AgriVoltaics World Conference 2022
The Management of Agriculture Production Under Photovoltaic Panels
https://doi.org/10.52825/agripv.v1i.607

Published: 06 Feb. 2024

Agrivoltaic in a Semi-Aride Climate: Co-Existence of Agricultural Activities in Utility-Scale Plants of EGP for Multiple and Sustainable Land Use

A Case Study of Pepper, Aloe Vera and Thyme

Virginia Hernández[1][https://orcid.org/0000-0002-3625-9677], Miriam Di Blasi[2][https://orcid.org/0000-0003-4647-7499], Maria Genovese[2][https://orcid.org/0000-0002-3374-8627], Roberto Andrés[3][https://orcid.org/0000-0003-4583-6998], José Cos[1][https://orcid.org/ 0000-0003-3041-6966], Fulgencio Contreras[1][https://orcid.org/0000-0002-8461-5971], Alfonso Guevara[1][https://orcid.org/0000-0002-9443-2394], Pilar Hellín[1][https://orcid.org/0000-0002-5130-7008], and Pilar Flores[1*][https://orcid.org/0000-0002-0493-8720]

[1]Instituto Murciano de Investigación y Desarrollo Agrario y Medioambiental (IMIDA), Spain.

[2]Enel Green Power, Italy

[3]Endesa, Spain

Abstract. The benefits deriving from the coexistence of energy production from a photovoltaic plant and crops growth on the same land have been investigated in Enel Green Power photovoltaic plant of Totana, in the semi-arid region of Murcia, in Spain. In this area, scarcity of water resources and high temperatures can have a major impact on production and agrivoltaic can be relevant for the potential benefits of shading on crops. Pepper “Bola”, aloe vera and thyme have been selected for their economic importance and adaptation to the conditions of the area. The results reported are related to the testing areas in the corridors between two modules rows and to the control area. For pepper, an increase of more than 60% in the agricultural yield and in fresh mean weight and of more than 30% for the fruits number have been observed in the corridors, with respect to the control area. For aloe and thyme in the corridor zone a higher plant biomass (more than 30% and 20%, respectively) has been recorded, compared to the control area. An increase of 11% in weight of the fresh biomass has also been detected for thyme in the corridor after about one year from the implementation. The results obtained in the first year have shown that the intermittent shade and microclimate generated by the photovoltaic panels in the corridor area could benefit pepper, aloe vera and thyme cultivation. These trials will continue in next crop cycles, to confirm the preliminary results.

Keywords: Agrivoltaics, Pepper, Aloe, Thyme, Semi-Arid Climate.

1. Introduction

In January 2021 Enel Green Power (EGP) launched a wide experimental agrivoltaic program, made up of nine demonstration tests in Europe (i.e., two in Greece, five in Spain, two in Italy) and one in Australia, aimed at investigating the coexistence of agrozoological solutions in large standard photovoltaic (PV) plants. A holistic vision for both brownfield and greenfield sites has been adopted, to mitigate their environmental/ecological impacts and social footprint, leading to the concept of Sustainable Solar Park. The target of this experimental program is based on two main pillars: 1) Solar inclusivity, which stands for multi-purpose land use (crops, vegetation, grazing) and for a collaborative multistakeholder approach, with the engagement of local communities and 2) Solar diversity, that means biodiversity integration everywhere, through the wildlife habitat preservation, as well as ecosystem services improvement. Different climate areas, PV standard technologies (fixed structures or trackers, equipped with mono or bifacial modules) and eight layouts (different sizes of free corridors from 3 m to 8 m) have been considered in the experimental program. In each agrivoltaic or agriphotovoltaic (APV) tests tailor made agro-zoological solutions have been implemented according to a common scientific protocol, consisting of a testing area ranging from 3 up to 6 ha, a five step methodology, shown in (Figure 1) (site visit, soil characterization, design, implementation and results evaluation), the crops implementation in two areas (in the corridors between two modules rows and in a control area producing the open field demonstration) and low height crops selection, ranging from aromatic species, food and medicinal crops and flowers mix. In some cases, and according to the specific crops and their needs or tolerance to the shadowing, the crops have been implemented also underneath the PV modules. In addition, the experimentation is enabling a massive data collection, through a proximity sensors network. These monitoring sensors will allow enabling sustainable and more effectiveness agricultural practices to support the markets competitiveness of the agricultural partners.

Figure 1. The common methodology considered in the demonstration tests.

