Emirates Journal of Food and Agriculture. 2017. 29(11): 863-871
doi: 10.9755/ejfa.2017.v29.i11.1496
http://www.ejfa.me/

REGULAR ARTICLE

Effect of irrigation frequency on growth and production of a cucumber crop under soilless culture

Georgios Nikolaou[1]*, Damianos Neocleous[2], Nikolaos Katsoulas[1], Constantinos Kittas[1]

[1]Department of Agriculture Crop Production and Rural Environment, University of Thessaly, Volos, Greece, [2]Department of Natural Resources and Environment, Agricultural Research Institute, 1516 Nicosia, Cyprus

ABSTRACT

Three irrigation frequencies were applied on a soilless cucumber crop, in a greenhouse located in the coastal area of southern Cyprus. Irrigation scheduling was based on solar radiation and performed whenever accumulated solar radiation energy outside the greenhouse reached 1.3 MJ m^{-2} [High Irrigation Frequency (HIF)], 1.9 MJ m^{-2} [Medium Irrigation Frequency (MIF)] and 3.0 MJ m^{-2} [Low Irrigation Frequency (LIF)]. The amount of water applied was 0.192 Kg m^{-2}, 0.288 Kg m^{-2} and 0.448 Kg m^{-2} for high, medium and low irrigation frequencies, respectively. Appropriately, the total volume of water applied was identical in each of the three cases. In order to study the effects of irrigation frequency on cucumber crops, multiple measurements were taken; the fresh and dry weight of plant organs (i.e. leaves, stem and fruit), marketable fresh yield production, and microclimate variables for a 75 day period, beginning in April and ending in June. The results revealed that the irrigation frequency did not influence the cucumber crop's growth and production. Plants at LIF were facing water stress conditions, as estimated from leaf temperature and stem micro variation measurements. However, HIF increased the transpiration rate of the plants, resulting in less water and nutrient losses.

Keywords: Drainage, Phyto-sensing, Rockwool, Transpiration, Water use efficiency

INTRODUCTION

Despite the revolutionary expansion of hydroponics in commercial horticulture, there are still some constrains which restrict further expansion, especially in environmentally protected areas (i.e. Nitrate Vulnerable Zones) where the discharge of drainage is not compatible under the EU Nitrate Directive (Savvas, 2002; Ferreira et al., 2016). In particular, open hydroponic cultures have considerable amounts of nutrients (i.e. nitrates and phosphates) depleting into the environment, as leaching fractions of 25-35% of irrigation solution is often recommended (Schroder and Lieth, 2002; Savvas et al., 2007; Slamic and Jug, 2016).

Without doubt, the scarcity of water resources had led farmers to improve their irrigation strategies, for providing crops with their exact water requirements (Morille et al., 2013). Interestingly, several studies carried out, show that irrigation events divided into shorter intervals, positively influenced the crop growth and production (Mekonnen, 2012; Adejumobi et al., 2015). However, in a soilless culture system, conflicting results often occur as the efficiency depends greatly on their design (i.e. various types of substrates and different types of growing systems) and how water and nutrients are managed (i.e. open or closed drainage systems; Grewal et al., 2011).

Rose and pelargonium, grown in rockwool and peat pots respectively, increasing the frequency of irrigation positively affected the rate of transpiration, improved water use efficiency and production (Katsoulas et al., 2006; Eiasu et al., 2012). Similarly, Pires et al. (2011) and Rodriguez-Ortega et al. (2016) reported that irrigation events divided into shorter intervals, grown either in coco-fibres or perlite substrates, favored tomato fruit yield. In contrast, Tsirogiannis et al. (2010) working with gerbera grown in pots filled with Nisyros pumice, concluded that the yield and quality characteristics (i.e. stem length and flower diameter) were almost equal for the two irrigation frequencies tested. In addition, water use efficiency was higher under the low irrigation frequency trial.

The effect of irrigation frequency, on the amount of nutrient outflow from the greenhouse, was also investigated

***Corresponding author:**
Georgios Nikolaou, Department of Agriculture Crop Production and Rural Environment, University of Thessaly, Volos, Greece.
E-mail: gnicolaounic@gmail.com

Received: 01 May 2017; **Revised:** 17 November 2017; **Accepted:** 19 November 2017; **Published Online:** 24 November 2017

by many researchers in an attempt to increase the water use efficiency and minimize the harmful effects of high nutrient concentrations discarded into the environment. This does take into account the scarcity of water resources, and local legislation regarding groundwater aquifers which may preexist in multiple countries (Morille et al., 2013; Ferreira et al., 2016). According to Silber et al. (2003), working with lettuce planted in pots filled with perlite, the amount of drainage solution was increased, as the frequency of irrigation decreased. In contrast, Savvas et al. (2007) recorded a restriction of the drainage solution volume of pepper crop, with a low irrigation frequency, in a closed-cycle hydroponic system.

Without a doubt, water deficit stress is one of the leading limitations to photosynthesis and plant primary productivity (Elshibli et al., 2016). For that reason, the prompt and timely evaluation of water status in plants through the use of physiological plant measurement sensors (i.e. canopy temperature/reflectance, sap flow, stem variation) has proven useful in irrigation control (Seelig et al., 2009). Therefore, accurate control of the irrigation scheduling, based on a real time plant feedback system - which allows adjustment of frequency and the quantity of irrigation - can lead to optimal water management and increased crop yield, particularly in areas of scarce water resources (Helmer et al., 2005; Steppe et al., 2008; Fernandez et al., 2010). However, even though a significant amount of work is being done in the field of phyto-sensing, to the authors' best knowledge only a few publications relate this technique to hydroponics.

