Quarter 2 and 3 Report

APV Phase Two

— March-August 2024 —

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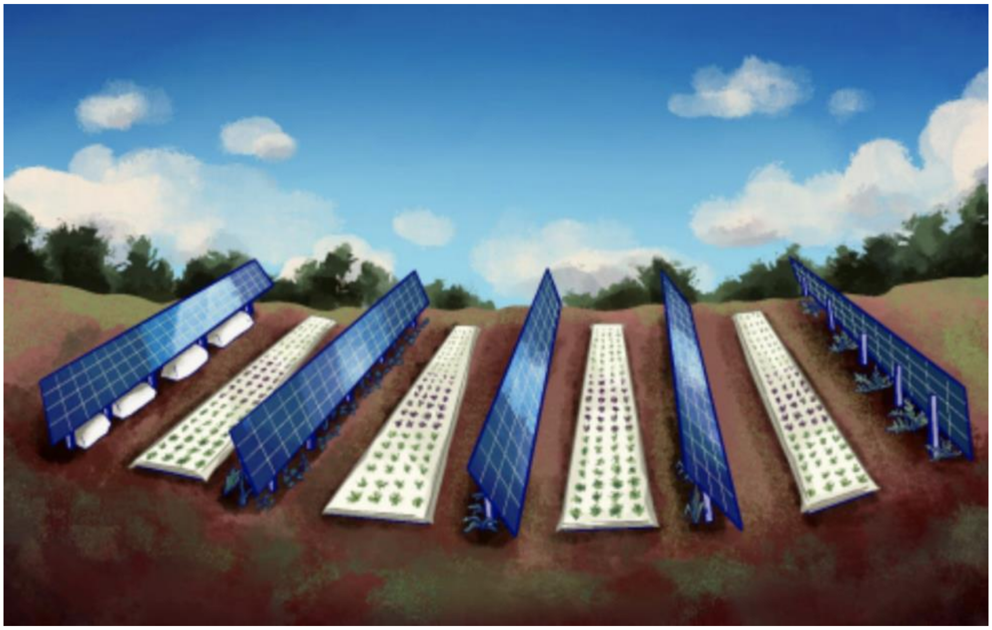


Executive Summary

- **Demonstration Site Update**
    - New perennial crops planted in under panel 3 including Tea, Coffee, Tamarillo,
    - Ginger, and Poha Berries
    - Two 180 ft rows of Quinault strawberries were planted for a crop screening process. Pending results, it could be moved up to a variety trial.
    - Honey from the demonstration site was harvested to give as gifts (makana) for tours.

- **Mililani 1 Crop Reporting**
    - Groundwork for establishing agrivoltaic plots in utility scale photovoltaic footprints.
    - Reorientation of the control plot and low maintenance redesign of experimental plots.
    - Experimental design details and comparison reports for tomatoes, broccoli, and cauliflower.
    - Crop Plan for the remainder of the year and ongoing data collection for comparison trials.

Lanikuhana Demonstration Site Updates

Updates

Vegetable Crop Screening Blocks

Between March and August, each 180-foot bed at the demonstration site was planted with new crops and a few varieties of previously tested crops with 12 different vegetable crops planted (Table 1). Preliminary results from blocks featuring novel crops such as 'Red Meat' radish, Tango celery, and Britton shiso show promise as potential high-value or import replacement crops, identified for larger-scale trials once field space becomes available.

Table 1. List of vegetable crop varieties trialed at demonstration site during March-August 24'.

Crop	Variety
Brussel Sprouts	*Purple*
Bok Choy	
Carrots	*Bolero*
Celery	*Pink*
	Tango
Radish	*Red Meat*
	Bravo
Peppers	*Brown Jalapenos*
Shiso	*Britton*

Due to its short growing period, Bravo purple radish was planted alongside the asparagus trial in two 180-foot lines; the two lines of Bravo radish produced over 500 pounds of radish that were subsequently donated to Aloha Harvest. Following the radish harvest, the bed was tilled, reshaped, and reseeded with two carrot varieties new carrot varieties and with an expected harvest in late September.

In early August, a larger-scale screening of Quinault strawberries was planted on the west and east sides of the perennial crops. Bred by Washington State University, this variety produces high-quality fruit and has been grown successfully in Waialua's full-sun plots. Growing strawberries within an agrivoltaic (APV) system presents an opportunity to improve yields and fruit quality by reducing heat stress, extending the growing season, and potentially increasing water efficiency. We also harvested approximately 25 pounds of honey from our onsite hives (Image 1). The honey will be used as gifts for our visitors and guests.

