Available online: www.notulaebotanicae.ro

Print ISSN 0255-965X; Electronic 1842-4309

Not Bot Horti Agrobo, 2018, 46(1):206-212. DOI:10.15835/nbha46110846

AcademicPres

Notulae Botanicae Horti Agrobotanici Cluj-Napoca

Original Article

Growth and Physiological Characteristics of Lettuce (*Lactuca sativa* L.) and Rocket (*Eruca sativa* Mill.) Plants Cultivated under Photovoltaic Panels

Angeliki KAVGA[1], Georgios TRYPANAGNOSTOPOULOS[1,2], George ZERVOUDAKIS[1*], Yiannis TRIPANAGNOSTOPOULOS[3†]

*[1]Technological Educational Institute of Western Greece, Department of Agricultural Technology, Terma Theodoropoulou, Amaliada 27200, Greece; akavga@teimes.gr; gzervou@teimes.gr (*corresponding author)*

[2]University of Patras, Department of Mechanical Engineering & Aeronautics, Patras 26500, Greece; gtrypanagn@upatras.gr

[3]University of Patras, Department of Physics, Patras 26500, Greece

†In memory of Professor Yiannis Tripanagnostopoulos

Abstract

Energy demand of greenhouses is an important factor for their economics and photovoltaics can be considered an alternative solution to cover their electrical and heating needs. On the other hand, plants cultivated under different solar radiation intensities usually appear different physiological adaptations. The objective of this research was to investigate the effect of photovoltaic panels' induced partial shading on growth and physiological characteristics of lettuce (*Lactuca sativa* L.) and rocket (*Eruca sativa* Mill.) plants. Our results indicate that lettuce productivity and the corresponding photosynthetic rate were not affected under the photovoltaic cultivation in comparison with the reference one. On the other hand, the rocket cultivation was less productive and showed lower photosynthetic rate under photovoltaic panels than in the reference greenhouse. The different physiological response between lettuce and rocket seems to be associated with the effect of environmental factors such as solar radiation intensity, temperature and humidity apart from the possible inherent characteristics of each plant species.

Keywords: gas exchange, greenhouse, photosynthesis, transpiration, stomatal conductance

Introduction

The controlled environment horticulture has been proposed as an innovative method for the maximization of food production, in order to deal with forthcoming changes in population and climate (Vadiee and Martin, 2014; Tsitsimpelis *et al.*, 2016) since the production yield of the commercial greenhouse can be 10 times higher than the corresponding open field cultivation. On the other hand, commercial greenhouses are known as the most energy consuming cultivation method (Vadiee *et al.*, 2016) as long as they require optimum combination values of their interior conditions, as lighting, heating, cooling and ventilation for maximum yield (Vox *et al.*, 2010; Giacomelli *et al.*, 2012). The operation of fans, window-opening motors, artificial lighting, irrigation, automation equipment and so on needs electricity power. A considerable percentage of the electricity demand in greenhouses can be covered by photovoltaic (PV) panels, therefore they have become more popular, especially in southern Europe (Vox *et al.*, 2008; Russo *et al.*, 2014; Buttaro *et al.*, 2016). Thereby, the production of electricity power by greenhouse PVs together with the possible cooperation of solar cooling (Vox *et al.*, 2014) or thermal (Ahmed *et al.*, 2016) greenhouse systems will contribute to the sustainable development in the horticultural industry.

At the same time, the installation of PV panels on the greenhouse roof will induce a partial shading of the cultivation (Rocamora and Tripanagnostopoulos, 2006). Solar radiation is rather the most significant environmental factor regulating the photosynthetic function and consequently the plant growth and survival. Thus, plant species reveal acclimation and plasticity, developing anatomical, morphological, physiological and biochemical alterations against the varying solar radiation intensities in their natural environment (Zhang *et al.*, 2003; de Carvalho Gonçalves *et al.*, 2005). According to previous studies, the

Received: 11 May 2017. Received in revised form: 02 Aug 2017. Accepted: 03 Aug 2017. Published online: 19 Sep 2017.

plant biomass (roots, stems, leaves) as well as the photosynthetic rate, the transpiration and the stomatal conductance are decreased under low solar radiation, while on the other hand the plant height is increased (De Salvador *et al.*, 2008; An and Shangguan, 2009; Wang *et al.*, 2009; Zervoudakis *et al.*, 2012). The shading by straight-line arranged PV panels on the greenhouse roof has been reported to decrease the plant growth and consequently the crop yield while the checkerboard arrangement may diminish the above inhibitory effect (Kadowaki *et al.*, 2012; Ureña-Sánchez *et al.*, 2012). On the other hand, it seems that the solar intensity demand for maximum plant growth differs between species considering that it has been reported that intermediate solar radiation conditions (about 50% of full ambient light) were more adequate for some species to reach higher levels of biomass productivity (de Carvalho Gonçalves *et al.*, 2005).

