Implementation of Photovoltaics on Greenhouses and Shading Effect to Plant Growth

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Abstract

Greenhouses are sophisticated structures, which require optimum combination of solar radiation, heating, cooling and ventilation to produce a good/high crop quality within a predictable and repeatable time schedule. Energy demand of greenhouses is an important factor for their economics and photovoltaics (PV) can be considered an alternative solution to cover their electrical and heating needs. On the other hand, the installation of PV panels on the greenhouses' roof reduces solar radiation that passes through roof glazing and falls to the plants into the greenhouse.

This reduction may affect the plant lighting and it should be studied regarding the optimal installation to maximize the solar radiation that enters the greenhouse interior space. In this paper, a PV system properly mounted to greenhouse' roof has been studied experimentally in two identical, small scale experimental greenhouses. The two greenhouse options were implemented with and without PV correspondingly. Lettuce is used as the test crop for a three months period.

The design and energy performance of the above PV installation modes is analyzed and results are presented. An analysis of plants' nutrients absorption is provided, which reveals the effect of shading in the PV greenhouse plants.

Keywords: solar radiation, greenhouse, photovoltaics, electrical energy, crop quality

1. Introduction

Greenhouses are intensive cultivation units for agricultural products, which require optimum combination of allocated particulars and proceeding, as lighting, heating, cooling and ventilation. The temperature of the air inside the greenhouse affects the canopy temperature and transpiration, influencing the plant growth. The temperature level inside the greenhouse depends on the solar input, as well as the ambient air temperature. The favorable temperature environment in the greenhouse is not always achieved and additional energy is necessary. Conventional fuels and electricity are usually the energy sources to cover the energy demand of greenhouses.

Considering greenhouses in South Europe and Mediterranean regions, they require both heating during winter and cooling during summer. Various methods are suggested for the control of internal space factors of these greenhouses, considering the climate conditions and installation and technical specification of their construction and operation. These technical solutions should adapt the plant organic cultivation requirements for an effective production, respecting sustainability and eco cultivation. To cover the energy needs of greenhouses, oil, gas and biomass boilers, electrical appliances and also geothermal heat pumps, are used.

Although the main function of greenhouses are based on solar energy, the exploitation of solar energy systems such as solar thermal collectors and photovoltaics, is still at the beginning, in terms for their exploitation. Tripanagnostopoulos et al. in 2005 suggested fresnel lenses to be applied as greenhouse covering material, instead of typical glass or plastic covers, combined with linear absorbers to receive and convert the concentrated solar radiation into heat, electricity or both. Rocamora and Tripanagnostopoulos, in 2006 suggested that photovoltaic/Thermal (PV/T) systems with dual operation (water or air) heat extraction mode are suitable solar energy systems to be effectively applied for solar control of greenhouses, providing also electricity, heat and ventilation. The mounting of the system can be on the south side of greenhouse roofs. Sonneveld et al. in 2010, studied the performance of a greenhouse where a near infrared radiator (NIR) was combined with electrical power generation, using hybrid PV/T collector modules.

The climatic conditions of Mediterranean countries differ from those of Central and Northern European countries and both heating and artificial lighting in winter is needed, as well as cooling and lighting control for the summer. These conditions make more complex the control of internal space conditions and difficult to find a cost-effective solution. The implementation of photovoltaics can adapt energy needs of greenhouses combined with heat pumps, reducing also their carbon footprint, compared to the use of conventional energy sources.

Photovoltaics can cover energy needs of greenhouses in dynamic ventilation, artificial lighting and other demands. PVs to greenhouse' roofs should be studied regarding installation modes, electricity output and effect to plant growing. PV panels are suggested to be mounted on the roof of greenhouses and cover a part of them, considering that the reduction of solar radiation entering the greenhouse interior space is as minimum as possible. The greenhouses can have east-west orientation, with the solar system facing south or north-south orientation, where PV panels are mounted on east and west facing greenhouse roof surfaces. In this case the shading from the installed panels is “moving” during day, avoiding permanent shading of the plants.

