AgriVoltaics World Conference 2024

Best Practices

https://doi.org/10.52825/agripv.v3i.1355

Published: 28 May 2025

Feasibility of AgriVoltaic Wheat Farming With Standard-Height, Utility-Scale Tracking Systems

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Abstract. This research focuses on AgriVoltaic systems, combining standard-height (1.5 meters) PV arrays with single-axis solar trackers for wheat cultivation. The study was conducted in Sorocaba/São Paulo, at the Nextracker Solar Study Laboratory situated at Flextronics Institute of Technology (FIT). This study reveals that wheat production between PV rows is minimally affected by shading. In the 2023 winter wheat season in Brazil, the production in Regular Agriculture was 12.04 ± 4.27 tons/ha. In the AgriVoltaics area, it produced 10.72 ± 1.52 tons/ha of wheat in addition to 2354.82kWh/kWp-year. In the area dedicated to energy production, it generated a performance of 2462.26kWh/kWp-year. Statistically, using the Tukey's test, it is possible to state that there is no difference in productivity, although there are differences in morphological and physiological performance, issues that should be better explored in future studies. Furthermore, AgriVoltaics systems observed a 40% reduction in irrigation requirements, making it economically feasible for both energy providers and local farming economies. So, this study demonstrates successful integration of cost-effective PV trackers, offering potential for large-scale co-production of food and renewable energy.

Keywords: Wheat Farming, AgriVoltaics, Productivity Comparison

1. Introduction

In the past, AgriVoltaic studies often focused either on grazing scenarios, low-growing high value crops, or solar arrays mounted high above the arable land (4 meters and higher) with material-intensive structures. Our research focuses on PV arrays with a single-axis, standard-height (1.5 meters) solar trackers and an industrially farmed crop, wheat, which is a worldwide staple food. In 2022, the global wheat supply was valued at US$ 153.2 billion, with a forecasted growth of 5.3% Compound Annual Growth Rate (CAGR) from 2024 to 2032 [1]. The United States and Brazil are ideal regions for wheat production with milder temperatures (ranging from 21ºC to 24ºC) and lower annual precipitation, resulting in drier soil conditions (*Figure 1*). Successfully combining wheat crops with cost-effective standard PV trackers opens a path to co-produce food and renewable energy on a large scale.

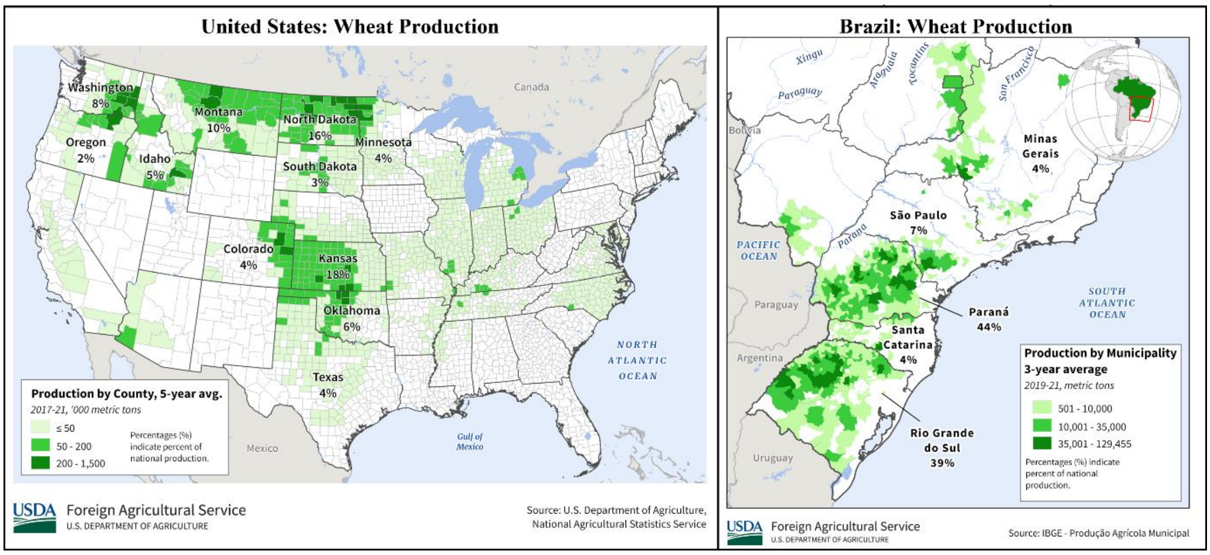

Figure 1. *Wheat Production from United States Department of Agriculture, 2023 [2].*

According to the literature, wheat in AgriVoltaics can suffer etiolation due to a deficiency in solar radiation, resulting in morphological changes such as increased size and length of stems. However, productivity is not significantly affected and can have an agricultural productivity range of -19% to +3% [3]. In addition, according to Amaducci *et al*. (2018), AgriVoltaics is a system that can improve the land use and also enhances the water balance of the soil, increasing water savings and stabilizing crop production yield [4].