Besides, it has been reported that some plants as lettuce (*Lactuca sativa* L., Asteraceae family), may achieve saturated photosynthetic rate even under 25% of full summer sunlight implying that these crops may be fully productive when they are cultivated under a partial shading (Tani *et al.*, 2014). Lettuce can be cultivated at any season of the year, both in open fields and in greenhouses and therefore be adapted to a wide range of solar radiation intensity environments (Marrou *et al.*, 2013).

Rocket (*Eruca sativa* Mill., Brassicaceae family) is a traditionally cultivated plant, especially in the Mediterranean area, with good adaptability in both open field and greenhouse cropping systems and that its consumer demand has increased because in recent years rocket has become popular also in the Central Europe (Doležalová *et al.*, 2013; Tsirogiannis *et al.*, 2013).

The aim of the present study was to examine the effect of PV panels' induced partial shading on growth and physiological characteristics of lettuce and rocket plants cultivated in a greenhouse, attempting to investigate the correlation between the greenhouse environmental conditions and the plants' physiology and productivity.

Materials and Methods

Greenhouse facilities

Two identical small-scale experimental greenhouses located at the Technological Educational Institute of Western Greece (Amaliada, South-West Greece) were used with and without PV panels on greenhouse roof, namely glass PV and glass (reference) covered greenhouse, respectively. The greenhouses were located at longitude 21°21'51.01"E, latitude 37°47'33.87"N and had an East-West ridge orientation. Both greenhouses were constructed of aluminium framework, with 3 mm thick glass panes. Their dimensions were: the width equal to 2.13 m, the length equal to 2.00 m, the eaves height equal to 1.00 m and the total height up to the top equal to 1.50 m. The occupied land surface area of each greenhouse was equal to 4.26 m^2, the area of the greenhouse cover was 14.05 m^2 and the volume of the greenhouse was 5.33 m^3 (Fig. 1).

Two polycrystalline silicon (pc-Si) PV panels were fixed (facing South) on the roof of the glass PV greenhouse with a total surface equal to 0.85 m^2. According to the configuration shown in Fig. 1, the PV array has covered the 12.4% of the greenhouse roof surface, while the ratio of the PV panels' total surface per the greenhouse area was equal to 20%. The particular configuration of the PV panels was selected in order to achieve a shading "moving" mode during the day and consequently to minimize the possible permanent shading for some plants in East-West orientation greenhouses (Trypanagnostopoulos *et al.*, 2017). Considering that it has been proposed a maximum of 25% PV shading, in order to achieve the optimal balance between shade reduction and energy production (Buttaro *et al.*, 2016), the coverage percentage of the experiment is similar with other studies which applicate 9.8-12.9% greenhouse PV coverage (Kadowaki *et al.*, 2012; Ureña-Sánchez *et al.*, 2012).

The interior microclimatic parameters as temperature at several locations at the inside air (T_{α}) and at the inside and outside surface of the greenhouse glazing cover (T_c), as well as the relative humidity (RH), the incoming solar radiation (SR) and the photosynthetically active radiation (PAR) were monitored in both greenhouses. In addition, the PV temperature (TPV) and the incoming solar radiation on them (SRPV) were recorded. The outdoor environmental conditions including temperature (T_{out}), wind speed (WS), relative humidity (RH_o), sky temperature (T_{sky}) and rain level were monitored at a height of 2.50 m above the ground level, on a meteorological mast close to the greenhouses. During the experimental period (from February to June 2016) all data from both greenhouse units were recorded every minute and stored in a data logger. The Analyzer 4.5 Data logger Software was used for the processing and statistical analysis of the data. The instrumentation used is depicted schematically in Fig. 1 and outlined in Table 1.

Plant material

Lettuce (*Lactuca sativa* L.) and rocket (*Eruca sativa* Mill.) were cultivated in the soil from February to April and from May to June of 2016, respectively. The fertilization of the chosen crop was based on soil analysis prior to the installation

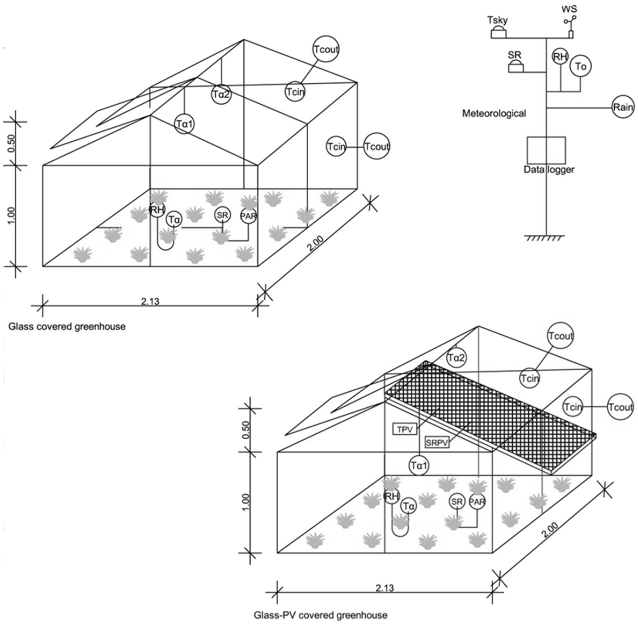

Fig. 1. The experimental greenhouses and the meteorological station

Table 1. Instrumentation and sensors used (symbols refer to Fig. 1)