The installation of PV panels on the roof of the greenhouses reduces solar radiation that passes through roof glazing and falls to the plants in the greenhouse. This reduction may be charged to the adequate plant lighting and optimal installation is needed. The electricity of PV panels is used for the operation of the required equipment, in order to achieve efficient operation of greenhouses (ventilators, heaters, heat pumps, lighting, etc), considering the mounting modes of PV panels on greenhouse roof. In the recently presented work, Tripanagnostopoulos et al, 2016, a detailed study for using PV panels on greenhouse roof has given interesting results regarding, mainly, electricity production. There are several types of PV panels that could be used as covering material of greenhouses (typical flat type, tube type, semi-transparent, concentrating). To avoid considerable reduction of the transmitted solar radiation, transparent thin film or organic photovoltaics can be used, but their efficiencies are low.

In this study, the application of photovoltaics on greenhouse’s roof is suggested to be studied regarding their effect to plant growing. Greenhouses with same cultivation (lettuce) with and without PV panels on their roofs can give a figure for the effect of shading and of the energy gain by the roof mounted PV panels. The results from the tested greenhouses could be used for a wider application of them, considering their cost effectiveness.

2. Materials and Methods

Two identical small-scale experimental greenhouses located in western Greece were used as the test bed of the two installation options with and without PV correspondingly. Both greenhouses were constructed of aluminum framework, with 3mm thick glass panels. They had the same orientation and were located in the same field with a sufficient distance between them to avoid mutual interference. Their dimensions are width 2.13 m, length 2.00 m, eaves height 1.00 m and total height up to the top 1.50 m. The base area of each greenhouse Ap is equal to 4.26 m^2, the area of the greenhouse cover is Ac =14.05 m^2 and the volume of the greenhouse is V=5.33 m^3.

On the roof of the one greenhouse we mounted two polycrystalline silicon (pc-Si) PV panels of 0.4 m^2 each, covering in total 0.8 m^2 of the roof surface. Thermocouples were attached on front and rear panel surface, to measure the PV temperature. In addition, a pyranometer was mounted parallel to panels plane, to measure the incoming solar radiation on it. Finally, by measuring the output in electricity, the produced electrical power could be calculated.

Interior microclimatic parameters monitored in both greenhouses were the temperature at several locations at the canopy, inside the greenhouses and at the inside and outside surface of the greenhouse glazing cover and of PV panel, as well as the relative humidity and radiation fluxes (incoming solar radiation and photosynthetically active radiation). The outdoor environmental conditions including temperature, wind speed, relative humidity, sky temperature and rain were monitored at a height of 2.50 m above the ground level, on a meteorological mast close to the greenhouses.

For the three (3) months operation period (actually 85 days) from February to April 2016 of both configurations, all data were recorded every minute, and 10 min averages and were stored in a data logger with a relay analogue multiplexer. Overall day-time and night-time mean values were also computed from the respective time series, based on the interval between the steep radiation and temperature changes at sunrise and sunset. The Analyzer 4.5 Datalogger Software was used for the processing and statistical analysis of the experimental data.

Lettuce, was used as the test crop. The plants are cultivated on the soil, in order to acquire results for the majority of greenhouses cultivations since hydroponics are limited in our country. The fertilization of the lettuce was based on soil analysis and in the amount of macro and micro elements that this absorb from the soil. Irrigation was optimized using real-time soil moisture measurements, in order to maintain the soil moisture at the field capacity level. In each greenhouse 16 young lettuce plants were planted, forming four rows of four plants each and planting distances were 36 cm x 24cm. (plant by plant x line by line).

A drip irrigation system was applied. The supply of each drip emitter was 2lit/h. The irrigation dose during the first 4 weeks was 0.3 lit per plant per week and then increased to 0.5 lit per plant per week. Fertilizing of the plants was done with a water-soluble 20-20-20 fertilizer. During the cultivation, 250 mg N, P_2O_5, K_2O were administered on each plant. For the fertilization program, the results of soil analysis prior to the installation of the plants were taken into account. The plants were removed from the glasshouse 9 weeks after transplanting. The fresh weight of each plant was measured, the length, the width, and the surface of the leaves, as well as the dry weight.

3. Results and Discussion

Investigation concerning the effects of shading produced by the photovoltaic panels to the plants has been performed. By this study some plant growing parameters were measured and especially the leaf area index, number of leaves, height and diameter of the shoot, dry weight of the shoot and leaves and the amount of macro and micro elements absorption. The experiment was performed for 85 days and from the collected data we present in the following figures the recorded and calculated results.