2. Experimental setup and Method

The research was conducted in Sorocaba, São Paulo, at the Nextracker Solar Study Laboratory situated at FIT (Figure 4).

Figure 2. *Image of the solar tracker used.*

The study used a 1.5-meter-tall solar tracker (*Figure 3*) with 1-in-portrait (1P) bifacial modules and an inter row pitch of 6 meters, considering a Ground Coverage Rate (GCR) of 31.47%. Wheat crops were cultivated in six randomized planting beds, with each bed measuring 6x1 meters, positioned perpendicular to the panel structures, as shown in *Figure 4*. With the proposed Design of Experiment (DOE) – planting beds perpendicular to the trackers – it was possible to map productivity as a function of solar radiation.

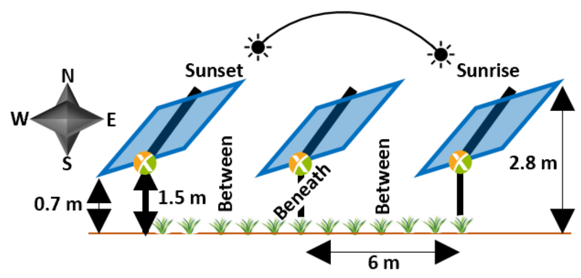

Figure 3. *Tracker schematic.*

Figure 4. *Design of Experiment (DOE).*

For the purpose of this feasibility study, productivity data was extrapolated to one hectare, assuming that the agricultural part of the Agrivoltaic system occupies two-thirds of the total area. This accounts for the areas underneath the modules, which were not cultivated due to lower plant productivity and to simplify tracker maintenance. The spacing between rows was fully compatible with standard agricultural machinery, measuring approximately 20 feet (about 6.1 meters) - machinery for soil preparation, planting, and harvesting. The study considered the wheat season to be four months long, and since it is considered a winter crop in the study region.

Solar radiation data was collected from two locations between the PV array rows, beneath trackers and the agricultural area, at one-minute intervals from July 2023 to September 2023, using an SN-522-SS Modbus Net Radiometer, which collected the photosynthetically active radiation (PAR). PAR indicates how much electromagnetic radiation is reaching the crop canopy and is available for plants to use as a source of energy for photosynthesis and their development/growth [5]. Researchers used stomatal conductance of leaves as an indicator of water stress, measured with an AP4 Porometer by Delta-T. Manual measurements with calipers and rulers were carried out to check the development of the plants, as well as weighing to control productivity. Productivity was measured by harvesting three one-square-meter plots, and the threshed wheat from these plants was weighed on a precision scale.

3. Results and Discussion

As this was an exploratory study with several variables to pre-assess AgriVoltaics and its influences on agricultural production and energy generation, the results and discussions were divided into parts.

3.1 Solar radiation behavior between trackers

Shading was observed at the beginning and end of the day in the AgriVoltaics area between the rows of PV panels (see Figure 5). This shading is characteristic due to the shadows cast by the tracker structures, which act as physical obstacles to the passage of radiation compared to the Regular Agriculture area. Similarly, it was also noted that there is a longer period of shading in the afternoon for the sensors installed in the AgriVoltaics area at the west drip-end of the structures. It is expected that this behavior will also be mirrored, with higher shading in the morning for sensors installed at the east drip-end of the structures in the AgriVoltaics area. For this study, it was not possible to collect this data due to the lack of a sensor; however, it is being considered for future steps.

