RESEARCH ARTICLE Legume Research- An International Journal, Volume 48 Issue 9: 1562-1565 (September 2025)

Effect of Agri-Photovoltaic System on Growth and Productivity of Soybean

Indra Mani[1], Sunita U. Pawar[1], Godawari S. Pawar[1], K.S.Baig[1], B.M. Kalalbandi[1], Rahul Rameke[1], Vikram M. Gholve[1], Vishal K. Ingle[1], S.T. Shirale[1], Uday M. Khodke[1]

10.18805/LR-5495

ABSTRACT

Background: The shade effect by panels, temperature and other alterations occur under photovoltaic system. Further height, tilt angle of solar panels, distance between two panels or spacing are other factors which influence the crop growth, development and ultimately yield levels of crops. The main objective of his study is to evaluate the growth and yield of soybean under photovoltaic conditions.

Methods: The field experiment was conducted at research farm of Agriphotovoltaics tq. Manwat site and district Parbhani, under collaborative research project between GIZ, Germany and Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (MS) during *kharif* season of 2023 and 2024. The experiment site includes different agrivoltaics setup with different APV designs *viz*. elevated structure 3.75 m and 1.75 m panels for below and interspaces cultivation, with fixed tilt of 11°.

Result: The experimental results revealed that soybean crop sown in between interspaces of 1.75 m panels as well as interspaces between panels having 3.75 m panel recorded seed yield comparable with each other and open space cultivation however 25.83% and 20% lower seed yield recorded with soybean sown below the panels of height 3.75 m, while 42.3% and 40% lower seed yield was recorded with soybean sown below the panels of height 1.75 m. The canopy, air and soil temperature differences were wider in below panel and between interspaces cultivation conditions in 1.75 m panel overhead as compared to 3.75 m panel overhead.

Key words: Agrivoltaics, Interspaces, Panel height, Production, Soybean, Temperature.

INTRODUCTION

Fossil fuels are heavily relied upon as energy sources and are sill the largest source of greenhouse gas emissions in the power generation sector, the increasing energy needs of fast growing population and problems like contribution to environmental pollution associated with conventional energy generation using fuels, new alternatives like solar power generation are getting more popular. The solar photovoltaic systems have numerous benefits over conventional like sustainability, enhanced efficiency, clean energy generation and vast accessibility. However using larger areas of land for solar farms may lead shortage for land resources required in food production to meet the ever-growing demand. This land competition becomes particularly acute in densely populated regions, mountainous areas and small inhabited islands and is further fueled by the increasing population of 1.15% per year [United Nations Dept. of Economic and Social Affairs, 2014]. Agrivoltaic system is utilization of land area parallel for solar energy generation and food production.

Further research on effect of photovoltaic system and the shade effect by panels, temperature and other alterations occur under photovoltaic system. These alterations definitely have impact on growth and development of crops grown underneath. Agrivoltaiv technology is being applied worldwide; there is very little accompanying scientific research to examine its effect on agronomic parameters, such as crop performance and crop yields. Thus this study examined how the growth and yield of soybean crop could be optimized when grown underneath different agri-photovoltaic systems.

[1]Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani-431 402, Maharashtra, India.

Corresponding Author: Sunita U. Pawar, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani-431 402, Maharashtra, India. Email: pawarsu7@rediffmail.com

ORCIDs: 5533-7879-900, 0000-0003-2312-7672, 0000-0002-2149-8026, 0000-0001-6499-0515, 0009-0007-7753-5846, 0000-0002-7199-6381, 0009-0005-2888-1879, 0000-0002-8718-3887, 0000-0002-3609-4884, 0000-0001-9584-1643

How to cite this article: Mani, I., Pawar, S.U., Pawar, G.S., Baig, K.S., Kalalbandi, B.M., Rameke, R., Gholve, V.M., Ingle, V.K., Shirale, S.T. and Khodke, U.M. (2025). Effect of Agri-Photovoltaic System on Growth and Productivity of Soybean. *Legume Research*. **48(9):** 1562-1565. doi: 10.18805/LR-5495.

