Scientific Papers. Series B, Horticulture. Vol. LXVI, No. 1, 2022
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

RESEARCH ON MODULAR HORTIVOLTAIC SOLUTIONS

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Abstract

The present paper aims to document and identify some possible modular hortivoltaic solutions, which efficiently combine horticultural production with the generation of photovoltaic electricity on smaller spaces than usual in agrivoltaic applications. This initiative involves the development of structures to support photovoltaic panels, under which horticultural species can be grown in containers of different sizes and whose irrigation is carried out in a significant proportion with the help of rainwater collected from the surface of photovoltaic panels. At the same time, an assessment will be made of the potential of green energy generated by the photovoltaic panel modules with the presentation of some species that can be cultivated for utilitarian and ornamental purposes. The solutions resulting from the synergy generated by the combination of photovoltaic panels - green roofs will be able to be generalized and recommended in a wide range of situations, thus responding to the current needs of resource reuse and combating climate change.

Key words: *Agrivoltaics, hortivoltaics, container gardens, carbon reduction, rainwater reused, terraces.*

INTRODUCTION

Agricultural production combined with the production of electricity using photovoltaic panels forms the essence of the agrivoltaic system concept, first mentioned at the Fraunhofer Institute in Germany (Goetzberger & Zastrow, 1982).
By raising the supporting structure of the photovoltaic panels by about 2 m and increasing the distance between the rows to about 3 times the height of its modules, they obtained a uniform radiation on the ground, allowing the movement of agricultural machinery under the structure.
A pergola-like solar sharing system was developed and patented in Japan (Nagashima, 2005), and later the effects on a corn crop were studied (Sekiyama & Nagashima, 2019).
At Lavalette, near Montpellier, France, an experimental structure consisting of photovoltaic panels installed 4 m above the ground was built and the shadow effect generated by solar panels placed at different distances between rows was studied (Dupraz et al., 2011).
In Montpellier, the effects of precipitation intensity at various angles of inclination of solar panels were studied (Elamri et al., 2018), but also the yields of lettuce crops with observations on plant morphology and physiology (Marrou et al., 2013).
A study from the University of Arizona showed that plants grown under solar panels 3.3 meters above the ground and a 32° incline (latitude of the University of Tucson, Arizona) can lower daytime air temperatures by more than 1°C. the temperature rises during the night by 0.5°C, the temperature at the level of the solar panels was lower by 9°C, and the soil dried more slowly between waterings.
Regarding the species tested, compared to the plants grown in the field, the chiltepin pepper (*Capsicum annuum* var. *glabriusculum*) produced a quantity of fruit 3 times higher, the jalapeño pepper (*Capsicum annuum* var. *annuum*) had a production with 11% more small, but consumed 65% less water, while cherry tomatoes (*Solanum lycopersicum* var. *cerasiforme*) - had a 100% higher yield using the same amount of water (Barron-Gafford et al., 2019). The period analysed in this study was 1990-2010. A study on a plot near the University of Hohenheim concluded that celery can be considered a suitable crop for cultivation under the solar panels of an agrivoltaic system

(Weselek et al., 2021). Other studies highlight the advantages of photovoltaic systems such as: dual land use (Mavani et al., 2019; Santra et al., 2017), their extended potential (Dinesh & Pearce, 2016), opportunities (Guerin, 2019), and perspectives on markets and communities (Pascaris et al., 2021).

There are many other ongoing studies in Germany, the Netherlands, Africa and Asia, but the results of the research have not yet been published.

However, before installing an agrivoltaic system, both the construction legislation (whether building permit is required) and the trade regulations, subsidies and tariffs applied in each country must be carefully studied (Vollprecht et al., 2021).

MATERIALS AND METHODS

There are many terraces of blocks of flats that are unoccupied and which, at least in theory, could house both plants and fotovoltaic panels for energy production.

