding, inter-culturing, harvesting, threshing)	273	273	273	308	308	308	308	332	255
Total cost of greengram cultivation (Rs./plot of 140 sq. m.)	318	318	318	353	353	353	353	377	300
Total cost of operation of agrivoltaic system (Rs./plot of 140 sq. m) (11 + 13)	13121	13121	13121	11764	13713	11764	11764	11232	300
Income from sale of electrical power (Rs.)	23484	23360	23319	23297	22202	23102	23075	22641	0
Greengram seed + Stover yield income (Rs./plot of 140 sq. m)	880	914	922	884	930	844	848	723	957
Net Realization (Rs.)	11243	11153	11126	12417	9335	12182	12159	12132	657

than treatments 4 to 8. Treatment-9 was the best overall, although it did not differ significantly from the first three treatments. Heightened strings made tractor operations easier, but string-8 had relatively longer tillage and sowing times due to high losses during turning, reversing, and adjusting. The string-8

performed poorly due to the lower height of the string.

(vi) Soil Moisture Content

The data suggests that the presence of solar panels above the agricultural plot partially shaded the area and retained more moisture in

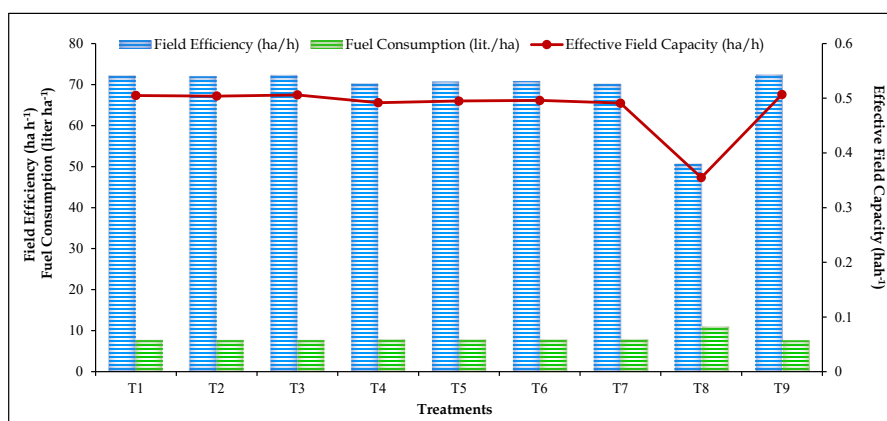


Fig. 8. Tractive performance for each treatment under an agrivoltaic system.

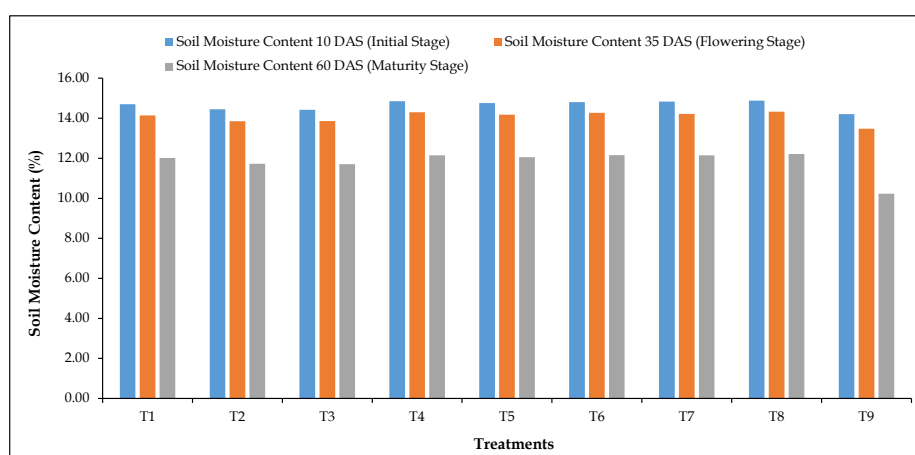


Fig. 9. Moisture Content (Dry Basis).

the soil. This effect was observed consistently throughout the observation period. The study also found that areas under PV solar panels had higher late-season biomass, resulting in a 90% increase in biomass, and was more water-efficient.

(vii) Seed and Stover Yield, Harvest Index, Land Equivalent Ratio (LER)

Figure 10 shows that all treatments, except for treatment 8, had similar results in terms of seed yield and Stover yield. Treatment 9 had the highest seed yield of 13.29 kg. 10.5-foot-heightened strings with equal-spaced solar panels gave better results. All treatments had comparable results for the crop harvest index, with green gram having a crop harvest index of 0.29 (Keerti *et al.*, 2017).

