Dynamic assessment of whitewash shading and evaporative cooling on the greenhouse microclimate and cucumber growth in a Mediterranean climate

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Abstract: An experiment with a soilless cucumber crop (cv. Phenomeno) was conducted in order to evaluate the influence of two different cooling systems (i.e., whitewash as opposed to fan-wetted pad evaporative) on the greenhouse microclimate and on plant growth under high 0.32 mm and low 0.24 mm irrigation dose treatments. The results revealed that the transpiration rate was higher in the whitewash compartment, which resulted in less outflow of nutrient solution into the environment. In regards to the total greenhouse water use efficiency, no differences were obtained between the two different cooling systems, taking into account the amount of water used by the evaporative system per se. Irrigation doses tested did not significantly affect crop production. According to the results obtained, whitewash shading proved to maintain greenhouse cucumber growth and production throughout the spring cropping period in comparison with the use of an evaporative cooling system.

Keywords: Leaf temperature, soilless culture, stem variation, water use efficiency.

1. INTRODUCTION

Being a scarce resource, unevenly distributed and often in low quality, water is the key element of agriculture in arid and semi-arid regions of the Mediterranean (Meric et al., 2011). Even though protected cultivation may be in favor in terms of water use as opposed to conventional open field farming, the initial investment and operational cost of heating and cooling systems may be extremely high; this is especially true for greenhouses located in harsh environmental conditions. Unlike heating, for which the technology is well established and straightforward, greenhouse cooling is costlier as it requires large quantities of good quality water to be evaporated within the greenhouse and frequently presents considerable problems related to their cooling efficiency (Seginer, 1994a; Sethi and Sharma, 2007).

Although natural ventilation is considered to be the most common passive method used worldwide for cooling a greenhouse, under extreme ambient environmental conditions (i.e. high air temperatures and low humidity), there is a weakness for natural or even for forced ventilation systems to remove the greenhouse surplus heat and to develop the appropriate greenhouse climate for optimal crop growth (Abdel-Ghany et al., 2012; Villarreal-Guerrero et al., 2012). Under these circumstances, in order to decrease the inside greenhouse air temperature significantly below the ambient air and increase the air humidity to the desired level, water is needed to evaporate directly within the greenhouse. This can be achieved only through operating dynamic cooling systems such as the fog or fan-wetted pad evaporative systems (Sethi and Sharma, 2007; Katsoulas and Kittas, 2011). Close to the Mediterranean coastal areas as well as high air temperatures, humidity levels are also high. Therefore, the most profitable cooling practice from water saving point of view, was proved to be the application of a white paint to the greenhouse cover during the warm season which in turn blocks out the infrared range which cause warming, combined with
natural ventilation (Baille et al., 2001; Mashonjowa et al., 2010). The main drawback of roof whitewash against other passive or active cooling methods (i.e. external / internal nets shading, fog) is that it may negatively affect the photosynthetic rate, crop growth and production, as it reduces light in hours when it is not in excess, while natural ventilation has a strong dependency on the exterior conditions such as the wind speed (Kittas et al., 2003; Jimenez et al., 2010; Villarreal-Guerrero et al., 2012).

In any case, for optimizing crop production and growers’ profitability, there is a clear need for comprehensive information on a real time basis, regarding crop water performance, as affected by changes to their environment. That could be achieved by directly monitoring only the plant responses to their environment rather than plant’s environment, with the application of plant smart sensing technology. Among different kinds of plant sensors used, monitoring of plant stem micro-variation and leaf-air temperature differences, were found to be the most promising indicators for scheduling irrigation and to determine plant water stress (Fernández and Cuevas, 2010; Isoda, 2010; Naeeni et al., 2014; Nikolaou et al., 2017b).