With the help of a well-known application - Google Maps - it is relatively easy to identify which are the favourable locations, respectively the surfaces facing south, southwest or southeast, unoccupied by other buildings or installations (antennas, generators, air conditioning units). Also, with the help of the application we can approximate with sufficient precision the dimensions of the terraces so as to sketch the location of some hortivoltaic systems.

Thus, we identified several buildings with horticultural potential in the UASVM Bucharest campus. We also built a schematic diagram of a hortivoltaic system consisting of several photovoltaic panels, the supporting structure, the container garden in which both the plants and the concrete slabs will be placed to stabilize the structure, as well as and the rainwater tank from which the plants will be irrigated mainly.

Some species of utilitarian and ornamental plants that have been grown in containers in different conditions of temperature, humidity and light in the botanical garden of the USAMV Bucharest campus will be exemplified.

Each hortivoltaic garden and terrace has its peculiarities of orientation towards the sun and the ability to take on additional loads generated by the forces of weight and wind, and the set of structures will be analyzed by a structural engineer who at the end will give its approval for their installation.

RESULTS AND DISCUSSIONS

The smallest module contains 2 x 2 = 4 photovoltaic panels, but can reach 4 x 3 = 12 panels, an area easy to organize, install and maintain. The minimum height of the structure is 1.2 meters, and the maximum can exceed 2.7 meters.

In Figure 1 we have a module 12 (M12) - under the 12 photovoltaic panels (0.4 kW each, dimension - 1 x 2m) there is a 500 litre tank that collects rainwater and sends it to the 16 containers with a volume of 130 litres through a pump (12V) and drip tubes. The 130-liter containers can contain 4 pieces of 10-liter containers or 1 piece of 50-liter container, and those that contain the vertical pillars of the support structure have concrete slabs inside for stabilization, over which 10-liter containers are placed. An M12 can generate a maximum of 12 x 0.4 Kw = 4.8 kWh of electricity every sunny hour and can accommodate 16 x 4 = 64 plants in 10 litre containers.

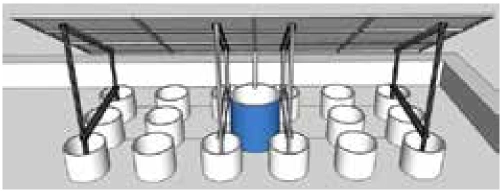

Figure 1. The M12 module contains 12 photovoltaic panels, 64 plants and can generate up to 4.8 kWh in every hour of full sun

In Figure 2 we have a photo with the positioning of the 10 litre containers in a 130 litre container.

The 130-liter containers protect the plant containers from excessive heat or frost, and depending on the engineering strength calculations, concrete slabs are provided at the bottom to stabilize the entire structure of the photovoltaic modules.

Figure 2. The M12 module contains 12 photovoltaic panels, 64 plants and can generate up to 4.8 kWh in every hour of full sun

A 10 litre container is also suitable for growing onion sets. Red, yellow and white onion varieties were planted (Figure 3).

Figure 3. *Allium cepa* 'Red Baron'

Container substrate contains an organic fertilizer in pellets which is particularly suitable for fertilizing horticultural crop. The optimal supply of nutrients and humus of the organic fertilizer is produced from chicken manure. In addition to organic matter, it contains all essential nutrients and it has a high content of organic matter which is essential for the maintenance of container soil fertility. The organic matter also improves the moisture retaining capacity of the substrate. It gradually releases its nutrients during the growing season of the plant.

In Figure 4 we can see *Salvia officinale*, *Lactuca sativa, Petroselinum* spp., *Levisticum officinale*. Containers containing these species will be placed in the sunniest areas.

Figure 4. Green leaves vegetables and herbs

In figure 5 we have *Lophantus anisatus*, a plant resistant to environmental conditions, with honey, therapeutic and culinary properties (Costache & Vînătoru, 2017). It is suitable for cultivation in the sunnier areas at the edge of photovoltaic modules.

