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Management of a Mobile Photovoltaic Shading Net in a Greenhouse. Preliminary Results

José-María Cámara-Zapata[1], Sofía Pardo[1], Julia Muñoz-Acero[1], Herminia Puerto[1], Carmen Rocamora[1], Santiago García-Martínez[1], Ricardo Abadía[1], Francisco-Javier Ferrández-Pastor[2]

[1] Instituto de Investigación e Innovación Agroalimentaria y Agroambiental de la Universidad Miguel Hernández, CIAGRO-UMH, Ctra de Beniel, sn, 03312, Orihuela, Alicante, Spain
[2] Instituto Universitario de Investigación Informática (IUII-UA). University of Alicante, Carretera San Vicente del Raspeig, s/n, 03690, San Vicente del Raspeig, Alicante, Spain
jm.camara@umh.es

Abstract. Nowadays, agricultural production faces many challenges, including adaptation and mitigation of climate change. A mobile photovoltaic shading net in a greenhouse reduces transpiration and prevents photosynthesis saturation, which can improve growth and production. In addition, the production of electrical energy for consumption in the greenhouse itself, such as in the fertigation installation, not only contributes to mitigating climate change but can also reduce the operating costs of the crop, improving economic results. To guarantee the proper use of this type of facility, it is necessary that both types of production, crop, and energy, are compatible. In this work, the management of a mobile photovoltaic shading net is evaluated based on its characteristics, those of the greenhouse and those of the crop. Two mobile photovoltaic nets are used in different crops and greenhouses. On the one hand, a mobile net with fine photovoltaic cells and a shading of approximately 50%, in a glass greenhouse with a crop of hemp (*Cannabis sativa* L.). On the other hand, a mobile net based on flexible photovoltaic panels, with practically complete shading, in tomato (*Solanum lycopersicum* L.) in a windbreak greenhouse. Total radiation values, PAR radiation, ambient temperature and humidity, growth, plant production, as well as energy production and consumption are monitored. The production and energy efficiency of the production system used in the windbreak greenhouse is higher than that of the glass greenhouse. The glass greenhouse reduces incident solar radiation on the photovoltaic grid to a greater extent than the windbreak greenhouse. In addition, tomato cultivation is more sensitive to light saturation than hemp cultivation. Nevertheless, it is necessary to evaluate the use of agrovoltaic installations in a comprehensive way to avoid unwanted effects on plant or energy production.

Keywords: Energy efficiency, *Cannabis sativa*, *Solanum lycopersicum*, PAR, Crop photo-sensitivity.

1 Introduction

The protection of plants in greenhouses from the outside climate contributes to the sustainability of plant production. Shading limits the incidence of solar radiation on the crop and reduces evapotranspiration. All nets reduce photosynthetically active radiation (PAR), so mobile ones are better than fixed ones, since they only extend when necessary. Despite the effect on PAR, shading improves climate homogeneity and increases crop productivity and quality [1].

Tomato (*Solanum lycopersicum* L.) is the second most cultivated vegetable in the world, with 189 million tons and 5.2 Mha in 2021 [2]. It has high water and nutritional needs and is sensitive to the reduction of photosynthesis due to photoinhibition (Mutale-Joan et al., 2020). Hemp is a fast-growing and highly profitable crop in Europe and North America, with China being the main producer and exporter [2].

In the current context of high energy and raw material costs, market uncertainty and price volatility, farmers are exposed to great economic risks that compromise the survival of the sector, and with it, the supply of the markets. In order to improve the resilience of agricultural production companies, it is necessary to develop innovative agronomic strategies that contribute to improving the sustainability of plant production. In this work, the agronomic and energy effect of two photovoltaic shading nets on tomato and hemp crops under greenhouse conditions is evaluated.

2 Materials and Methods

The Institute for Agro-Food and Agro-environmental Research and Innovation of the Miguel Hernández University located in Orihuela, Alicante, Spain, has a multi-span net greenhouse, with an area of 1000 m^2, with 10-density transcarnated monofilament net x 16. A short spring-summer cycle of the Muchamiel tomato has been carried out inside (transplantation on April 4 and removal of the plants on July 20, 2023). A photovoltaic net has been used, with a width of 7 m and a length of 9 m, containing 36 photovoltaic plates made of monocrystalline silicon cells, with a unit width of 0.612 m and a length of 1.055 m with a nominal power of 100 W. The daily deployment of the photovoltaic net is carried out between 12:00 and 17:00 for 80 days, starting on May 1, 2023. When the photovoltaic panels produce energy, their plane forms an angle of 20º with the horizontal plane (Fig. 1).

The Plant Experimentation Unit of the University of Alicante, Spain, has a 45 m^2 glass greenhouse with a 30 m^2 net that includes 15 m^2 of CIGS photovoltaic cells. The net has a power rating of 1.2 kW and is kept fixed throughout the experiment (Fig. 1). Inside the module, hemp is cultivated in individual 4-L pots with coconut fiber substrate in a spring-summer cycle, with a transplant on April 5 and harvest on July 21, 2023.

