AgriVoltaics World Conference 2022

The Management of Agriculture Production Under Photovoltaic Panels

https://doi.org/10.52825/agripv.v1i.532

Effect of Shading in an Agri-PV System on Structure and Growth of Ornamental Plants

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Abstract. The impact of shading on selected ornamental plant species was investigated by monitoring plant growth under a nontransparent roof in a nursery in Jülich and in an AgriPV-System in Rathenow. Plants were continuously measured using different RGB camera systems. Shading led to an increase in projected leaf area, increased petiole length and specific leaf area. Morphological changes in shade-sensitive *Geranium cinereum* plants led to a loss of plant marketability. Flowering time of Hydrangea sp. was not affected in a long term experiment in the AgriPV-System. Pigment composition was not altered significantly in *Rhododendron* plants. Experiments will be continued with a local nursery in a novel AgriPV-System established near Jülich.

Keywords: Ornamental Plants, Plant Growth, Plant Physiology

1. Introduction

Many ornamental plant species require at least partial shade for optimal growth and development. In this context, combining plant production in tree and shrub nurseries with PV power production is of special interest, as the reduction of irradiation on plant level caused by installed PV modules can potentially have desirable effects during plant production, as for instance an increase of flower size [1]. Additionally, the PV installation can protect the leaves and flower buds from hazardous weather (e.g. hailstorms).

In Germany, nurseries cover an area of approximately 170 km² [2], a relatively small portion compared to the land-use by agriculture. Nevertheless, nurseries can contribute to climate-neutral energy production. For understanding how producers of ornamental plants can implement photovoltaics in their production processes and existing facilities, it is essential to understand the impact of shading by PV-panels on plant growth.

We investigated the effect of shading on different species of ornamental plants varying in their light requirements. The aim of the study was to document and quantify important traits for ornamental plant production, like growth dynamics, plant pigment composition, onset of flowering, and overall effect of shading on plant aesthetics and marketability.

2. Material & Methods

2.1 Nursery

Plants were grown in pots at a commercial nursery (Baumschule Böcking) near Jülich and were afterwards transferred under a nontransparent roof mimicking the shadowing by an Agri-PV system at a different location within the nursery (Fig. 1). In the nursery setup, a total of 5 species was investigated (*Hydrangea sp.*, *Rhododendron* sp., *Geranium cinereum*, *Spirea japonica* and *Physocarpus nigra)*. In this paper, results of two species (*Hydrangea* sp. and *G. cinereum*) are shown, as due to time restrictions the other species were not monitored in sufficient replication for reliable analysis. Pots of each species were distributed underneath and around the roof. The experimental setup did not allow calculations of daily light sums on plot level, instead plants were pooled in two different experimental groups (shade and full sun). Plants in full sun light did not receive any shading by the roof during the experiment. Shade

Figure 1. Experimental setup at the nursery in Jülich. Plants were grown under a nontransparent roof (max. height 3.6 m, min height 2.5 m) for 6 weeks.

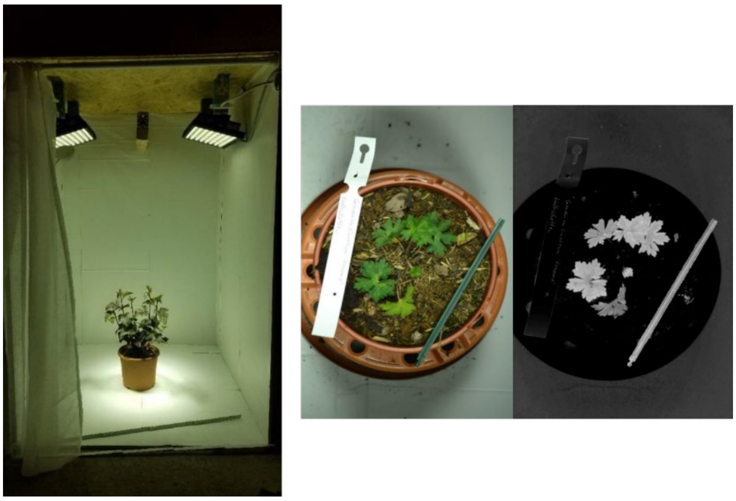

Figure 2. Custom-made photo-box used for imaging of plants grown at the nursery (left). Top and side view images were taken, green pixels were masked out using GIMP and ImageJ software packages for calculation of projected leaf area (right).

plants were covered by the roof during midday, only occasionally receiving direct sunlight during morning and evening hours. Therefore there was some heterogeneity in light conditions within plants pooled in the shade group. Light intensity on was measured on selected dates using the PAR-sensor of a MINI-PAM photosynthesis yield analyzer (Walz, Effeltrich, Germany).