Submitted: 25-03-2025 **Accepted:** 23-05-2025 **Online:** 04-07-2025

On the other hand selection and research on performance as well as suitability of crops on under varied shading levels offered by varied panel heights, panel spacing, tilt angles needs to be focused as these factors influence the vegetative as well as reproductive growth of crops. On the other hand partial shading offered by agri-photovoltaic can help the shade loving and temperature sensitive crops along with protection from excessive heat. Shade tolerance depends on the radiation interception efficiency (RIE) of the leaves and is not influenced by the degree of shading. Therefore, when lettuce is cultivated under shaded conditions, it compensates for the consistent RIE by increasing its leaf area to better capture the available solar radiation (Marrou *et al*., 2013).

Considering the above facts in view, to assess the performance of soybean crop under agriphotovoltaic systems of different panel heights with other specifications and its impact on growth and yield of crops as well as overall efficiency of agrivoltaic system.

MATERIALS AND METHODS

The field experiment was conducted at Agri Photo Voltaics Research Farm at Manoli site tq. Manwat and district Parbhani under collaborative research project between GIZ, Germany and Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (MS) during *kharif* season of 2023 and 2024. The research site includes various agrivoltaics setup with different APV designs *viz.* elevated structure 3.75 m , 1.75 m bifacial and 1.75 m monofacial panels for below and interspace cultivation, with fixed tilt of 11°. The lightly alkaline in reaction low in organic carbon, medium in available nitrogen and phosphorus, but marginally high in available potassium. The annual rainfall received during 2023 was 632 mm while 955 mm during 2023 and 2024 respectively.

The experiment was conducted with different panel specifications *viz.* Panels having 1.75 m height Bifacial with Overhead 1.75 m, fixedtilt 11° and Pitch distance of 10 m, secondly panels having over head 3.75 m, fixed tilt of 11°, pitch distance 5.64 m. Soybean crop raised under five conditions which were named as different treatments *viz*. cultivation below the panel of 1.75 m height (T_1), cultivation in the interspaces of 1.75 m panel (T_2), cultivation below the panel of 3.75 m height (T_3), cultivation in the interspaces of 3.75 m panel (T_4) and open space cultivation (T_5) (Fig 1). The crops were grown on broad bed furrow (BBF) below as well as in between the panel space, so that the runoff water from panels is collected in the channels/ furrows formed between the broad beds. Soybean variety MAUS-162 was sown at spacing 45 cm × 5 cm. The air, canopy and soil temperatures were measured using a portable infrared thermometer at different growth stages. Chlorophyll measurements were taken using a SPAD (Soil and Plant Analysis Development). The plants from each net plot were threshed and seeds were cleaned. The cleaned seeds obtained from each net plot were weighed in kg which was then converted into seed yield (Kg ha^{-1}) by multiplying hectare factor. For straw yield, after separation of seeds from biological yield, remaining material was considered as straw yield and its final weights were recorded in kg per net plot, which was then converted into straw yield (Kg ha^{-1}) by multiplying with hectare factor. The biological yield was obtained by adding seed yield and straw yield. The harvest index was calculated as the ratio of seed yield to the total above ground biomass.

RESULTS AND DISCUSSION

Experimental data related to growth attributes *viz*. plant height, number of leaves, dry matter accumulation per plant (g) and yield attributes *viz.,* seed yield $plant^{-1}$ (g) along with the seed, straw, biological yield per hectare and harvest index of soybean under different panel heights and interspaces during the course of investigation are critically interpreted and results are presented below.



Fig 1: Performance of soybean in interspaces and below panels of overhead 3.75 m, 1.75 m height and open space.

Table 1: Growth and yield parameters of Soybean as influenced by agrivoltaic systems.

Treatments	Plant height (cm) 90 DAS		Dry matter/ plant (g)		Chlorophyll (SPAD)	
	2023	2024	2023	2024	2023	2024
T_1: Soybean below panel overhead 3.75 m	114.37	98.13	10.61	12.63	49.5	46.4
T_2: Soybean between interspaces of panel overhead 3.75 m	105.45	92.85	12.65	13.22	47.54	44.54
T_3: Soybean below panel overhead 1.75 m	112.62	100.5	8.32	9.05	50.29	47.22
T_4: Soybean between interspaces of panel overhead 1.75 m	102.56	95.5	13.21	14.05	48.34	43.22
T_5: Open space cultivation	104.26	99.5	13.39	14.65	48.87	46.15
SEm(±)	2.40	1.50	0.24	0.54		
CD (5%)	7.81	4.65	0.83	1.66		