Irrespectively of monitoring the plant or not, the question arises whether it is necessary to shorten or lengthen the watering intervals (i.e., frequency of irrigation) with smaller or larger amount of water (i.e., dose of irrigation), as the irrigation scheduling proved to affect plant growth and production but also the percentage of nutrient amount outflow from the greenhouse to the environment in the case of soilless cultures (Savvas et al. 2007; Ta et al., 2012; Incrocci et al., 2014). Usually there are compromises with irrigation by slowing the submission of watering or watering with smaller sized irrigation norms. As a result, plants experiencing water stress, which react differently depending on plant development (Kalaydjieva et al., 2015; Leila et al., 2016).

However, despite a significant amount of work being done for soil cucumber open fields and greenhouse cultivation in relation to optimal crop water requirements, water use efficiency, growth and production (Şimsêk et al., 2003; Alomran et al., 2013), to the authors’ best knowledge there is very little published information available for soilless cucumber crops, with emphasis on different irrigation doses used and as affected by different cooling methods.

Hence in the present study an experiment was conducted with different irrigation doses (i.e. high/low irrigation dose) under two different cooling methods in order to evaluate the effects (i) on the greenhouse environmental parameters, (ii) on hydroponically cucumber crop grown, water uptake, drainage and water use efficiency, and (iii) on crop responses as measured with different plant sensors (e.g. leaf temperature, stem variation) under Mediterranean climate conditions.

2. MATERIALS AND METHODS

2.1. Greenhouse Facilities

The experiment conducted from April to June 2016 in an East-West oriented, three spans, polyethylene-covered greenhouse at the Agricultural Research Institute, of Cyprus (lat. 33°44′N, long. 33°19′E, altitude 5 m) in the coastal area of southern Cyprus. The geometrical characteristics of the greenhouse were as follows: eaves height 3.50 m, ridge height 5.00 m, spans width 7 m, total length 24 m, ground area 504 m², volume 2016 m³. The greenhouse was divided into two compartments as shown in Fig. 1. The one compartment was cooled by a combination of fan-wetted pad evaporative besides with natural and dynamic ventilation. Natural ventilation performed by a single continuous roof vent in the middle span and a side vent at one wall for natural ventilation. The roof vent were 24 m long and 1 m wide with a maximum opening area of 24 m², whereas the side vent was 18 m long and 2.20 m wide with a maximum opening area equal to 52.8 m². Dynamic ventilation was performed by two fans, one at each span (air flow rate for each fan was 31500 m³ h⁻¹) when greenhouse air temperature exceeded 25°C. Fan-wetted pad evaporative cooling system started operated after 12 DAT, when greenhouse air temperature exceeded 26°C.

To the other compartment 12 days after transplanting (DAT) whitewash shading (suspension of calcium carbonate) applied to the roof and side walls of the greenhouse. Dynamic ventilation performed by a single span operated at daytime when greenhouse air temperature exceeded 25°C, and at night when relative humidity exceed 75%. The greenhouse floor was completely covered by white plastic film in both compartments.

2.2. Plant material, irrigation system schedule and control

Cucumber plants (n=360) (Cucumis sativus L. cv Phenomenon) which had been raised in rockwool started cubes (10 cm x 10 cm x 6.5 cm), were transplanted on 08th April 2016, in rockwool slabs (100 cm x 20 cm x 7.5 cm) (Grodan Company; Denmark), resulting in a plant density of 1.6 pl. m⁻². The plants were supported by plastic twine.
attached 2.2 m above the plant row on a horizontal wire and trained to one stem per plant by pruning all auxiliary shoots and continuous removal of old or damaged leaves. The number of plants in the whitewash shading greenhouse compartment (hereinafter referred to as “WS”) was 120, and in the compartment with clear roof and evaporative cooling (hereinafter referred to as “C”) there were 240 plants. In each compartment there was a high irrigation dose treatment 0.32 mm [High Irrigation Dose (HID)] and a low irrigation dose treatment 0.24 mm [Low Irrigation Dose (LID)].