Exploiting the Microclimate

The underutilized spaces directly under the panels, which provide the most shade, would be difficult to cultivate within APV systems and present unique opportunities for innovative crops, such as cultivating culinary mushrooms on logs made from invasive tree species. Utilizing these shaded areas for mushroom production could offer dual benefits: addressing an invasive species issue while producing a high-value crop in Hawaii's food market. These systems could help diversify local agricultural outputs and increase profitability for farmers.

We have also integrated native Hawaiian plants like Maile (*Alyxia stellata*) and others traditionally used for lei-making and cultural practices into our agrivoltaic demonstration site that could potentially provide both ecological and economic benefits. Maile, a vine-like plant highly valued for its use in lei, thrives in shaded environments, making it well-suited for the microclimates created under solar panels. Cultivating Maile in these conditions can support both the local lei industry and the preservation of cultural traditions while promoting biodiversity and conservation of native species. Other native plants, such as palapalai fern, ʻilima (*Sida fallax*), and other native plants, could also be cultivated in shaded areas under solar panels, contributing to cultural preservation and sustainable production of materials for traditional Hawaiian ceremonies and practices. These plants play an important role in maintaining cultural connections and supporting local artisans and florists who rely on sustainably grown native species for lei production and most of which have a low-water demand.

Our one-and-a-half-year-old māmaki *(Pipturus albidus)* planting takes full advantage of the consistent shading provided by the panels. Māmaki, a native plant used to make medicinal tea, benefits from the moderated temperatures in agrivoltaic systems, where reduced light stress could enhance both growth and flavor. This native plant holds significant economic potential, given the rising demand for māmaki tea in both local and global markets.

Our trellis demonstration garden includes vanilla, another high-value crop that can also thrive in the shaded, controlled environment under solar panels. Vanilla cultivation, which typically requires partial shade and stable temperatures, fits well into agrivoltaic systems and has shown promising results through the duration of our time at the demonstration site. This integration not only reduces land use conflicts but also provides farmers with an additional source of income from a valuable, in-demand product. By incorporating native Hawaiian plants and high-value crops like vanilla into agrivoltaic systems, we can enhance ecological health, support cultural practices, and boost economic sustainability for local communities.

The ongoing maintenance of these diverse crops at our demonstration site not only supports potential future formal agrivoltaic research but also plays a crucial role in public engagement and potentially sparking the interest of farmers, both new and seasoned, who are interested in innovative systems. The site has become a vital resource for tours that help the public and policymakers understand the potential and versatility of agrivoltaic systems, showcasing how these systems can support a variety of crops and provide multiple benefits for local food production and sustainability.

Cover Cropping

We have also integrated cowpea and buckwheat as cover crops into our beds, serving both educational and soil health purposes. These cover crops bring numerous benefits to the demonstration and research sites, including improved soil structure, enhanced nitrogen fixation, and weed suppression. Cowpea, being a legume, contributes to nitrogen enrichment, improving fertility for subsequent crops, while buckwheat rapidly grows and shades out weeds. Both cover crops support microbial diversity, increase organic matter, and reduce erosion, making them valuable components for maintaining long-term soil health and demonstrating sustainable agricultural practices during tours and educational sessions.

Image 1. Demonstration site update from left to right: Three hives, Maile trellis planting, , Strawberry (*Quinault*) planting, Carrots (*Bolero*) developing.

Image 2. Demonstration site update from left to right: Bravo Purple Radish, Britton Shiso, Cowpea and Buckwheat cover crop.

Asparagus Trial Update

We tested asparagus as a perennial crop under solar panels presents an opportunity to explore its potential as a low-maintenance, passive crop in agrivoltaic systems. Asparagus, with its deep root system and ability to thrive for decades once established, is well-suited for long-term production under the partial shade provided by solar panels.

We wanted to test asparagus because to date, there is very little information about their performance in agrivoltaic production. By growing asparagus directly beneath solar arrays, this perennial crop can serve as a "bumper" crop, requiring minimal intervention while taking advantage of the moderated microclimate and reduced water evaporation. The integration of asparagus into agrivoltaic systems could increase land-use efficiency and diversify farm income with minimal additional labor. For our planting, we chose four unique varieties: two recommended by CTAHR for their high yield and two selected for their potential market value. We selected Jersey Giant and Jersey Knight for yield, and Purple Passion and Millennium for their high market value. The crowns purchased from Urban Farmer were all the same price per crown except for the Millennium which cost $1 per crown (Table 2).

Image 3. After one year of growth, asparagus was pruned and regrowth harvested for market.