Figure 5. *Lophantus anisatus* in September and March, respectively, after wintering outside without frost protection

Figure 6. shows easy to grow and low maintenance *Heuchera* spp. They grow well in containers, because the substrate is not too wet or too dry. Partial shade suits well heucheras, so is a good plant to grow under photovoltaic panels.

Figure 6. *Heuchera* spp.

Figure 7 shows 4 species of ferns, one of which is of the genus *Asplenium.*
Research has shown that *Asplenium nidus* Linn. has high rates of CO2 and HCHO removal, raises relative humidity and reduce temperature (Ying-Ming & Chia-Hui, 2015)
These features that reduce air pollution and carbon footprint, which are important for indoor cultivation, along with proven shade and cold tolerance on the outside, recommend ferns for growing in containers under photovoltaic panels. In the year 1990, dairy cows represented 59.46% of the cattle livestock and in the year 2010, they registered just 53.73%

Figure 7. Ferns in partial shade

In Figure 8 we can see an example of a terrace with M12 modules, arranged to allow the access of the maintenance staff but also of the eventual visitors. The spaces between the modules must also consider the latitude at which the panels are installed, the orientation towards the sun, the wind speed in the respective area, the existing obstacles on the terrace, as well as the strength calculations of the construction engineers. An additional water source must also be provided to supply the tanks installed under the modules if required.

Figure 8. Rooftop with M12 modules

A building can have several terraces, and in Figure 9 we can see how one of the faculties on the USAMV campus can contain up to 650 photovoltaic panels that produce 260 Kwh of energy per hour of sunshine, well above the building's own consumption, the amount additional energy can be delivered to the national grid. Also, more than 3,000 plants in 10-liter containers can be grown under the panels installed on the building.

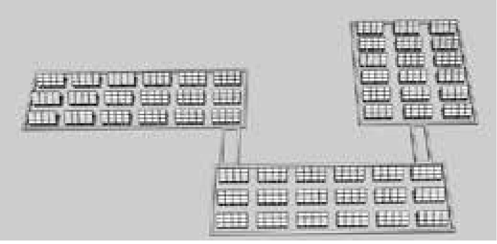

Figure 9. Multiple terraces of a faculty from USAMV Bucharest

Preliminary assessments can be made using the Google Maps application which provides us with valuable information on the orientation of the terraces towards the cardinal points and the existing obstacles on the respective terrace, as can be seen in Figure 10. However, the final solution can be adopted only after visits with all stakeholders and specialists, as unforeseen situations may arise, such as the renovation and consolidation of the building soon. Moreover, such an action can be an opportunity, because a horticultural solution can be taken into account in the structural calculation, which can be beneficial for both energy generation and the environment.

Figure 10. Orientation of the terraces towards the cardinal points and the existing obstacles

Finally, Figure 11 represents a sketch on a close scale of an important part as an area of terraces in the buildings located in the USAMV Bucharest campus, respectively the roofs of the student hostels and the canteen. Together with the terraces of other buildings on campus, we have reached an area of 18,800 square meters, which can be arranged with 26,000 plants and 5,000 photovoltaic panels of 0.4 kWh each, which can produce in a single hour of full sun almost 2 MW of electricity.

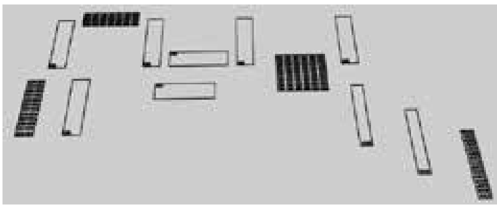

Figure 11. Student hostels and canteen terraces in USAMV Bucharest

CONCLUSIONS

Agrivoltaics is one of the areas of great interest at present, with research being carried out on all continents. It allows a dual use of land both to produce electricity from photovoltaic sources and for agricultural production. In this study, we defined "Hortivoltaics" as a branch of "Agrovoltaics" that refers to small cultivation areas, as well as to the terraces of public or residential buildings that can house under photovoltaic panels plants grown in containers, irrigated as much as possible by rainwater. recovered from the surfaces of photovoltaic panels, but which also have a backup power supply in case of drought. Cultivated plant species are utilitarian but also ornamental, with varying requirements for light requirements, although most of them will be tolerant of shade, heat and water stress. It is necessary to develop prototypes of light photovoltaic modules, but resistant to wind and seismic forces, whose weight resulting from structures and containers to be supported by the terraces of buildings.