In Figure 1 the variation of the temperatures during the three months period is shown. The presented graphs are for the ambient temperature (T_a), the inside temperature of the reference greenhouse (T_{gh}) and of the greenhouse with the photovoltaics (T_{ghPV}). From the diagrams of this Figure, one can see that the temperatures inside the two greenhouses are almost at the same level, with slightly higher inside the reference greenhouse. This observed small temperature difference is due to the PV shading and the ventilation that was kept in both greenhouses during the testing period, which resulted to have a continues refreshment of the inside air.

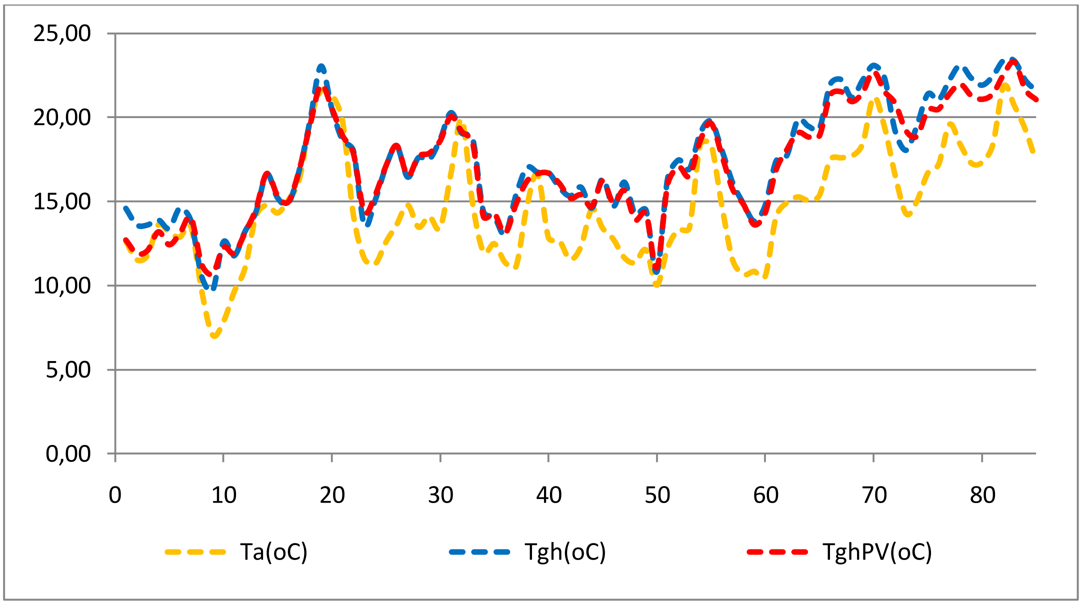

Figure 1. Variation of ambient and inside greenhouses temperatures

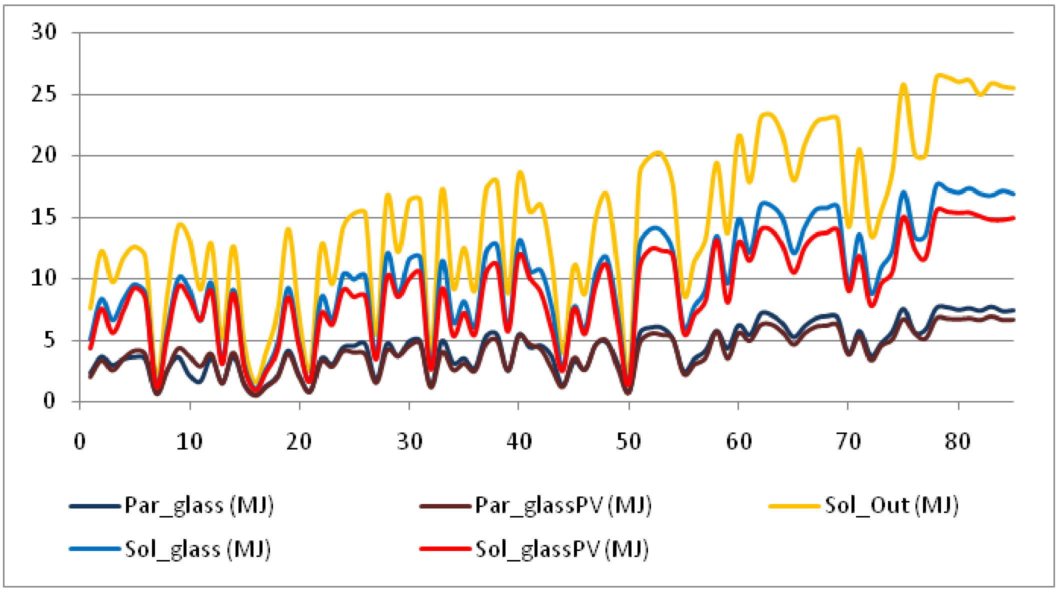

Figure 2. Variation of solar radiation and PAR measurements during the three months period

In Figure 2 there is shown the variation of the incoming solar radiation, outside and inside the two greenhouses, as well as the measurements of PAR inside them. The values of the solar radiation inside the greenhouses are