In view of the above, the objectives were to (a) compare the effects of three different irrigation frequencies; fresh and dry weight, crop leaf area and production growth of soilless cucumber crop (*cv. "Phenomenon"*) under Mediterranean climate conditions and (b) to indicate the use of plant based measurement sensors for evaluating physiological plant response, induced by changes in plant water status (e.g. leaf temperature, stem variation) enabling a more efficient management of the water resource, without a significant loss in agricultural productivity.

MATERIALS AND METHODS

Greenhouse description

The experiment conducted from April to June 2014 in an East-West, three spans, polyethylene-covered greenhouse at the Agricultural Research Institute, of Cyprus (lat. $33^0$44'N, long. $33^0$19E, alt. five meters) on the coastal area of southern Cyprus. The geometrical characteristics of the greenhouse were as follows: eaves height 3.50 m, ridge height five meters, spans width seven meters, total length 24 m, ground area 504 m^2, volume 2016 m^3. The greenhouse was equipped with a single continuous roof vent in the middle span and a side vent at the two walls. The roof vent were 24 m long and one meter wide with a maximum opening area of 24 m^2, whereas the side vent was 18 m long and 2.20 m wide with a maximum opening area equal to 52.8 m^2 (Fig. 1). Dynamic ventilation was performed by three fans one at each span (air flow rate for each fan was 31500 $m^3 h^{-1}$) when greenhouse temperatures exceeded 25°C and at night, when relative humidity exceeded 75%. The wet evaporative pad system operated when the temperature exceeded 26 °C.

Plant material, irrigation scheduling 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 2nd April 2014, in rockwool slabs (1 m x 0.2 m x 0.075 m) (Grodan Company; Denmark), resulting in a plant density of 1.6 plant m^{-2}. Three different irrigation doses and application frequency treatments were followed on a number of every 120 plants (Fig. 1). All 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. Irrigation control for the first 14 days after transplanting was performed with 0.24 Kg m^{-2} periodically at fixed time intervals as per usual practices by local growers.

Eventually, the irrigation frequency was based on solar radiation, according to (Katsoulas et al., 2006) and performed whenever accumulated solar radiation energy outside the greenhouse reached 1.3 MJ m^{-2} (HIF), 1.9 MJ m^{-2} (MIF) and 3.0 MJ m^{-2} (LIF). The amount of water applied per irrigation event were 0.192 Kg m^{-2} (HIF), 0.288 Kg m^{-2} (MIF) and 0.448 Kg m^{-2} (LIF). The total daily amount of water applied was equal for the three treatments. Night time irrigation was also performed to avoid substrate dryness. During daytime a safety factor of maximum 180 minutes without irrigation was applied. Complete nutrient solutions were applied in all irrigation events. Nutrient solution compositions were based on recommendations by Savvas et al. (2013).

Crop monitoring

One representative plant in MIF and LIF treatment 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 moisture, EC and temperature sensor (Model SMTE-3z). Data was sent wirelessly to the main system unit, phyto-Logger with micro SD card

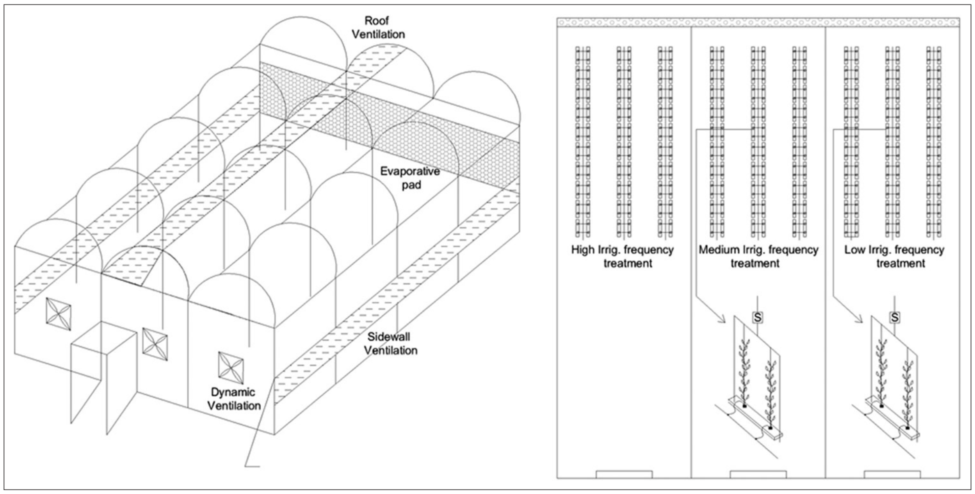

Fig 1. Schematic description of the greenhouse, positioning of plant material and measuring equipment (lysimeters).

and received to a PC. Sensors were purchased from Bio Instruments Company, Chisinau, Moldova. Data was collected every 10 minutes.

Data recorder 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 (R_{Go}, 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 greenhouse. All measurements were recorder on a data logger system (Galileo controller; Galcon, Kfar Blum, Israel). Data was recorder at 30 seconds intervals and a ten minute average was estimated.