To date, yields have been light, each variety performing similarly both in vigor of growth as well as yield. Yields for the 180-foot panel were about 10 pounds of marketable yield after the first pruning cycle. We are currently letting the crowns reestablish for another heavier harvest in the last quarter of 2024. We are anticipating larger harvests from the planting and differentiation once the plants have longer to establish in the ground. Asparagus harvests can take up to two years to fully develop (CTAHR, 2000).

Table 2. Actual Cost and Visual representation of Asparagus varieties provided by Urban Farmer

Asparagus Variety	Urban Farmer Representation	Quantity (Crowns)	Total Cost
Purple Passion		50 Crowns	$45.00
Jersey Giant		50 Crowns	$45.00
Jersey Knight		50 Crowns	$45.00
Millennium		50 Crowns	$50.00

Perennial Screening Progress

Establishing a small perennial block trial under solar panels presents a unique opportunity to evaluate long-term crop performance in agrivoltaic systems. Perennial crops, which typically require multiple years to reach full maturity, allow for the study of interactions between crop growth, microclimatic conditions, and solar panel shading over time. This extended establishment period is crucial for assessing the long-term viability and productivity of perennials in agrivoltaic environments, providing valuable insights into both agricultural yield and energy production optimization.

The perennial panel has been fully replanted into a “variety garden” with blocks of blueberries, tea (*Camellia sinensis*), dwarf tamarillo (*Solanum betacerum*), dwarf coffee (*Coffea arabica, variety Laurina)*, ginger (*Zingiber officinale*), and poha berry (*Physalis peruviana*). These crops are being tested as potential high value fruit crops that could complement commercial scale vegetable crop production or hydroponic crop production as an opportunity to optimize use of space and profitability.

Image 4. From left to right: Ginger, Coffee, and Poha Berry planting with coffee chaff mulch.

Mililani I Updates

Establishing Agricultural Plots in Photovoltaic Systems

Converting land previously used for utility-scale photovoltaic (PV) systems into agrivoltaic (APV) systems requires careful land preparation to optimize crop growth while maintaining efficient energy production. Agrivoltaic systems, which integrate agricultural production with solar energy generation, present a unique opportunity to enhance both food production and renewable energy output. However, the transition from a purely solar energy site to a productive agricultural system presents several challenges, especially in areas like Central Oahu, where soil compaction, debris from prior agricultural use, and degraded soil health are common.

Effective land preparation begins with soil rehabilitation, which is critical for creating an environment conducive to plant growth. This includes mechanical processes like soil ripping and tilling to alleviate compaction, conducting a thorough soil nutrient analysis, and incorporating high-quality compost to improve soil structure and fertility. Moreover, the selection of appropriate machinery and implements is essential to ensure efficient land management, and additional considerations, such as the timing of auto-tracking solar panels, must be made to ensure full coverage during tilling and planting.

One of the main challenges we have encountered in converting PV land to agrivoltaic use is dealing with compacted soil. Over time, areas dedicated solely to photovoltaic installations may experience soil compaction due to limited agricultural activity and heavy machinery traffic. Compacted soil restricts root growth, reduces water infiltration, and hampers the movement of nutrients, all of which are critical for healthy crop production.

To address this, deep ripping and tilling are essential first steps in preparing the land. Ripping breaks up the compacted layers, allowing roots to penetrate deeper into the soil, while tilling helps to incorporate organic matter and aerate the soil. These processes significantly improve water retention, drainage, and root development, laying the groundwork for successful crop establishment in an agrivoltaic system.

Before planting begins, a comprehensive soil nutrient analysis should be conducted to assess the fertility levels and determine any nutrient deficiencies. In Central Oahu, soils can be nutrient-poor due to long-term agricultural use, necessitating amendments to improve fertility. The analysis will guide the addition of specific nutrients such as nitrogen, phosphorus, and potassium, calcium, magnesium as well as any necessary pH adjustments. It is also important to assess the manganese content for Central Oahu as it is known to cause toxicity in some crops.

Adding high-quality compost is another critical step to enhance soil health. Compost improves soil structure by increasing organic matter content, which enhances water-holding capacity and promotes beneficial microbial activity. This, in turn, contributes to better nutrient cycling and overall soil fertility, making the land more productive for crops. For the best results, large quantities of high-quality compost should be worked into the soil during tilling to ensure uniform distribution and integration.

