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Editorial: Exploring agrivoltaics: balancing crop production and solar energy for sustainable agriculture

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Editorial on the Research Topic

Exploring agrivoltaics: balancing crop production and solar energy for sustainable agriculture

Many agricultural areas of the world are facing unprecedented climate crises characterized by aridification, extreme temperatures, and shifting rainfall patterns with prolonged dry periods. These changes threaten the resilience of many crops, ranging from fruit crops to cereals or vegetables. Despite the natural adaptability of many species to even difficult pedoclimatic conditions, such climate shifts are placing intense pressure on their physiological processes. Moreover, intensive farming coupled with these climatic changes can reduce water availability and exacerbate biodiversity loss.

In this context, agrivoltaics (AV) – the simultaneous use of land for solar energy production and crop cultivation – emerges as a high-efficiency solution (Dupraz et al., 2011). Recent studies showed that integrating photovoltaic panels above crops, as is typical of agrivoltaic systems, can modulate the local microclimate, reduce thermal and water stress, and improve the resilience of high-value crops, especially in Mediterranean regions that are particularly vulnerable to climate change (Ferrara et al., 2023). These systems protect crops from environmental stressors, while supporting the transition to renewable energy sources (Amaducci et al., 2018). In areas with limited water availability and high temperatures during the growing season, such as Mediterranean countries, agrivoltaics represent a potential solution to sustain agricultural productions, sustain biodiversity, and generate energy (Magarelli et al., 2025a). Changing rainfall patterns and extreme temperatures are currently threatening traditional soil water reserves, and AV can help preventing the overexploitation of aquifers, thereby promoting long-term environmental sustainability (Dubrovský et al., 2014; Iglesias and Garrote, 2015). To achieve optimal results, site-specific designs adapted to local microclimatic conditions, together with appropriate layout criteria

for the grown crops, can minimize the negative effects of shading while optimizing crop growth and yield and ensuring clean energy production, even with low-input technological solutions (Magarelli et al., 2025b). However, in cooler climates, the productivity of AV vineyards may decrease, and anthocyanins, total soluble solids (TSS), and polyphenols may be reduced (Ferrara et al., 2023).

Considering growing awareness among scientists, farmers, and consumers – and in a global context in which fossil fuels costs are highly sensitive to market price fluctuations – the present Research Topic ‘Exploring Agrivoltaics: Balancing Crop Production and Solar Energy for Sustainable Agriculture,’ focused on the coexistence of solar panels and crops on the same land. This Research Topic features five original research articles and reviews addressing different aspects of AV systems.

Strub et al. assessed the economic performance of AV systems for grapevines. The study focused on the geographic and climatic conditions of Geisenheim, Germany, and simulated various scenarios based on key variables such as capital expenditures (CAPEX), operational expenditures (OPEX), and revenue from grape and energy production. Additional factors, including solar radiation, panel transparency, and regulatory impacts, were also considered. The results indicated that under current conditions in Germany, AV systems are not economically sustainable in all situations. CAPEX and energy prices emerged as critical factors, while viticulture-related costs and revenues had a minor impact on overall profitability. However, potential future developments – such as premium wine pricing, higher feed-in tariffs, and increased self-consumption of energy – could significantly improve the sustainability of these systems for many German vineyards. In particular, substantial reductions in installation costs, increases in energy prices, or technological advances in efficiency are required to achieve full profitability of AV systems. Promising configurations combining multiple favorable changes suggest that complete profitability may be attainable. In conclusion, the paper highlighted key considerations: the need for further research to better evaluate viticultural impacts and synergistic benefits; the importance of accounting for changing revenue streams, cost structures, and regulatory frameworks; and the evaluation of environmental and social benefits alongside economic output.

Scheerlinck et al. investigated raspberry (*Rubus idaeus* L.) under two different AV layouts in the Netherlands to evaluate crop responses. At one site, semi-translucent and opaque panels were compared with a control (conventional polyethylene tunnel), whereas at the second site, an opaque system was compared with an open-field control. The semi-translucent panels provided more uniform light distribution than opaque panels. Moreover, opaque panels reduced canopy temperature (≤ 0.5 °C), whereas semi-translucent panels occasionally induced midday warming of approximately 0.4 °C. Overall, AV created microclimatic conditions comparable to conventional plastic polytunnels used for raspberry cultivation, while simultaneously generating renewable energy.

In another fruit species, cranberry (*Vaccinium macrocarpon* Ait.), Priya et al. analyzed how different shading levels (30%, 35%, 37%) in AV systems affected cranberry physiology and metabolism. Moderate shading mitigated environmental stress and improved water status but simultaneously reduced photosynthetic activity and carbon reserves. At 37% shade, the decline in antioxidants and protective osmolytes such as proline and trehalose became significantly more pronounced. These findings highlight the importance of optimizing panel spacing to balance solar energy production with the biochemical performance and yield of cranberries.

Regarding microclimate modifications, Priya et al. also reviewed this critical aspect across different crops. The paper described how altered light intensity and microclimatic conditions influence physiological processes, metabolic pathways, and overall yield responses in various species. Reduced light intensity and modified microclimates can enhance water-use efficiency, stabilize photosynthetic function, and trigger beneficial metabolic adjustments. However, responses remain highly species-specific and strongly dependent on regional climate conditions and panel configuration.

Yield performance in AV systems vary widely among vegetables, grains, pulses, and fruit crops, highlighting the necessity of optimal crop selection for specific AV configurations. There is still limited understanding of the molecular and omics-level mechanisms underlying plant adaptation to AV systems. Despite the many benefits of AV, concerns remain regarding initial investment, technological adaptation, social and legal barriers, and potential shade-induced yield penalties.

Aly reviewed AV systems from a global sustainability perspective. AV systems can provide substantial economic advantages to farmers by ensuring stable income streams and enhancing profitability, while also contributing significantly to clean energy generation. A critical aspect of AV implementation is structural engineering, as current standards often underestimate wind loads, necessitating advanced simulations. Wind load engineering represents a major technical challenge, frequently misestimated by existing codes. Advanced approaches, such as Computational Fluid Dynamics simulations and open-jet testing, are essential to ensure structural resilience. The future of AV also depends on integrating artificial intelligence (AI) and Internet of Things (IoT) technologies for dynamic control and analytics. Furthermore, comprehensive design standards are needed to replace inadequate traditional testing methods. The development of flexible policy instruments and shared data repositories will help refine existing models. Ultimately, cross-sector collaboration is essential to building sustainable energy and agricultural systems.

In conclusion, AV systems represent a vital link between climate resilience and clean energy, offering a sustainable model for land optimization in many agricultural regions worldwide. The future large-scale adoption of AV as a global agricultural standard will depend on several factors, including improved integration of AI and IoT for dynamic microclimate control; site-specific designs

tailored to crops and local conditions; cost reductions through technological innovations; and strengthened cross-sector collaborations supported by flexible policy frameworks.

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