

# Impacts of a Vertical Bifacial Agrivoltaics System on Field Corn in Northern Colorado, USA

## Performance of Silage Corn in the Establishment Year

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**Abstract.** The integration of vertical bifacial photovoltaic (PV) modules in agrivoltaics (AV) systems presents a novel opportunity to optimize land use by co-locating energy and food production. Vertical racking systems hold bifacial panels upright and stationary so that they can absorb sunlight from both sides while eliminating the need for sun-tracking mechanisms and large land footprints. This study evaluated the impact of vertically installed bifacial PV panels on the growth and productivity of silage corn during the 2024 growing season. Corn was planted between north-south oriented PV panel rows, with the following treatments: center, east (morning light/afternoon shade), west (morning shade/afternoon light), and an unshaded control with three replicates. Results showed no significant differences in silage or grain yields across treatments ( $p > 0.05$ ), indicating this vertical PV system did not negatively impact crop productivity. However, significant differences in instantaneous net photosynthetic rate (Pn) and photosynthetically active radiation (PAR) were observed ( $p < 0.05$ ), with the solar-east treatment exhibiting the highest Pn and PAR levels in the morning. These results support the viability of vertically mounted bifacial PV systems on a shade-sensitive crop. Furthermore, such systems can sustain corn productivity while accommodating energy infrastructure.

**Keywords:** Agrivoltaics, Silage Corn, North-South Oriented Solar Panels

## 1. Introduction

Bifacial solar modules installed vertically in fence-like rows is an innovative PV design aimed at enhancing land-use efficiency in AV systems (Figure 1). Vertical racking systems hold bifacial panels upright and stationary so that they can absorb sunlight from both sides while eliminating the need for sun-tracking mechanisms and large land footprints. This makes them a good candidate for co-locating solar production with agriculture, as they minimize land occupation while still producing substantial energy. This design is particularly well suited for agricultural settings because it allows for the interoperability of large-scale farming equipment between panel rows, reduces installation and maintenance costs, and limits land disturbance. The customizable row spacing also enables better integration with row crop production systems, offering additional flexibility to farmers.

The United States is the largest global producer of corn. In 2022/23, the USA was responsible for almost one-third of the world's corn production. Most of the corn grown in the USA is agronomic field corn. Colorado ranks tenth in corn silage production in the USA with a yield of 54,920 kg/ha fresh weight and production of  $5.22 \times 10^9$  kg in the year 2023 [1].

Implementing AV systems in corn fields offers a strategic opportunity to optimize land use while preserving productive farmland. To evaluate this potential, a vertical bifacial system was installed in northern Colorado and planted to field corn to integrate photovoltaics infrastructure and assess crop productivity. These insights will inform best practices for AV deployment and contribute to the development of scalable, efficient, and sustainable land-use solutions.

Recent studies by Jansson et al. [2] have highlighted that, in many regions of the United States, the expansion of utility-scale solar energy projects face constraints due to land-use competition and localized opposition, particularly in areas where prime agricultural land coincides with high solar potential [3-4]. This intersection has prompted growing interest in AV systems, which aim to integrate crop production with PV energy generation on the same land. A significant body of research has examined the competing demands of food and energy production and increasingly points to AV as a promising dual-use strategy to address these challenges [5–11]. By reducing spatial conflicts and enhancing land-use efficiency, AV presents a compelling opportunity to promote sustainable energy development. Notably, estimates suggest that allocating less than 1% of global cropland to such systems could substantially offset worldwide energy needs [12]. Existing research with corn grown under fixed PV modules has shown promising results with minimal yield losses that can be mitigated by the revenue produced from PV power generation [13]. To our knowledge, there has been no prior research on vertical bifacial agrivoltaics systems in corn production in Colorado.

The objective of this experiment was to evaluate the agronomic performance of flood-irrigated field corn planted in the establishment year of a vertical bifacial agrivoltaics system in northern Colorado, USA.

## 2. Experimental Methodology

A vertical bifacial PV system (Sunzaun, Novato, CA, USA), consisting of three fence-like rows of 10 panels each, was installed in April 2024 at Colorado State University's Agricultural Research, Development, and Education Center-South (ARDEC-S) in Fort Collins, Colorado, USA. The panel rows were oriented north-south and spaced 10.7 m apart. Silage corn hybrid '195-51STXRIB' (Bayer Crop Science, Leverkusen, Germany) was planted on 8 May 2024. Each PV module measured 1001 mm × 2031 mm and was installed with a ground clearance of approximately 0.6 meters (2 feet).