Irrigation control for the first 12 days after transplanting was performed with 0.24 mm periodically at fixed time intervals as per usual practices by local growers. Eventually, the irrigation frequency was based on solar radiation measured by a pyranometer located outside the greenhouse (to avoid transient sensor shading problems resulting from structural elements) as described by Katsoulas et al. (2006). The integral of solar radiation intensity, at which an irrigation event was triggered, was regularly adjusted on plant size to values aimed at maintained drainage fraction close to 35-40% (HID), and 20-25% (LID) in the greenhouse compartment with whitewash. Accordingly different daily amount of water applied in HID and LID treatments. Nighttime irrigation was also performed, account for transpiration during the hours of darkness in order to avoid the dryness of the substrate (Beeson, 2011). Complete nutrient solutions were applied in all irrigation events. Nutrient solution compositions were based on Savvas et al. (2013) recommendations.

2.3. Data recording and measurements

Outside greenhouse weather data i.e., air temperature (Ti, °C), relative humidity (RH, %) (Sensor type PT 100; Galcon, Kfar Blum, Israel) and net solar radiation (RGo, W m⁻²) (Sensor pyranometer type TIR-4P; Bio Instruments Company, Chisinau, Moldova) were recorded. Sensors of the same type were used for monitoring climatic variables within each greenhouse compartment. All measurements were recorder on a data logger system (Galileo controller; Galcon, Kfar Blum, Israel). Data was recorder at 30 seconds intervals and average was estimated.

Plant transpiration of HID treatment (WS) and (C) was monitored directly by a weighting lysimeter consisting of a load cell “S type” (Model 9363; Vishay Precision Group, Malvern, USA) mounded from the greenhouse ceiling to a plant supporting system with a growing media of two plants in each treatment (Fig. 1). The cell had a capacity of 50 Kg (±0.02 g). The weight loss
measured by the electronic balance was assumed to be equal to crop transpiration. Drainage water was automatically collected four times daily at fixed interval times from each treatment, as an indirect method to estimated plant water uptake, following Romero-Aranda et al. (2001). Irrigation water use efficiency (IWUE) was estimated as the ratio of the crop yield to irrigation water applied as cited in Al-Jamal et al. (2001). A flow meter was installed to measure the amount of water used by the fan and pad evaporative cooling systems, in order to estimate the total greenhouse water use efficiency (WUE), according to Sabeih et al. (2006). Data were recorded every 5 days.

The leaf area index (LAI: m² leaf m⁻² ground) of the crop was estimated by destructive measurements of the leaf area of sample plants by means of a scanner (F4280; HP, Deskjet, Japan). Leaf area measurements were carried out five times during the experimental period on the 15, 30, 45, 60 and 75 day after transplanting (DAT) and the leaf area, the length, and width of the individual leaves of three plants per treatment and date were measured. To calculate the leaf area, software was applied to leaf scanned images according to Varma and Osuri (2013).

A series of measurements were made in three labeled plants and on three randomly selected in each irrigation treatment. Namely 15, 30, 45, 60 and 75 DAT measurements on plant height, length and width of each leave. Harvesting was made during the morning, twice to three times per week and started at 23 DAT. The total number of fruit production and total weight was measured in each treatment and on three labeled plants per treatment.

Plant destructive measurements were repeated three times in order to determined fresh and dry weight of different organs (stem, fruit and leaves). Four plants were randomly chosen in each irrigation treatment on the 15, 45 and 75 day after transplanting (DAT). Fresh weight were determined by means of a weighting balance (BJ 41000Dd 0.1 gr; Precisa, Swiss Made) and the dry weight after dehumidification at 180°C for 48 hours by means of drying oven (Heraeus t 5050, Germany).

One representative plant on HID treatment (WS) and (C) were monitored by means of a Phyto Sensor system. The plant sensors in each treatment, were a leaf temperature sensor (Model LT-1z), a stem micro-variation sensor (Model SD-5z), and a substrate temperature sensor (Model SMTE-3z). Data were sent wireless to the main system unit, phyto-Logger with micro SD card and received to a PC. Sensors were purchase from Bio Instruments Company, Chisinau, Moldova. Data were collected every 10 minutes. All indicators were used and correlated both for short and long term detection of plant growth, as affected by irrigation and greenhouse microclimate.