Plant transpiration was directly monitored, 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 MIF and LIF treatments. 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 and measured from the lysimeters, these determinations were made daily at the same time. The water uptake which was equal to crop transpiration rate was also estimated by using continually measurements of the water volume supplied to the crop and the water collected by the drainage system in each treatment by means of a simplified water balance model (as cited in Tsirogiannis et al., 2010). Water use efficiency was calculated as the ratio of the total yield to the total applied irrigation solution (Meric et al., 2011).

The leaf area index (LAI: m^2 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 Varna and Osuri (2013).

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

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 selected in each irrigation treatment on the 15, 45 and 75 day after transplanting (DAT). Fresh weight was 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). All the plants removed for destructive measurements were replaced by back up plants of the same size.

Statistical analysis

Selected data was 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).

RESULTS

Greenhouse and crop microclimate

The monthly mean values, for both inside and outside the greenhouse's microclimate during the daylight hours are presented in Table 1. It indicates that was a higher mean indoor air temperature difference of 1.5 °C, compared to the ambient air recorded during the initial phase of the crop, decreased to 0.5 °C as the crop grew.

Matching the leaf temperature-based water stress indices highly correlated with the frequency of irrigation. This was with exception the early morning and late afternoon hours where the leaf temperature of LIF trial was higher and closer to the greenhouse air temperature especially, throughout the midday hours as illustrated in Fig. 2. Between the hours of 10:00 to 16:00, over the course of an eight day representative period (DAT 61-68), a significant higher mean difference in leaf temperature was recorded by 1.23°C in LIF trial, comparing to MIF. The mean estimated leaf temperature values (± standard deviation) were 29.59(±5.84) for MIF and 30.82(±5.12) for LIF, for a number of observations 300 in both cases (DAT 61-68).

In addition, linear regression modeling developed for leaf temperature as a dependent variable, and the time, the amount and the frequency of irrigation of MIF and LIF, as predictors. All three parameters tested, showed to significantly predict the leaf temperature with a β value for the treatment of -.898, ($p=0.002$), for irrigation amount 0.021 ($p=0.003$) and for the time of irrigation 6,569E-5 (p=0,001).

The substrate temperature was also affected by the irrigation frequency, with higher differences between treatments recorded by the end of the experimental period. On a typical day of June (DAT 63), when the maximum temperature of the greenhouse air reached was 32.4°C at 14:00 h, where the substrate temperature was 34°C for (LIF) and 31.1°C for (MIF). As illustrated in Fig. 2, the temperature of the substrate for both treatments was progressively increased after sunrise, followed by a drastic drop in the early afternoon hours. Additionally over the course of the eight day representative period (DAT 61-68), between the hours of 10:00 to 16:00, the mean estimated temperatures in the substrate were 30.97°C (±3.15) MIF and 31.64°C (±3.15) LIF ($n=300$), and differences between

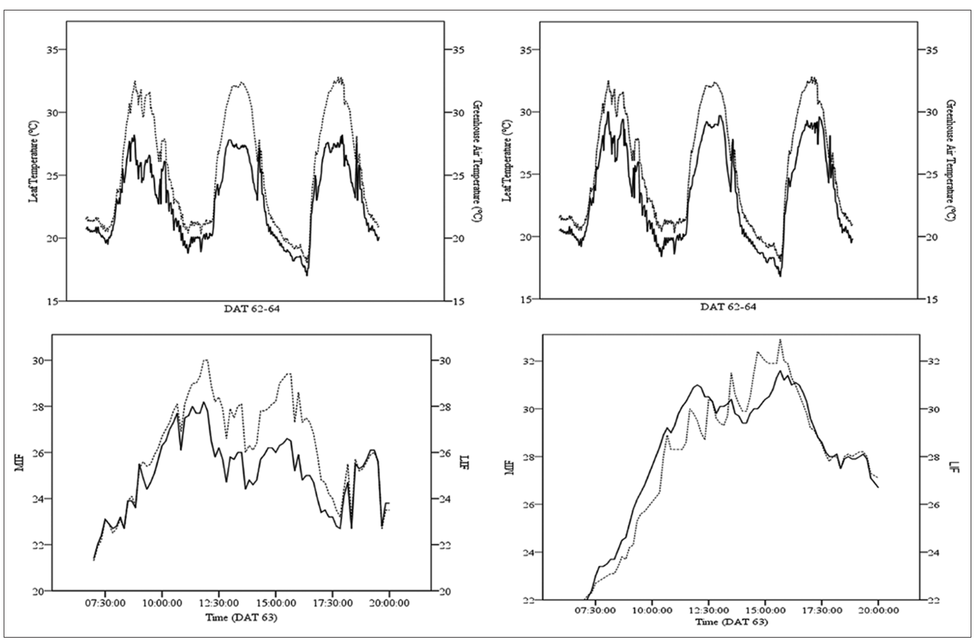

Fig 2. Greenhouse air and leaf temperature (˚C) during a three days measurement period (DAT 62-64) for medium irrigation frequency treatment (MIF-upper left side) and for low irrigation frequency treatment (LIF-upper right side). Diurnal daily variation of leaf temperature (˚C), (DAT 63) for (MIF-bottom left side-continuous line, LIF-bottom left side-dotted line) and substrate temperature (˚C) for (MIF-bottom right side-continuous line, LIF-bottom right side-dotted line).