Fig. 1. Views of the greenhouse with the net with monocrystalline silicon plates (A and B) and with the CIGS mesh (C and D).

3 Results

The use of the net with monocrystalline silicon photovoltaic panels tends to increase the ambient temperature in the crop area with respect to the interior and exterior of the greenhouse. Fig. 2 shows the daily evolution of these temperatures on July 16, 2023.

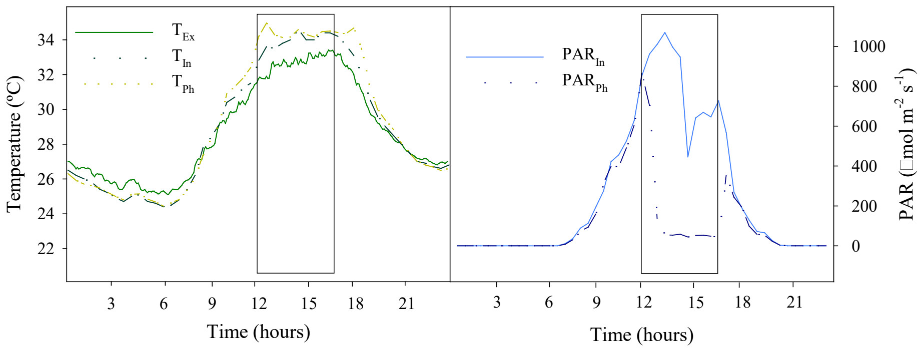

Fig. 2. Daily time course (07/16/2023) of the outside temperature (T_{Ex}), inside (T_{In}) and between the nomocrystalline silicon net and the plants (T_{Ph}). Daily time course of PAR radiation inside (PAR_{In}) and between the nomocrystalline silicon net and the plants (PAR_{Ph}).

The use of this photovoltaic grid between 12 and 17 h greatly reduces the PAR in the cultivation area. The PAR value reaches approximately 800 µmol m^{-2} s^{-1} before 12 h and 300 µmol m^{-2} s^{-1} after 17 h.
Table 1 shows the average values of the solar energy available for photovoltaic energy production, the photovoltaic energy produced, the efficiency and the maximum photovoltaic power per unit of photovoltaic area.

Table 1. Mean values of the variables related to the energy efficiency of the photovoltaic installations throughout the experiment.

	Monocrystalline silicon
Available energy in the shading (12/17 h, kW h)	65.4±1.7
Photovoltaic energy of the shading (12/17 h, kW h)	4.29±0.08
Efficiency of the photovoltaic shading (%)	6.6±0.1
Maximum photovoltaic power (W m^{-2} photovoltaic cells)	80
	Copper-Indium-Gallium-Selenium (CIGS)
Daily available energy in the shading (kW h)	91±2
Daily photovoltaic energy of the shading (kW h)	2.6±0.4
Efficiency of the photovoltaic shading (%)	2.9±0.1
Maximum photovoltaic power (W m^{-2} photovoltaic cells)	25

4 Discussion

The use of the photovoltaic grid with monocrystalline silicon plates tends to increase and stabilize the ambient temperature (Fig. 2). In addition, a drastic reduction of the PAR takes place on the vegetation cover. However, when the net is folded, the PAR value reaches sufficient values to guarantee the photosynthesis of the plants (Fig. 2). The tomato and hemp plants grown under the photovoltaic nets of both greenhouses present a production and quality similar to those of the plants in the rest of the greenhouses (data not shown).

The CIGS net has an efficiency of 2.9% and a maximum power of 25 W m^{-2}. This value represents approximately 30% of the nominal value of the installed CIGS cells, established at 80 W m^{-2} according to the manufacturing company. On the other hand, the average efficiency of the monocrystalline silicon net is 6.6% and the maximum power value is 80 W m^{-2}. This value represents 50% of the nominal value of the plates used. The difference between the maximum power produced by both nets in such similar conditions may be due to the dirt on the glass of the greenhouse roof where the CIGS net has been installed.

In tomato, it is recommended that fixed photovoltaic installations do not exceed 20% shading and it is estimated that shading the entire crop area reduces solar radiation by 80% and causes a 70% decrease in production. These values vary depending on the outside climate, the arrangement of the panels, the orientation and the structure of the greenhouse [3]. Under the conditions of our experiment, the efficiency of the monocrystalline silicon installation is 6.6% and its unit energy production is 5.5 kW h m^{-2} of net area. For its part, the CIGS installation has a yield of 2.9% and a unit production of 6.8 kW h m^{-2} of net area.

5 Conclusions

Mobile photovoltaic nets are compatible with greenhouse cultivation if the management of the installation is carried out taking into account the needs of the plants. The use of a photovoltaic installation in a greenhouse during the hours of maximum solar radiation allows the combination of plant and energy production. The overall efficiency of the system depends on many factors, such as the crop, the photovoltaic technology, the type of greenhouse, the cover material, the location, the orientation, the outside climate, the dirtiness of the cover, etc.

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