Combining solar panels and food crops on the same land maximizes land use. Land Equivalent Ratio (LER) was highest for treatments 2 and

3, and treatments 1, 4, 5, 6, and 7 had similar results. Treatment 8 had the lowest LER. The study showed that heightened string with equal-spaced solar panels performed better than conventional solar systems, presenting an LER of 1.41 for a mixed cropping system (Santra *et al.*, 2017).

(viii) Techno-Economics Analysis

Economic analysis was conducted using the straight-line method. The cost of operating a solar power plant and the expenses involved in cultivating green gram was calculated. The net realization was determined by considering income from power generation, seed, and stover. Table 2 and Fig. 11 provide detailed economics of the agrivoltaic system. The data shows that income from solar power generation exceeded income from agriculture. Income from power generation was higher for the first four treatments and treatments 6 and 7

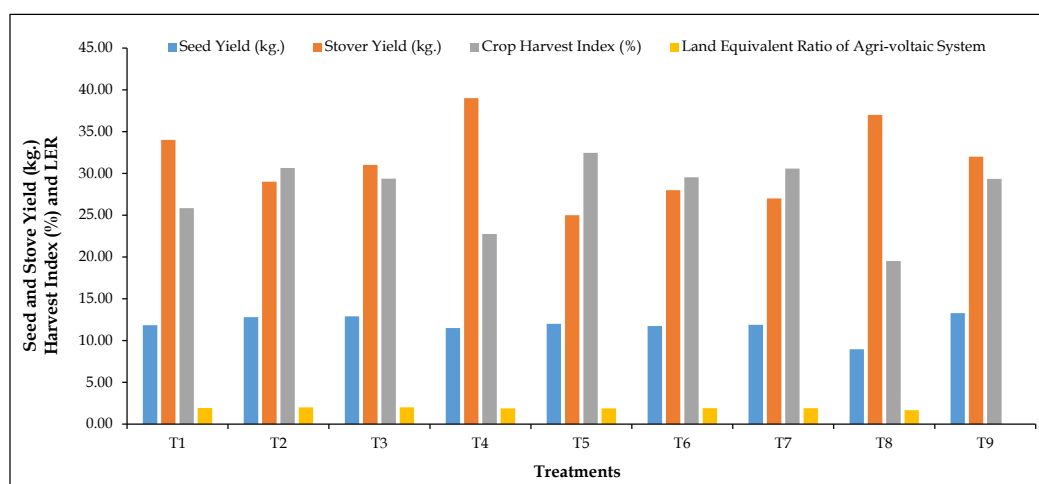


Fig. 10. Seed and Stover Yield, Harvest Index, LER.

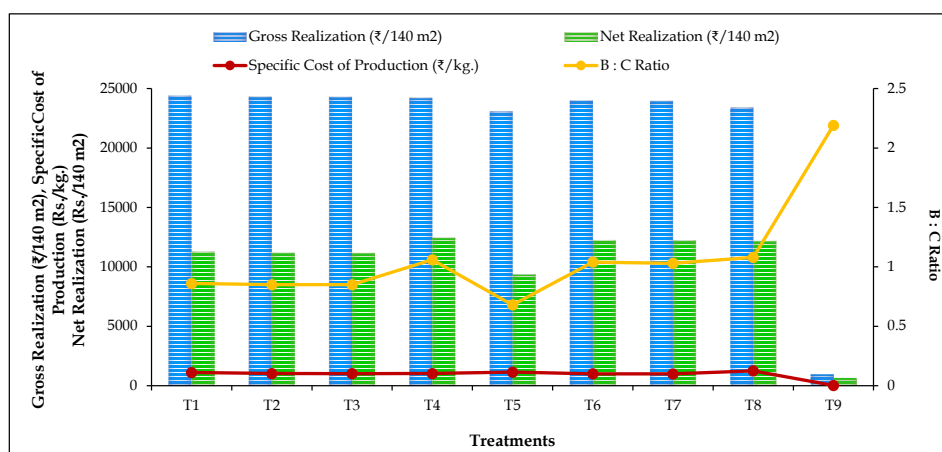


Fig. 11. Effect of treatments on net realization and Benefit: Cost ratio.

than for treatments 5 and 8. The lower income for treatment 5 was due to the lower power generation efficiency of transparent solar panels. The low income from treatment 8, which included conventional low-height solar power plants, was due to quick dust formation and shading effects caused by farming operations and the labor movement. Income from green gram yield was higher for treatments 2, 3, 5, and 9. The open field provided the highest income in terms of green gram yield.

