AgriVoltaics World Conference 2024
Plant & Crop Physiology
https://doi.org/10.52825/agripv.v3i.1372

Published: 26 Mar. 2025

The Impact of Photovoltaic on Permanent Grassland Composition and Productivity in Central Italy

Michele Moretta[1,*], Riccardo Rossi[1], Gloria Padovan[1], Nicolina Staglianò[1], Enrico Palchetti[1], Marco Bindi[1], Pietro Elia Campana[2], and Marco Moriondo[3]

[1]Department of Agriculture, Food, Environment and Forestry, DAGRI, University of Florence,50144 Firenze, IT

[2]Mälardalen University, Future Energy Center, Västerås, Sweden

[3]Institute of BioEconomy, Italian Research Council (IBE-CNR),50145, Sesto Fiorentino, IT

*Correspondence: Michele Moretta, michele.moretta@unifi.it

Abstract. Climate change and population growth put a strain on energy and food resources, prompting a shift to renewable energy. The EU is aiming for 40 per cent renewable energy by 2030 and photovoltaic solar systems are expected as the primary source of electricity by 2035. However, the expansion of photovoltaics generates conflicts over land use, especially in agriculture. Agrivoltaic (AV) systems, which integrate photovoltaic panels with agricultural practices, offer a promising solution by providing crops with partial shade, thus potentially mitigating excessive sunlight and reducing water stress. This study evaluates the effects of an AV system on a 70 ha pasture in Ravenna, Italy, examining changes in pasture composition and productivity. In order to identify variations along the shadow gradient, four sampling areas were chosen along the transect perpendicular to the panel row, where plant species were identified and crop biomass sampled throughout the growing season in 2023. The results revealed a dominant presence of Grasses, with percentages of Leguminous ranging from 20 to 40% in less shaded areas, and other species present mainly in shaded areas, particularly in the back edge of the panel. Biomass yield showed considerable variation along the transect, with higher yields near the panels and lower below the central panels. The biomass peaks highlight the role of shading, sunlight and water drainage in production. These results emphasize the critical influence of shading in AV systems, providing insights for optimizing pasture management and crop selection to increase productivity under different light conditions.

Keywords: Agrivoltaic System, Grassland, Renewable Energy

1. Introduction

Climate change and population growth are creating significant pressures on energy and food supply while the EU has stipulated that 40 percent of energy consumption must come from renewable resources by 2030 to mitigate greenhouse gas emissions. Advances in photovoltaic (PV) technology and lower production costs are key to this transition. The International Energy Agency (IEA) predicts that solar PV will become the main source of electricity generation by 2035, with a capacity of 16% of global electricity production [1]. This rapid expansion leads to land-use conflicts, emphasizing the need to consider the impact of photovoltaic installations on arable land.

To address these challenges, an innovative concept has been proposed: Agrivoltaic (AV), a system that combines food and photovoltaic energy production on the same land. This system involves installing photovoltaic panels over crops, providing partial shading that can protect crops from excessive sunlight and reduce evapotranspiration during periods of water and heat stress [2] [3].

In this context, Italy is moving towards sustainable growth to meet EU targets with AV systems playing a crucial role. Over the next decade, the number of AV systems in Italy is expected to increase, supported also by PNRR funding [4].

Studies on AV systems have examined several crops, including lettuce, potatoes, maize, winter wheat, rice, raspberries, cherry tomatoes and chillies. The results indicate a nonlinear relationship between crop yields and reductions in solar radiation for all crop types. Most crops can tolerate up to a 15% reduction in solar radiation, exhibiting a yield decline that is less than proportional [5][6][7]. Herbaceous species, such as fescue and alfalfa, seem promising for growing under AV systems as they suffer water stress during summer and shading could improve their growth during these periods [8][9][10]. However, further research is needed to understand how micro-environments under solar panels interact with management strategies and influence botanical composition and forage production [11].

This study presents a one-year investigation of the impact of an agrivoltaic system on a pasture ecosystem in Italy, with the objective of quantifying the adaptive responses of pasture composition and productivity in different areas of an agrivoltaic field.