2.4. Statistical analysis

Selected data were analyzed and comparisons of means were tested using ANOVA by using a Statistical Package for the Social Sciences (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp).

<table>
<thead>
<tr>
<th>Outside greenhouse</th>
<th>Whitewash compartment (WS)</th>
<th>Evaporative cooling compartment (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DAT</strong></td>
<td><strong>RGo</strong></td>
<td><strong>T_o</strong></td>
</tr>
<tr>
<td>7-13</td>
<td>712(316)</td>
<td>29.3(4.2)</td>
</tr>
<tr>
<td>14-20</td>
<td>647(337)</td>
<td>27.5(3.7)</td>
</tr>
<tr>
<td>30-45</td>
<td>690(339)</td>
<td>28.8(3.8)</td>
</tr>
<tr>
<td>46-61</td>
<td>694(340)</td>
<td>30.0(3.8)</td>
</tr>
<tr>
<td>62-81</td>
<td>730(335)</td>
<td>31.1(4.4)</td>
</tr>
</tbody>
</table>

RGo, outside greenhouse solar radiation (W m⁻²); T_o, outside greenhouse air temperature (°C); RH_o, outside greenhouse air relative humidity (%); RGws, inside whitewash greenhouse compartment solar radiation (W m⁻²); Tws, inside whitewash greenhouse compartment air temperature (°C); RHws, inside whitewash greenhouse compartment air relative humidity (%); VPDws, inside whitewash greenhouse compartment air vapor pressure deficit (kPa); RGc, inside evaporative cooling greenhouse compartment solar radiation (W m⁻²); Tc, inside evaporative cooling greenhouse compartment air temperature (°C); RHc, inside evaporative cooling greenhouse compartment air relative humidity (%); VPDc, inside evaporative cooling greenhouse compartment air vapor pressure deficit (kPa); DAT, days after transplanting.

**Tab. 1** - Mean values (± standard deviation) of inside greenhouse microclimate and outside greenhouse climatic data (day-light hours).

**Tab. 1** - Valori medi (± deviazione standard) del microclima interno della serra e dati climatici esterni alla serra (ore diurne).
3. RESULTS

3.1. Effect on greenhouse microclimate, leaf and growing media temperature

Significant differences were found in relation to the greenhouse environment (i.e., air temperature, humidity, VPD) between different cooling systems tested, as whitewash reduced the greenhouse transmittance of global radiation from 31% \( (C) \) to 45% \( (WS) \). The two-week mean values (± standard deviation), for both inside and outside the greenhouse’s microclimate during the daylight hours are presented in Tab. 1. It indicated an average solar radiation difference of 100 W m\(^{-2}\) between whitewash and evaporative cooling compartment. The diurnal variation of mean solar radiation values outside and inside two greenhouse compartments for a 46 day period (17-63 DAT) is illustrated in Fig. 2.

Additionally, from Tab. 1 it can be observed that following the application of whitewash, correspondingly the mean air temperature values decreased to the same values of those of the ambient air until the end of the experimental period. However it remained higher by 1.43°C in comparison to the air temperature of the evaporative cooling compartment. The mean air temperature recorded values were 29.2 (±3.61)°C outside greenhouse, 29.5 (±3.64)°C for \( (WS) \) and 28.07 (±3.44)°C for \( (C) \). From Fig. 3, it can be seen that differences between the greenhouse air compartments, were greater by the end of the experimental period as affected by higher external air temperature values. However, the daily diurnal variation of greenhouse air temperatures as illustrated in Fig. 4 over the course of a three day representative period (55-57 DAT) indicated that three to four hours after sunshine each day, the temperature of the air in the greenhouse of the whitewash compartment was slightly increased above the ambient air and after midday decreasing below. At 56 DAT when the maximum greenhouse air temperature was 34.1°C \( (WS) \) as recorded at 14:30 h., the external air temperature was 33.9°C, and 32.1°C for the \( (C) \) compartment. Two hours later, even the outside air temperature increased to 34.1°C, the greenhouse air temperature decreased to 32.6°C \( (WS) \) and 31.5°C \( (C) \). At the same time the VPD decreased from 2.5 kPasc to 2.05 kPasc \( (WS) \) and then remained constant at around 1.9 kPasc at \( (C) \).