The results reported in this study are related to some of the APV testing progress at Totana PV plant, located in Murcia Region (Spain) included in EGP above mentioned experimental program and developed with the support of IMIDA. This area has exceptional conditions for photovoltaic energy (3.4 10^6 h year^{-1} of sunshine and 5.7 kW h^{-1} m^{-2} day^{-1}). Thus, agrivoltaic is a system with great potential in this semi-arid region to promote both the PV and agricultural sectors, while at the same time obtaining synergies between both sectors. On the other hand, South-eastern Spain is the most extreme arid region in Europe and the Iberian Peninsula. In this area, the yield and quality of this vegetable are affected by several environmental factors including suboptimal temperatures (Del Pozo et al., 2019, [1]). In particular, high temperature stress becomes one of the main limiting factors for the proper development of crops since a large part of the production of vegetable products is carried out during the spring and summer months. Heat stress leads to important changes in the plant at physiological, biochemical, and molecular levels (Chaves-Barrantes and Gutiérrez-Soto, 2017, [2], Lokesha et al., 2019, [3]) and as a result, it has adverse effects on fruit yield due to increased flower abortion (Penfield, 2008, [4]). Under these limiting conditions for crops, growing under the influence of solar panels can bring benefits by limiting solar radiation and daytime temperature and increasing ambient and soil humidity, thus reducing light and heat stress (Hassanien et al. 2018, [5]). The aim of this work was to study the development during the first year of cultivation of three species of interest in the selected area (pepper, aloe vera and thyme) in an APV system. Thus, the study includes short-medium and long-cycle species, with different uses in the food, cosmetic, phytochemical, and even perfume industries. Specifically, this study focuses on the 'Bola' or 'Ñora' pepper, which is a variety of pepper with a long tradition in the Guadalentín Valley and which is mostly used to produce paprika with the designation of origin "DO Pimentón de Murcia". Aloe vera is crassulacean acid metabolism (CAM) plant adapted to arid and semi-arid climates due to its low water requirements and tolerance to high temperatures, and water and salt stress conditions (Huerta et al., 2013, [6]). Finally, red thyme is the most commercial Spanish thyme, largely due to the economic importance of the presence of thymol (phenolic monoterpene) in its essential oil (Sotomayor et al., 2004, [7]). This variety of thyme represents the one with the greatest agronomic interest, adapted to the soil and climatic conditions of the trial growing area and with a wide market potential, mainly in the pharmaceutical, food (flavouring and food preservative), in phytochemical and even in perfume industries.

2. Materials and Methods

2.1 Totana PV plant

The study has been carried out at a PV plant located in Totana (Murcia) owned by EGP. The soil of the test area has been classified as alkaline soil (pH>7.5) and has presented a range of textures from sandy-loam to silt-loam with high salinity level (EC 5.71 mS cm^{-1}), mainly due to high concentrations of sodium (43.4 meq L^{-1}), chloride (52.4 meq L^{-1}) and sulphate (61.6 meq L^{-1}) in the 1:2 soil: water extract.

2.2 Crops monitoring

The selected species have included pepper (*Capsicum annuum* cv. Bola), aloe vera (*Aloe Barbadensis* Mill.) and thyme (*Thymus zygis*). Pepper and aloe vera have been implemented in three testing areas: in the corridors between two modules rows, underneath the modules and in a control area, reproducing the open field cultivation. Thyme plants have been grown in the corridors and in a control area. The results reported in this study are related only to the control area and corridors (Figure 2), as the data have shown that the selected species growth is not suitable for the light conditions underneath the panels.