Greenhouses	
SR, SRPV	Silicon-type pyranometer (model SP-LITE, range 400-1100 nm, accuracy ±5%, Kipp & Zonen, Delft, The Netherlands)
PAR	Photosynthetic active radiometer (model PAR-LITE, 400-700 nm, accuracy ±5%, Kipp & Zonen, Delft, The Netherlands)
RH-T_α	Temperature and relative humidity probe (model S3CO3, accuracy ±1% RH, ±0.3 K, Rotronic, Bassersdorf, Switzerland)
T_α, TPV, T_{c_in}, T_{c_out}	Thermocouples (type T, copper-constantan, 0.2 mm diameter, accuracy 0.5 °C, TC Ltd., UXBRIDGE, United Kingdom)
Meteorological mast	
Data logger	Data logger with two relay analog multiplexer units, (CR1000X, Measurement and control module, Campell Scientific, Logan, USA)
SR	Thermopile-type pyranometer (model CMP3, range 300-3000 nm, accuracy ±5%, Kipp & Zonen, Delft, The Netherlands)
RH_o-T_o	Temperature and relative humidity probe (model MP101A, accuracy ±1% RH, ±0.2 °C, Rotronic, Bassersdorf, Switzerland)
Rain	Rain gauge (model 52203, accuracy 2%, R.M. Young Company, Traverse City, Michigan, USA)
WS	Anemometer (model A100K, accuracy 1%, threshold sensitivity 0.15 m s^{-1}, Windspeed Ltd, North Wales, United Kingdom)
T_{sky}	Pyrgeometer (model CGR3, spectral range 4500 - 42000 nm, accuracy ±10%, Kipp & Zonen, Delft, The Netherlands)

of the plants. Fertilizing of the plants was done with a water-soluble 20:20:20 (N:P:K) fertilizer via the irrigation system. During the cultivation, 250 and 200 g of the fertilizer were administered on each greenhouse for lettuce and rocket, respectively. A drip irrigation system was applied. The irrigation dose for lettuce during the first 4 weeks was 0.3 L per plant per week and then increased to 0.5 L per plant per week. The irrigation dose for rocket during the first 2 weeks was 0.7 L per plant per week and then increased gradually until 1.8 L per plant per week. In each greenhouse, 16 young seedlings of the same height (about 10 cm) obtained from a local nursery were planted, forming four rows of four plants each and planting distances were 36 cm × 24 cm (plant by plant x line by line).

At the end of the respective cultivation period after transplanting, the plants were removed from the soil carefully in order not to damage the root system. The roots were washed thoroughly to remove all dirt. The height and the fresh weight of each plant (including the roots) were measured. Then, the aboveground part of the plant was cut and its height and weight were measured.

Then, the number of the mature leaves of each plant was counted as well as the length and width of the 5th, 6th, 7th and 8th leaf of each plant, numbering from the base of the plant. Each of these leaves of every plant was captured on graph paper, and their surface was determined.

All leaves of each plant separately were entered in paper bags and placed in an oven at 70 °C for 72 hours. The same procedure was done for the roots of each plant. At the end, the leaves and roots were weighed, extracting their dry weight.

Leaf gas exchange

Nondestructive measurements of the photosynthetic and transpiration rate and the stomatal conductance obtained with the LCpro-SD Portable Photosynthesis System (ADC, BioScientific Ltd., England) at 11:30 a.m. of sunny days on healthy, completely expanded young leaves of representatively growing plants. The measurements were conducted 7 and 10 weeks after the lettuce plants' installation to the different greenhouse conditions while for rocket plants the measurements were conducted 4 and 5 weeks after their corresponding installation. Gas exchange measurements were conducted from 7-10 plants per greenhouse treatment.

Data analysis

The growth variables results were obtained from 14-16 independent measurements per treatment. The gas exchange results were obtained from 7-10 independent measurements per treatment. All results are expressed as mean ± standard error of the mean (SEM). All data were plotted using Microsoft Office Excel 2007. Statistical differences between the means of the different variables were calculated by implementing a Student's *t*-test in MS-Excel for statistical level of significance a = 0.05.

Results

Greenhouse environmental conditions

According to the monitored measurements during the daytime in both greenhouses, the PV installation induced an average of 7.2% and 10.5% decrease of the Photosynthetically Active Radiation (PAR) for the lettuce and rocket cultivation periods, respectively.

Table 2 shows the averages for temperature (T) and relative humidity (RH) monitored in both greenhouses during the daytime, the night and the time period of the leaf gas exchange measurements (11:30 a.m.-12:30 p.m.), throughout the cultivation periods of both experimental plants. During the daytime, the PV installation induced 2.2 °C and 2.9 °C temperature decrease, for lettuce and rocket cultivation periods, respectively. Besides, during the lettuce cultivation period (from February to April) the glass PV greenhouse presented a 4.1% increased RH while there is no corresponding difference for rocket (from May to June). For both cultivations, there are not any remarkable differences between the greenhouses' night conditions.

