Application of Agrivoltaic Systems on Microclimate, Water Use Efficiency, and Yield of Shade-Tolerant Crops

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ABSTRACT

Agrivoltaic systems co-locating photovoltaic (PV) modules with agricultural crops present a promising dual-land-use strategy for regions experiencing climate stress and water scarcity. Evidence indicates that shading beneath solar panels can improve microclimatic conditions by moderating temperature, reducing evapotranspiration, and increasing soil moisture retention (Adeh et al., 2018). These changes enhance water use efficiency (WUE), particularly for shade-tolerant crops that naturally thrive in lower light conditions. Studies show that many shade-adapted vegetables, herbs, and forage species maintain or increase yields under agrivoltaic conditions due to reduced heat stress and improved physiological performance (Barron-Gafford et al., 2019; Valle et al., 2017). The extent of benefits is influenced by PV configuration, shading intensity, and crop physiology. Overall, agrivoltaics offer a viable pathway toward integrated food–energy systems that enhance climate resilience and resource efficiency. Continued research is needed to optimize system designs and crop-specific management strategies.

INTRODUCTION

Agriculture is increasingly affected by rising temperatures, declining water resources, and competition for land. Agrivoltaic systems provide a dual-use solution by integrating PV energy generation with agricultural production, improving land productivity while modifying microclimatic conditions (Dupraz *et al*., 2011). Shade-tolerant crops are ideally suited to such systems because they require less solar radiation and are more responsive to moderated environmental stress (Marrou *et al*., 2013). Understanding how agrivoltaics affect microclimate, WUE, and yield is critical for designing efficient food-energy-water systems. As global demand for both food and renewable energy continues to rise, agrivoltaics presents a strategic pathway for optimizing land use while contributing to long-term ecological and economic sustainability.

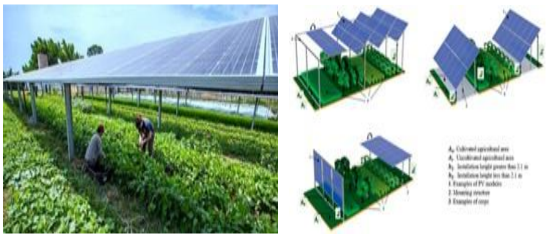

Figure 1: Typical Agrivoltaic Layout and Microclimate Zones

1. Effects of Agrivoltaic Systems on Microclimate

PV-induced shading reduces solar radiation and moderates soil and canopy temperatures, which can decrease heat stress by 2-8°C in various field conditions (Armstrong *et al*., 2016; Adeh *et al*., 2018). Relative humidity often increases under shaded zones, and lower wind speed further stabilizes microenvironmental conditions (Marrou *et al*., 2013). These microclimatic adjustments are central to improved crop performance and water conservation.

Table 1. Summary of Microclimatic Effects of Agrivoltaic Systems

Microclimate Parameter	Effect Under Agrivoltaics	Key References
Solar radiation	20-60% reduction depending on panel density	Dupraz *et al.* (2011)
Soil temperature	Decrease of 2-8 °C	Adeh *et al.* (2018); Armstrong et al. (2016)
Canopy temperature	Reduced midday peak temperatures	Barron-Gafford *et al.* (2019)
Relative humidity	Increase due to moderated vapor pressure	Marrou *et al.* (2013)
Wind speed	Slight reduction due to structural shading	Toledo and Scognamiglio (2021)

Figure 2. Microclimatic Modifications Under Solar Panels

2. Water Use Efficiency (WUE):

Agrivoltaic systems significantly improve WUE through reduced evapotranspiration and enhanced soil moisture conservation. Research has documented WUE improvements of 10-40% across diverse climates (Adeh *et al*., 2018; Marrou *et al*., 2013). These improvements arise from reduced radiation loads, moderated temperatures, and optimized stomatal responses.

Table 2. Mechanisms Contributing to Increased Water Use Efficiency

Mechanism	Description	Example Findings	References
Reduced evapotranspiration	Lower heat load decreases water loss	15-25% ET reduction	Marrou *et al.* (2013)
Increased soil moisture retention	Less direct sunlight reduces evaporation	Up to 30% higher soil moisture	Adeh *et al.* (2018)
Improved stomatal regulation	Reduced stress enhances WUE	Higher physiological water-use productivity	Barron-Gafford *et al.* (2019)
Shaded microclimate	Cooler temperatures prolong water availability	Enhanced water savings in arid climates	Toledo and Scognamiglio (2021)

3. Yield Responses of Shade-Tolerant Crops

Shade-tolerant crops frequently benefit from the moderated microclimate of agrivoltaics, showing stable or improved yields.

Table 3. Yield Responses of Selected Shade-Tolerant Crops Under Agrivoltaic Conditions

Crop Type	Representative Crops	Yield Response Under Agrivoltaics	References
Leafy vegetables	Lettuce, spinach, Swiss chard	5–20% increase due to moderated heat	Valle *et al.* (2017)
Herbs	Mint, basil, coriander	Improved quality and biomass	Barron-Gafford *et al.* (2019)
Rhizomes	Turmeric, ginger	Stable yields with lower water inputs	Marrou *et al.* (2013)
Forage crops	Clover, ryegrass	Equal or improved biomass production	Dupraz *et al.* (2011)

Leafy vegetables, herbs, and certain root crops respond positively to reduced heat stress and enhanced moisture availability (Dupraz *et al.*, 2011; Valle *et al*., 2017).

CONCLUSION

Agrivoltaic systems effectively modify microclimatic conditions, improve water use efficiency, and support the productivity of shade-tolerant crops. These benefits make agrivoltaics a promising climate-smart agricultural solution, especially in regions where water scarcity and heat stress challenge traditional agriculture. Continued research should emphasize crop-specific responses, optimal panel–crop spacing, and long-term feasibility assessments.

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