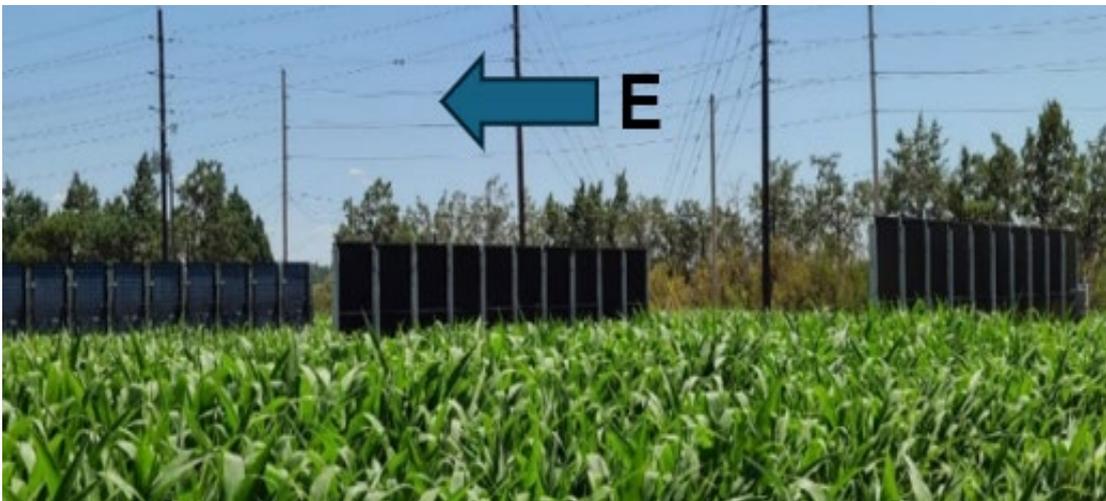
Corn was seeded in rows spaced 76 cm apart, with 13 crop rows established between each set of solar panel arrays (Figures 1 and 2). To minimize edge effects, corn was sown continuously between the solar panels and in a half-hectare area surrounding the experiment. Each experimental unit consisted of one row of 10 bifacial PV panels. Complete block design (CBD) was used, and randomization of treatments was constrained by the fixed array configuration and the need to maintain interoperability with standard farm equipment. Therefore, treatment placement was adjusted to accommodate operational logistics while maintaining experimental validity.

The experimental design included four treatments (13.7 m x 4 rows each treatment plot) each with 3 replications. The control treatment was corn grown on the southern end of the solar panel rows that experienced no shading. The three solar treatment groups consisted of; (1: east) corn rows located directly east of the panels that experienced unobstructed morning light with afternoon shading, (2: west) corn rows located directly west of the panels experiencing morning shading with full afternoon sun, and (3: center) corn rows centrally located between solar panel rows. The corn crop was flood irrigated once a week throughout the growing season, following the standard practice in Colorado, and did not experience drought stress.

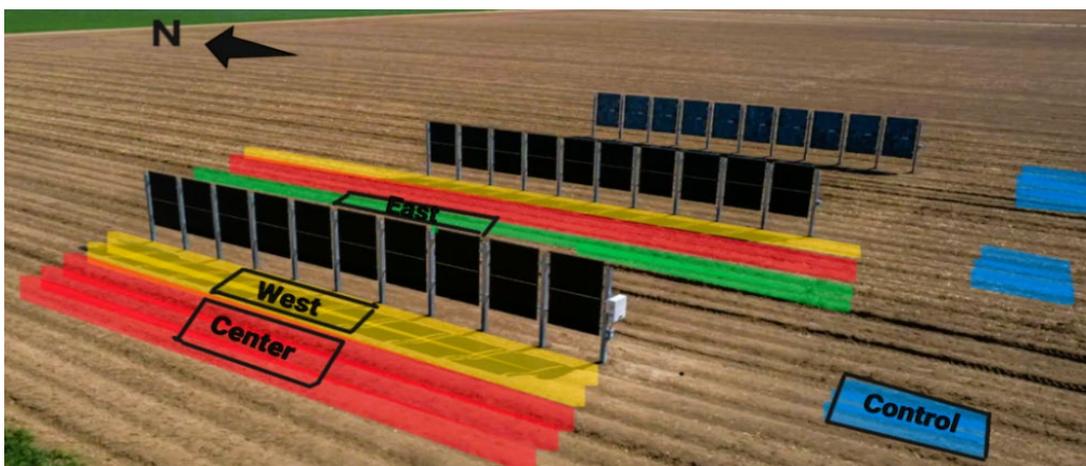
Gas exchange survey measurements were conducted on 20 September 2024, between 09:00 AM and 11:00 AM, using a LICOR 6400xt portable photosynthesis system (LICOR,

Lincoln, NE, USA). Three randomly selected corn plants were chosen from each treatment for gas exchange measurements. The system was used to directly measure photosynthetically active radiation (PAR), CO<sub>2</sub> and H<sub>2</sub>O exchange (in and out of the chamber), incident and transmitted light and leaf temperature. From these measurements, we calculated net photosynthetic rates. All measurements were taken under ambient light using the clear-top chamber with CO<sub>2</sub> concentration set to 400 ppm and ambient temperature and humidity conditions maintained throughout the data collection.

To assess silage biomass yield, twelve randomly selected corn plants per plot were destructively harvested on 24 September 2024. To minimize edge effects, plants from the northern and southern edges of the plots were excluded from sampling. The remaining plants were left to mature in the field until 8 November 2024 (Fig 3), when two – 13.7 m rows of corn per plot were harvested with a small plot research combine to collect grain yield data. The grain moisture content ranged from 12.6% to 26.6% at harvest and was standardized to 15% moisture content for analysis of data.