The selection of the right-sized tractor and implements is key to efficient land preparation in agrivoltaic systems. The tractor should be appropriately sized for the scale of the operation and the spacing between the solar panels. For example, a compact tractor with implements like a subsoiler for ripping, a rotary tiller for breaking up clods, and a spreader for compost application can make the land preparation process more effective. Timing also plays an important role, particularly when using auto-tracking photovoltaic panels. To maximize access to the entire plot and avoid missing areas beneath the panels, tilling should be scheduled when the panels are at a vertical or near-vertical position. This will provide sufficient clearance for tractors and implements to work the land thoroughly without damaging the solar infrastructure.

Another major challenge in preparing Central Oahu's agricultural land for agrivoltaic use is the presence of debris left by previous tenants. Items such as mulching plastic, drip tape, tires, and general trash must be removed to prevent obstruction during planting and to ensure the long-term health of the soil.

Converting photovoltaic land into agrivoltaic systems requires thorough land preparation to ensure soil health and optimal crop growth. Addressing soil compaction through ripping and tilling, improving soil fertility with nutrient analysis and compost additions, selecting the right equipment, and managing debris are all essential steps. By following these best practices, farmers can successfully transform PV-dedicated land into productive agrivoltaic systems that enhance both agricultural yield and renewable energy production.

Image 5. Conversion of conventional PV landscape to Agrivoltaic footprint. From left to right: ripped and disked ground ready for amendments and a follow up disking to incorporate the amendments, undisturbed environment in typical photovoltaic landscape of Guinea Grass and wild plants, ripped but not tilled soil preparation.

Experimental Design for Plots and Low Maintenance Row Cover

We reoriented the control plot to run north to south, matching the agrivoltaic experimental plots for a more accurate comparison. This ensures that the only variable being tested is the presence or absence of solar panels, as consistent sunlight exposure is maintained across all plots. This approach allows us to isolate the effects of the agrivoltaic system on crop performance without confounding factors like plot orientation.

Additionally, we manually installed landscape fabric in the walkways between the experimental beds. This approach was intended to suppress weed pressure effectively, helping to reduce labor and input costs associated with frequent weeding. By controlling weed growth in the walkways, we could concentrate our weeding efforts on the experimental beds themselves, improving the overall efficiency of land management and reducing the need for herbicides.

The distance between support posts for the solar arrays in the agrivoltaic research site is 21 feet. We utilized 3-foot-wide landscaping fabric and created 3-foot-wide beds, allowing us to establish a total of three beds. This layout provides an ideal design, with one bed positioned in the east, one in the west, and one in the center, fitting our experimental design setup. As the project progresses, we hope to create an “optimized” grown design for different crops and their ideal growing conditions within the APV plots.

Image 6. Redesign of experimental plots. Left to Right: Control plot expanded and reoriented from north to south, APV plot defined into 3 ft beds and 3-foot walkways for East, West, and Center beds with two drip irrigation lines.

Skyway F1 Tomato Comparison Trial

Skyway is a large, beefsteak-type tomato variety bred specifically for the southern U.S., known for its broad disease resistance. The fruits are attractive, moderately ribbed, red tomatoes weighing between 8–12 ounces. This variety's multiple disease resistances contribute to vigorous plant health, ensuring robust growth. Skyway tomatoes are noted for their very good flavor and fruit quality. Being a determinate variety, they have a defined growth cycle and reach maturity in approximately 78 days. Seeds were sourced from Johnny's Select Seeds. The planting spacing was set at 18 inches between plants, with rows spaced 36–48 inches apart, allowing for proper air circulation, healthy plant development, and easier access for maintenance and harvesting. Harvest took place in June.

It is important to note that this growing period coincided with an unusually wet May 2024, which saw record-breaking rainfall. The timing of planting may have significantly impacted both the overall yield and quality of the tomato crop.

Yield and Performance Analysis

Data were collected to compare the mean yield of tomatoes per plot (10 plants) across three locations—Center, East, and West—for both agrivoltaic (APV) and control conditions (Figure 1). Statistical differences in yield were denoted by "a" and "b," with "b" representing higher yields. The control system consistently outperformed the APV system, especially in the West location, where the highest yields were observed, likely due to increased exposure to afternoon sunlight. The data also shows that the APV system performed best in the center location.

Although there were statistical differences between the APV and control systems in yield, with the APV system producing significantly lower yields, we can see from the data that the highest-producing location within the APV plot was the center location.

Fruit Size and Marketability

Marketable fruit size between the APV and control systems was not statistically different (Figure 2). However, there was a significant difference in the proportion of unmarketable fruit, with the control system producing more unmarketable fruit compared to the APV system. Approximately 78% of the tomatoes from the APV system were marketable, compared to 68% from the control system. While marketable fruit size was similar between the two systems, the APV system led to a higher proportion of marketable produce, suggesting it may offer an advantage in terms of product quality, but not higher overall yields as compared to the control plot. It was also noted from a few consumers who were able to taste the tomatoes that the quality of the tomatoes being produced in the agrivoltaic plot had a higher improved quality in sweetness and overall flavor. While no formal sensory evaluation was performed, we would like to set up a future trial to include sugar content (Brix) and other qualitative measurements.