2. Materials and Methods

The study was conducted in 2023 at a large agrivoltaic (AV) system in Ravenna, Italy, at Sant'Alberto (44°30'36.69" N, 12°9'18.72" E), where fixed photovoltaic panels are installed on a 70 ha permanent grassland. The grassland was sown in 2018, both between and beneath the panels, maintaining a 50 cm distance on both the right and left sides of the poles supporting the panels, and consists of a mixture of *Festuca arundinacea*, *Dactylis glomerata*, *Trifolium repens*, and *Medicago sativa*.The panels are 3 m long, have an inclination of 35 degrees with respect to the horizontal plane and are oriented along east-west direction. The side closest to the ground is mounted at a height of 1.30m, while the far side at 3 meters. The space between the poles supporting the structure is 8 meters, resulting in a Ground Coverage Ratio (GCR) of 38%. The experimental setup consisted of 3 randomized blocks with 3 replicas each, characterized by 4 selected areas along the transect perpendicular to the panel rows: G1, G2, G3, and G4 (Fig.1).

The sampling started in November 2022 and the last date was April 9, 2024 (sampling dates are specified in Fig. 1 and 2).

To investigate the impact of the AV system on grassland growth, species identification was conducted in each area, determining the percentage of Grasses, Leguminous, and Other species (GLA categories). Furthermore, to assess the influence on grassland productivity, systematic mowing was performed within designated 0.5 m x 0.5 m square plots for each area. The samples were dried at 65°C for 48 hours to calculate the percentage of dry matter and subsequently weighed.

This setup allowed for a detailed analysis of the effects of AV shading on both species composition and biomass yield of the grassland, providing insights into the interactions between AV systems and underlying vegetation.

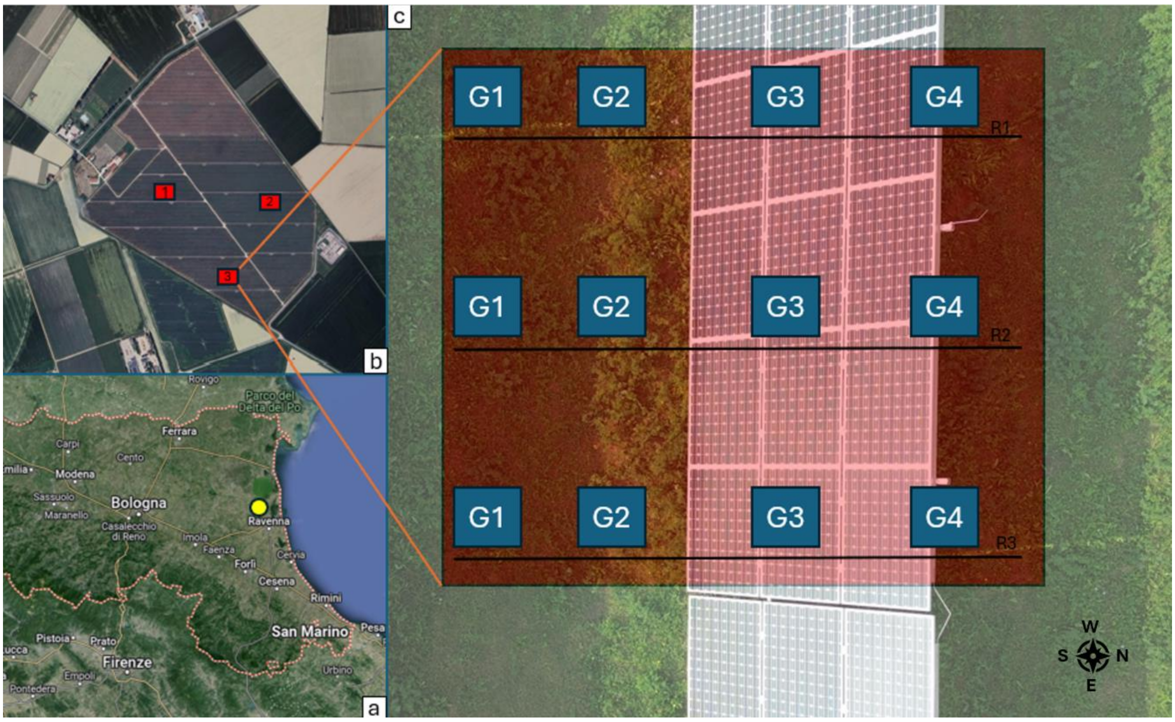

Figure 1. *a) Location of the site in Emilia-Romagna, Italy. b) Experimental Field, Experimental Blocks in red. C) Spatial representation of sampling Areas. G1: the uncovered interspace adjacent to each panel; G2: front edge of each panel; G3: beneath the center of each panel; G4: back edge of each panel.*