In relation to other greenhouse climatic factors, i.e., relative humidity and vapor pressure deficit (VPD) even though differences between compartments were not ideal (Tab. 1) they were statistically significant (at a significance level of 0.05, t-test used).
environmental conditions. Within a representative day, stem micro variation measurements followed quite a similar trend in the two compartments preceded by diurnal VPD fluctuations (Fig. 6). The influence of whitening on plant growth rate examined at two different representative experimental periods, related to the first and late crop stage. Between a seven day period (25-31 DAT), the stem growth rate was higher for the whitewash shading compartment with absolute stem increase value of 2.2 mm, in contrast with 1.7 mm at the fan-wetted pad evaporative cooling compartment. By the end of the experiment, between 60-66 DAT, the absolute values of the stem increase was higher within the fan-wetted pad cooling compartment, as the estimated stem values increased to 1.2 mm (C) and 0.4 mm in the (WS).

3.3. Effect on plant transpiration and water use efficiency.

Differences in transpiration rates between HID treatments estimated through the use of lysimeters for daylight hours (13-82 DAT) were significant. Even though the incoming solar radiation was lower in the whitewash compartment, the transpiration rate was higher, with mean daily estimated values (± standard deviation) of 145.53 W m⁻² h⁻¹ (± 54.62) (HID, WS) and 133.82 W m⁻² h⁻¹ (± 60.33) for (C) compartment. Leaf temperature of the HID trials were evaluated and indicated lower values in comparison to the greenhouse air temperature in both cooling systems tested during the experimental period. In the greenhouse compartment with whitewash, the mean recorded leaf temperature values for daylight hours were 25.56 (±2.68)°C, 3.94°C lower than the greenhouse air temperature. In the compartment with evaporative cooling the mean leaf temperature values were 24.56 (±2.68)°C, 3.51°C lower than the greenhouse air temperature. The evaluation of the hourly mean leaf and greenhouse air temperature within the two compartments during the course of the three day representative period (DAT 60-62), is presented in Fig. 5. Significantly higher substrate temperature values were found in behalf of whitewash shading by 1.2°C between 56 to 66 DAT. During the entire experimental period the mean recorded values for daylight hours were 26.2 (±3.24)°C (WS) and 25.69 (±3.58)°C (C).

3.2. Effect on stem micro variations

Stem micro variation was also being monitored as an indicator of plant growth and plant water content, associated with the vegetation stage and estimated values were 1.72 (±0.69) kPasc, and 60.61% (±11.17) RH for (WS) and 1.44 (±0.54) kPasc and 64.08% (±10.48) RH for (C) compartment.
The total cucumber production values for the (WS) compartment were 13.26 Kg m\(^{-2}\) (HID), 13.94 Kg m\(^{-2}\) (LID) and for the (C) compartment 15.76 Kg m\(^{-2}\) (HID) and 15.60 Kg m\(^{-2}\) (LID). Therefore, the estimated Irrigation Water Use Efficiency (IWUE) were 28.39 Kg m\(^{-3}\) (HID), 33.50 Kg m\(^{-3}\) (LID) for (WS) and 33.75 Kg m\(^{-3}\) (HID) and 37.50 Kg m\(^{-3}\) (LID) for the (C) compartment.