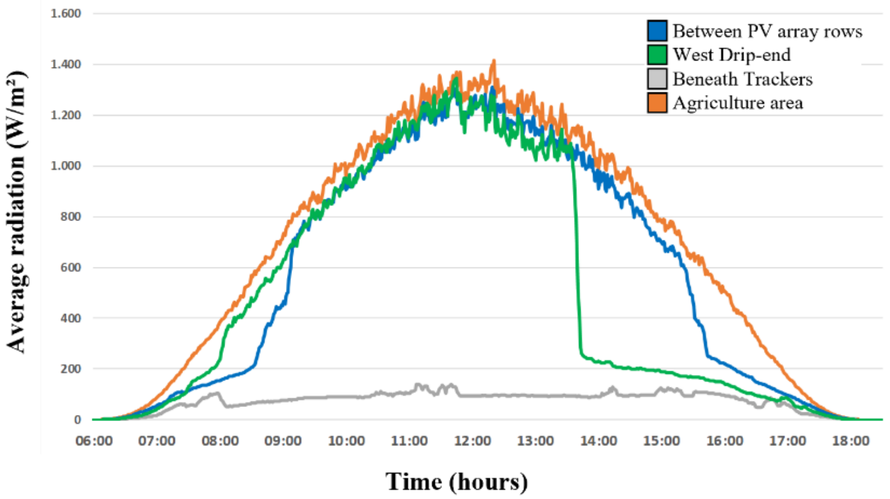

Figure 5. *Average radiation behavior from Jul-Sep/2023.*

3.2 Wheat production behavior between trackers

To better understand the influence of the planted location between the trackers in this exploratory study, wheat harvesting was carried out in randomized plots for the six repetitions (see Table 1). It is notable that despite the differences in productivity, the Tukey test reveals a significant difference with 95% reliability only for cultivation under the trackers compared to the other locations. Therefore, the productivity between AgriVoltaics (between the PV array rows) and Reference Agriculture does not present statistically significant differences; they are similar. This finding aligns with observations by Bhandari *et al*. (2021) [6], which also reported around 12 tons/ha when wheat was harvested between the arrays.

Table 1. *Wheat productivity (tons/ha) in different AgriVoltaics scenarios compared to Reference Agriculture.*

Repetition	AgriVoltaics				Agriculture
	Between the PV array rows *Sunset*	**Beneath the PV array rows**	**Between the PV array rows *Sunrise***	**AgriVoltaics *Average Sunset + Sunrise***	
1	17.61	5.37	7.86	12.74	14.32
2	10.44	5.66	9.54	9.99	17.18
3	10.20	3.71	9.80	10.00	11.13
4	9.03	1.87	7.69	8.36	6.72
5	14.72	1.93	10.32	12.52	6.56
6	12.40	3.71	9.04	10.72	16.34
Average ± Error	12.40 ± 2.96	3.71 ± 1.48	9.04 ± 0.97	10.72 ± 1.52	12.04 ± 4.27
Tukey's test | %	*a | 103%*	*b | 31%*	*a | 75%*	*a | 89%*	*a | 100%*

Considering the reference agricultural productivity as 100%, productivity between PV array rows on the sunset side was 103%, compared to 75% between PV array rows on the sunrise side and 31% beneath PV array rows. The average across PV array rows (average of sunset and sunrise sides) was 89%. These wheat productivity results fall within the range found by Weselek *et al.* (2021) [3]. The low average radiation present beneath the trackers (Figure 5) directly influenced agricultural performance, as shown in Table 1. In addition to productivity, crop growth – both physiological and morphological – was also studied. Researchers collected data on wet and dry mass, plant diameter and height, and stomatal conductivity (see Table 2). For this more specific study, AgriVoltaics was considered as the average of data collected from plants grown only between the PV array rows (average of sunset and sunrise).

In general, it was observed that despite the dry and wet mass being statistically similar for AgriVoltaics and Regular Agriculture, according to the Tukey's test, the shade influenced the development of wheat in AgriVoltaics. The smaller diameter of the AgriVoltaics plants indicates signs of etiolation, suggesting a lack of sufficient radiation. Furthermore, AgriVoltaics systems observed a 40% reduction in irrigation requirements due to reduced evapotranspiration. This indicates that the increased water content in the AgriVoltaics wheat leaves signifies greater water availability for the plants, consequently reducing water stress. This behavior of lower evapotranspiration in AgriVoltaics and similar wheat production compared to Regular Agriculture was also found by Pataczek *et al*. (2023) in their studies [7]. Due to the high soil moisture and low evapotranspiration, AgriVoltaics wheat grains had a higher moisture content of 11%.