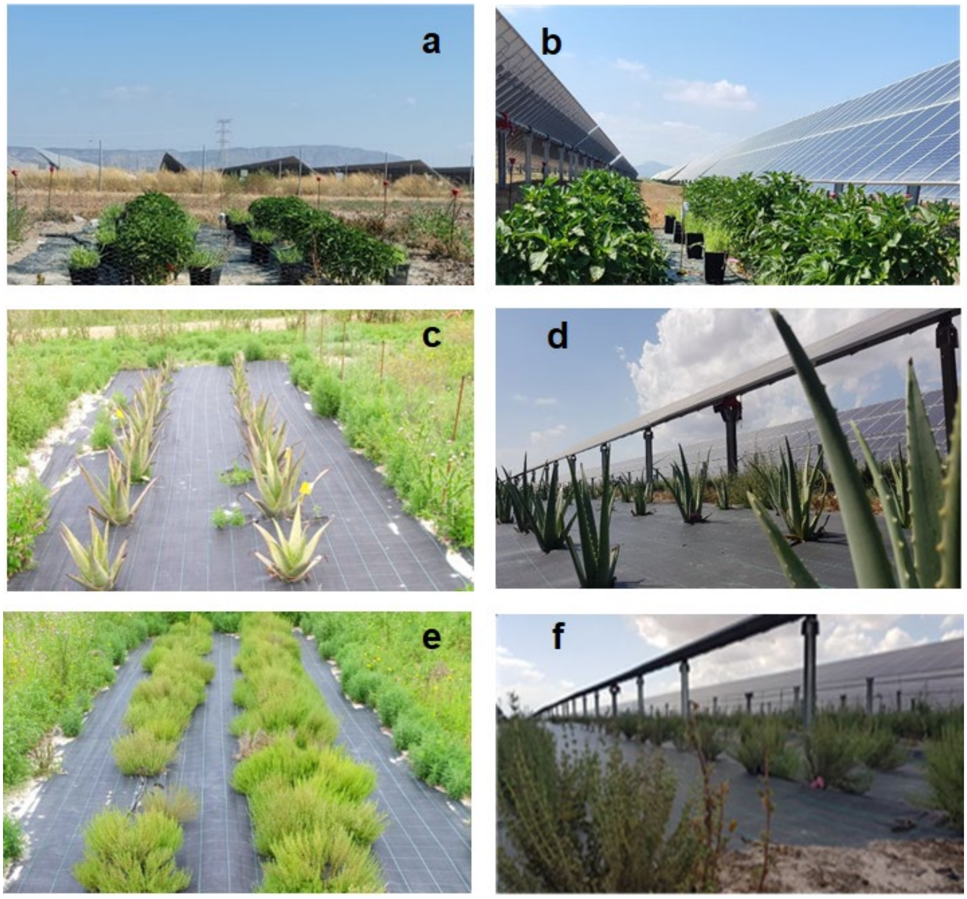

Figure 2. Crop images: pepper control (2a) and in the corridors (2b), aloe vera control (2c) and in the corridors (2d) and thyme control (2e) and the corridors (2f).

Drip irrigation was used, with a single drip line for each row of plants, one emitter per plant and a flow rate of 2 L h^{-1}. The pepper plants have been transplanted on 30 April 2021 and the growing cycle ended on 29 September 2021. Aloe vera plants have been transplanted on 25 March 2021 and leaf volume measurements have been taken 122, 222, 318, 370 and 410 Days After Transplanting (DAT). Thyme plants have been transplanted on 29 April 2021 and measurements of aerial part volume have been carried out 89 and 188 DAT. Moreover, at the end of the first growing season (413 DAT), the thyme plants have been harvested and the weight of the aerial part has been determined. The parameters that have been used to assess the impact of the APV system depended on the specific characteristics and applications of each species. For pepper, biomass has been evaluated by the measurement of plant weight and leaf area (calculated by approximation to the area of an ellipse). Net photosynthesis (A_N) has been measured using a Licor LI-6400XT portable photosynthesis meter equipped with a broadleaf chamber (6 cm^2). All measurements have been taken at a reference CO_2 concentration of 400 µmol mol^{-1} and at a saturating photosynthetic photon flux of 1500 µmol m^{-2} s^{-1} supplied by a red/blue light source (6400-02B LED). Pepper yield has been assessed by weighing all fruits produced per plant. Intrinsic water use efficiency (WUEi) values have been calculated as the ratio between A_N and stomatal conductance (g_s). For aloe vera, the volume of the most developed leaf has been calculated by the formula given by Hernández-Cruz et al. (2002) [8], as reported below:

$$V=(L/12)*\pi*W*T \tag{1}$$

The results have been statistically analysed using IBM SPSS Statistic 25 using analysis of variance (ANOVA). For thyme, biomass has been assessed by calculating the volume of the aerial part by approximation to the volume of a cone.

3 Results and Discussion

In pepper, no significant differences in A_N have been observed between plants in the control and corridor zones (Table 1). The higher WUE_i value and the larger leaf area of the peppers grown in the corridor zone have suggested a mechanism other than stomatal opening to adapt to the specific conditions generated by the solar panels (Hernández et al., 2022, [9]).

Table 1. Net photosynthesis (A_N), intrinsic water use efficiency (WUE_i) and leaf area of pepper grown in control and corridor zones in the APV system.