2. Results

In Fig. 2, a distinct pattern is evident where Grasses (G) have a predominant presence in most of the samples analyzed. Leguminosae (L), on the other hand, show variable percentages ranging between 20% and 40%. The other species (O) show a significant presence in some samples, particularly in the back edge of each panel, G4 group.

In the sample collected on 23 May 2023, the G3 group shows a very high predominance of Grasses, amounting to 90%. In the sample of 11 October 2023, group G1 shows a high proportion of other species, at 40%.

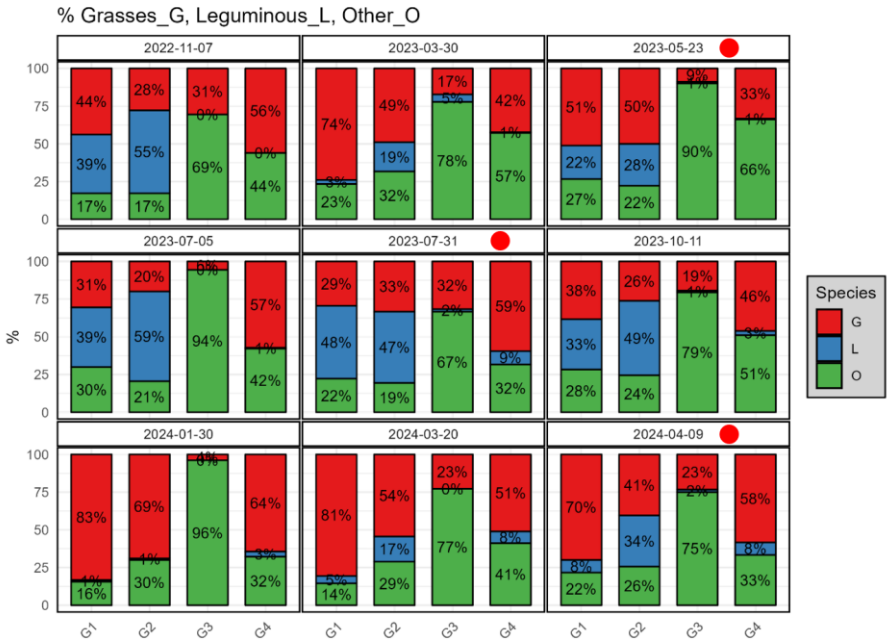

Figure 2. *Evolution of the average GLO % detected in the sampling plots during the experiment.*

In summary, in the sunniest areas, specifically G1 and G2, legumes tend to dominate over grasses and other species, particularly during the warmest periods. Conversely, in shadier areas, legumes are less prevalent. In G3, grasses and legumes consistently constitute a minority compared to other species. However, in G4, grasses exhibit an ability to adapt to conditions of very low direct radiation.

Fig.3 clearly illustrates how the biomass yield varies significantly over time and between the different distance groups. The most obvious peaks are observed on 23 May 2023, with group G1 and G2 showing significantly higher yields, and on 5 July 2023 with a peak for G2. Other increases are observed in the mowing periods, such as 31 July 2023 and 9 April 2024. However, in general, yields tend to be low, with only a few significant increases on certain dates and groups. The influence of the shading gradients of the AV panels is evident: the areas adjacent to the panels (G1 and G2) show a stronger seasonal trend and higher yields overall, influenced only by partial shading in the morning (G1). In 2023, the total biomass yield on five sampling dates was about 8.5 T DM/ha in the open locations (G1 and G2) and 4.8 T DM/ha under the panels (G3 and G4). This translates into a relative biomass yield of 78%, taking the yield of G2 as the reference point. The areas under the panels (G3 and G4) maintain more stable but generally lower yields, further suggesting the critical role of sunlight exposure and rainwater drainage in biomass production in these environments.