Recommendations for Future Trials

Optimizing planting time to account for specific tropical conditions, such as selecting varieties suited to high humidity and heat, could further enhance these results. Adjusting genetics to breed tomatoes with traits favorable to tropical climates—such as disease resistance and tolerance to fluctuating light levels—could also help maximize productivity. Replicating this trial with different genetics and incorporating additional variables like Brix (sugar content) and the nutritional composition of the fruits would provide further insights. The plants for this trial were seeded in nurseries in late March and out-planted in April, coinciding with the unusually wet May. Future trials could also exclude the west and east side beds, focusing production in the center area with the greatest amount of sun.

Market Potential

The local Hawaii market for high-quality tomatoes presents a unique opportunity. A significant portion of locally produced tomatoes is geared toward the fast-food industry, which prioritizes quantity over quality. However, there is a growing demand for premium produce among high-end restaurants, resorts, and specialty grocers, which value superior flavor, texture, and appearance. This niche market could be catered to by producing tomatoes with exceptional qualities, such as heirloom varieties or those grown in agrivoltaic systems, which may offer improved taste and consistency due to optimal growing conditions. With an emphasis on locally sourced and sustainable food, Hawaii's fine dining and hospitality industries could significantly benefit from these premium, locally grown tomatoes.

Scaling and Support for Farmers

Growing tomatoes at scale in agrivoltaic systems could effectively serve Hawaii's niche market for high-quality produce. The APV setup offers advantages like improved water efficiency and reduced heat stress, which enhance fruit quality. However, the initial capital costs for setting up APV systems—including insect netting and trellising—are significantly higher compared to traditional systems. Subsidizing rent and water costs within these spaces could help farmers offset these expenses, enabling them to focus on producing premium tomatoes while making the market more accessible for local farmers.

Incentives such as subsidies could lower the financial barrier for farmers, encouraging greater investment in high-quality, niche products. This would support the local food system, promote sustainable practices, and meet the growing demand for superior, locally sourced produce.

Image 7. Skyway F1 tomatoes harvested from Agrivoltaic plot (top left and right) and control plot (bottom right)

Figure 1. Comparison of Skyway Tomato – Mean yield (g) per plot (10 plants) by location and site