Growth, yield attributes and yield of soybean crop

A perusal of data presented in Table 1 revealed that, maximum plant height of soybean was recorded with Soybean below panel overhead 3.75 m and was at par with Soybean below panel overhead 1.75 m this might be due to competition for light which resulted in increased plant height with the treatments where soybean was grown below the panels of 3.75 m and 1.75 m panel height as compared to soybean grown in interspaces of both the panels. Soybean between interspaces of panel overhead 1.75 m (T_4) recorded dry matter accumulation was at par with soybean between interspaces of panel overhead 3.75 m. Whereas Numerically higher values for SPAD chlorophyll values were recorded with Soybean below panel overhead 1.75 m (T_3) and Soybean below panel overhead 3.75 m (T_1). Increased elongation growth in response to shading is considered a shade-avoidance strategy, predominantly found in species less adapted to shaded environments (Gommers *et al.,* 2013 and Ruberti *et al.,* 2012). Yuan *et al.* (2022) from his studies on compensatory growth of soybean after shade reported shade negatively affects soybean leaf area, aboveground dry weight and grain yield of soybean.

Significantly higher soybean seed yield (Table 2) was recorded with cultivation of soybean under open space and between interspaces of panel overhead 1.75 m which was further at par with cultivation of Soybean between interspaces of panel with overhead 3.75 m. Soybean below panel overhead 3.75 m was next best treatment recording significantly superior seed yield of soybean over cultivation of soybean below panel 1.75 m. Similar experimental results were recorded with respect to highest recorded harvest index in open space cultivation of soybean, cultivation between interspaces of panel overhead 3.75 m and 1.75 m. Bing *et al.* (2020) reported that, light enrichment significantly increased number of flowers and pods in two cultivars of soybean.

Data on air, canopy and soil temperature indicated that, air temperatures (Table 3) were maximum in open space cultivation followed by cultivation in between interspaces of panel with overhead 1.75 m. Lowest air temperature recorded with soybean cultivation below panel with overhead 1.75 m. The air temperature difference below panel and between interspaces cultivation conditions were maximum in 1.75 m overhead as compared to 3.75 m panel overhead during different stages of soybean. Lower Soybean canopy temperature (Table 4) was recorded with below panel conditions as compared to cultivation between interspaces of panels with overhead 1.75 m and 3.75 m as well as open space cultivation. Soybean crop sown in open space and interspaces of panels recorded higher soil temperature as compared to cultivation below panels. However soil temperature differences in interspaces and below panel cultivation wider in 1.75 m panels as compared to panels with overhead 3.75 m. The variation in soil temperatures at 60 and 75 days after sowing across different panel conditions in soybean cultivation was less pronounced as compared to initial stages of crop growth (Table 5). Leaves in the shade experienced more constant values. The results corroborate with the findings of Chopard *et al.* (2022).

Table 2: Soybean seed, straw, biological yield and harvest index as influenced by agriphotovoltaic system.

Treatments	Soybean seed yield (kg/ha)		Straw yield (kg/ha)		Biological yield (kg/ha)		Harvest index (%)	
	2023	2024	2023	2024	2023	2024	2023	2024
T_1: Soybean below panel overhead 3.75 m	1851	1,958	2651	2574	4502	4532	41.11	43.20
T_2: Soybean between interspace of panel overhead 3.75 m	2382	2279	3192	2759	5475	5258	43.52	45.25
T_3: Soybean below panel overhead 1.75 m	1438	1381	2142	2032	3580	3413	40.16	40.46
T_4: Soybean between interspace of panel overhead 1.75 m	2417	2297	3363	2865	5780	5162	41.82	44.50
T_5: Open space cultivation	2370	2,456	3424	2918	5898	5375	42.28	45.70
S.Em.±	46.72	63.98	63.13	79.83	109.32	114.06		
C.D. at 5%	144.16	197.16	194.57	246.00	336.92	351.49		

Table 3: Effect of agriphotovolaics system on air temperature.

Air temp. (°C)	30 DAS	45 DAS	60 DAS	75 DAS
T_1: Soybean below panel overhead 3.75 m	29.87	30.07	29.85	29.92
T_2: Soybean between interspace of panel overhead 3.75 m	29.63	31.90	29.87	29.67
T_3: Soybean below panel overhead 1.75 m	28.27	30.10	30.82	30.13
T_4: Soybean between interspace of panel overhead 1.75 m	30.07	32.02	31.57	30.75
T_5: Open space cultivation	30.16	32.14	31.80	30.97

Table 4: Effect of agrivoltaics system on canopy temperature.