Zone	**A_N** (µmol CO_2 m^{-2} s^{-1})	**WUE_i** (µmol CO_2 mol^{-1})	**Leaf area** (cm^2)
Control	32.6 ± 2.1	96.2 ± 3.4	75.0 ± 4.4
Corridor	30.8 ± 1.9	115.0 ± 5.0	115.0 ± 5.0
Notes	n.s. - non-significant at P = 5%	Significant differences between means at 1% level of probability	Significant differences between means at 0.1% level of probability

In addition, in the corridor zone, an increase of more than 60% has been recorded for the yield and for the mean fresh weight, as well as an increase of more than 30% in the number of fruits with respect to the control area (Figure 3). This increase in production in the corridor zone compared to the control zone can be attributed to the limitation of excess radiation and of high temperatures during the summer months, provided by the modules, which could lead to flower abortion and therefore reduce fruit set (Hernández et al., 2019, [10]).

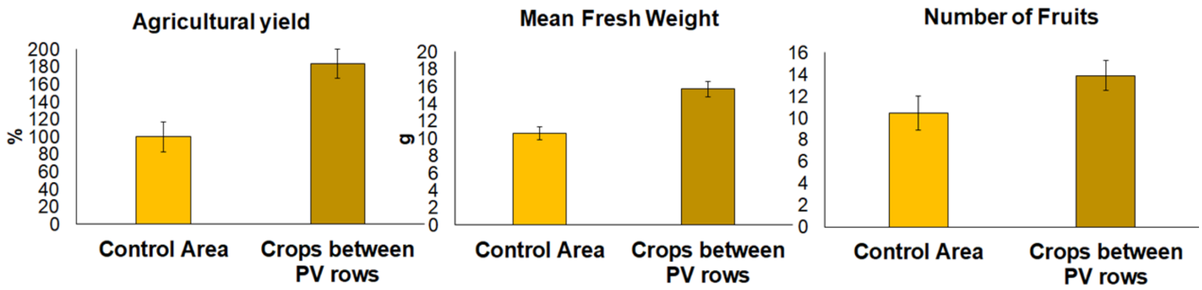

Figure 3. Agricultural yield, mean fresh weight and number of fruits for pepper in the corridor's areas compared to the control areas.

In the case of aloe vera, the leaf biomass (volume) of the plants in the corridors has been more than 30% higher than that of the plants in the control area from 222 DAT and this trend has continued in the following year (up to 410 DAT) (Figure 4). This could represent a potential benefit of cultivation in the corridor zone to increase aloe productivity, as leaf volume is a relevant morphological parameter according to the harvesting criteria usually considered in aloe cultivation (3-4 fully developed mature leaves per plant are harvested at each harvest) (Cristiano et al., 2016, [11]).

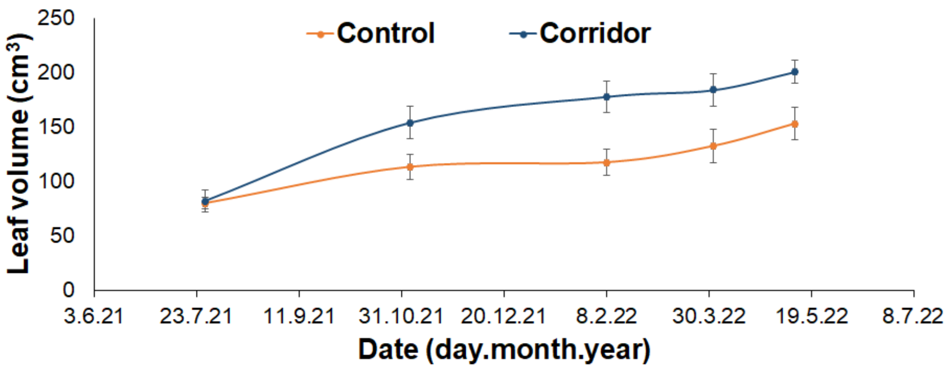

Figure 4. Aloe vera leaf volume development during the first year of cultivation for corridors and control areas.

Regarding thyme, the plants implemented in the corridor area have presented an increase of more than 20% in biomass (shoot volume) from 188 DAT, than plants grown in the control zone, against an apparent reduction observed from 89 DAT (late spring) (Table 2).

Table 2. Shoot volume from 89 and 188 DAT and shoot weight from 413 DAT of thyme grown in control and corridor zones in the APV system.