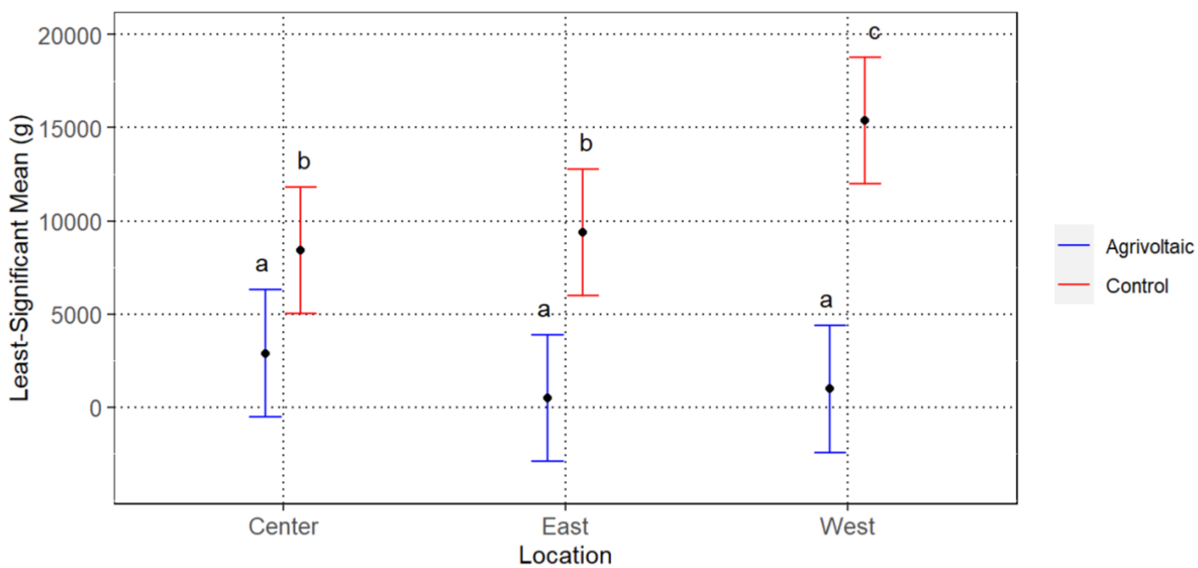
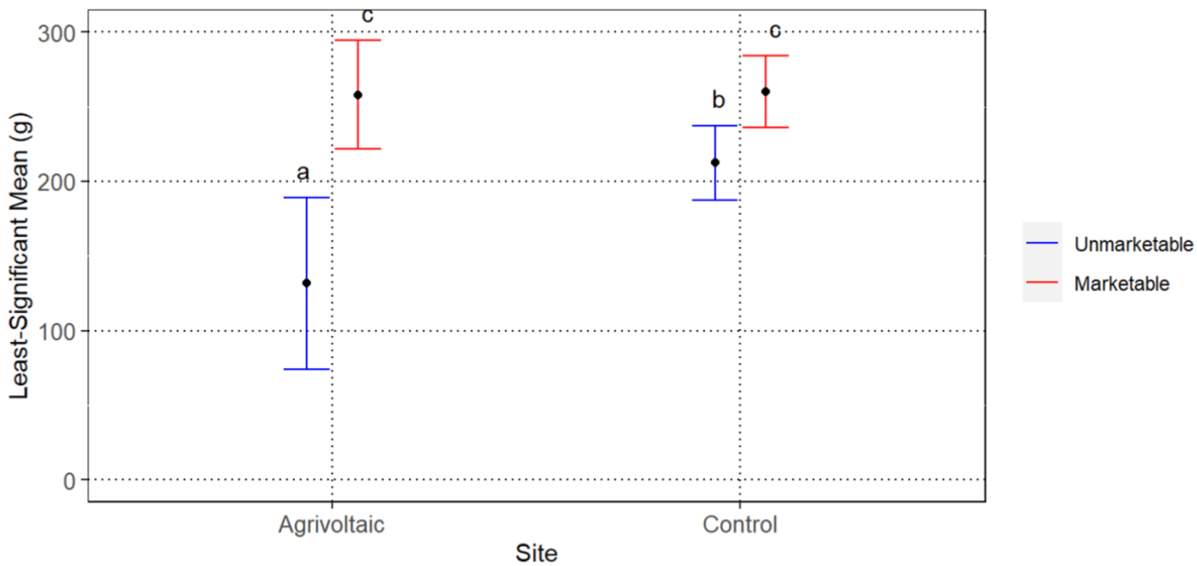


Figure 2. Comparison of Skyway Tomato - Fruit size by site and marketability



Purple Moon Cauliflower and F1 Green Magic Broccoli Trial

Green Magic broccoli is known for its excellent heat tolerance, making it well-suited for summer harvests in warmer climates. The heads are smooth, well-domed, and highly uniform in maturity, providing a visually attractive and consistent crop. With a days-to-maturity period of 57 days, Green Magic offers reliable and predictable harvests. Purple Moon cauliflower produces medium-dark purple heads that are visually striking and uniform. This variety has shown to be one of the best-performing purple cauliflowers in warm weather and is also highly suited for fall harvests. With a days-to-maturity period of 62 days, Purple Moon is both versatile and resilient in a variety of growing conditions. We planted 18 inches apart, with rows spaced at 36 inches. This spacing allows for adequate airflow between plants, reducing the risk of fungal diseases and promoting overall plant health while not compromising too much on overall yield. Both the agrivoltaic plot and control plot were planted on the same day from the same nursery stock which were planted in the ground on March 29th. Harvest started on May 9th and extended until June 20th 2024.

Both Green Magic broccoli and Purple Moon cauliflower were selected from previous crop screening trials for their high market value and reliability. Growing these varieties in an agrivoltaic system in Hawaii offers significant potential to reduce dependence on imports, improve water efficiency, and enable year-round cultivation in the warmer regions of Central Oahu. The shading provided by solar panels creates a cooler microclimate, which helps mitigate heat stress on broccoli and cauliflower, crops that typically struggle in warmer environments. This microclimate effect could extend the growing season and allow for continuous production throughout the year, even in hotter areas.

Additionally, the reduced sunlight lowers evapotranspiration rates, decreasing water demand—a critical factor for water-intensive crops like broccoli and cauliflower. By conserving moisture and reducing irrigation needs, agrivoltaic systems provide a more resource-efficient method for growing these high-value crops (Barron-Gafford et al., 2021).