Table 1: Means±SD of inside microclimate greenhouse and outside greenhouse climatic data (daylight hours)

Month	T_i (°C)	RH_i (%)	VPD_i (kPa)	RG_i (W m^{-2})	T_o (°C)	RH_o (%)	RG_o (W m^{-2})
April	27.3 (3.1)	57.2 (9.7)	1.6 (0.5)	465 (196)	25.8 (2.6)	57.3 (6.7)	700 (333)
May	27.5 (3.2)	62.1 (10)	1.5 (0.5)	441 (206)	27.0 (3.2)	57.6 (10.4)	710 (350)
June	29.9 (3.4)	61.1 (8.9)	1.7 (0.7)	459 (200)	29.4 (2.5)	55.7 (7.9)	742 (340)

T_i, greenhouse air temperature; T_o, outside greenhouse; RH_i, greenhouse air relative humidity; R_o, outside greenhouse; VPD_i, greenhouse air vapor pressure deficit; RG_i, inside greenhouse solar radiation; RG_o, outside greenhouse; SD, standard deviation treatments were statistically significant. In order to identify predictors of substrate temperature, linear regression modeling is utililsed, with three predictors for the irrigation frequency (i.e. MIF and LIF), water amount and time of irrigation developed with substrate temperatures as a dependent variable. All three parameters examined, showed to be significant predictors with β value for the treatment of -.635, (p=0.005), for the irrigation amount of 0.015 (p=0.003) and for time of irrigation 8.903E-5 (p=0.001).

Plant growth parameters and yield

A higher, but not significant mean in height was recorded in the LIF trial by 13.13% and 10.22%, compared to the HIF and MIF trials, respectively. The mean estimated values (± standard deviation) of plant height were 137.20 cm (±76.70) HIF, 151.20 cm (± 86.62) MIF and 155.07 cm (± 93.48) LIF, and the mean leaf numbers per plant were 16.60 (± 7.85) HIF, 17.87 (± 8.41) MIF and 17.8 (± 8.47) LIF. Maximum height values per plant, observed at 75 DAT and they were 260 cm (HIF), 256 cm (MIF) and 293 cm (LIF).

Table 2 shows, mean estimated values of LAI (m^2 leaf m^{-2} ground), which followed quite the same trend, between treatments over the experimental period. As indicated, the crop leaf biomass rapidly increased after transplanting, until 43 DAT, followed by a drastic drop as a result of removing of old and damage leaves. The mean estimated values of LAI were 1.30 (±0.72) HIF, 1.34(±0.79) MIF and 1.33 (±0.73) LIF and were unaffected by the irrigation frequency. The maximum estimated values of LAI observed at 43 DAT (data not show) and they were 2.45 (HIF), 2.78 (MIF) and 2.55 (LIF).

The leaf area S (cm^2) of every leaf on each labeled plant were plotted against its length L (cm) and width W (cm) in different treatments, revealing a linear dependence of (S) on (L*W) in all cases. The straight lines obtained by are presented in table 3. The slope of each regression line represents the corresponding leaf area. From the results shown in table 3, a t-test was used, indicating that the slopes of the regression equations are not different, despite the different irrigation frequency applied. Hence, a simple relationship linking the area S (cm^2) of a leaf to its length L (cm) and with W (cm) was established with a determinations coefficient R^2 of 0.97.

$$S=1.629L * W \tag{1}$$

With respect to fresh and dry weight of leaves, stem and fruit, significant differences between treatments were recorded only at 75 DAT (Table 4). The results indicated a higher total fresh weight of LIF trial by 55.79% and 34.40% comparing with HIF and MIF treatment respectively (75 DAT). Similarly, a higher total of dry biomass production in favor of LIF trial by 42.82% (HIF) and 25.68% (MIF) was recorded.

The number of fruit related to their weight is the primary indicators of the market value of the cucumber production. Interaction between production and frequency of irrigation have not been found, as the cumulative recorded cucumber values per plant after a harvesting period of 51 days, were 7480 gr. (HIF), 7370 gr. (MIF) and 7670 gr. (LIF). The total amount of harvested fruit per plant was 63.05 (HIF), 61.85 (MIF) and 62.73 (LIF).

Plant transpiration and water use efficiency

The daily mean variation of the canopy transpiration rate (W m^{-2}) in MIF and LIF treatments, as measured with the use of lysimeters (13-67 DAT), is presented in Figs. 2 and 3. Differences in transpiration rates between treatments were significant, with mean estimated values (± standard deviation) of 147.79 W m^{-2} (± 60.32) for MIF and 139.36 W m^{-2} (± 51.81) for LIF. From Figs. 2 and 3, it can be clearly seen that higher transpiration rate differences

Table 2: Means±SD of leaf area index (m^2 leaf m^{-2} ground)

DAT	HIF	MIF	LIF
13	0.10 (0.01)	0.09 (0.009)	0.07 (0.003)
28	1.04 (0.14)	1.02 (0.11)	1.08 (0.13)
43	1.57 (0.15)	1.54 (0.20)	1.58 (0.22)
59	0.87 (0.15)	0.97 (0.06)	1.27 (0.26)
75	1.05 (0.21)	1.51 (0.02)	1.70 (0.37)