Zone	**Shoot volume 89 DAT** (L)	**Shoot volume 188 DAT** (L)	**Shoot weight 413 DAT** (g)
Control	1.75 ± 0.24	3.32 ± 0.41	231 ± 22
Corridor	0.92 ±0.17	4.13 ± 0.97	257 ± 24
Notes	Significant differences between means at 1% level of probability	n.s. - non-significant at P = 5%	n.s. - non-significant at P = 5%

This can be explained as a consequence of a reduction in the exposure of the thyme plants to solar radiation during the summer period and, therefore, to light and high temperature stress in the corridor area. In addition, a first harvest has been performed from 413 DAT, showing an increase of 11% in weight of the fresh biomass for the plants grown in the corridors, compared to the ones in the control area. New monitoring campaigns will be carried out on thyme in next crop cycle to validate these data and to increase the statistical analysis.

4 Conclusions

The benefits of intermittent shading on crop yields are particularly evident in arid and semi-arid areas such as the one under study. It is generally accepted that reduced solar radiation is the main factor affecting crop development in APV systems. In many cases, shading generated by solar panels can have a negative effect on crop yields, with significant reductions described for shading rates above 20% (Touil et al., 2021, [12]). On the other hand, in hot climates, excessive solar radiation and the resulting increase in temperature have negative effects on yield and fruit quality (López-Marin et al., 2012, [13]). Under those conditions, crops can benefit from the use of photovoltaic panels to avoid excessive temperature, reduce solar radiation, and thus enhance synergies between the agricultural and photovoltaic sectors. This is especially relevant for crop cycles that take place during the summer period in arid and semi-arid areas (Touil et al., 2021, [12]). Previous studies on peppers grown under different levels of solar panel shading in greenhouses showed that pepper plants performed similarly (Kavga et al., 2019, [14]) or even better than those grown in panel-free areas, due to the protection provided by the panels against UV radiation (Zisis et al. 2019, [15]). However, open-field studies are scarce or even non-existent for crops such as aloe vera or thyme.

Here, pepper cultivation has been favoured by the microclimate generated by the photovoltaic panels, achieving significantly higher yields (more than 60%), higher mean fresh weight (more than 60%) and more than 30% in the number of fruits, than in the control area In addition, the development of the aloe vera crop in the corridor zone has shown potential advantages of the APV system compared to its cultivation in the control zone, with an increase of more than 30% in the biomass (volume) in the corridors. Finally, the results obtained for thyme have shown an increase, after about one year from DAT, of more than 20% in volume and of 11% in the fresh biomass weight for the plants implemented in the corridors, with respect to the control area, from 413 DAT. All these results highlight the potential of APV systems and the convenience of carrying out more experiments on the effects of APV on crop development, especially in arid and semiarid climates. New monitoring campaigns will be carried out during next crops cycles, to assess these data and to increase the statistical analysis.

Data availability statement

Due to the confidential nature of the information used, supporting data are not available.

Author contributions

Conceptualization, R.A. M.di B., M.G., P.F. and J.C.; methodology, V.H., P.F. and J.C.; software, J.C., R.A., V.H. and A.G.; validation, P.F., V.F. and J.C.; formal analysis, V.H., P.F. and P.H.; investigation, P.F. and V.H.; resources, V.H. and A.G.; data curation, P.F. V.H. and J.C.; writing—original draft preparation, P.F and M.G; writing—review and editing, M.di B. and P.H.; visualization, V.H., P.F. and P.H.; project administration, P.F. and J.C.; funding acquisition, R.A., M.di B. and M.G. All authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare that they have no competing interests.

Acknowledgement

The authors thank the technical work provided by Jose Daniel Jiménez, Carlos Colomer, Inmaculada Garrido, Inmaculada Fernández, Elia Molina and María Molina.