Growth of plants

As shown in Fig. 2, most of the glass PV lettuce growth characteristics seem to be lightly affected in comparison with the reference glass ones. In particular, plant, stem and root length, and average leaf length, width and surface are increased only by 7%-13%. On the other hand, plant and stem dry weight and root fresh weight are decreased by 14%-25% and only root dry weight was strongly (46%) decreased. Moreover, the characteristics which are the more important for the commercial usage of the crop (plant and stem fresh weight and the number of mature leaves) are unaffected under the glass PV greenhouse.

On the contrary, all the rocket growth characteristics seem to be decreased under glass PV cultivation comparing with the corresponding reference glass one, as shown in Fig. 3. Moreover, the decrements were substantial for the majority of them. In particular, the whole plant, stem and root dry weight decreased by 48%, 53% and 28% respectively, while the corresponding fresh weights decreased 39%, 41% and 33%. The average leaf length, width and surface decrements were 14%, 29% and 33% respectively while the whole plant, stem and root length ones were 19%, 10% and 24%. Finally, the mature leaves quantity decreased by 26%. All the above results indicate a significant decrement of the rocket productivity when it is cultivated under glass PV conditions.

Leaf gas exchange physiological characteristics

Regarding the lettuce cultivation, the leaf gas exchange characteristics were measured 7 and 10 weeks after the plant installation in the greenhouses. The photosynthetic rate was unaffected under the glass PV greenhouse compared with the reference glass one (Fig. 4A) while the transpiration rate decreased (Fig. 4B) and the stomatal conductance was increased (Fig. 4C). The respective transpiration rate decrements were 14% and 23% while the stomatal conductance increments were 56% and 38%.

Regarding the rocket cultivation, the physiological variables were measured 4 and 5 weeks after the plant installation. The glass PV photosynthetic rate was rather unaffected during the fourth week of the cultivation but it showed 21% decrement the fifth week, compared with the glass one (Fig. 5A). The transpiration rate revealed a similar pattern with a 10% decrement during the fifth week (Fig. 5B). On the contrary, the stomatal conductance increased during the both measurements, with 35% and 18% increments respectively (Fig. 5C).

Discussion

As shown in Fig. 2, the greenhouse lettuce cultivation is lightly affected under PV shading. The only growth variable which is strongly affected was the root dry weight revealing a 46% decrement. In particular, the dry weight was decreased (by

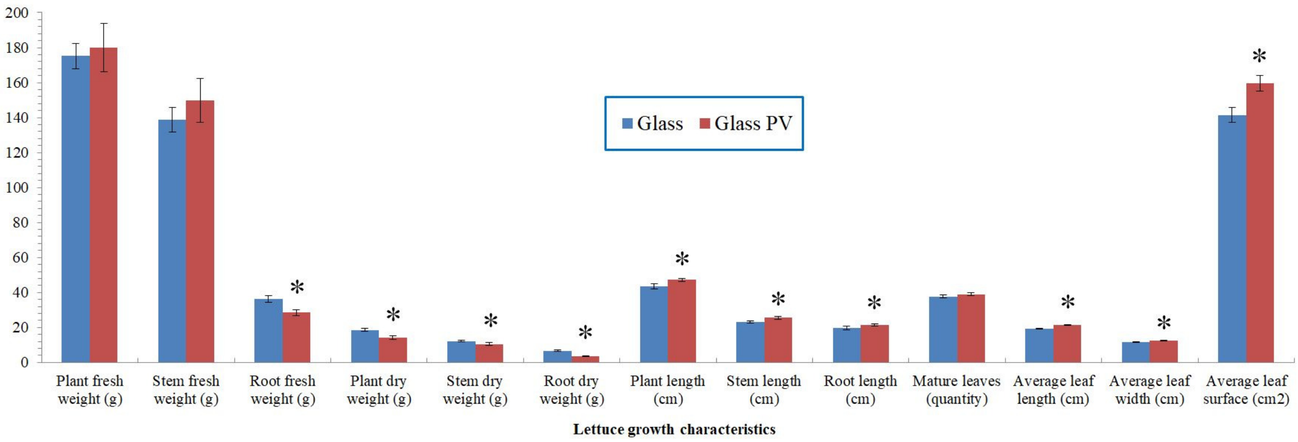

Fig. 2. Growth variables of lettuce cultivated under reference glass and glass PV greenhouses. Vertical bars represent mean ± SEM ($n \geq 14$). Means with asterisk are significantly different from the corresponding reference variables ($p < 0.05$). Six of the lettuce growth variables (plant fresh weight, plant dry weight, plant length, mature leaves, average leaf length and average leaf surface) have been also presented by Trypanagnostopoulos et *al.* (2017, in press article)