**Figure 1.** The location of four treatments shown between three vertical bifacial photovoltaic rows at Colorado State University's Agricultural Research, Development, and Education Center South in 2024



**Figure 2.** Field corn growing between the three vertical bifacial photovoltaic rows at Colorado State University's Agricultural Research, Development, and Education Center South in July 2024



**Figure 3.** Corn grain harvest from the vertical bifacial photovoltaic site at Colorado State University's Agricultural Research, Development, and Education Center South in November 2024

### 3. Results and Discussion

Statistical analysis was conducted using R version 4.2.2. and data were subjected to single factor analyses of variance (ANOVA) to identify significant differences for each measured variable. The ad-hoc procedure for mean separation is based on Fischer's protected least significant difference ( $p < 0.05$ ). These results are based on a single year (2024) of data collection. Interestingly, all measured factors for silage and grain yield were statistically insignificant regardless of their location relative to the PV modules (Table 1). The average Pn and PAR of the solar-east and control plots was significantly higher ( $p=0.0215$  and  $p=0.0327$  respectively) than the solar-west treatment. Results from the Sturchio et al. [14] study showed that in the semi-arid grassland ecosystem where the above-ground net primary production (ANPP) measured at the end of the growing season was significantly higher at the eastern edge of PV panels than all other experimental and control plots ( $p < 0.001$ ), which is similar to our results of Pn and PAR. Riaz et al. [15] introduced a crop-specific metric that indicated potential AV performance for a given PV array design. They found among fixed tilt systems, vertical bifacial solar systems were particularly promising because they produced the smallest variability in seasonal yield in corn. Another study by Tahir and Butt [16] explored daily and monthly PAR variations under various tracking and fixed-tilt AV configurations and proposed strategies to minimize shade-induced crop yield loss. They found that vertically installed PV modules facing east-west provided the best spatial homogeneity and a higher intensity of net daily incident PAR. The spatial variation in the crop yield correlated well with that of the net daily PAR spatial pattern in the case of the shade sensitive crops (e.g., tomato).

**Table 1.** Field corn silage and grain yield, net photosynthetic rate, and photosynthetic active radiation impacts when grown in a vertical bifacial PV system in Fort Collins, CO, USA.

Treatment	Silage Yield (kg/12 plants)	Grain Yield (kg ha <sup>-1</sup> ) <sup>z</sup>	Net Photosynthetic Rate (Pn) (μmol CO <sub>2</sub> ·m <sup>-2</sup> ·s <sup>-1</sup> )	Photosynthetically Active Radiation (PAR) (μmol·m <sup>-2</sup> ·s <sup>-1</sup> )
Solar - Center	9.4 ay	8963 a	Not measured	Not measured
Solar - West	10.1 a	9523 a	1.1 b	53 b
Solar - East	8.7 a	7283 a	4.2 a	268 a
Control	8.8 a	9399 a	3.2 a	145 ab
p-value <sub>x</sub>	0.8220	0.4827	0.0215	0.0327
SD	2.0	1896	0.98	73
LSD	3.7	3569	1.96	147

<sup>z</sup> Grain yield at 15% moisture content sample size of 13.7 m x 2 rows converted to kg/ha.

<sup>y</sup> Means within a column followed by the same letter are not significantly different based on Fisher's protected least significant difference (p<0.05).

<sup>x</sup>p-values reported for each column are based on three replicates of data subjected to single factor analyses of variance.

## 4. Conclusions

Results from 2024 indicate there may be a small numerical increase in silage and grain yield on the western side of the panels, although it was not significant in this single year of data collection. Additional seasons of data with silage corn would help to confirm this result.

Instantaneous PAR and Pn measurement results from the Licor-6400xt confirm the significant short-term shading effect of the panels on the corn crop. In this study we saw significant and expected PAR and Pn differences in our "snapshot" survey measurements on 20th September in the fall. However, these differences did not translate to season-long yield differences. Time of day and shading duration will influence which side of the panels may show season long shading effects, if present. Although this work demonstrates potential integration of vertical bifacial infrastructure into an agronomic crop, there are also potential problems. These include the crop shading panel surfaces, while the panels can restrict light penetration into the crop canopy. In addition, there is also a risk of mechanical damage to panels during field operations (for example- mechanical seeding, spraying).

## Data Availability Statement

Data supporting the results of this manuscript can be accessed in the FAIR-aligned public repository, FAIRDOMHub. DOI: <https://doi.org/10.15490/fairdomhub.1.datafile.8043.1>

## Author Contributions

The authors' contributions are as follows: DK was involved in investigation, writing reviews and writing the original draft. JD was responsible for data curation, data analysis, visualization and editing. MEU was responsible for conceptualization, funding acquisition, methodology, project administration, supervision, and validation.

## Competing Interests

The authors declare that they have no competing interests.

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