The total water used (i.e. evaporated), by wetted pad evaporative system during the 70 days period (DAT 12-82) was 71 m\(^{3}\) with a mean estimated value of 72 l m\(^{-2}\) d\(^{-1}\). By the end of the experimental period and as the outside conditions became warmer the water used by evaporative pad, increased to 104 l m\(^{-2}\) d\(^{-1}\). Taking into account the amount of water used by the evaporative system, the total greenhouse water use increased for the (C) compartment, resulting in a decrease of the total greenhouse water use efficiency (WUE) to 29.29 Kg m\(^{-3}\) (HID) and 32.02 Kg m\(^{-3}\) (LID).

3.4. Effect on plant growth and production
Tab. 2 presents the comparison of mean values of plant growth (i.e., height, number of leaves, LAI) and marketable production (number and weight of fruit per plant) as affected by different cooling methods and irrigation doses tested. It can be observed that despite no significant differences observed between treatments, the plant height was positively affected by whitewash shading, as higher mean values of 33.33 % (HID) and 15.79 % (LID) were recorded, compared to the same replications in the evaporative cooling compartment. The indirect transpiration rate estimated values with the water balance method indicated similar results. Over the course of an eight day representative period (50-57 DAT) the mean water uptake, for the whitewash shading compartment were 2.63 l pl\(^{-1}\) (± 0.43) HID, 2.54 l pl\(^{-1}\) (± 0.66) LID and for the cooling compartment 2.48 l pl\(^{-1}\) (± 0.29) HID, 2.16 l pl\(^{-1}\) (± 0.58) LID.

As expected a close relationship was observed, between transpiration rates and the amount of nutrients outflow from the greenhouse to the environment (i.e. drainage). The drainage volume, was higher within the fan-wetted pad evaporative cooling compartment with mean daily estimated values of 39.16% (± 12.05) (HID,C), 38.87% (± 9.97) (LID,C) compared to 36.47% (± 13.23) (HID,WS) and 26.35% (± 9.90) (LID,WS). Significant differences were found between high and low irrigation dose treatments only in the whitewash compartment and between different compartments at LID (WS) treatment comparing with HID (C) or LID (C). It is also noteworthy, that two hours after sunshine each day, when the water automatically collected and measured, the amount of drainage was negligible either for evaporative cooling or shading compartment in the case of low irrigation dose treatments as observed, especially by the middle and middle-end stage of the crop growing season (data not shown).
compartment. Additionally the maximum plant height values recorded were 252 cm (HID, WS), 220 cm (LID, WS), 189 cm (HID, C) and 190 cm (LID, C). However, differences of plant height were statistically significant and in favor of (HID, WS) compared to (HID, C and LID, C) as results indicated, if measured data for the first destructive measurement are excluded (data not shown). Different irrigation volume applied did not affect the plant height, be it negatively or positively, as no differences were found between treatments of different irrigation volume, within the same greenhouse compartment. No differences were observed relating to the number of leaves per plant with mean approximation values of 18 leaves per plant. Similarly no statistical differences were detected relating to LAI (m² leaf m⁻² ground) even though slightly higher mean estimated values were observed within the whitewash shading compartment (Tab. 2). Maximum values observed of LAI were estimated, in the last destructive measurement (67 DAT) and they were 1.73 (HID, WS), 2.12 (LID, WS) and 2.01 (HID, C), 2.16 (LID, C).

Harvesting of cucumbers commenced on 25 DAT, with 23 harvests being conducted for each treatment until 82 DAT. Evaporative cooling positively affected production, which was found to be higher, by 18.8% (HID) and 12.05% (LID) compared to same replications under the whitewash shading compartment. The mean weights of the harvested fruits per plant / harvest were higher for the greenhouse compartment with evaporative cooling as indicated in Tab. 2. Even thought, those differences were not statistically significant.