Table 2. Averages of temperature and relative humidity in reference glass (G) and glassPV (PV) greenhouses during the cultivation periods

Cultivation	Time period	Temperature (°C)		Relative Humidity (%)	
		T_G	T_{PV}	RH_G	RH_{PV}
Lettuce cultivation period (February to April)	daytime	27.7	25.5	54.0	58.1
	11:30 a.m.-12:30 p.m	33.3	30.3	40.7	45.7
	night	12.7	13.1	93.7	93.8
Rocket cultivation period (May to June)	daytime	35.4	32.5	44.2	44.3
	11:30 a.m.-12:30 p.m	41.6	37.5	31.1	33.2
	night	18.4	17.1	92.9	88.9

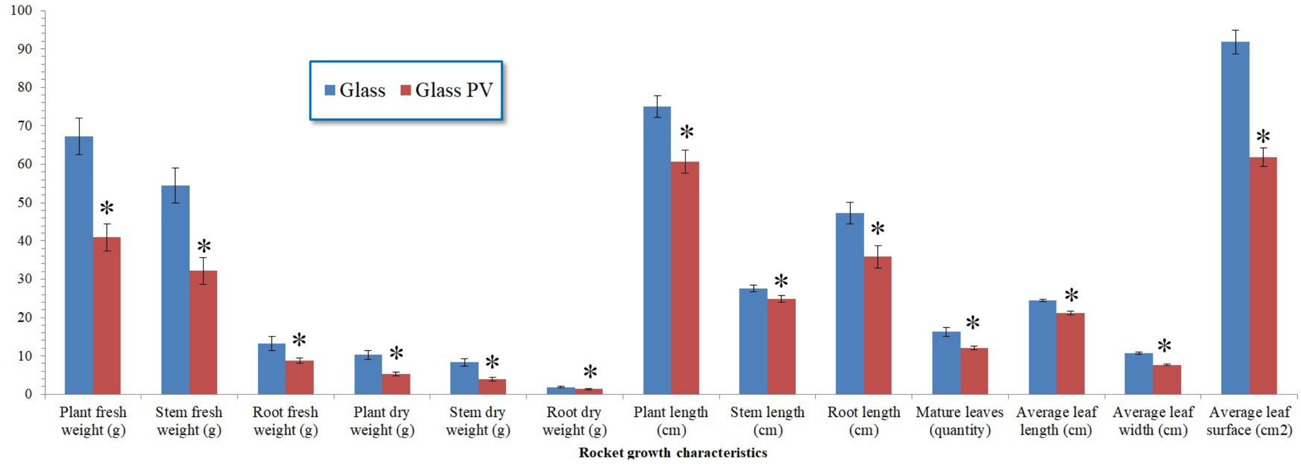

Fig. 3. Growth variables of rocket cultivated under reference glass and glass PV greenhouses. Vertical bars represent mean ± SEM (n ≥ 14). Means with asterisk are significantly different from the corresponding reference variables ($p < 0.05$)

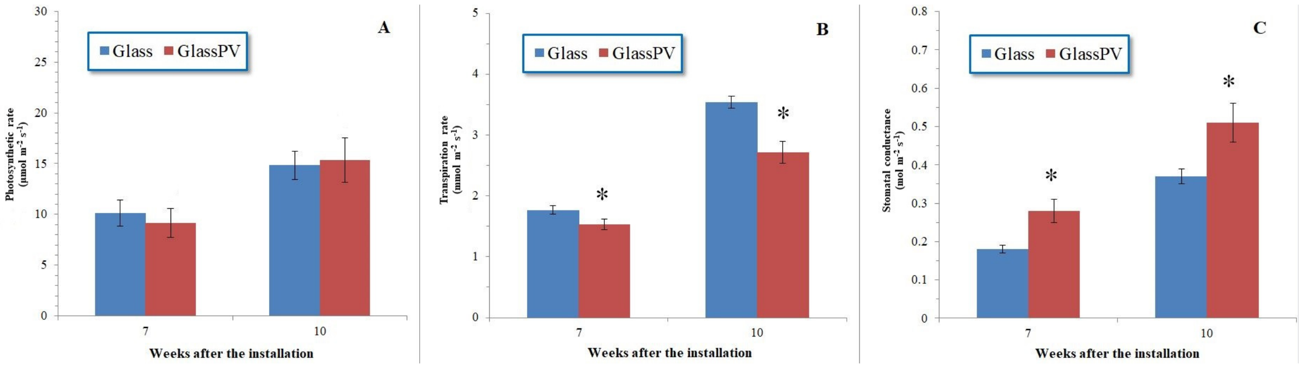

Fig. 4. Leaf gas exchange characteristics of lettuce cultivated under reference glass and glass PV greenhouses. Vertical bars represent mean ± SEM (n ≥ 7). Means with asterisk are significantly different from the corresponding reference variables ($p < 0.05$)

