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## Scope of Agrivoltaic Systems for Sustainable Production of Fruit Crops

\*D. Naga Harshitha

Assistant Professor, College of Horticulture, Malyal, Sri Konda Laxman Telangana Horticultural University, Mulugu, Siddipet, India

\*Corresponding Author's email: [harshi.dmg@gmail.com](mailto:harshi.dmg@gmail.com)

Agrivoltaics combining solar energy production with agriculture reduces microclimatic stress, improves land-use efficiency, and generates dual revenue from crops and renewable power. It is important for promoting energy security, sustainable agriculture, and economic resilience for farmers with limited resources. In line with the objectives of global sustainability, it provides a revolutionary way to balance energy and food production while encouraging rural growth and environmental preservation. By raising solar panels, fruit growers can generate electricity while protecting crops from adverse weather conditions, reducing water evaporation, and stabilizing fruit yields. Agrivoltaics in fruit crops has a bright future since it enables sustainable "dual-harvesting" of food and energy, especially in areas with limited water resources and high climate risk.

### Introduction

In an effort to meet the growing demand for food from an expanding human population, efforts to increase agricultural yields have led to an unbalanced use of agrochemicals to compensate for lower crop production at higher costs. There is a gradual effort to create effective solutions in all economic activities, including agricultural, to address the growing environmental and climate issues. In order to compensate for the decreased crop yield and changes in the physical, chemical, and biological features of the soil, production expenses rose. Solar power is really taking off as the go-to renewable energy source if we want to get to a climate-neutral economy. The problem is that setting up big solar farms needs a lot of land, and sometimes this can mess with local wildlife, disrupt ecosystems, and cut down on food production. That's where agrivoltaics come in as a neat solution, especially for orchards. Basically, agrivoltaics let us use the same land for both growing crops and generating solar power. When we combine solar panels with nets that protect from hail and can filter light, they can actually shield the plants, reduce heat stress, prevent fruit damage, help plants use water better, and even improve light conditions. This all adds up to better quality fruit and bigger harvests. It's a win-win that makes fruit farms more robust and productive.

### Agrivoltaics

Agrivoltaics, sometimes called agrisolar or dual-use solar, is basically about using the same piece of land for both growing food and making solar power. It's like merging farming with solar tech by putting up solar panels over or in between the crops, or on fields where animals graze. This method really makes the most of the land, offers some shade to protect the crops, and gives farmers an extra way to earn money. It's been around since the 1980s, but it's becoming more and more popular everywhere because it's a clever way to get food and renewable energy from the same spot. This is especially a big deal for places like India, where land is scarce and energy demand is high.

## Agrivoltaic Systems for fruit crops

The potential to partially replace the present widespread practice of utilizing plastic cover/net protections for a variety of climate dangers (heavy rainfall, rain, sunburn, hail, etc.) is another factor contributing to the positive uptake of solar PV use in orchards. However, agrivoltaic systems introduce a permanent anchoring (concrete or reversible) of the mounting framework in place of temporary protection mechanisms. This raises a significant concern about fruit quality, agricultural productivity, and the microenvironment. With respect to arable and horticultural crops, a consistently low number of fruit tree species have been subjected to AV studies focusing on growth, yield, and quality. Studies on some fruit species have been mostly carried out under 30- 60% shade, with yield losses ranging from 16 to 42% (Magarelli *et al.*, 2024).

## Agrivoltaic Systems for Orchards

- **Elevated/Stilt-Mounted PV Structures (High-Clearance):** This is the most suitable system for orchards, where panels are mounted at least 2 metres—often 3 to 3.5 metres—high on stilts. This allows tractors and other agricultural machinery to operate underneath for managing fruit trees (e.g., guava, mango) and harvesting.
- **Interspace/Ground-Mounted Row System:** With this ground-mounted setup, solar panels are put on the ground, but there's plenty of room between the rows so you can grow fruit trees there.
- **Vertical/Bi-facial PV Mounting:** Solar panels are mounted vertically on the orchard borders or in rows, acting as a fence. This design is excellent for maximizing land use, minimizing shading during the day for light-intensive fruit crops, and maximizing power at sunrise/sunset, which is useful in arid regions.
- **Smart/Tracking Agrivoltaics:** While more advanced, some systems use single-axis tracking, where panels follow the sun, allowing for specific light management in orchards. This is particularly useful in arid climates to manage evaporation and water consumption.
- **Agrivoltaics farming**
- Agrivoltaics focuses on optimizing the use of a single land area by integrating agriculture and solar energy generation. It visualizes lines of solar panels positioned above fields or livestock. These panels harness sunlight to generate electricity, while the area below continues to be utilized for cultivating plants or raising animals.
- **Practical application:**
- **Raised solar panels:** Rather than installing solar panels directly on the soil, they are positioned on frameworks elevated enough to allow sunlight and rain to access the plants beneath.
- **Partial shading:** The panels cast shade, assisting in shielding crops from intense heat and decreasing water evaporation from the soil. This establishes a cooler, more consistent atmosphere for plants to thrive, particularly in hot or arid areas.
- **Dual purpose of land:** By having solar panels produce electricity while crops or livestock flourish underneath, farmers obtain dual advantages from the same land—food and renewable energy.
- **Power for the farm and more:** The solar energy generated on an agrivoltaic farm can energize agricultural activities, lowering electricity expenses. If there's surplus energy, it can be returned to the grid, generating extra revenue.
- **By accommodating the requirements of agriculture and energy production, agrivoltaics transforms farmland into a multifunctional area that fosters sustainable farming while generating clean power simultaneously**