References

1. A. del Pozo, N. Brunel-Saldias, A. Engler, S. Ortega-Farias, C. Acevedo-Opazo, G. A. Lobos, R. Jara-Rojas, M. A. Molina-Montenegro, “Climate change impacts and adaptation strategies of agriculture in mediterranean-climate regions (MCRs)”, Sustainability, vol.11, no.10, pp. 2769, May, 2019, doi: https://doi.org/10.3390/su11102769.
2. N. F. Chaves-Barrantes, M. V. Gutierrez-Soto, “Crop physiological responses to high temperature stress. I. Molecular, biochemical and physiological aspects”, Rev. Agron. Mesoam., vol.28, no.1, pp. 237-253, 2017, doi: https://doi.org/10.15517/am.v28i1.21903.
3. A. N. Lokesha, K. S. Shivashankara, R. H. Laxman, G. A. Geetha, A. G. Shankar, “Effect of high temperature on fruit quality parameters of contrasting tomato genotypes”, Int. J. Curr. Microbiol. App. Sci., vol.8, no.1, pp. 1019-1029, Feb., 2019, doi: https://doi.org/10.20546/ijcmas.2019.803.124.
4. S. Penfield, “Temperature perception and signal transduction in plants”, New Phytol., vol.179, no.3, pp. 615-628, May, 2018, doi: https://doi.org/10.1111/j.1469-8137.2008.02478.x.
5. R. H. E. Hassanien, L. M. Li, F. Yin, “The integration of semi-transparent photovoltaics on greenhouse roof for energy and plant production”, Renew. Energy, vol.121, pp. 377-388, Jun., 2018, doi: https://doi.org/10.1016/j.renene.2018.01.044.
6. C. Huerta, M. Freire, L. Cardemil, “Expression of hsp70, hsp100 and ubiquitin in *Aloe barbadensis* Miller under direct heat stress and under temperature acclimation conditions”, Plant Cell Rep., vol.32, no.2 pp. 377-388, Feb., 2018, doi: https://doi.org/10.1007/s00299-012-1363-4.
7. J. A. Sotomayor, R. M. Martínez, A. J. García, M. J. Jordan, “*Thymus zygis* subsp gracilis: Watering level effect on phytomass production and essential oil quality”, J. Agric. Food Chem., vol.52, no.17, pp.5418-5424, Jul., 2004, doi: https://doi.org/10.1021/jf0496245.
8. L. Hernández-Cruz, R. Rodríguez-García, D. Rodríguez, J. L. Angulo-Sánchez, J. Janick, A. Whipkey, “Aloe vera response to plastic mulch and nitrogen”, in Trends in New Crops and New Uses. Proceedings of the Fifth National Symposium, Atlanta, (Georgia), USA: J. Janick, A. Whipkey (Eds), 2002, pp.570-574.
9. V. Hernández, P. Hellín, M. A. Botella, E. Vicente, J. Fenol, P. Flores, “Oligosaccharins alleviate heat stress in greenhouse-grown tomatoes during the spring-summer season in a semi-arid climate”, Agronomy, vol.12, no.4, pp.5418-5424, Apr., 2022, doi: https://doi.org/10.3390/agronomy12040802.
10. V. Hernández, P. Hellín, J. Fenoll, P. Flores, “Interaction of nitrogen and shading on tomato yield and quality”, Sci. Hortic. vol.10, no.255, pp. 255-259, Sept., 2019, doi: https://doi.org/10.1016/j.scienta.2019.05.040.
11. G. Cristiano, B. Murillo-Amador, B. De Lucia, “Propagation techniques and agronomic requirements for the cultivation of Barbados Aloe (*Aloe vera* (L.) Burm F.)-A Review”, Front. Plant Sci., vol.7, pp. 1410, Sept., 2016, doi: https://doi.org/10.3389/fpls.2016.01410.
12. S. Touil, A. Richa, M. Fizir, B. Bingwa, “Shading effect of photovoltaic panels on horticulture crops production: a mini review”, Rev. Environ. Sci. Biotechnol., vol.20, pp. 281-296, Mar., 2021, doi: https://doi.org/10.1007/s11157-021-09572-2.
13. J. López-Marin, A. Gálvez, C. González, A. Egea-Gilabert, J.A. Fernandez,“Effect of shade on yield, quality, and photosynthesis-related parameters of sweet pepper plants”, Acta Hort., vol.956, pp. 545-552, Jun., 2002, doi: https://doi.org/10.17660/ActaHortic.2012.956.65.
14. A. Kavga, I. F. Strati, V.J. Sinanoglou, C. Fotakis, G. Sotiroudis, P. Christodoulou, P. Zoumpoulakis, “Evaluating the experimental cultivation of peppers in low-energy-demand greenhous-es. An interdisciplinary study”. J. Sci. Food Agric., vol.99, no.2, pp. 781-789, Aug., 2019, doi: https://doi.org/10.1002/jsfa.9246.

15. C. Zisis, E. M. Pechlivani, S. Tsimikli, E. Mekeridis, A. Laskarakis, S. Logothetidis, “Organic photovoltaics on greenhouse rooftops: Effects on plant growth”, Materials Today, vol. 21 pp. 65-72, Nov., 2020, doi: https://doi.org/10.1016/j.matpr.2019.07.658.