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Influence of Agriphotovoltaics on performance of turmeric (*Curcuma longa* L)

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ABSTRACT

An experiment was conducted to integrate turmeric crop production under the GM-APV system, so as to analyse the performance and also elaborate the feasibility of the concept. The experiment was conductedusing randomized block design with five treatments as growing conditions of the turmeric crophaving three replications. The details of treatments were T_1 -Sole 3.75 m panel, T_2-Sole 1.75 m panel, T_3 – Turmeric below 3.75 m panel, T_4 -Turmeric between 3.75 m panel, T_5 -Turmeric below 1.75 m panel, T_6- Turmeric between 1.75 m panel and T_7 Open conditions (Sole Turmeric). Results revealed that different GM APVs influenced the growth and yield parameters of turmeric cultivar Salem significantly, except emergence count at 60 DAP which differed non significantly. The treatment T_3 where turmeric planted below 3.75 m recorded significantly more number of tillers clump^{-1} (3.96), pseudostem height clump^{-1} (32.50 cm), number of leaves clump^{-1} (22) and leaf area clump^{-1} (72.60 cm^2), Chlorophyll content (35.40 Spad), crop duration (306.48 days), rhizome yield plant^{-1} (0.65 kg),fresh rhizome yield ha^{-1} (40.70 t) and dry rhizome yield ha^{-1}(8.75 t).

***Keywords*:** Ground mounted agrivoltaic systems, growth, turmeric, yield.

INTRODUCTION

India has started the energy generation from renewable recourses and set the goal of generating half of its electricity from renewables by 2030 and has established 18 Gegawatt (GW) of solar photovoltaics in 2022. Energy generation from coal will be surpassed by Solar photovoltaics power capacity by 2027 and it will become the largest energy generating capacity in the world (Anamalagundam *et al*., 2023). However, the biggest challenge in large scale adaption is requirement of large area for these ground mounted solar panels*i.e.,* usage with approximately 1.2-1.7 hectare per installed mega wat power (MW_P) (Anas *et al*., 2023; Axel *et al*., 2019; Max *et al*., 2019).According to the Japanese energy policy, crop yield under Agriphotovoltaics should not be less than 80% of those grown in open-field (OF) conditions to ensure food security (Elborg, 2017). Thus, achieving crop yield, and the arrangement of solar panels that allows cultivation, has become important area of research.

Turmeric is shade lovingand has adaptation to low light saturation hence intensive cultivation in the form of inter-cropping with castor crop is regular practice in the region (Thombre, 2022).The APV system is an emerging concept and very few studies highlighting the crop response to AVP systems was carried out by the earlier workers (AL-Agele *et al*., 2021; Moon *et al*., 2022; Ko *et al*., 2023). Therefore, a wide range of investigation is needed to be initiatedin orderto develop effective management strategies for the horticulture crops so as to fully exploit the potential benefits of GM-APV system that offers.Very scanty information is available of growing turmeric crop under solar panels is seen. Therefore, present study on turmeric performance under GM- APV has been conducted.

MATERIALS AND METHODS

The field study was performed at Manvat Dist. Parbhani (19°18'0N76°30'0'E). The ground mounted (GM) Photovoltaic panels (PVPs) have been arranged in north-south oriented strips with installation capacity of 1.4 MW_{DC} spread over area of 4.2 acres having five sections (Four APV and one open section).Panel specification comprises of 540 kWp bifacial panels with 20% efficiency having tilt of 11° and ground clearance of 3.75m and 1.74 m and pitch distance of 5.4 m and 10 m, respectively having approximate cost of Rs 2 crores per MW. The site soil is clay loam with bulk density of in range of 1.35-1.40 g/cc, top soil pH ranging from 7.95 to 8.14, EC in the range of 0.24 to 0 .37 dS/m, $CaCO_3$ content of 7.2 % and0.47 to 0.79 % range of organic matter content. Parbhani district comes under assured rainfall region with semi-arid climate. The average annual precipitation of the district is 844 mm and the region has been categorized as an assured rainfall agro-climatic zone. The region experiences hot dry summer (March - May), cold dry winter (October - February) and wet humidity with medium rainfall in monsoon season (June - September). Rainfall received during experimental year (2023-24) was 890.8 mm and distributed in 49 rainy days. During the period of experiment the mean maximum temperature ranged from 28.2 to 44.6^0 C whereas, mean minimum temperature ranged from 8.1 to 0.1^0 C while relative humidity was seen 48 to 97 per cent in morning period and 14 to 82 per cent during afternoon hours.