Table 2. *Plant growth in AgriVoltaics (Agri-PV) and Agriculture (Agri).*

Repetition	**Parameters**									
	Production of Fresh Mass (g)		**Production of Dry Mass (g)**		**Plant diameter (cm)**		**Plant height (cm)**		**Stomatal Conductivity**	
	Agri	**Agri-PV**	**Agri**	**Agri-PV**	**Agri**	**Agri-PV**	**Agri**	**Agri-PV**	**Agri**	**Agri-PV**
1	32,23	28,66	28,04	20,13	4,89	3,48	72,00	71,78	28,62	42,98
2	38,66	22,48	33,63	16,73	4,69	3,57	76,22	66,00	39,83	56,30
3	25,04	22,51	21,78	13,48	4,74	4,31	65,33	57,89	19,10	38,59
4	15,12	18,81	13,15	12,12	3,91	3,86	61,00	59,22	17,77	46,33
5	14,76	24,13	12,84	16,01	4,53	3,34	65,89	54,33	28,40	36,17
6	36,76	28,18	31,98	17,60	4,83	4,93	76,50	67,78	19,43	38,44
Average ± Error	27.10 ± 9.60	24.13 ± 3.43	23.57 ± 8.35	16.01 ± 2.63	4.60 ± 0.33	3.91 ± 0.55	69.49 ± 5.82	62.83 ± 6.11	25.53 ± 7.76	43.14 ± 6.77
Tukey's test | %	a | 100%	a | 89%	a | 100%	a | 68%	a|100 %	b | 85%	a | 100%	a | 90%	a | 100%	b | 169%

3.3 Performance behavior

Considering data were collected during the winter season in Sorocaba, Brazil, the energy generation performance was measured at 2354.82 kWh/kWp-year for AgriVoltaics and 2462.26 kWh/kWp-year for the area exclusively dedicated to photovoltaic energy generation. This resulted in a 4% reduction in energy generation for the AgriVoltaics setup. It is important to note that these results reflect the use of different panel technologies in each area, which may have influences performance. To address this, a new structure with standardized panel technology is being installed to eliminate this variable in future studies.

4. Conclusion

Mechanized wheat farming seamlessly aligns with a 1.5-meter tall 1-P tracker, eliminating the necessity of using extra tall solar trackers that cause extra costs and environmental impacts. Comparing the wheat productivity between Regular Agriculture and AgriVoltaic systems showed no significant wheat productivity loss but yielded significant water savings. The results of this study support the idea that dual land use is economically viable for both energy providers and the local agricultural economy.

Data availability statement

The data presented in this paper is restricted by legal constraints.

Author contributions

Milena Chanes de Souza contributed by leading the technical aspects of the experiment design and the overall organization of this study. Ricardo Castro Nery provided technical support for all assessments and cultural treatments in agriculture. Benhur Azambuja Possato contributed with the technical expertise to the performance studies. Matthias B. Krause and Sol Hutson contributed by aligning the research methodology with the client's know-how, managing the technical aspects of the study, and reviewing this article.

Competing interests

The authors declare that they have no competing interests.

Funding

The authors express their gratitude to FIT and Nextracker for their financial and structural support.

Acknowledgement

The authors express their gratitude to FIT and Nextracker for their invaluable partnership in Research and Development between Brazil and United States.

References

[1] Expert Market Research (EMR), “Global Buckwheat Market Report and Forecast 2024-2032,” in Agriculture and Farming, https://www.expertmarketresearch.com/reports/buckwheat-market (February 20th, 2025)
[2] United States Department of Agriculture (USDA), “Crop Production Maps,” 2023, https://ipad.fas.usda.gov/ogamaps/cropproductionmaps.aspx (February 20th, 2025)
[3] W. Axel; B. Andrea; H. Jens; Z. Sabine; L. Iris; H. Petra, “Agrivoltaic system impacts on microclimate and yield of different crops within an organic crop rotation in a temperate climate,” in Agronomy for Sustainable Development, 2021, 41:59, doi: https://doi.org/10.1007/s13593-021-00714-y
[4] A. Stefano; Y. Xinyou; C. Michele, “Agrivoltaic systems to optimize land use for electric energy production,” in Applied Energy, 2018, vol.220, pp. 545-561. doi: https://doi.org/10.1016/j.apenergy.2018.03.081
[5] M. Lu. Silvia; Z. Sebastian; B. Stridh; A. Avelin; A. Stefano; C. Michele; E. C. Pietro, “Photosynthetically active radiation decomposition models for agrivoltaic systems

applications," 2022, vol.244, pp. 536-549. doi: https://doi.org/10.1016/j.solener.2022.05.046

[6] S. N. Bhandari; S. Sabine; K. Wilhelm; S. Holger; A. Rabani; B. Ramchandra, "Economic Feasibility of AgriVoltaic Systems in Food-Energy Nexus Context: Modelling and a Case Study in Niger," in Agronomy, 2021, vol.11, pp. 1-22. doi: https://doi.org/10.3390/agronomy11101906

[7] P. Lisa; W. Axel; B. Andrea; H. Petra; L. Iris; Z. Sabine; S. Andreas, "Agrivoltaics mitigate drought effects in winter wheat," in Physiologia Plantarum, 2023, vol.175, doi: https://doi.org/10.1111/ppl.14081