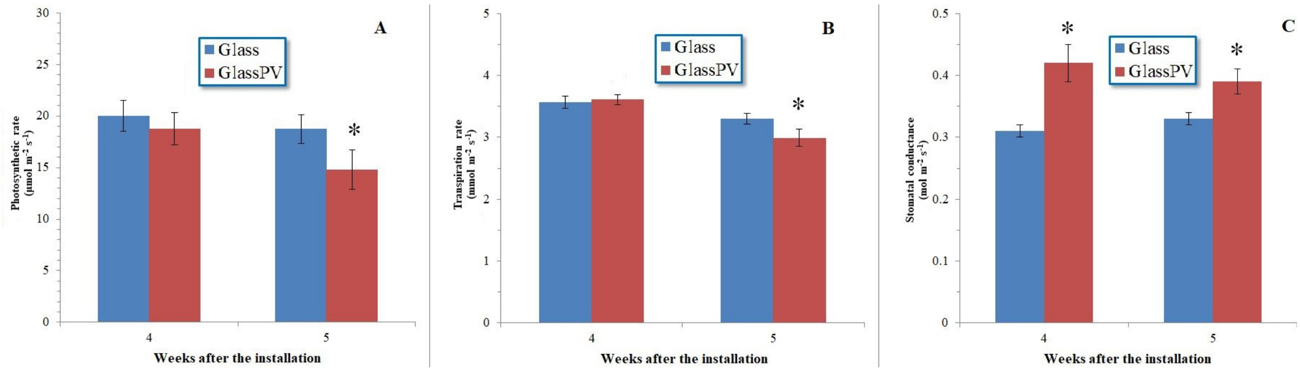

Fig. 5. Leaf gas exchange characteristics of rocket cultivated under reference glass and glass PV greenhouses. Vertical bars represent mean ± SEM (n ≥ 7). Means with asterisk are significantly different from the corresponding reference variables ($p < 0.05$)

25%, 14% and 46% for whole plant, stem and root, respectively) as already has been shown for lettuce (Marrou *et al.*, 2013; Tani *et al.*, 2014) and other shaded plants, too (Mielke and Schaffer 2010; Zervoudakis *et al.*, 2012; Buttaro *et al.*, 2016). Besides, other growth characteristics (plant, stem and root length and leaf length, width and surface) were slightly increased (up to 13%) by shading which is in agreement with previous studies on lettuce (Marrou *et al.*, 2013; Tani *et al.*, 2014) and other plants (Yang *et al.*, 2007; Wang *et al.*, 2009; Zervoudakis *et al.*, 2012).

On the other hand, it is very important that the main growth characteristics of commercial interest (plant and stem fresh weight and the number of mature leaves) are unaffected under the glass PV greenhouse.

Seeing that photosynthesis affects crucially the plant physiology and consequently the crop productivity, the growth variable results correspond with the lettuce photosynthetic rate which was rather unaffected under the PV induced shading compared with the reference greenhouse (Fig. 4A). The results obtained in this research are in accordance with previous studies which refer that lettuce can be adapted to different solar radiation environments considering that it does not require high solar radiation intensity to achieve maximum photosynthesis. Therefore, our findings confirm the previously supported viewpoint that lettuce can be planted in greenhouses providing high yield, especially under spring planting and moderate shading conditions (Marrou *et al.*, 2013; Tani *et al.*, 2014) just like our experiment was carried out.

On the contrary, the rocket glass PV cultivation pattern was quite different. As shown in Fig. 3, all rocket growth variables decreased. Moreover, most of them reveal a significant decrement on the order of 24%-53%. Only three growth variables (plant and stem length and average leaf length) show a smaller decrement on the order of 10%-19%. It is also quite interesting that a decrement of about 40% is revealed for both plant and stem fresh weight, implying lower rocket productivity in glass PV greenhouse. The above rocket growth variables results are in accordance with the 21% decrement of the PV greenhouse cultivated plants' photosynthetic rate which was observed during the fifth week after the plant installation in the greenhouses (Fig. 5A).

As far as we know, there is no sufficient bibliography about the growth and productivity of plants cultivated in greenhouses covered with PV panels. Except for lettuce which has been discussed before, studies have been conducted on Welsh onion, tomato, wild rocket, basil and zucchini (Kadowaki *et al.*, 2012; Ureña-Sánchez *et al.*, 2012; Minuto *et al.*, 2009; Cossu *et al.*, 2014; Buttaro *et al.*, 2016). Although the inherent characteristics of different species or varieties of the same species may play a role for the plant growth response against shading (Marrou *et al.*, 2013), the PV induced shading effect on plants' growth characteristics and crop productivity seems to depend on several other factors, too. Thereby, it has been reported that the percentage of the PV covered greenhouse roof can be determinant either for the possible reduction of the crop yield (Buttaro *et al.*, 2016) or even its increment as has been observed for a lettuce variety (Marrou *et al.*, 2013). The PV-array formation seems also to be important considering that the straight-line PV arrangement shade induces significantly lower crop productivity while the checkerboard one diminishes the phenomenon (Kadowaki *et al.*, 2012). Besides, for some plants the appropriate cultivation season may diminish the PV induced shading effect on the crop yield as has been found for the spring lettuce cultivation (Marrou *et al.*, 2013).

