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Clean Energy Extension

Butternut Squash and Lettuce Production Under Agrivoltaic Solar Array in Grafton, MA

Information Sheet: First Year Preliminary Results
March 2024

Agrivoltaics is the simultaneous production of both solar energy and crops on the same land. This entails trade-offs that are poorly understood and requires optimization between two objectives for which there is little research-based guidance. The presence of solar panels above the crops can modify the microclimate variables such as light intensity, photoperiod, and temperatures. To study the dynamics of agrivoltaic systems on crop production, two different crops were chosen for the experiment under an on-farm solar array in Grafton, MA in 2023. Butternut squash, known as heat tolerant and sun-loving, and lettuce, characterized as cool-seasoned and shade tolerant, with contrasting growth requirements, can provide valuable insights about the potential and challenges of integrating crop and energy production using agrivoltaics. Changes in the sun's angle, panel height and orientation, tracking system, and spacing between panels create distinct microclimate environments for crops underneath panels. Therefore, we evaluated microclimate variables such as photosynthetically active radiation, relative humidity, air temperature , and soil temperature at different transect positions throughout the crop growing seasons along with crop growth and yield of butternut squash and lettuce.

Materials and Methods

The soil type was Paxton fine sandy loam with a pH of 5.9; additional soil analysis was done before and after construction but is not reported here. This field had historically been used for hay and grazing and wooded field edges and did not experience frequent tillage in recent years, until 2022. The array is a southeast-facing (azimuth 135 degrees) fixed-tilt configuration constructed in 2021 with a capacity of 0.24 MW DC. The height of the lowest panel edge is 10.5 ft. Panels are 3.25 by 6.5 ft. and arranged vertically so that the edge-to-edge table length is 13 ft. Every third panel was removed within the racking table to reduce shading, such that there are grids of four panels 6.5 by 13 ft. alternating with gaps of 3.25 by 13 ft. The space between panel edges (between the front edge of one row and the back edge of the next row) is 16.7 ft. The shading tool used by Massachusetts Department of Energy Resources to evaluate dual-use applications calculated that this configuration should result in 64.5% of the array experiencing shading of 30% or less between March and October, 31.8% of the array experiencing shading of 30%-40%, and 3.7% experiencing shading of 40%-50%. The projected maximum

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shade is 46% and the average shade is 26%. Butternut squash was directly seeded on June 1, 2023, and Boston lettuce was transplanted on May 15, 2023. One replication contained four rows of butternut squash and four rows of romaine lettuce (Fig.1). Two crops were separated by one line of solar panels. The microclimate sensor stands were installed only in the butternut squash field in four beds: 1) leading panels (BP 1), 2) between two panels (BP 2 and BP 3), and 3) under the back panel (BP 4) replicated three times (Fig. 2) to measure variations compared to control and within the array.

Figure 1. Experimental layout of butternut squash and lettuce under array and control.

Figure 2. Field layout of butternut squash.

Figure 3. Field layout of lettuce.

The control area was located near the fence line due to space limitations. A sensor mounting system was designed for stability, accurate data collection, and ease of installation and periodic removal to accommodate farm operations (Fig. 4). The wireless sensors gathered data every 5 minutes on photosynthetically active radiation (PAR), leaf wetness, rainfall, ambient temperature (Tair), relative humidity (RH), and temperature. Microclimate sensors on removable field stands (with construction details published in a separate fact sheet) were installed in both the array and control on May 26, 2023, and removed from the field on Nov 15, 2023.

The chlorophyll index (CI) was measured three times non-destructively with the portable SPAD 502 Chlorophyll Meter (Minolta Co., Ltd.) in butternut squash leaves on July 20, August 3, and August 17, 2023.

An independent sample t-test was conducted to compare the control group with each bed position within the array. To compare the effects of bed positions within the array without control, one-way analysis of variance (ANOVA) was done. Mean separation for statistically significant effects was performed using Tukey’s HSD test.