Plant growth was continuously monitored by RGB imaging. Pots were transferred to a custom-made photo box (Fig. 2) and photographed using a digital camera (Nikon D3100). Images were taken under standardized light conditions, provided by two LED light sources. The measurement angles remained constant throughout the experiment, images were taken from top-view and side-view. For analysis, images were formatted using GNU Image Manipulation Program (GIMP) [3] and projected leaf area was calculated using ImageJ [4].

2.2 Rathenow

A different set of plants of same provenance was transferred from the nursery to the Agri-PV developed by Sunfarming GmbH in Rathenow, Germany. The agrophotovoltaics system (Fig. 3) consists of eight buildings on a total area of 15,550 m^2 and has 730kWp of installed PV capacity generating energy of around 690 MWh per year. The experimental setup (Figure 3) was set up under one part of the shaded roof hall. Here, the PV-panels are oriented North-South, tilted 15° from the horizontal towards South.

Figure 3. SUNfarming Food & Energy system (left) and experimental setup (right). Positions of the cameras used for monitoring plant growth under the panel and the acrylic glass section of the system marked with red circles. Plants were grown for 12 weeks after being transferred from the nursery to Rathenow.

One group of plants was placed underneath the PV panels, whereas the second group was placed under the transparent acrylic glass covering the space in between the panels. Plants were watered on a daily base using a drip irrigation system. Plant growth was continuously monitored (one image per hour) from July 1 to September 2 using wildlife cameras (SecaCAM Homevista, Fig. 4) mounted at APV framework at a height of approximately 2 m (Fig. 3). The objective of image analysis was to determine plant growth under the shaded and open region in non-lab conditions by using the cost effective camera setup. Every week plant images with the best lighting condition were selected for image analysis. The selection was done according to best natural lighting condition for differentiating plant leaves from the image background.

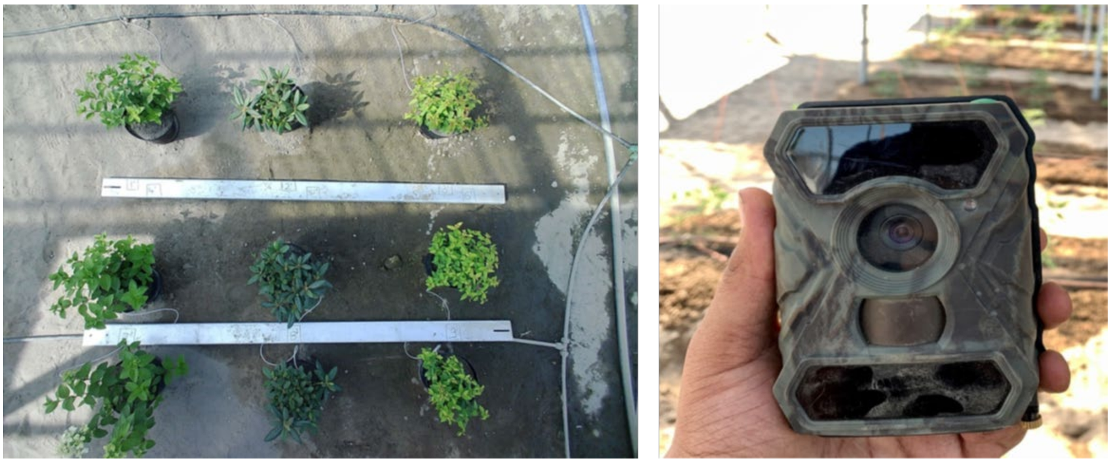

Figure 4. Wildlife camera system used for continuous monitoring of plants in the Food & Energy system (right) and one image taken and used for analysis of projected leaf area (left).

Here, evenly distributed light across the entire plant combined with conditions with low reflection made analysis most accurate. This was usually the case in the evening hours or in cloudy conditions. Projected leaf area was calculated from images using ImageJ software. Plants were separated from the background by applying a color threshold for green pixels. Segmented images were converted into a binary image and leaf area was calculated by counting white pixels. Distance per pixel (in cm/pixel) was determined by placing an object of known dimensions in the camera's field of view.