Data and Performance Analysis

The data collected compares the crown size (in kg) of broccoli and cauliflower across agrivoltaic and control sites (Figure 3). The results indicate no statistically significant differences between the two crop types or between the site treatments, as both broccoli and cauliflower exhibited similar crown sizes in both the agrivoltaic and control systems. The “a“ annotations suggest comparable growth performance, implying that the presence of solar panels did not adversely affect the crown development of either crop under the conditions tested.

The data for mean yield by crop and site (Figure 4) shows the mean yield (kg) per plot (6 plants) for broccoli and cauliflower in both agrivoltaic and control sites. There is a significant difference in plot yield between the agrivoltaic (APV) and control environments, with broccoli showing a larger difference in yield between the two systems. While broccoli yields are statistically higher in the control environment, both crops performed similarly in the agrivoltaic system. Cauliflower exhibited a smaller difference between the two environments compared to broccoli, though the overall mean yield per plot for both crops was not statistically different from one another.

It is important to note the extreme weather conditions in May 2024 on Oahu, yields may have been affected, particularly at the agrivoltaic (APV) site. The intense rainfall likely introduced additional variables such as waterlogging or nutrient leaching, and increased pest pressure from the Diamondback moth and Cabbage Looper moth which could have impacted the performance of the crops under the agrivoltaic system. Repeating this trial under more typical weather conditions would help determine whether the lower yields observed in the APV system were a result of the environmental conditions or the system itself.

Given the results from this trial, continued research is crucial to fully understand the impact of agrivoltaic systems on both crop quality and nutritional content compared to traditional control plots. While yields were statistically lower in the APV plot, factors such as nutrient density, flavor, and shelf life may differ under the modified light and temperature conditions in the APV system. In addition to replicating this trial, further investigation into quality metrics, alongside more detailed nutritional analyses, will provide valuable insights into how agrivoltaic systems might affect the marketability and health benefits of agrivoltaic crops.

Market Potential

In Hawaii, locally grown broccoli and cauliflower are considered high-value crops due to their relatively low supply and high demand, particularly among local markets, restaurants, and consumers who prioritize fresh, locally sourced produce. The profitability of these crops is enhanced by reduced transportation costs and increased market prices for locally grown, sustainable produce. Broccoli and cauliflower typically fetch premium prices, especially during off-season periods when imports dominate. With proper agronomic practices and the use of agrivoltaic systems to extend growing seasons, the profitability of these crops can be further optimized.

Image 8. Green Magic Broccoli and Purple Moon Cauliflower Trial. Left to right: mass of crowns, diameter of crowns, a sample of harvest of both brassicas, visual of trial planted in late April 2024.