Canopy temp. (°C)	30 DAS	45 DAS	60 DAS	75 DAS
T_1: Soybean below panel (overhead 3.75 m)	26.75	26.48	26.85	27.00
T_2: Soybean between interspaces of panel (overhead 3.75 m)	27.28	28.55	28.25	27.10
T_3: Soybean below panel (overhead 1.75 m)	25.91	27.10	27.86	27.68
T_4: Soybean between interspaces of panel (overhead 1.75 m)	26.51	27.33	27.90	27.80
T_5: Open space cultivation	28.63	28.80	28.20	27.90

Table 5: Effect of agriphotovlotaic system on soil temperature.

Soil temp °C	30 DAS	45 DAS	60 DAS	75 DAS
T_1: Soybean below panel overhead 3.75 m	28.58	27.75	27.63	28.43
T_2: Soybean between interspace of panel overhead 3.75 m	28.23	29.15	26.35	28.35
T_3: Soybean below panel overhead 1.75 m	26.10	28.10	27.35	28.00
T_4: Soybean between interspace of panel overhead 1.75 m	27.30	29.05	27.78	28.38
T_5: Open space cultivation	28.70	29.84	27.24	29.58

CONCLUSION

Based on the findings of present investigation, conducted for two years to study the performance of soybean under agrivoltaics system with different agrivoltaics setup with panel height 3.75 m, 1.75 m panels with fixed tilt of 11° it can be concluded that, Soybean crop sown in between interspaces of 1.75 m panels as well as interspaces between panels having 3.75 m panel recorded seed yield comparable with open space cultivation. About 25.83 and 20 per cent lower seed yield was recorded with soybean sown below the panels of height 3.75 m, while 39.33 and 42 per cent lower seed yield was recorded with soybean sown below the panels of height 1.75 m as compared to open space cultivation during first and second year of experimentation respectively.

Thus the interspaces which gave comparable yield with open space cultivation can be successfully used for soybean cultivation in agrivoltaics system.

ACKNOWLEDGEMENT

The present study was conducted under collaborative research project funded and supported by GIZ, Germany along with necessary facilities in carrying out the present investigation and processing charges.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

REFERENCES

Gommers, C.M.M., Visser, E.J.W., Onge, K.R.S., Voesenek, L.A.C.J., Pierik, R. (2013) Shade tolerance: When growing tall is not an option. *Trends Plant Sci.* **18:** 65-71.

Jérôme, C., Lopez, G., Persello, S. and Fumey, D. (2022). Modelling canopy temperature of crops with heterogeneous canopies grown under solar panels: AgriVoltaics World Conference Agrivoltaics Systems. https://doi.org/10.52825/agripv.v1i.561.

Liu, B., Dening, Q., Jianliang, L. (2020). Light enrichment, flowering asynchrony and reproduction success in two field-grown soybeans in Northern China. *Legume Research.* **43(2):** 241-246. doi: 10.18805/LR-510.

Marrou, H., Guilioni, L., Dufour, L., Dupraz, C., Wery, J. (2013). Microclimate under agrivoltaic systems: Is crop growth rate affected in the partial shade of solar panels? *Agricultural and Forest Meteorology.* **177:** 117-132.

Ruberti, I., Sessa, G., Ciolfi, A., Possenti, M., Carabelli, M., Morelli, G. (2012) Plant adaptation to dynamically changing environment: The shade avoidance response. *Biotechnol. Adv.* **30:** 1047-1058. [CrossRef].

United Nations Dept. of Economic and Social Affairs, (2014) at http://www.un.org/en/development/desa/population/publications/pdf/trends/Concise%2 0Report%20on%20the%20World%20Population%20Situation%202014/en.pdf (accessed on April 10, 2015).

Yuan, X., Kai, L., Jia, Z., Shanshan, L., Taiwen, Y., Wenyu, Y. (2022). Compensatory growth of soybean after shade during vegetative promotes root nodule recovery. *Legume Research.* **45(10):** 1273-1277. doi: 10.18805/LRF-689.