Finally, we have to take into account that for some plants the PV induced shading may affect their growth characteristics (some of them with commercial interest), just as leaf development, fruit size or color, without affecting their yield (Minuto *et al.*, 2009; Ureña-Sánchez *et al.*, 2012). Moreover, it has also been reported that the PV shading effect may favor the development of fungal diseases (Minuto *et al.*, 2009) a phenomenon which may be associated with possible changes of the greenhouse environmental conditions caused by the shading as the decrement of the temperature or the increment of the relative humidity, as we observed during our experiment (Table 2).

According to our results, the similar photosynthetic rate for reference glass and glass PV lettuce cultivation (Fig. 4A) corresponds with the resembling plant's growth and productivity profile between the greenhouses (Fig. 2). On the other hand, the decrement of the rocket glass PV photosynthetic rate during the fifth week seems to be associated with the significant decrement of the rocket productivity when it is cultivated under glass PV conditions (Fig. 3).

Further, it is quite interesting that while the photosynthetic rate is unaffected or decreased under the glass PV greenhouse (Figs. 4A, 5A), the transpiration rate is decreased (Figs. 4B, 5B) and, on the contrary, the stomatal conductance is increased (Figs. 4C, 5C). A negative relationship between stomatal conductance and photosynthesis (Via *et al.*, 2014), and stomatal conductance and transpiration (Bunce, 1996) has been previously reported.

It is known that stomata play an essential role in leaf gas exchange, controlling both water losses and CO_2 uptake. Since their aperture is controlled by the guard cells turgor pressure, stomata have the capacity to respond quickly against continually changing environmental conditions as solar radiation, temperature and air humidity (Chaves *et al.*, 2003; Baroli *et al.*, 2008; Damour *et al.*, 2010; Padhi *et al.*, 2012). Moreover, water loss via leaf transpiration is dependent on the same environmental factors (Padhi *et al.*, 2012). Considering that, at any given moment, various stomatal mechanisms may be responding to a complex set of environmental factors (Chaves *et al.*, 2003), we suppose that the negative correlation between stomatal conductance and both transpiration and photosynthesis under PV greenhouse conditions (Figs. 4, 5) is associated with the specific greenhouse environmental conditions. In particular, the PV shading seems to induce the decrease of the photosynthetic rate while both the temperature decrease and the humidity increase favour the increased stomatal conductance and the reduced transpiration.

In conclusion, the productivity of PV greenhouse cultivation is affected by several environmental factors since the PV induced shading may in turn affect the greenhouse temperature and humidity. All these environmental parameters, combined with the particular plant species inherent characteristics, the crop season, the PV-array formation and coverage percentage, influence the physiological functions of the plants and consequently their productivity.

References

Ahmed NM, Fahmy FH, Farghally HM (2016). Modeling and control of medical herb greenhouse based on solar thermal system. International Journal of Applied Engineering Research 11:3042-3049.

An H, Shangguan ZP (2009). Effects of light intensity and nitrogen application on the growth and photosynthetic characteristics of *Trifolium repens* L. Acta Ecologica Sinica 29: 6017-6024.

Baroli I, Price GD, Badger MR, von Caemmerer S (2008). The contribution of photosynthesis to the red light response of stomatal conductance. Plant Physiology 146:737-747.

Bunce JA (1996). Does transpiration control stomatal responses to water vapour pressure deficit? Plant, Cell & Environment 19:131-135.

Buttaro D, Renna M, Gerardi C, Blando F, Santamaria P, Serio F (2016).

Soilless production of wild rocket as affected by greenhouse coverage with photovoltaic modules. Acta Scientiarum Polonorum 15:129-142.

Chaves MM, Maroco JP, Pereira JS (2003). Understanding plant responses to drought – from genes to the whole plant. Functional Plant Biology 30:239-264.

Cossu M, Murgia L, Ledda L, Deligios PA, Sirigu A, Chessa F, Pazzona A (2014). Solar radiation distribution inside a greenhouse with south-oriented photovoltaic roofs and effects on crop productivity. Applied Energy 133:89-100.

Damour G, Simonneau T, Cochard H, Urban L (2010). An overview of models of stomatal conductance at the leaf level. Plant, Cell & Environment 33:1419-1438.

de Carvalho Gonçalves JF, De Sousa Barreto DC, Dos Santos Jr. UM, Fernandes AV, Barbosa Sampaio PDT, Buckeridge MS (2005). Growth, photosynthesis and stress indicators in young rosewood plants (*Aniba rosaeodora* Ducke) under different light intensities. Brazilian Journal of Plant Physiology17:325-334.

De Salvador FR, Scarascia Mugnozza, G, Vox G, Schettini E, Mastrorilli M, Bou Jaoudé M (2008). Innovative photoselective and photoluminescent plastic films for protected cultivation. Acta Horticulturae 801:115-121.