determined as Sol_glass and Sol_glassPV, for the greenhouse without and with PV panels, correspondingly. Both these values are lower than the values on the horizontal pyranometer out of greenhouses (Sol_Out), because of the reduction of the measured solar radiation due to the reflection and absorption of it by the glass cover. Comparing the two greenhouses regarding the entering solar radiation, the presented values confirm that the greenhouse with the PV panels operates at lower level than the reference greenhouse, because of the shading by PV panels. A similar figure one can observe from the obtained results for the PAR measurements.

In Figure 3 the accumulated energy results for the parts that consist the operated systems for the total testing period are given. The solar radiation that enters inside the greenhouses presents almost same PAR data. PAR and Sol measurements are lower because of PV shading.

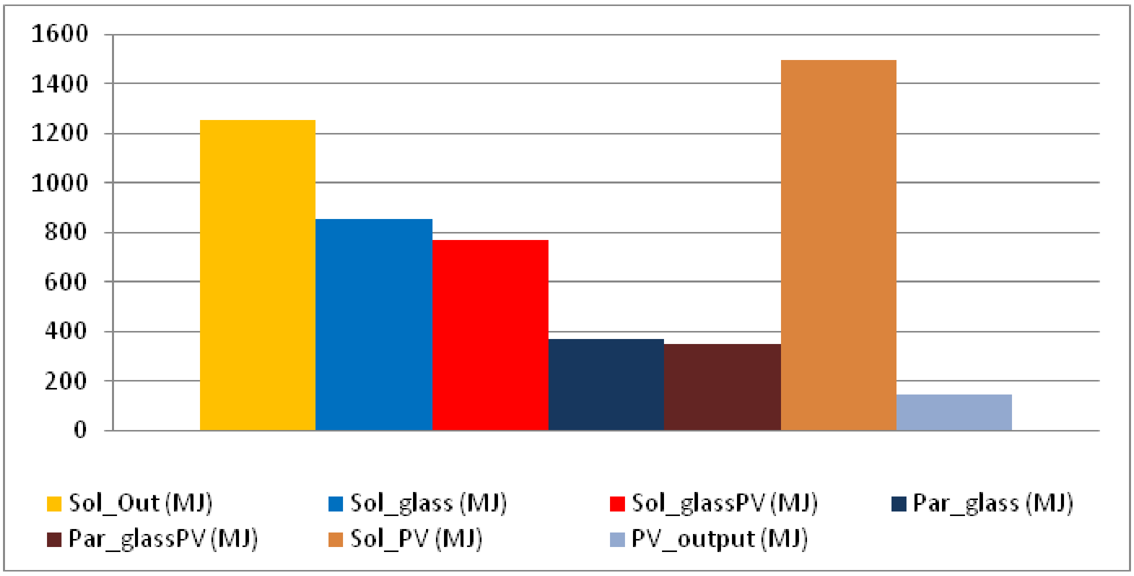

Figure 3. Accumulated energy results of incoming and transmitted solar energy to greenhouses, PAR and PV input and output, for the three months testing period