The example in this study referred to the terraces identified in the USAMV Bucharest campus using the Google Maps application, but other areas and terraces with a high horticultural potential can also be identified.

REFERENCES

Barron-Gafford G.A., Pavao-Zuckerman M.A., Minor R.L. et al. (2019). Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands. *Nat Sustain* 2, 848–855.

Costache N., Vînătoru C. 2017 - Lofant. Lophantus. Lophantus anisatus. Agastache foeniculum. *Buzău: Alpha MDN*, 55-57.

Dinesh H., Pearce J.M. (2016). The potential of agrivoltaic systems. Renew. *Sustain. Energy Rev*. 54, 299–308.

Dupraz C., Marrou H., Talbot G., Dufour L., Nogier A., Ferard Y. (2011). Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes. *Renewable Energy*, Volume 36, Issue 10. 2725-2732.

Elamri Y., Cheviron B., Mange A., Dejean C., Liron F., et al. (2018). Rain concentration and sheltering effect of solar panels on cultivated plots. *Hydrology and Earth System Sciences, European Geosciences Union*, 22 (2), 1285-1298.

Guerin T.F. (2019). Impacts and opportunities from large-scale solar photovoltaic (PV) electricity generation on agricultural production. *Environ. Qual. Manag*. 28, 7–14.

Goetzberger A., Zastrow A. (1982). On the coexistence of solar-energy conversion and plant cultivation. *International Journal of Solar Energy*;1(1):55–69.

Marrou H., Wery J., Dufour L., Dupraz C. (2013). Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels. *European Journal of Agronomy*, 44, 54–66.

Mavani D.D., Chauhan P.M., Joshi V. (2019). Beauty of agrivoltaic system regarding double utilization of same piece of land for Generation of electricity & food Production. *Int. J. Sci. Eng. Res*., 10, 118–148

Nagashima A. (2005). Sunlight Power Generation System. Patent No. 2005-277038A.

Pascaris A.S., Schelly C., Burnham L., Pearce J.M. (2021). Integrating solar energy with agriculture:

industry perspectives on the market, community, and socio-political dimensions of agrivoltaics. *Energy Res. Soc. Sci*., 75, 102023.

Santra P., Pande P.C., Kumar, S., Mishra D., Singh, R.K. (2017). Agri-voltaics or solar farming—The concept of integrating solar PV based electricity generation and crop production in a single land use system. *Int. J. Renew. Energy Res*., 7, 694–699.

Sekiyama T, Nagashima A. (2019). Solar Sharing for Both Food and Clean Energy Production: Performance of Agrivoltaic Systems for Corn, *A Typical Shade-Intolerant Crop. Environments*, 6(6):65.

Trommsdorff M., Schindele S., Vorast M., Durga N., Patwardhan S., Baltins K., Söthe-Garnier A., Grifi G. (2019). Feasibility and Economic Viability of Horticulture Photovoltaics in Paras, Maharashtra, India. Fraunhofer Institute for Solar Energy Systems (ISE).

Vollprecht J., Trommsdorff M., Hermann C. (2021). Legal framework of agrivoltaics in Germany. AIP Conference Proceedings 2361, 020002.

Weselek A., Bauerle A., Zikeli S., Lewandowski I., Högy P. (2021). Effects on crop development, yields and chemical composition of celeriac (*Apium graveolens* L. var. *rapaceum*) cultivated underneath an agrivoltaic system. *Agronomy*. 11.4

Ying-Ming S., Chia-Hui L. (2015). Removal of Indoor Carbon Dioxide and Formaldehyde Using Green Walls by Bird Nest Fern. *The Horticulture Journal* 84(1):69-76.