With respect to fresh and dry weight per plant, (HID) and (LID) treatments follow almost the same trend (Tab. 3) during the period of measurements and statistical analysis showed that

<table>
<thead>
<tr>
<th>Treatment</th>
<th>HID, WS</th>
<th>LID, WS</th>
<th>HID, C</th>
<th>LID, C</th>
</tr>
</thead>
<tbody>
<tr>
<td>LFW</td>
<td>498.37 (121.12)</td>
<td>592.68 (247.23)</td>
<td>545.65 (170.03)</td>
<td>472.80 (58.43)</td>
</tr>
<tr>
<td>SFW</td>
<td>229.97 (70.25)</td>
<td>267.36 (91.28)</td>
<td>243.68 (93.49)</td>
<td>229.77 (54.16)</td>
</tr>
<tr>
<td>FFW</td>
<td>311.90 (228.44)</td>
<td>321.30 (53.65)</td>
<td>406.60 (224.26)</td>
<td>306.70 (116.68)</td>
</tr>
<tr>
<td>LDW</td>
<td>60.25 (15.15)</td>
<td>76.58 (37.74)</td>
<td>76.85 (40.05)</td>
<td>62.53 (13.27)</td>
</tr>
<tr>
<td>SDW</td>
<td>20.92 (8.92)</td>
<td>26.85 (10.88)</td>
<td>22.32 (10.66)</td>
<td>22.57 (10.74)</td>
</tr>
<tr>
<td>FDW</td>
<td>18.85 (12.77)</td>
<td>19.81 (8.72)</td>
<td>21.98 (8.72)</td>
<td>17.84 (5.97)</td>
</tr>
</tbody>
</table>

LFW, Leaves fresh weight; SFW, Stem fresh weight; FFW, Fruit fresh weight; LDW, Leaves dry weight; SDW, Stem dry weight; FDW, Fruit dry weight; HID, High Irrigation Dose (0.32 mm); LID, Low Irrigation Dose (0.24 mm); WS, whitewash shading greenhouse compartment; C, fan-wetted pad evaporative cooling; for the same characteristic no significant differences were found among treatments (p=0.05).

Tab. 3 - Mean values (± standard deviation) of fresh and dry weight in grams per plant of leaves, stem and fruit.
Tab. 3 - Valori medi (± deviazione standard) del peso fresco e secco in grammi per pianta di foglie, fusto e frutta.
there were no significant differences in terms of fresh or dry weight per plant, regarding leaves, the stem and fruit in spite of the cooling method used.

4. DISCUSSION
The high radiation loads which are usually observed under harsh Mediterranean climate conditions enhance cooling during a large part of a year which in most cases is costly in terms of energy and implies the use of water which is important to consider in areas with scarce water resources. Therefore, two irrigation doses evaluated in a cucumber soilless cultivation, under two different cooling systems (whitewash against fan-wetted pad evaporative) in an attempt to identify future perspectives for better control of the greenhouse environment and crop growth in relation to the water used.

The results obtained in the current study, imply that (I) there is a possibility for a hydroponically cucumber crop to grow and produce even throughout the spring crop period of the year, without the use of an energy and water demanding evaporative cooling system, (II) whitewash shading in combination with force ventilation, enhances the transpiration rate and reduces the outflow nutrient solution, (III) irrigation doses tested does not significantly affect crop production and (IV) an irrigation dose (LID, 0.24 mm) maintaining a drainage fraction of 20-25% ensures a better water use by the cucumber crop.