The value of solar radiation on the horizontal outside pyranometer (Sol_Out) for the 85 days of the experiment is in total 1257.61 MJ. The values for solar energy of pyranometer inside the reference greenhouse (Sol_glass) and inside the greenhouse with PV panels (Sol_glassPV) are 856.36 MJ and 768.82 MJ respectively. These values are lower than the value of the Sol_Out, because of the reflection and absorption from the glass cover of greenhouses, as noticed above. The PAR for the reference greenhouse (Par_glass) was calculated 368.83 MJ and for the PV greenhouse (Par_glassPV) 346.94 MJ. The total radiation that the pyranometer sensor on the roof of the greenhouse with the same slope of PV panels (Sol_PV) was recorded 1498.46 MJ and the corresponding output electrical energy of PV panels (PV_output) has given 146.30 MJ. The incoming solar energy on PV surface is higher than the Sol_Out because of the inclination of PV panels and the period of the experiment. Based on the totally recorded data for the incoming solar radiation on PV panels and the output electricity, the PV system has produced electrical energy with efficiency of about 12%.

The reduction of about 10% between the Sol_glasPV and Sol_glass incoming solar radiation is not the real one and a correction should be considered regarding the Sol_glassPV energy. The calculation of the totally incoming solar radiation the PV greenhouse is less than that of the actually incoming solar radiation, because of the position of the sensor inside the greenhouse. The same can be also noticed for the PAR results, as PAR sensors are also placed at greenhouse center, besides the pyranometer sensors. The solar radiation sensor and the PAR sensor don’t send to datalogger the real lighting level of the total greenhouse internal space due during the day, because of their placement inside the greenhouse. An image that makes clearer the reason that the correction is necessary is presented in Figure 4.

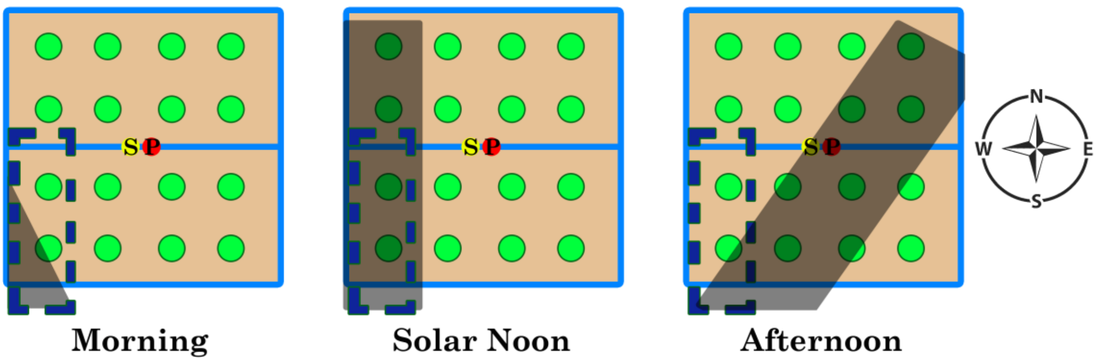

Figure 4. Images of shading on greenhouse ground surface, for three different solar times

In this Figure we can see the shading of the internal space for the partially PV covered greenhouse, in the timeline of a day. The solar radiation sensor and the PAR sensor don't send to data logger the accurate values, to calculate the mean lighting of the internal greenhouse space, because of the existing form of shading in solar noon. The sensor for the Sol_glassPV gives, for example, more incoming solar radiation than the totally entering the greenhouse during noon (tthe values of the incoming solar radiation are at their higher level). On the contrary, during afternoon the sensor gives lower value than the real one, but the actually incoming solar radiation is considerably lower, of less significance effect to the inside space lighting. It is estimated that at solar noon the actual radiation that the greenhouse has received in total is near to 75% of the value that is calculated by the data sent to data logger from the sensors. This problem is observed mainly from the morning up to 2 hours after the solar noon. That's means that the solar radiation and PAR of greenhouse with PV is not about 10% lower than the reference greenhouse, but it can be considered actually about 15% or more. In order to correct this inconsistency in our experiments for the next planting period, we intent to use more radiation sensors inside the greenhouse placed in several positions, or to apply another method, to adapt a better calculation of the incoming solar radiation inside the greenhouse with the roof mounted PV panels.