HIF: High irrigation frequency; MIF: Medium irrigation frequency; LIF: Low irrigation frequency; DAT: Days after transplanting; SD: Standard deviation; there were no statistically significant differences in LAI (p=0.05)

Table 3: Regression coefficients (95% confidence) for the three treatments

Treatment	n	d.f	β	SE	R^2
HIF	116	115	1.653	0.013	0.993
MIF	97	96	1.619	0.014	0.992
LIF	93	82	1.611	0.014	0.994

HIF: High irrigation frequency; MIF: Medium irrigation frequency; LIF: Low irrigation frequency; n: Number of observations; d.f: Degrees of freedom; β,beta coefficient (i.e. slope); S.E: Standard error

Table 4: Means±SD of fresh and dry weight in grams per plant of leaves, stem and fruit

75 DAT	HIF	MIF	LIF
LFW	317.82 (±72.81)^c	486.22 (±59.40)^b	672.57 (±144.55)^a
SFW	233.60 (±30.90)^c	364.45 (±27.32)^b	476.07 (±101.06)^a
FFW	184.80 (±94.25)^{cb}	241.83 (±85.66)^b	516.93 (±143.60)^a
LDW	76.75 (±18.91)^b	94.62 (±19.13)^a	123.84 (±34.13)^a
SDW	22.45 (±2.30)^c	36.37 (±2.90)^b	44.54 (±9.94)^{ab}
FDW	11.48 (±5.93)^{cb}	12.86 (±4.55)^b	25.19 (±5.10)^a

LFW: Leaves fresh weight; SFW: Stem fresh weight; FFW: Fruit fresh weight; LDW: Leaves dry weight; SDW: Stem dry weight; FDW: Fruit dry weight; DAT: Days after transplanting; HIF: High irrigation frequency; MIF: Medium irrigation frequency; LIF: Low irrigation frequency; SD: Standard deviation; in each column, values followed by the same letter (a, b, c) are not significantly different (p=0.05) observed between 40 to 50 DAT, with mean estimated values of 177.71 W m^{-2} (± 63.54) for MIF and 147.46 W m^{-2} (± 78.23) for LIF. Similarly, the mean daily water uptake positively affected by a higher irrigation frequency intervals rate, as the mean estimated values calculated with the water balance method (40-50DAT) were 2.15 Kg m^{-2} (±0.28) HIF, 2.13 Kg m^{-2} (±0.29) MIF and 1.85 Kg m^{-2} (±0.26) LIF.

Statistically, significant interactions between irrigation frequency and the percentage of drainage solution were observed as was expected, resulting from differences in transpiration rates between treatments. The mean daily values, estimating the nutrient solution outflow from the greenhouse to the environment were 40.15% (± 12.56) for HIF, 42.62% (± 13.19) for MIF and 48.85% (± 13.34) for LIF. Additionally the first drain in the morning delayed, as the frequency of irrigation decreased. For the LIF trial, the first drain was recorded approximately two hours later, between 10.00 to10.30 h., compared to the first drain of the HIF treatment (data not show).

In regards to the water use efficiency (WUE), roughly similar values were obtained between treatments. As the total volume of irrigation applied in each treatment for a ten week period was 180 Kg m^{-2}, and the total production values were 11.97 kg m^{-2} (HIF), 11.79 kg m^{-2} (MIF), 12.27 kg m^{-2} (LIF), the water use efficiency values estimated were 66.45 kg m^{-3} for (HIF), 65.45 kg m^{-3} (MIF) and 68.12 kg m^{-3} (LIF).

Plant water status

Plant indicators of relative water loss and growth rate as estimated from stem micro variation measurements, presented a good association within different irrigation treatments. The diurnal variation in the stem was associated

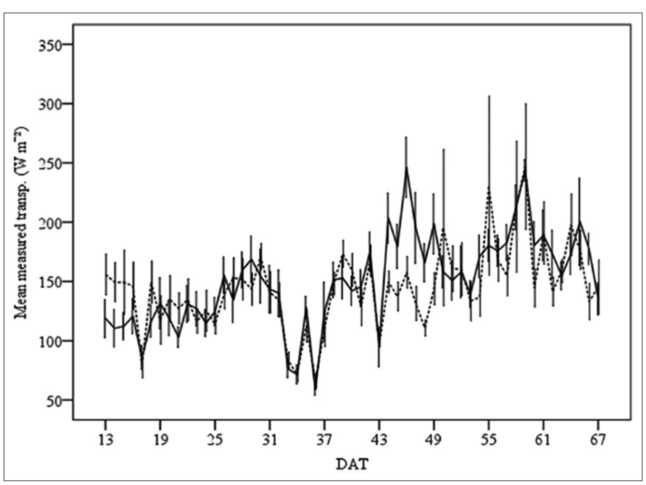

Fig 3. Mean transpiration values (W m^{-2}) of cucumber plants measured by weighing lysimeters for medium irrigation frequency treatment (MIF-continuous line) and low irrigation frequency treatment (LIF-dotted line), error bars (± standard error).

with the diurnal variation in VPD (Fig. 4), agreeing with previous experimental work of several authors (Lee and Shin, 1999; Galardo et. al., 2006; De Swaef and Steppe, 2010). From curves to figures, it can be observed that considerably less explicit trunk depression occurred under the high irrigation frequency treatment. Similarly the daily diameter increment (i.e. general growth rate of a plant) for a four day representative period (DAT 25-28) indicated a significant increase as the irrigation events were divided into shorter intervals, with an estimated stem growth rate of 0.705 mm in (LIF) and 1.154 mm in (MIF).