Doležalová I, Duchoslav M, Dušek K (2013). Biology and yield of rocket (*Eruca sativa* Mill.) under field conditions of the Czech Republic (Central Europe). Notulae Botanicae Horti Agrobotanici Cluj-Napoca 41:530-537.

Giacomelli GA, Sase S, Cramer R, Hoogeboom J, MacKenzie A, Parbst K, Scarascia- Mugnozza G, Selina P, Sharp DA, Voogt JO, van Weel PA, Mears D (2012). Greenhouse production systems for people. Acta Horticulturae 927:23-38.

Kadowaki M, Yano A, Ishizu F, Tanaka T, Noda S (2012). Effects of greenhouse photovoltaic array shading on Welsh onion growth. Biosystems Engineering 111:290-297.

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.

Mielke MS, Schaffer B (2010). Photosynthetic and growth responses of *Eugenia uniflora* L. seedlings to soil flooding and light intensity. Environmental and Experimental Botany 68:113–121.

Minuto G, Bruzzone C, Tinivella F., Delfino G., Minuto A (2009). Photovoltaics on greenhouse roofs to produce more energy. Informatore Agrario (Suppl.) 65:16-19.

Padhi J, Misra RK, Payero JO (2012). Estimation of soil water deficit in an irrigated cotton field with infrared thermography. Field Crops Research 126:45-55.

Rocamora MC, Tripanagnostopoulos Y (2006). Aspects of PV/T solar system application for ventilation needs in greenhouses. Acta Horticulturae 719:239-246.

Russo G, Anifantis AS, Verdiani G, Scarascia Mugnozza G (2014). Environmental analysis of geothermal heat pump and LPG greenhouse heating systems. Biosystems Engineering 127:11-23.

Tani A, Shiina S, Nakashima K, Hayashi M (2014). Improvement in lettuce growth by light diffusion under solar panels. Journal of Agricultural Meteorology 70:139-149.

Trypanagnostopoulos G, Kavga A, Souliotis M, Tripanagnostopoulos Y (2017). Greenhouse performance results for roof installed photovoltaics. Renewable Energy (in press article). http://dx.doi.org/10.1016/j.renene.2017.04.066.

Tsirogiannis IL, Katsoulas N, Savvas D, Karras G, Kittas C (2013). Relationships between reflectance and water status in a greenhouse Rocket (*Eruca sativa* Mill.) cultivation. European Journal of Horticultural Science 78:275-282.

Tsitsimpelis I, Wolfenden I, Taylor CJ (2016). Development of a grow-cell test facility for research into sustainable controlled-environment agriculture. Biosystems Engineering 150:40-53.

Ureña-Sánchez R, Callejón-Ferre AJ, Pérez-Alonso J, Carreño-Ortega A (2012).Greenhouse tomato production with electricity generation by roof-mounted flexible solar panels. Scientia Agricola 69:233-239.

Vadiee A, Martin V (2014). Energy management strategies for commercial greenhouses. Applied Energy 114:880-888.

Vadiee A, Yaghoubi M, Martin V, Bazargan-Lari Y (2016). Energy analysis of solar blind system concept using energy system modeling. Solar Energy 139:297-308.

Via SM, Zinnert JC, Butler AD, Young DR (2014). Comparative physiological responses of *Morella cerifera* to RDX, TNT, and composition B contaminated soils. Environmental and Experimental Botany 99:67-74.

Vox G, Schettini E, Lisi Cervone A, Anifantis A (2008). Solar thermal collectors for greenhouse heating. Acta Horticulturae 801:787-794.

Vox G, Teitel M, Pardossi A, Minuto A, Tinivella F, Schettini E (2010). Sustainable greenhouse systems. In: Salazar A, Rios I (Eds). Sustainable Agriculture: Technology, Planning and Management. Nova Science Publishers, Inc. pp 1-79.

Vox G, Blanco I, Scarascia Mugnozza, G, Schettini E, Bibbiani C, Viola C, Campiotti CA (2014). Solar absorption cooling system for greenhouse climate control: Technical evaluation. Acta Horticulturae 1037:533-538.

Wang Y, Guo Q, Jin M (2009). Effects of light intensity on growth and photosynthetic characteristics of *Chrysanthemum morifolium*. Zhongguo Zhongyao Zazhi 34:1633-1635.

Yang XY, Ye XF, Liu GS, Wei HQ, Wang Y (2007). Effects of light intensity on morphological and physiological characteristics of tobacco seedlings. Chinese Journal of Applied Ecology 18:2642-2645.

Zervoudakis G, Salahas G, Kaspiris G, Konstantopoulou E (2012). Influence of light intensity on growth and physiological characteristics of common sage (*Salvia officinalis* L.). Brazilian Archives of Biology and Technology 55:89-95.

Zhang S, Ma K, Chen L (2003). Response of photosynthetic plasticity of *Paeonia suffruticosa* to changed light environments. Environmental and Experimental Botany 49:121-133.