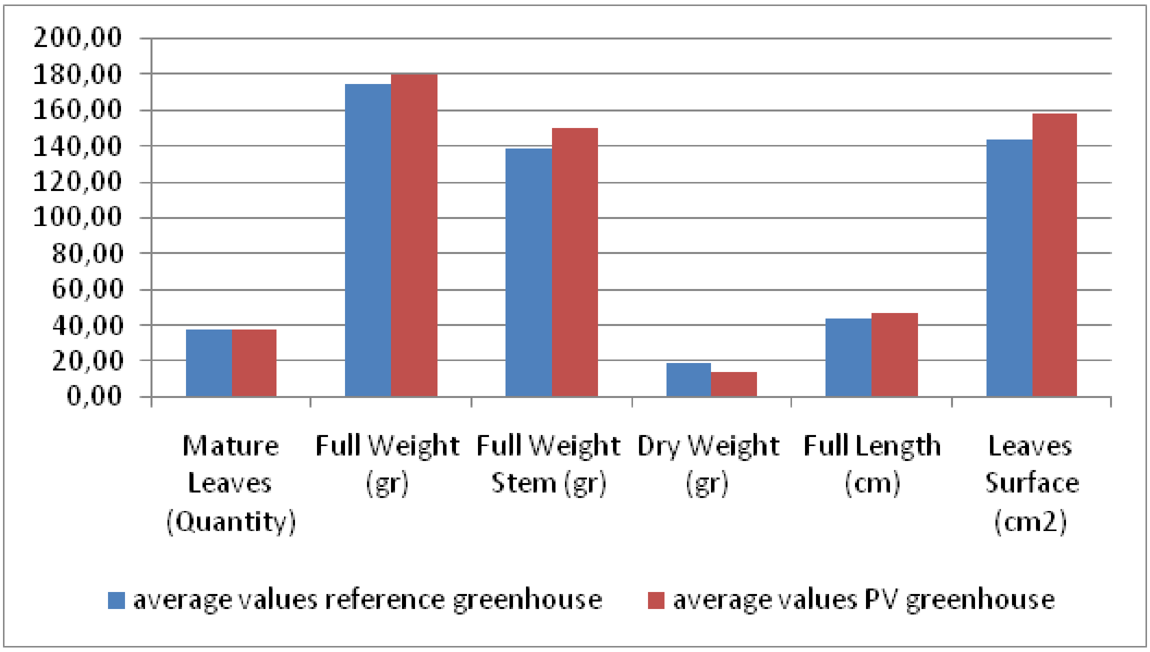

Figure 5. Average values of plant grow indicators I

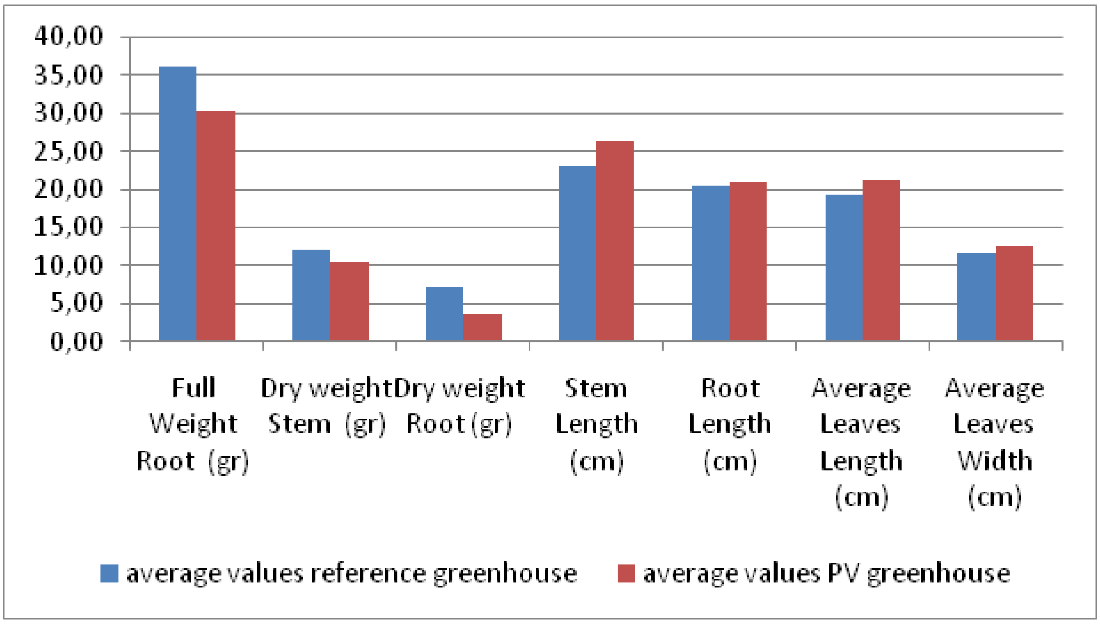

Figure 6. Average values of plant grow indicators II

In Figures 5 and 6 the results of plants grow indicators are presented. In Figure 5 the results for the quantity of mature leaves, the fresh and dry weight, the length and the leave surface give a figure of different grow between the lettuce plants of the reference and the PV covered greenhouses. One can observe that the plants of PV greenhouse have slightly higher growth, except their dry weight. In Figure 6 the results regarding the growing of roots, stem and leave length are shown. From these results it is noticed the lower values of full root weight and dry root weight of the plants of PV greenhouse, compared to those of the plants of the reference greenhouse.

Discussing these results we can conclude that regarding weight, the small difference between lettuce grow in the PV covered greenhouse and the reference greenhouse is not a significant point. The slightly higher weight, length and leave surface that is recorded to the plants of the PV covered greenhouse, compared to the reference greenhouse, can be explained by the higher stressed conditions for plant growing in the reference greenhouse unit, because of the higher level of lighting and temperature.

We have to notice also that the plant growing period that we tested the greenhouse units was a rather warmer period than the usual for these months (Feb, March, April) and thus the PV shading provided a cooler environment for the plant growing, which resulted to less stressed conditions. In addition, the lower solar radiation in the PV covered greenhouse “pushed” the plants to increase their height and leave surfaces, in order to get more light for the photosynthesis. On the other hand, we can remark the lower weight of roots of the plants inside the PV covered greenhouse.

Considering all above plant growing results we can estimate that the effect of PV shading to lettuce growing was small and rather not bad. The differences in the grow indicators are not significant and is estimated that for the warmer cultivation period (May to October) the PV shading would give better results. We’ll intend to test the suggested system for the warmer and for the cooler period in order to get accurate results for the whole year plant cultivation.