Figure 4. Mounting unit assembly with sensors.

Preliminary Results

Microclimate variables:

- Mean and maximum PAR were significantly higher in control than array, except BP 3.
- PAR values (mean, median, and maximum) were highest in the following order: BP 3 > BP 2, BP 4 > BP 1 within the array.
- Higher air temperature (Tair) but lower relative humidity (RH) in control than in array.
- Similar mean and maximum Tair within different bed positions in the array.
- Mean soil temperature (Tsoil) was higher in control than BP 1 and BP 2 under array.
- Mean Tsoil was highest in BP 4 and lowest in BP 1 within the array.

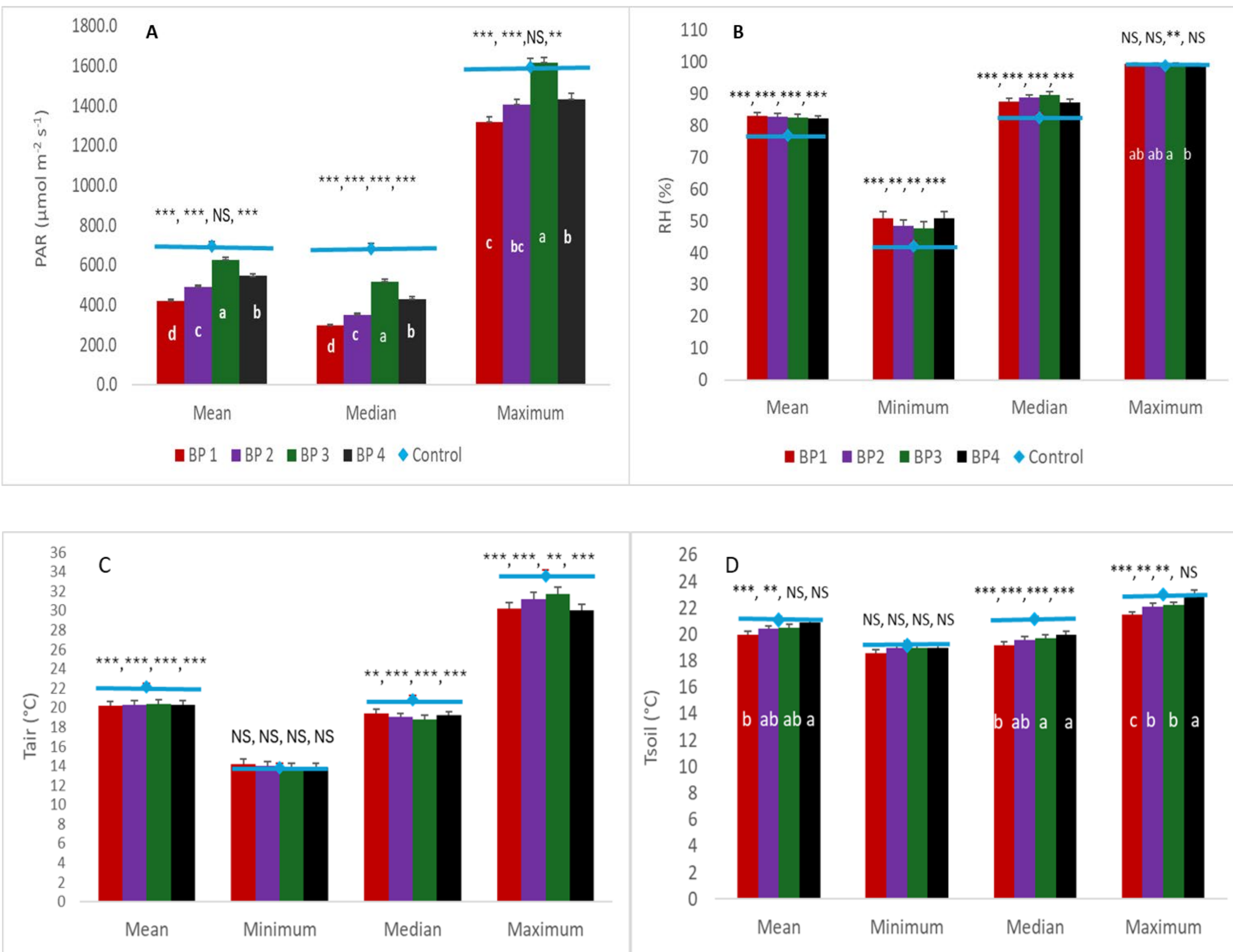

Figure 5. Variables measured in control and three different bed positions within the array in butternut squash. Treatments with the same letter are not significantly different from each other.

A) Photosynthetically active radiation (PAR)
B) Relative humidity (RH)
C) Air temperature (Tair)
D) Soil Temperature (Tsoil)

Crop response:

- There was a strong negative correlation between mean chlorophyll index (CI) and mean PAR. This response was probably due to the adaptive nature of butternut squash under low light conditions that allow them to capture available light energy for photosynthesis.