Whitewash shading, combined with force ventilation reduced the greenhouse air temperature to the same levels of ambient air. However, there are reports on a difference reduction between the inside-external air temperature by up to 9°C, in the whitewash roof glass cover greenhouse combined with natural ventilation (Baille et al., 2001; Chauhan et al., 2003). Therefore in our case it appears that a significant amount of water which evaporated through the transpiration processes probably transferred directly to the outside atmosphere through the continual operation of forced ventilation, not allowing for the crop to interact with the greenhouse microclimate, resulting in similar external-internal air temperature values in the whitewash compartment (Katsoulas et al., 2001; Ahemd et al., 2016). However, the operation of force ventilation systems cannot be avoided in cases where the external air flow rate is too low (Ganguly and Ghosh, 2011; Santolini et al., 2017). Nonetheless no differences were observed regarding plant growth characteristics (i.e., LAI, leaves number), plants within the whitewash compartment during the initial crop phase indicated higher growth rate as estimated with stem micro variation measurements, which resulted in greater mean height values during the whole experimental period as illustrated in Tab. 2. This may be attributed to higher air temperatures which were recorded within the whitewash compartment compared to the fan-pad evaporative cooling compartment which enhances plant development. Similarly, other researchers have reported greatest growth in cucumber plants in higher day air temperatures (Papadopoulos and Hao, 2000; Särkkä et al., 2017). In addition, Seginer et al., (1994b) reported that the older the plant the lower is the temperature that leads to maximum growth. In our case, by the end of the experimental period, as the mean external air temperature increased from 28°C to 32°C, higher air temperatures in the whitewash compartment, negatively affected the growth rate of plants, as the estimated absolute values of the stem increase was higher in the fan-pad cooling compartment.

In any case the difference in air-leaf temperature indicated that the plants were not facing any stress conditions either in whitewash or evaporative cooling greenhouse compartment.

Even though, it is well known from other pieces of literature, that there is a strong correlation between transpiration and solar radiation (Aschonitis et al., 2015; Valipour et al., 2017), also supported for cucumber soilless cultivation (Yang et al., 1990; Medrano et al., 2005), it seems that under our experimental conditions influences of other environmental factors on transpiration were stronger, as plants within the whitewash compartment at lower solar radiation values indicated higher transpiration rates in comparison to plants in the evaporative cooling compartment with a clear polyethylene cover. As there was no interaction between crop growth (i.e., leaf area index and the number of leaves per plant) and different cooling methods tested or volume of water apply, differences in transpiration rate could be attributed due to differences of greenhouse air temperature values between compartments (higher by 1.43°C at whitewash), and higher air turbulence above the canopy as affected by almost continual operation of the force ventilation system within the whitewash compartment, also reported by Seginer (1994a) and Kittas et al. (2003). The study shows that higher IWUE values
in both compartments were obtained for the LID treatments, taking into account the water used by wetted pad evaporative system (mean estimated value of 72 l m$^{-2}$ d$^{-1}$). The increase of the IWUE values seems to be the result of the lower amount of irrigation water applied or decreased transpiration rates which were observed for the LID in both compartments, as also reported by Ikkonen et al. (2015). However, lower water consumption values of 11 l m$^{-2}$ d$^{-1}$ for the evaporative pad in a greenhouse filled with a full canopy of tomato plants, and assisted with 40% shading when inside radiation was above 650W m$^{-2}$, reported for a typical summer day in Tucson, Arizona, USA, indicating the drastic effect of shading in water consumption as cited in Villarreal-Guerrero et al. (2012). In contrast, the amount of water consumed was 3.3 l m$^{-2}$ d$^{-1}$ for the operation of a fog cooling system, from May till September, in an experiment conducted with soilless eggplant crop on the coastal area of western Greece, reported by Katsoulas et al. (2009).

Regarding the percentage of nutrient emission outflow from the greenhouse to the environment, significantly higher values were recorded as a result of the lower transpiration rate in the evaporative cooling compartment. The strong correlation, between cucumber transpiration and the amount of water and nutrients that outflow from the greenhouse into the environment was reported in author’s previous work (Nikolaou et al., 2017a). 5. CONCLUSIONS The findings of the current study suggest that whitewash shading combined with force ventilation in Mediterranean greenhouses supports cucumbers’ growth and production without unacceptable losses during the spring cropping period. Furthermore, irrigation of soilless cucumber with an amount of water 0.24 mm with a target drainage fraction 20-25% ensures a better water use by the crop.

REFERENCES