The incorporation of PV panels on greenhouse roof provided 146.30 MJ, or a mean amount of 1.7 MJ per day, which is a satisfactory electrical energy contribution to the corresponding electricity demand of that greenhouse unit. Therefore, the suggested method of PV mounting on greenhouse roof, with a covering ratio less than 20%, can be considered effective in plant growing and energy contribution, but more experiments are needed to confirm these positive issues.

4. Conclusions

Photovoltaics can cover energy needs of greenhouses in dynamic ventilation, artificial lighting and other demands. An installation of PV panels on a greenhouse roof was studied regarding the effect to the inside temperature, the transmitted solar radiation and PAR into greenhouse space, the electricity output and the effect to plant growing. This greenhouse operated at the same time and under the same weather conditions with a same size greenhouse, which was the reference greenhouse, to extract comparison results. The greenhouses have east-west orientation, where the solar system was facing south. PV panels of pc_Si type were used, covering a small part of the greenhouse roof surface. Out of greenhouses was placed a horizontal pyranometer and inside the two greenhouses were placed one pyranometer and one PAR meter. For the testing procedure, lettuce plants were used to determine their growing effect due to PV shading.

The planted greenhouses were operated for three months, with cultivation of lettuce plants. It was found that the PV greenhouse gave satisfactory results regarding the studied indicators. The collected data were categorized by the existing system parts and were compared to get a clear idea about the effect of photovoltaics on greenhouse roofs. The obtained results showed small difference for the inside temperature. Comparing the energy that enters the PV covered greenhouse the measured results showed a shading ratio of about 10%, but as it was explained it was about 15% to 20%.

After the three months cultivation of lettuce plants, we measured the growing indicators. According to the obtained results there was not a significant in amount and essential in form difference in plant growing in the two greenhouses. The main differences were in root and leave length, as well as in leave surface, with the plants inside the PV covered greenhouse to give higher values. For the dry weight, the plants inside the reference greenhouse presented higher values. Based on above results we can conclude that for a low covering ratio of greenhouse roof by photovoltaics, as of lower than 20% of the greenhouse roof, we can achieve a considerable energy contribution to the greenhouse demand without significant bad effect to plant growing, under the mild weather conditions of south-west Greece.

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