The experiment with five treatments was laid out in a Randomized Block Design (RBD) with three replications. Turmeric variety Salem was planted on raised beds at spacing of 60 x 25 cm on 3rd June 2023.The details of treatments were T_1– Turmeric below 3.75 m panel, T_2 -Turmeric between 3.75 m panel, T_3 -Turmeric below 1.75 m panel, T_4- Turmeric between 1.75 m panel and T_5 Open conditions (Sole Turmeric). The observations regarding growth parameters *viz*. emergence count, No. of tillers clump,$^{-1}$ *pseudo* stem height (cm) clump^{-1} 210 DAP, number of leaves clump^{-1} 210 DAP, leaf area(cm^2) clump^{-1} 210 DAP, chlorophyll content (Spad units), rhizome yield (kg/plant), rhizome yield (tha^{-1}), dry rhizome yield (tha^{-1}) were recorded at the time of harvest i.e on 24th of April 2024 . The data collected was subjected to statistical analysis of variance as suggested by Panse and Sukhatme (1985).

RESULTS AND DISCUSSION

Perusal of data presented in Table 1 clearly revealed that different GM - APVs influenced the growth and yield parameters of turmeric cultivar Salem significantly except, emergence count at 60 DAP which differed non significantly. Emergence count taken at 60 DAP showed that turmeric planted in open field showed more emergence count (84.15 %) as compared to the treatments of turmeric planted in ground mounted agriphotovoltaics (GM- APVs). Less emergence count (83.67 %) was recorded in the treatment T_1 where turmeric was planted below 3.75 m panel having pitch of 5.4 m. However, the emergence count differed non significantly among all treatments under study. It might be due to external factors affecting emergence *i.e.*,diurnal changes during day and night period do not vary too much as it was July and August period of monsoon season.

The data regarding number of tillers clump^{-1} of turmeric differed significantly in different treatments under study and ranged from 3.03 to 3.96. The treatment T_1 where turmeric planted below 3.75 m recorded more number of tillers clump^{-1} (3.96) followed by the treatment T_5(3.70) and T_2 (3 .4) and where found statistically at par with each other. Minimum number of clump^{-1} was recorded in a treatment T_4 (3.03). *Pseudostem* height clump^{-1} of turmeric recorded at 210 DAP ranged from 22.3 cm to 32.50 cm in different treatments under investigation. Significantly more pseudostem height clump^{-1} (32.50 cm) of turmeric planted below 3.75 m panel was recorded and was followed by the treatment T_2 (29.4) and was found at par with each other. While less pseudostem height clump^{-1} (22.3 cm) was recorded in turmeric planted under open conditions.

It was evident from the data presented regarding the number of leaves clump^{-1} and leaf area clump^{-1} recorded at 210 days DAP clearly showed that turmeric planted below 3.75 m panel recorded more number of leaves (22.24) and leaf area (72.16 cm^2) and was closely followed by the treatment T_2 (20.82 and 68.64 cm,^{2} respectively) and were found at par with each other. While minimum the number of leaves clump^{-1} (19.22)and leaf area clump^{-1} (60.26 cm^2) was recorded in the treatment where turmeric was grown in open field. Chlorophyll content was recorded more in the treatment T_1 (35.40 Spad units) where turmeric was planted below 3.75 m panel and was followed by the treatment T_2, T_3 and T_4 and where found at par with each other. While,minimum chlorophyll content was recorded in the treatment T_5 (28.84 Spad units) i.e in open field conditions.(Trommsdorff *et al*., 2022; Max *et al*., 2019) found that soil temperature at night under the modules was lower than that of soil temperatures under full sunny morning hours. Further evapotranspiration reduced the temperature of the surrounding atmosphere under the APV system by around 1 to 1.5^{0}C than ambient temperature. Valle *et al*., 2022 reported a decline of about 14% to 29% of evapotranspiration. Hence, moisture levels near soil and air would be higher beneath PV system. APV panels lessen the impact of heavy rainfall, frost, hail storms and high temperatures on crops grown underneath of it. Kostik *et al*., (2020) and Williams *et al*., (2023) suggested good plant growth can be anticipated in the regions of hot windy, and turbulent conditions as they act like windbreaks and this could helps to minimize wind erosion.