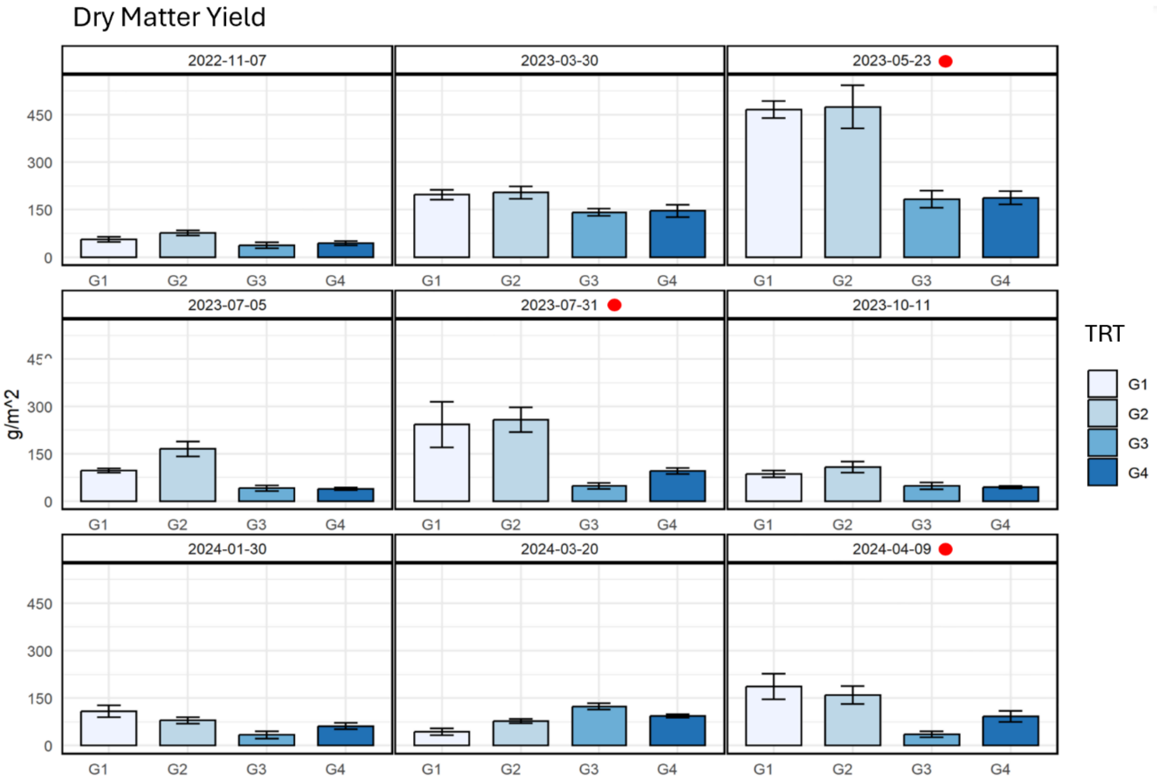

Figure 3. *Barplots depicting the production of dry weight biomass (g/m2) in sampling plots during the experiment. The red icon indicates the harvest date.*

4. Conclusion

This study demonstrates how the botanical composition and productivity of permanent grassland within Agrivoltaic (AV) systems with fixed photovoltaic panels are significantly influenced by shading conditions. Grasses were found to be the dominant species across most samples, while Leguminous and other species varied in presence depending on the shading gradient and temporal factors. Biomass yields showed notable variation, with higher yields observed in areas adjacent to the panels (G1 and G2) and lower, more consistent yields under the center (G3) and rear edge (G4) of the panels. The data suggest that optimizing shading management, such as increasing panel spacing or using adjustable tracking systems, could mitigate the negative effects of shading and potentially improve grassland productivity. These findings offer preliminary insights that can help farmers explore species-specific strategies and adaptive grassland management practices to mitigate the challenges of shading and optimize the benefits of AV systems. The results of this study can be used as input into crop simulation models for future AV plant designs. Future agrivoltaic systems should explore strategies aimed at improving radiation management and water storage, supported by further research measuring key environmental factors such as light availability, soil moisture, and water dynamics.

Data availability statement

Data available upon reasonable request.

Author contributions

Conceptualization: Michele Moretta, Riccardo Rossi, Marco Moriondo.