## Advantages of agrivoltaics farming

- Farmers can get way more out of their land, boosting productivity. This setup lets them produce clean energy while still farming. It cuts down on the hassle of figuring out where to put solar farms without messing up good farmland, helping us meet solar energy goals without sacrificing valuable agricultural land.

- Having solar panels overhead can help crops stand up better to tough conditions and produce more. The shade they cast helps keep the soil moist, cuts down on water evaporating, and keeps temperatures from getting too extreme.
- Farmers can also make more money by mixing farming or raising animals with using solar power for their operations. They get to save money on electricity, power their farm work with clean energy, and sometimes even sell extra power back to the grid, which makes their income more dependable.
- It is good for the environment and wildlife. Agrivoltaic sites can help make ecosystems healthier by protecting local plants and creating places for pollinators like bees to live. These green spaces also help manage rainwater and cut down on the need for weed killers, which means less harm to the environment and lower upkeep costs.
- Offers Grazing Opportunities: Livestock such as sheep and chickens can graze beneath solar agriculture panels. This not only naturally manages vegetation but also provides animals with shade and protection, enhancing their welfare and reducing maintenance needs.
- Improves Working Conditions for Farm Laborers: By offering shade, solar agriculture installations enhance the comfort and safety of farm workers who spend extended periods outdoors. They are shielded from intense heat and harmful UV rays.
- Helps combat climate change: Agrivoltaics in India contributes to regional and national goals for reducing greenhouse gas emissions and building climate resilience in agriculture. This is achieved by generating clean, renewable energy and decreasing reliance on fossil fuels.
- Reduces water consumption: In drought-prone areas, the shade provided by agrivoltaics farming minimizes water loss from plants and soil through transpiration and evaporation, promoting more sustainable agricultural practices.

### Challenges and limitations of agrivoltaics

- High initial investment costs: Setting up agrivoltaics systems involves significant upfront expenses. For farmers with limited resources, these costs can be unaffordable without government subsidies.
- Technical integration challenges: The correct positioning and height of panels are essential for balancing sunlight for crops and optimizing energy generation. Poor planning can negatively impact both crop yields and solar panel efficiency.
- Aeolian dust deposition: In dry areas, dust settling on solar panels can reduce their efficiency by as much as 25%. Frequent cleaning raises operational costs and is problematic in regions with water scarcity.
- Awareness and training gaps: A lack of understanding about agrivoltaics hinders its uptake and effective system upkeep.
- Policy and infrastructure constraints: Current renewable energy policies often fail to consider the dual-use aspect of agrivoltaics. Limited grid access and inadequate energy storage facilities in rural areas further impede adoption.
- Land-use and crop compatibility: Agrivoltaics is not suitable for all crops. Therefore, choosing shade-tolerant, high-value crops is crucial for maximizing profitability.

### Conclusions

Agrivoltaics is clearly attracting growing interest, and we're witnessing rapid advancements in solar technology and system design. However, the examination of the growth efficacy of crops, particularly fruit crops, has not been thoroughly addressed. The majority of existing research has predominantly relied on computational simulations or a review of existing literature to ascertain the sensitivity of crops to shading within agrivoltaic systems. Nonetheless, determining the actual performance of a fruit crop is highly contingent upon the specific environmental context and the configuration of the system, as substantial variability has been observed in fruit yield outcomes. The spatial arrangement of the panels, their elevation, their capacity to follow the solar trajectory, and their geographical positioning all

contribute to the formation of distinct microclimatic conditions. This phenomenon influences various environmental parameters such as illumination, thermal conditions, atmospheric movement, and moisture levels, as well as edaphic factors, with these variations potentially occurring at different intervals throughout the diurnal cycle. Because of all this, agrivoltaic systems are really different from controlled environments like greenhouses. This means we need a new way of thinking about designing these structures, one that's more focused on farming needs, like dealing with pests or how to harvest mechanically. To make it easier to compare different studies, it would be helpful to have standard ways of measuring the microclimate and to consider how much of the ground is covered by panels, along with other design factors like how high the panels are and their tilt angle. Even though they sound great, agrivoltaics haven't caught on everywhere yet, mainly because they're expensive to start, there aren't enough helpful policies, and we still don't fully grasp how they affect local weather and ecosystems. We need to fill in these knowledge gaps and get better policies in place to see them used more widely. Ultimately, that we need more research and policy work to really make the most of them in sustainable farming.

## References

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