The data regarding crop duration of turmeric cv. Salem also revealed significantly difference as influenced by the growing conditions of APVs. Relatively more crop duration (306.48 days) was taken by turmeric grown below 3.75 m panel in comparison with rest of growing conditions, except treatment T_2 and T_3 which were found at par with each other. Turmeric crop grown in open conditions was earlier to be harvested (272.44 days) among all treatments studied. Crop duration depends upon total heat that accumulated in the field over time which can be directly related to growing degree days. As field accumulated crop experience accelerated growth leading to earlier maturity. In this investigation the crop required more number of days to reach maturity under GM-APVs conditions for want of more field heat to be accumulated in the crop in comparison to open field conditions.

It was clear from the data presented in Table 2 regarding yield parameters of turmeric as influenced by different growing conditions of APVs varied significantly. Turmeric planted below 3.75 m panel recorded significantly more rhizome yield plant^{-1} (0.65 kg), fresh rhizome yield ha^{-1} (40.70 t) and dry rhizome yield ha^{-1}(8.75 t). The next best treatment in this regard was the treatment where turmeric was planted between the panels of 3.75 m (0.58 kg plant^{-1}, 36.32.70 t ha^{-1} and 6.9 t ha^{-1}, respectively). Turmeric planted in open condition recorded minimum rhizome yield plant^{-1} (0.4 kg), fresh rhizome yield ha^{-1} (25.04 t) and dry rhizome yield ha^{-1}(4.5 t). Horticulture PV system provides shading which may lead to crop growth increase of decrease depending on crop. Shading also improves protection against heat waves and strong precipitation such as hail as reported by Guerin (2019);Hiebsch and McCollum (1987).Studies on yield impact showed wide variations in results. Leafy vegetables and legumes increase yield, while crops like rice and wheat showed a significant reduction in yields, and most other crops revealed mixed results as suggested by Homma *et al*., 2016;Gonocruz*et al*., 2021; Weselek *et al*., 2019; Zang *et al*., 2025). It is clear from the above literature reviews that the performance of the crop is subject to factors like type of crop selected, growing agroclimatic conditions and erected panel elevations.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 1: Influence of different GM-APVs on growth performance of turmeric cv. Salem

Treatmentdetails	**Growth parameters of turmeric**						
	Emergence count (%) at 60 DAP	**No. of tillers clump^{-1}**	**Pseudo stem height (cm) clump^{-1} 210 DAP**	**Number of leaves clump^{-1} 210 DAP**	**Leaf area(cm^2) clump^{-1} 210 DAP**	**Chlorophyll content (Spad units)**	**Crop duration (Days)**
T_1- Turmeric below 3.75 m panel	83.67 (97.02)*	3.96	32.50	22.24	72.16	35.40	306.48
T_2- Turmeric between 3.75 m panel	83.85 (97.10)	3.40	29.403	20.82	68.64	35.20	302.6
T_3 -Turmeric below 1.75 m panel	83.90 (97.60)	3.10	27.48	20.10	65.26	33.40	298.34
T_4- Turmeric between 1.75 m panel	84.05 (97.88)	3.03	23.15	19.80	62.60	29.30	289.26
T_5- Open conditions (Sole Turmeric)	84.15 (97.90)	3.70	22.35	19.22	60.26	28.84	272.44
SE $\pm$	0.65	0.22	1.61	1.21	2.07	2.56	6.72
CD at 5%	NS	0.66	4.83	3.63	6.221	7.68	11.16

***** Figures in the brackets are angular transformed value of %.

Table 2: Influence of different GM-APVs on yield performance of turmeric cv. Salem

Treatment details	**Yield parameters of turmeric**		
	Rhizome yield (kg/plant)	**Fresh Rhizome yield (tha-^{1})**	**Dry Rhizome yield (tha^{-1})**
T_1- Turmeric below 3.75 m panel	0.65	40.70	8.75
T_2 - Turmeric between 3.75 m panel	0.58	36.32	6.9
T_3 -Turmeric below 1.75 m panel	0.52	32.56	5.86
T_4- Turmeric between 1.75 m panel	0.47	29.43	5.21
T_5 - Open conditions (Sole Turmeric)	0.40	25.04	4.5
SE $\pm$	0.02	1.11	1.21
CD at 5%	0.06	3.33	3.63