At the end of the experiment, specific leaf area (SLA) of a subset of leaves (the youngest fully developed leaves of 8 branches per individual plant) was measured. After harvesting the leaves, leaf area was measured using a LI-3100 leaf area meter and leaf biomass was measured after drying samples for 48 hours.

Additionally, plants of *Rhododendron* sp. were used for investigating plant pigment compositions and physiology. The youngest fully developed leaves of plants grown under the panels or acrylic glass, respectively, were used for measurements. Plant pigment composition was measured using the PolyPen RP410 UVIS (Photon System Instruments, Drasov, Czech Republic). The PolyPen is an active leaf-contact spectrometer measuring leaf reflectance in a range from 330-790 nm with a spectral resolution of 1 nm. From the acquired data, Vegetation Indices were calculated using the Spectrapen software.

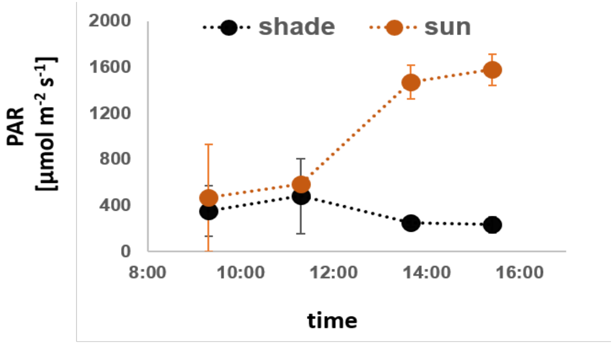

Figure 5. Comparison of light intensities received by *Geranium cinereum* plants under the roof (shade) and in sun light. Data taken on June 25, with cloudy conditions in the morning and sunny conditions in a. Mean ± SD, n=5.

3. Results and Discussion

Due to the nontransparent roof, light conditions for plants in the nursery setup different largely between experimental plants, as shown for *G. cinereum* (Fig. 5). Plant morphology was altered by the shading (Fig. 6). The size of individual leaves increased, while an increase internode and petiole length was observed, especially for *G. cinereum*. These are frequently observed reactions of plants to low light conditions, also documented before for *Geranium* sp. [5]. Overall this led to a less compact growth of plants. These effects on plant aesthetics are undesirable for plant producers as they negatively influence the marketability of plants. *G. cinereum* is adapted to high light conditions and is usually used as ground cover in dry and stony environments.

Figure 6. Representative plants of *Geranium cinereum* grown in the shade of the roof in the nursery (left column) or in full sun light (right column).

Figure 7. Representative plants of *Hydrangea* sp. grown in the shade of the roof in the nursery (left column) or in full sun light (right column)

Leaf area of the light sensitive species *Hydrangea sp.* reacted similar to *G. cinereum* with an increase of projected leaf area (Figs. 7 and 8). Hortensia species mostly originate from forest environments where at least partial shading is frequently present. Consequently, it was expected that light protection under the roof is likely beneficial for *Hydrangea* plants. Evaluation of plant aesthetics by the producer did not yield any major negative impact on marketability of plants. However, the increased plant size may be challenging for transport and may reduce the time to produce marketable plants.

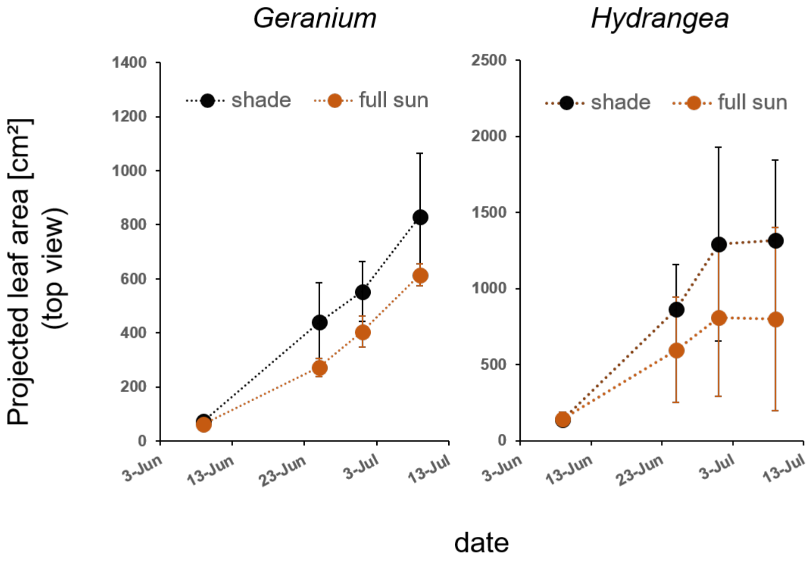

Figure 8. Changes of projected leaf area of *Geranium* (left) and *Hydrangea* (right) plants grown in shade or in full sunlight in the nursery. Mean ± SD, n=5.