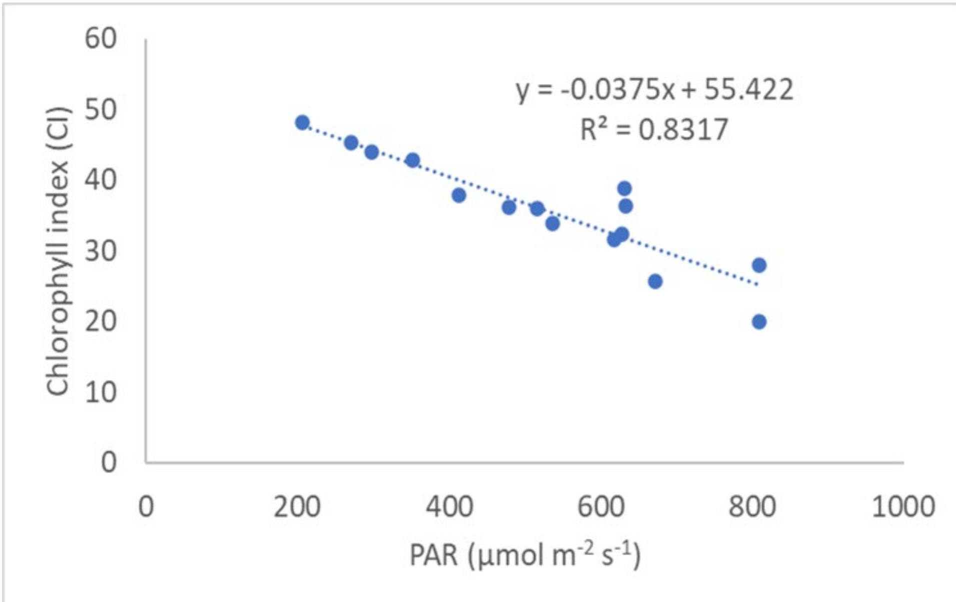

Figure 6. Relationships between chlorophyll index (CI) and PAR under array and control in butternut squash.

The current study captures the overall impacts of solar panels on microclimate variables of the entire crop season on average. To get a deeper understanding of daily, weekly, and monthly variations in microclimate in different bed positions under the array and control areas, further analysis will be conducted using time-series methods. In addition, factors like weed pressure in control areas and heavy rainfall in 2023 added complexity to crop yield and biomass data of both butternut and lettuce. Lessons learned in 2023 will be applied during the 2024 season.

This information sheet has been prepared by Mamata Bashyal, PhD, Post-Doctoral Researcher, in coordination with Samantha Glaze-Corcoran, PhD and Clem Clay, UMass Extension. For more information about this project, visit: https://ag.umass.edu/clean-energy/research-initiatives/solar-agriculture/researching-agricultural-economic-impacts-of-agrivoltaics-dual-use-solar