DISCUSSION

In the experiment, it was determined the effect of three different irrigation frequencies in soilless cucumber growth and production. The prevailing assumption, before the start of the experiment, was that the irrigation frequency affects the crop growth rate, the production and the plant physiological responses. Therefore, proper irrigation scheduling should be implemented for maintaining crop productivity, with minimal nutrient losses to the environment, without plants having to face any water stress conditions. 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).

The data from this study confirms that cucumber evapotranspiration increased, as the daily irrigation frequency increased from 6 events to 12 and 16, resulting in a lower drain, and thus less water and nutrient outflow from the greenhouse into the environment. Differences in transpiration could probably be ascribed to easier water uptake from the substrate, as shortening of the irrigation intervals could lead to a constant availability of water and nutrients, decreasing the matric and osmotic potentials on the rhizoplane (Raviv et al., 2001).

On the other hand, statistical analysis indicated that cucumber growth parameters (i.e. height, number of leaves, LAI) and production, were unaffected by the irrigation frequency, even though plants under a low irrigation frequency scheduling, were higher than those in the medium or high irrigation frequency, with maximum differences in height between treatments recorded by the end of the experimental period. Significantly higher differences in the fresh and dry matter weight were observed in favor of LIF trial, also at 75 DAT. Those differences are most likely attributed to higher air temperatures. Similarly, Rodriguez-Ortega et al. (2016) reported greatest vegetative growth in soilless tomatoes plants in low irrigation

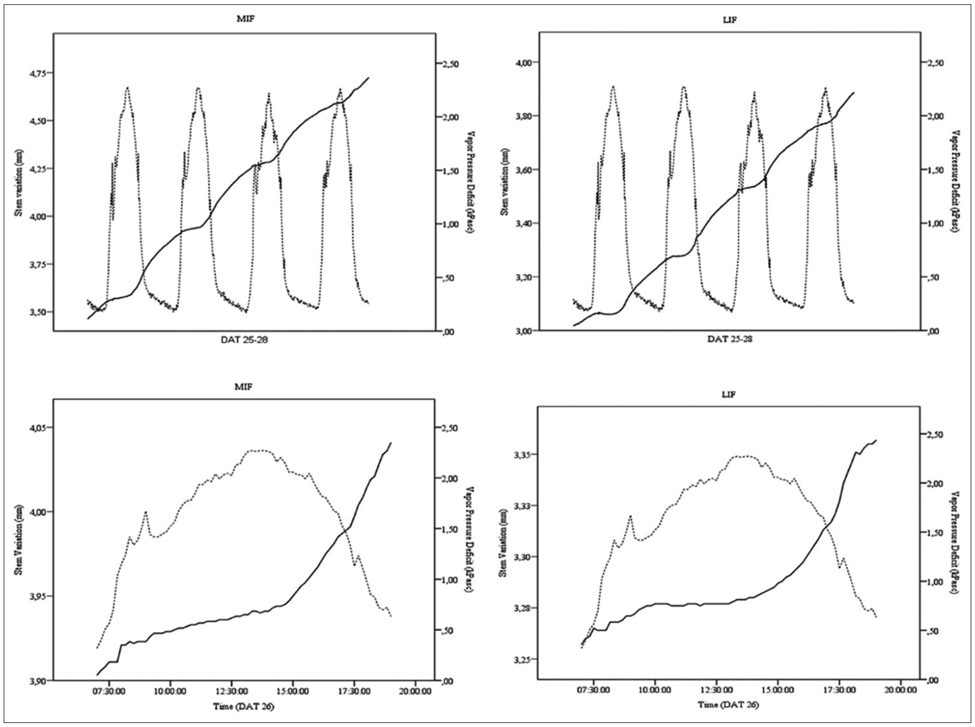

Fig 4. Stem micro variation measurements (mm) (continuous line), and vapor pressure deficit (kPasc) (dotted line), during a four days measurement period (DAT 25-28) for medium irrigation frequency treatment (MIF-upper left side) and for low irrigation frequency treatment (LIF-upper right side) and during a day (DAT 26) for (MIF-bottom left side) and (LIF-bottom right side).

frequency trial at 32 °C, but no differences observed between different irrigation frequencies treatments at 26 °C. From these results it could be concluded that there would be of great value in investigating the effects of different irrigation frequencies in cucumber crop growth and production, as affected by higher ambient air temperatures.

In this study, data from phyto-sensing (i.e. leaf temperature, stem variation), rule out that plants following a low irrigation frequency schedule (0.448 Kg m^{-2}) were facing water stress conditions. During the midday hours, as the irrigation interval time was greater than one hour under the LIF trial (data not shown), there was a time lack and a difficulty of irrigation supply to meet the demand of transpiration rates, resulting in a closure of leaf stomata and an increase of the leaf temperature. At that time the stem contraction amplitude (i.e. relative water loss) as estimated through the use of a stem variation sensor, was higher during the LIF trial, consistent with the notion that the water moves from stem to fruits - resulting in a negative pressure in the xylem.