In Rathenow, *Hydrangea* plants grown under the glass grew faster compared to plants under the panels (Fig. 9). Light conditions under the glass were not equal to full sun light, yet higher than under the panels. In contrast to the nursery experiment, this resulted in a partly-shaded (glass) and a shaded treatment (panels). Consequently, the results were not directly comparable across the two experiments. Unfortunately, light intensity on plot level was not recorded during the growth period of *Hydrangea* in Rathenow, however measurements end of September revealed 15-20% lower PAR-values under the panels compared to areas under the glass.

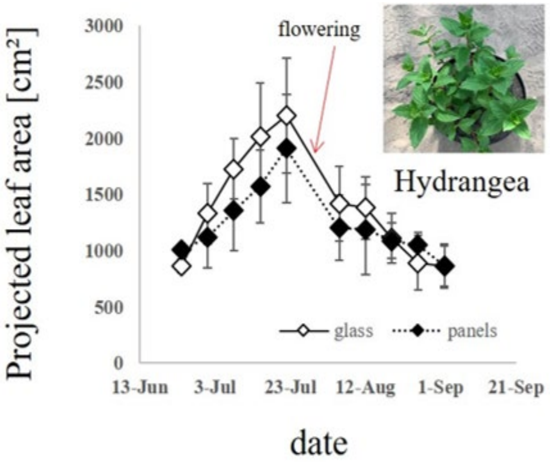

Figure 9. Changes of projected leaf area of *Hydrangea* plants grown under acrylic glass or under PV panels in the AgriPV-System in Rathenow. Mean ± SD, n=5.

A drop of projected leaf area indicated the onset of flowering, caused by a reduction of green pixels in the field of view. Flowering started simultaneously in both experimental groups, overall development of plants was not affected by growth under the PV panels. Specific leaf area of *Hydrangea* plants was lower for plants grown under the acrylic glass (17.1 m^2 kg^{-1}) in comparison to plants under the panels (18.0 m^2 kg^{-1}). It was previously shown that low light conditions lead to higher SLA values [6]. The effect observed in this experiment was only minor and does not reflect visual differences in plant appearance from a customer's perspective.

Measurements of leaf reflectance did not reveal any major changes of plant pigment composition in Rhododendron plants despite long-term exposure under the panels. Vegetation indices quantifying chlorophyll (NDVI, MCARI, SIPI), anthocyanins (ARI), and carotenoid (CRI) content remained unchanged. Leaf reflectance measurements are frequently used for assessing (ornamental) plant performance, as for example in fungal disease management [7] or customized application of nitrogen fertilizer [8].

4. Outlook

The results of this work gave first insight into the reaction of several ornamental plant species on leaf shading in Agri-PV systems. The data will help in assessing chances and risks of combining ornamental plant production with PV power production on a nursery scale. Here, Hortensia seem to be a promising species for production, whereas strictly light-dependent species as *Geranium* can clearly lose marketability by shading in an Agri-PV system. Furthermore, the developed image processing methods for detailed and long-term analysis of plant growth parameters will help in future monitoring of plant performance in Agri-PV systems. The developed techniques and analytical algorithms will be applied to the plant measurement setup installed in the new Agrivoltaic research park close to Jülich, Germany. This will include detailed measurements and modelling of light conditions under the panels, as this information will be essential for an evaluation of potential settings in plant nurseries in terms of panel transparency and spacing.

Data availability statement

Data will be made available with DOI:10.5281/zenodo.6895513 on https://zenodo.org/

Author contributions

0: Conceptualization, 1: Methodology, 2: Software, 3: Formal Analysis, 4: Investigation,
5: Visualization, 6: Writing – original draft, 7: Writing – review & editing 8: Supervision, 9: Resources, 10: Funding acquisition, 11: Project administration

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Competing interests

The authors declare no competing interests.

Funding

This work was carried out in the framework of projects funded by the Federal Ministry of Education and Research in Germany: BioökonomieREVIER -- APV 2.0 (031B0918A), YESPV-NIGBEN (03SF0576A) and BioökonomieREVIER -- Agri FEe (031B1137DX).

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