Data curation: Michele Moretta, Riccardo Rossi, Marco Moriondo,Gloria Padovan.

Formal analysis: Michele Moretta, Riccardo Rossi.

Funding acquisition: Marco Bindi, Enrico Palchetti.

Investigation: Michele Moretta, Riccardo Rossi, Gloria Padovan, Marco Moriondo, Nicolina Staglianò.

Methodology: Michele Moretta, Riccardo Rossi, Gloria Padovan, Marco Moriondo,Nicolina Staglianò, Pietro Elia Campana.

Resources: Enrico Palchetti, Marco Moriondo, Marco Bindi.

Writing – original draft: Michele Moretta, Riccardo Rossi, Gloria Padovan, Marco Moriondo.

Competing interests

The authors declare no competing interests

Funding

This material is based upon work supported by Tozzi Green S.p.A., Ravenna, Italy.

Acknowledgement

The authors like to thank Tozzi Green S.p.A. for funding part of the activities.

References

[1] International Energy Agency (2023), *World Energy Outlook 2023*, IEA,

[2] C. Dupraz, H. Marrou, G. Talbot, L. Dufour, A. Nogier, and Y. Ferard, “Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes,” Renew. Energy, vol. 36, no. 10, pp. 2725–2732, Oct. 2011, doi: https://doi.org/10.1016/j.renene.2011.03.005

[3] H. Marrou, L. Guilioni, L. Dufour, C. Dupraz, and J. Wéry, “Microclimate under agrivoltaic systems: Is crop growth rate affected in the partial shade of solar panels?,” Agric. Forest Meteorol., vol. 177, pp. 117–132, Apr. 2013, doi: https://doi.org/10.1016/j.agrformet.2013.04.012

[4] Ministry of Ecological Transition, “Guidelines on Agrivoltaic Installations, Italy,” 2022.

[5] T. Reher *et al.*, “Potential of sugar beet (*Beta vulgaris*) and wheat (*Triticum aestivum*) production in vertical bifacial, tracked, or elevated agrivoltaic systems in Belgium,” Appl. Energy, vol. 359, p. 122679, 2024, doi: https://doi.org/10.1016/J.APENERGY.2024.122679

[6] S. Touil, A. Richa, M. Fizir, and B. Bingwa, “Shading effect of photovoltaic panels on horticulture crops production: A mini review,” Rev. Environ. Sci. Bio/Technol., vol. 20, no. 2, pp. 281–296, 2021. DOI: https://doi.org/10.1007/s11157-021-09572-2

[7] Laub, M., Pataczek, L., Feuerbacher, A. et al. Contrasting yield responses at varying levels of shade suggest different suitability of crops for dual land-use systems: a meta-analysis. Agron. Sustain. Dev. 42, 51 (2022). https://doi.org/10.1007/s13593-022-00783-7

[8] C. Dupraz, “Assessment of the ground coverage ratio of agrivoltaic systems as a proxy for potential crop productivity,” Agrofor. Syst., vol. 98, pp. 2679–2696, 2024, doi: https.doi.org/10.1007/s10457-023-00906-3

[9] Andrew, A. C., Higgins, C. W., Smallman, M. A., Prado-Tarango, D. E., Rosati, A., Ghajar, S., Graham, M., & Ates, S. (2024). Herbage and sheep production from simple, diverse, and legume pastures established in an agrivoltaic production system. *Grass and Forage Science*, 79(2), 294–307. doi: https.doi.org/10.1111/gfs.12653

[10] S. Edouard, D. Combes, M. Van Iseghem, M. Ng Wing Tin, and A. J. Escobar-Gutiérrez, "Increasing land productivity with agriphotovoltaics: Application to an alfalfa field," *Appl. Energy*, vol. 329, no. 120207, Jan. 2023, doi: https.doi.org/10.1016/j.apenergy.2022.120207

[11] J. Madej, L. Loan, C. Picon-Cochard, C. l'Ecluse, C. Cogny, L. Michaud, M. Roncoroni, and D. Colosse, "One Year of Grassland Vegetation Dynamics in Two Sheep-Grazed Agrivoltaic Systems," *AgriVoltaics Conf. Proc.*, vol. 1, no. 1, Jan. 2024, doi: https.doi.org/10.52825/agripv.v1i.692