The timing and volume of irrigation, strongly correlated with leaf and substrate temperature, and was negatively affected as the irrigation frequency decreased. The pre-existing strong correlation, between leaf temperature and the timing of irrigation also reported by Naeeni et al, (2014), concluded that a drop of leaf temperature of soilless cucumber detected 5 minutes even after irrigation. Similarly a well-watered crop is expected to have cooler leaves as it affected by higher values of transpiration observed (Abraham et al., 2000). Regarding high recorded substrate temperatures, past studies have pointed out that it is common in for hydroponic cultures for the temperature of the substrate to exceed 30°C or even 35°C, negatively affecting the growth of the crop (Du et al., 1994; Klock, 1995).

From these results, it could be drawn that unnecessary water loss and plant stress could be reduced by applying an adequate irrigation strategy (Juarez-Maldonado et al., 2014; Shun and Son, 2015). However, the results observed in this study could not be simply generalized for other crops. Further research is still needed under different prevailing greenhouse environmental conditions, with emphasis on to the temperatures of the greenhouse, continuing the measurements for a longer period of time, in order to clearly discriminate and strongly support the above mentioned results.

CONCLUSION

In the study, three different irrigation frequencies were tested in order to evaluate the effect of cucumber water consumption, crop fresh and dry weight, leaf area and production. The findings support that the irrigation frequency may not affect cucumber growth rate or production, but it significantly affects the rate of transpiration and the amount of water and nutrients that outflow from the greenhouse into the environment. Therefore, the irrigation scheduling of soilless cucumber, should be based on higher irrigation intervals rates (HIF treatment; 0.192 Kg m^{-2}), as it proved to minimized the drainage amount by 24%, in comparison to lower irrigation intervals rates (LIF treatment; 0.448 Kg m^{-2}). Lastly low irrigation frequency scheduling, is best avoided, as plants faced water stress conditions, as estimated from leaf temperature and stem variation measurements. In conclusion, this study demonstrates that the amount and the timing of irrigation, can even show to be significant predictors for leaf and substrate temperatures, therefore sensing technology should be implemented as a tool for irrigation monitoring. The findings of the study highlight a promising irrigation strategy for cucumber soilless culture, with the aim of ensuring a more efficient water management strategy, especially in environmentally sensitive zones.

Author's contributions

The work has been completed under the supervision of C.K, N.K, D.N.; C.K and N.K designed the research plan, organized the study. G.N.: performed research, performed statistical analysis and data interpretation and in assistance with D.N wrote the manuscript which was read and approved by all authors.

REFERENCES

Abraham, N., P. S. Hema, E. K. Sarithaand, and S. Subramannian. 2000. Irrigation automation based on soil electrical conductivity and leaf temperature. Agric. Water Manage. 45: 145-157.

Adejumobi, M. A., S. K. Aremu, D. O. Idowu and O. I. Ojo. 2015. Effects of irrigation frequency and manure on growth parameters, crop coefficient and yield of Okro (*Abelmoscus esculeutus*). Environ. Eart. Sci. 5: 18.

De Swaef, T. and K. Steppe. 2010. Linking stem diameter variations to sap flow, turgor and water potential in tomato. Funct. Plant Biol. 37: 429-438.

Du, Y. C. and S. Tachibana. 1994. Effect of supraoptimal root temperature on the growth, root respiration and sugar content of cucumber plants. Sci. Hort. 58: 289-301.

Eiasu, B. K., J. M. Steyn and P. Soundy. 2012. Physiomorphological response of rose-scented geranium (*Pelargonium* spp) to irrigation frequency. S. Afr. J. Bot. 78: 96-103.

Elshibli, S., E. M. Elshibli and H. Korpelainen. 2016. Growth and photosynthetic CO2 responses of date palm plants to water availability. Emir. J. Food Agric. 28(1): 58-65.

Fernández, M. D., S. Bonachela, F. Orgaz, R. Thompson, J. C. López, M. R. Granados, M. Gallardo and E. Fereres. 2010. Measurement and estimation of plastic greenhouse reference evapotranspiration in a Mediterranean climate. Irri. Sci. 28: 297-509.

Ferreira, D., J. A. De Almeida, M. Simões and M. Pérez-Martín. 2016. Agricultural practices and geostatistical evaluation of nitrate pollution of groundwater in the Júcar river Basin district, Spain. Emir. J. Food Agric. 28(6): 415-424.

Gallardo, M., R. B. Thompson, L. C. Valdez and M. D. Fernández. 2006. Use of stem diameter variations to detect plant water stress in tomato. Irri. Sci. 24: 241-255.

Grewal, H. S., B. Maheshwari and S. E. Parks. 2011. Water and nutrient use efficiency of a low-cost hydroponic greenhouse for a cucumber crop: An Australian case study. Agri. Water Manage. 98: 841-846.

Helmer, T., Ehret, D. L. and S. Bittman. 2005. Crop assist, an automated system for direct measurement of greenhouse tomato growth and water use. Comput. Electron. Agric. 48: 198-215.

Juárez-Maldonado, A., A. Benavides-Mendoza, K. De-Alba-Romenus and A. B. Morales-Diaz. 2014. Estimation of the water requirements of greenhouse tomato crop using multiple regression models. Emir. J. Food Agric. 26(10): 885-897.