Figure 3. Brassicas - Crown size by site and crop

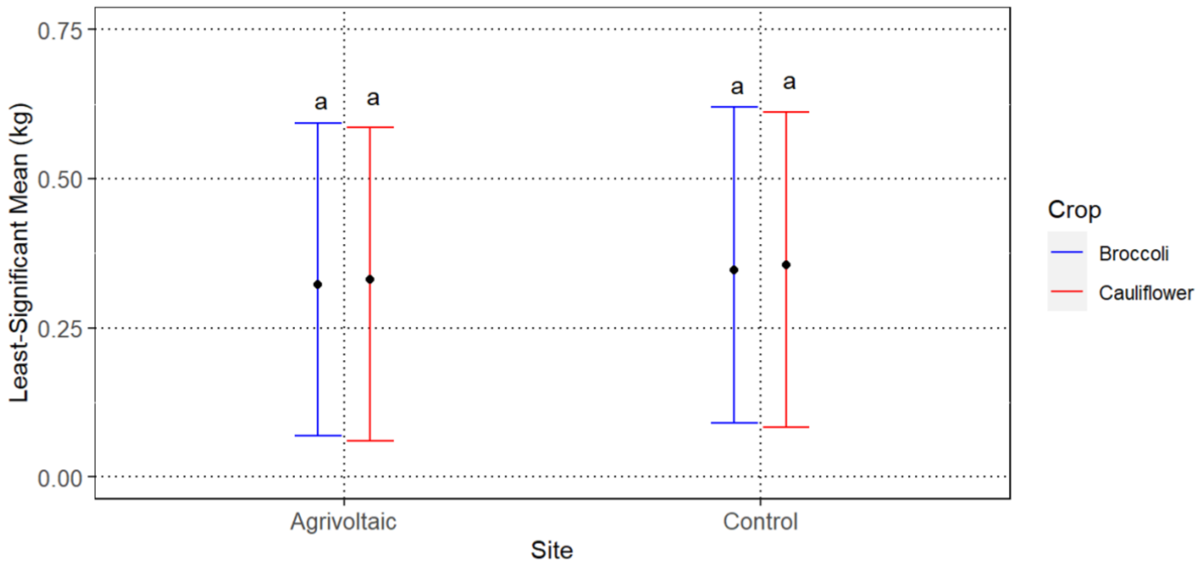
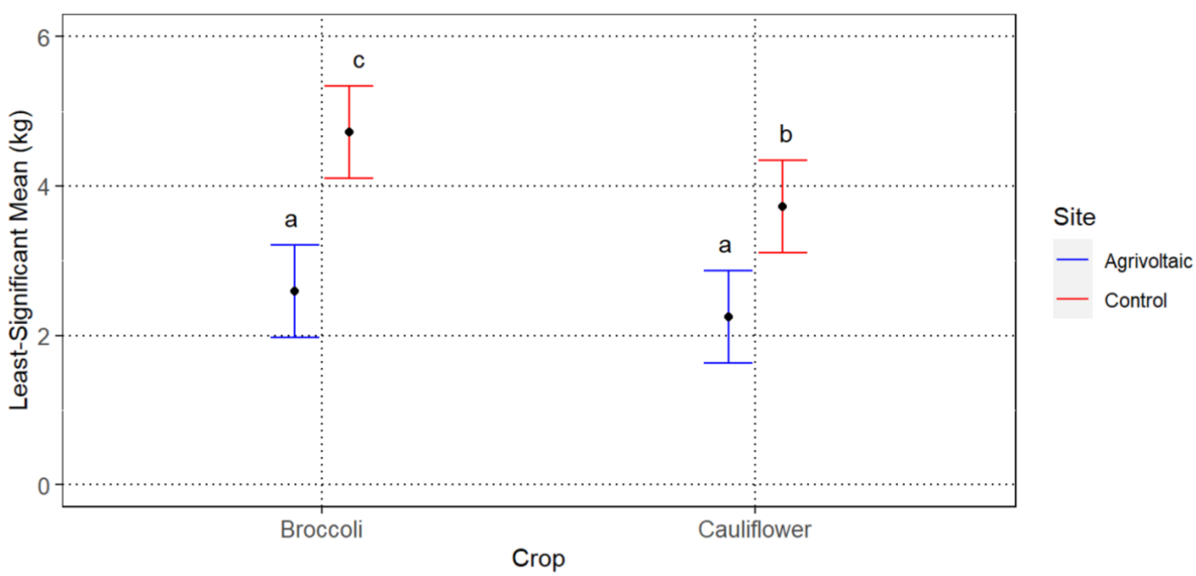


Figure 4. Brassicas - Mean yield (kg) per plot (6 plants) by crop and site.



Upcoming Crop Comparison

For the upcoming Quarter 4 report, we will be reporting on yield comparison trials for Prospera Basil, and Provider Green Beans which have concluded, and a Brown Jalapeño peppers comparison which is ongoing (Image 7). We are also planning new plantings of cabbage, celery, garlic, and cilantro, some will also be included but some crops will extend into Quarter 1 of 2026.

These trials will not only help compare yields between agrivoltaic and control systems but also allow us to identify the ideal growing locations within the agrivoltaic system for each crop for the best yields.

We will also develop crop performance reports tailored specifically for farmers. These documents will feature more diagrams and visual aids to present profitability data by bed foot, making the information more accessible and practical for those looking to implement these systems. Each report will focus on individual crop performance, allowing farmers to quickly reference the data most relevant to their operations.

Image 9. Upcoming crop analysis for Peppers, Basil, and Green Beans (left to right).

Public Outreach

Educational Tours and Workdays Summary

Since the start of the year, our agrivoltaic research and demonstration site has hosted an average of one educational tour per week, attracting a wide range of engaged and enthusiastic visitors. Guests, including policymakers, committee members from the Land Use Commission (LUC) and Department of Planning and Permitting (DPP), senators, and representatives, have shown keen interest in the potential of agrivoltaics. Highlights include two tours with over 40 attendees from the Blue Planet Alliance, visits from UH graduate students, and Punahou's sustainability fellows. The Commonwealth Parliamentary Association, with 20 delegates from island nations, toured the site and were so inspired by the potential of agrivoltaics that discussions shifted to exploring how similar systems could be implemented in their own countries. Additionally, the USDA, Oahu Office of Planning and Sustainable Development, and HARC's Seeds for Tomorrow summer program also engaged with the site, showcasing the far-reaching interest in agrivoltaic solutions for sustainable agriculture and energy.

These site visits have not only educated visitors but also sparked meaningful discussions about policy shifts, sustainable practices, and the versatility of agrivoltaics in meeting agricultural and energy goals.

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