Conclusion

In terms of power generation, string-1 (a string of 3.2 m in height with a continuous module) was found best, with a total power output of 6757.82 kWh during the study period. The performance ratio was highest for string 1, second-lowest for string 8 (conventional low height), and lowest for string 5 (transparent). The first three strings with a height of 3.2 m, were better for growing green grams. The design of the rows allows for increased power generation, easy tractor operation and other farm activities, improved moisture retention, higher seed yield, and better profit margins. In terms of green gram yield, the control treatment (open field) produced the highest yield at 13.29 kg of seeds. However, treatment-3 (a 3.2 m string with a chessboard pattern) provided a seed yield of 12.89 kg and generated 6714.77 kWh of power, making it the optimal choice when considering both agriculture and power generation. Treatment-1, with a 10.5 feet string and continuous pattern, yielded the highest income from power generation and green gram yield (24364.00 Rs.). In terms of net realization, Treatment-4 (with 1.82 m string and continuous

pattern) provided the highest return of 12417.00 Rs. due to its lower capital cost. Treatment-5, which involved transparent panels, was found to be better for the photosynthesis process of the green gram crop, as it provided the highest yield (12.99 kg) under the agrivoltaic system.

References

- Adeh, E.H., Good, S.P. and Calaf, M. 2019. Solar PV Power Potential is Greatest Over Croplands. *Scientific Reports* 9: 11442. <https://doi.org/10.1038/s41598-019-47803-3>.
- Denholm, P. and Margolis, R.M. 2008. Land-use requirements and the per-capita solar footprint for photovoltaic generation in the United States. *Energy Policy* 36(9): 3531- 3543.
- Dupraz, C., Marrou, H., Talbot, G., Dufour, L., Nogier, A. and Ferard, Y. 2011. Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes. *Renewable Energy* 36(10): 2725-2732.
- Harinarayana, T. and Vasavi, K. 2014. Solar energy generation using agriculture cultivated lands. *Smart Grid and Renewable Energy* 5: 31-42.
- Keerti, Math, G. and Raghuveer 2017. Evaluation of green gram (*Vigna radiata* L. Wilczek) genotypes for mechanical harvesting. *International Journal of Pure & Applied Bioscience* 5(4): 1691-1696. <http://dx.doi.org/10.18782/2320-7051.5115>.
- Kumar, B. and Sudhakar, K. 2015. Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. *Energy Reports* 1: 184-192.
- Kumar, P.R., Raju, D.K., Kar, R.K. and Devi, V.V. 2017. Performance metrics of grid connected solar pv power plant - A practical case study. *Journal of Green Engineering* 7(1&2): 99-128.
- Macknick, J. 2019. Co-location of agriculture and solar: Opportunities to improve energy, food,

- and water resources. <https://www.nrel.gov/docs/fy19osti/73696.pdf>.
- Mavani, D.D., Chauhan, P.M. and Joshi, V. 2019. Beauty of Agrivoltaic System regarding double utilization of same piece of land for generation of electricity and food production. *International Journal of Scientific & Engineering Research* 10(6): 118-148.
- Milosavljevic, D.D., Pavlovic, T.M. and Pirs, D.S. 2015. Performance analysis of a grid-connected solar PV plant in Niš, Republic of Serbia. *Renewable and Sustainable Energy Reviews*. 44: 423-435.
- Pandey, K.K., Tiwari, D. and Upadhyay, S. 201). An economic study on marketed surplus of chickpea in Rewa district of Madhya Pradesh. *International Journal of Plant, Animal and Environmental Sciences* 3(3): 55-59.
- Santra, P., Pande, P.C., Kumar, S., Mishra, D., and Singh, R.K. 2017. Agri-voltaics or Solar farming: The Concept of Integrating Solar PV Based Electricity Generation and Crop Production in a Single Land use System. *International Journal of Renewable Energy Research* 9(1): 694-699.
- Thompson, E.P., Bombelli, E.L., Shubham, S., Watson, H., Everard, A., D'Ardes, V., Schievano, A., Bocchi, S., Zand, N., Howe, C.J. and Bombelli, P. 2020. Tinted Semi-Transparent solar panels allow concurrent production of crops and electricity on the same cropland. *Advanced Energy Materials* 10: 2001189. <https://doi.org/10.1002/aenm.202001189>.