Kalaydjieva, R., A. Matev and Z. Zlatev. 2015. Influence of irrigation regime on the leaf area and leaf area index of French bean (*Phaseolus vulgaris* L.). Emir. J. Food Agric. 27(2): 171-177.

Katsoulas, N., C. Kittas, G. Dimokas and C. Lykas. 2006. Effect of irrigation frequency on rose flower production and quality. Biosyst. Eng. 93(2): 237-244.

Klock, K. A. 1995. Root-zone Temperature Effects on the Nutrient Uptake of Horticultural Crops. Ph.D. Dissertation. Iowa State University, Iowa. pp. 4.

Lee, B. W. and J. H. Shin. 1998. Optimal irrigation management system of greenhouse tomato based on stem diameter and transpiration monitoring. Agric. Inf. Tech. Asia Oceania. 23: 87-90.

Mekonnen, S. A. 2012. Irrigation frequency and plant density affect phenology and crop growth of haricot bean (*Phaseolus vulgaris* L.). Afr. J. Plant Sci. 6: 34-39.

Meric, M. K., I. H. Tuzel, Y. Tuzel and G. B. Oztekin. 2011. Effects of nutrition systems and irrigation programs on tomato in soilless culture. Agric. Water Manage. 99: 19-25.

Morille, B., C. Migeon and P. E. Bournet. 2013. Is the penman-monteith model adapted to predict crop transpiration under greenhouse conditions? Application to a new guinea impatiens crop. Sci. Hort. 152: 80-91.

Naeeni, A.B., E. M. Esfahani, M. B. Harchegani, M. Jafarpour and M. Golabadi. 2014. Leaf temperature as an index to determine the irrigation interval. Res. Crop. Ecophysiol. 9/1(2): 89-95.

Pires, R. C. M., P. R. Furlani, R. V. Ribeiro, D. B. Junior, E. Sakai, A. L. Lourenção and A. T. Neto. 2011. Irrigation frequency and substrate volume effects in the growth and yield of tomato plants under greenhouse conditions. Sci. Agric. (Piracicaba, Braz.) 68(4): 400-405.

Raviv, M. and T. J. Blom. 2001. The effect of water availability and quality on photosynthesis and productivity of soilless-grown cut roses. Sci. Hort. 88: 257-276.

Rodriguez-Ortega, W. M., V. Martinez, R. M. Rivero, J. M. Camara-Zapata, T. Mestre and F. Garcia-Sanchez. 2016. Use of a smart irrigation system to study the effects of irrigation management on the agronomic and physiological responses of tomato plants grown under different temperatures regimes. Agric. Water Manage. 183: 158-168.

Savvas D., G. P. Gianquinto, Y. Tüzel and N. Gruda. 2013. "Soilless culture", In: Good Agricultural Practices for Greenhouse Vegetable Crops. Principles for Mediterranean Climate Areas. Food and Agriculture Organization of the United Nations (FAO), (Rome: FAO, Plant Production and Protection Paper 217), Rome, pp. 303-354.

Savvas, D. 2002. General introduction. In: D. Savvas and H. Passam, (Eds.), Hydroponic Production of Vegetables and Ornamentals. Embryo Publishing, Athens, Greece, pp. 15-26.

Savvas, D., E. Stamati, I. L. Tsirogiannis, N. Mantzos and P. E. Barouchas. 2007. Interactions between salinity and irrigation frequency in greenhouse pepper grown in closed-cycle hydroponic systems. Agric. Water Manage. 91: 102-111.

Schröder, F. G. and J. H. Lieth. 2002. Irrigation control in hydroponics. In: D. Savvas and H. Passam, (Eds.), Hydroponic Production of Vegetables and Ornamentals. Embryo Publishing, Athens, Greece, pp. 265-296.

Seelig, H. D., A. Hoehn, L. S. Stodieck, D. M. Klaus, W. W. Adams and W. J. Emery. 2009. Plant water parameters and the remote sensing R 1300/R 1450 leaf water index: Controlled condition dynamics during the development of water deficit stress. Irri. Sci. 27: 357-365.

Shin, J. H. and J. E. Son. 2015. Development of a real-time irrigation control system considering transpiration, substrate electrical conductivity, and drainage rate of nutrient solutions in soilless culture of paprika (*Capsicum annuum* L.). Eur. J. Hortic. Sci. 80(6): 271-279.

Silber, A., G. Xu, I. Levkovitch, S. Soriano, A. Bilu and R. Wallach. 2003. High irrigation frequency: The effect on plant growth and on uptake of water and nutrients. Plant Soil. 253: 466-477.

Slamic, B. and T. Jug. 2016. Lettuce growth in extreme conditions. Emir. J. Food Agric. 28(6): 398-401.

Steppe, K., D. J. W. Pauw and R. Lemeur. 2008. A step towards new irrigation scheduling strategies using plant- based measurements and mathematical modeling. Irri. Sci. 26: 505-517.

Tsirogiannis, I., N. Katsoulas, and C. Kittas. 2010. Effect of irrigation scheduling on gerbera flower yield and quality. Hort. Sci. 45(2): 265-270.

Varma, V. and M. A. Osuri. 2013. Black spot: A platform for automated and rapid estimation of leaf area from scanned images. Plant Ecol. 214(12): 1529-1534.