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ORIGINAL PAPER

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BIOMETRICAL AND BIOCHEMICAL PROPERTIES OF FRUITS OF MINI CUCUMBER PLANTS GROWN UNDER VARIOUS IRRIGATION REGIMES IN AN UNHEATED GREENHOUSE

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ABSTRACT

The study aimed to determine the most appropriate irrigation scheduling for mini-type cucumber plants grown as a spring-summer cycle crop. The research was conducted in a greenhouse structure in the fields of the Research Institute in Kirklareli. Marathon cucumber plants were used as the plant material in the trials. The split plot design experimental layout in 3 replications was used in the research. Four different plant–pan coefficients (0.75, 1.00, 1.25 and 1.50) and two irrigation intervals (2 and 4 days) were applied as subplots and main plots of the study, respectively. As a result of the 3-year investigation, it was determined that yields, number of cucumber fruits, and fresh cucumber fruit weight, length and diameter increased with the increase in the irrigation water amount. The highest average total soluble solids (Brix) value of 5.0 was recorded under conditions of most severe stress imposed on the plots with lowest water application rates of Kcp 0.75. While the lowest values of 4.0–4.1 were obtained for plants growing under more favorable moisture conditions in plots with application of Kcp 1.25 and 1.50. Statistically significant positive linear relationships were obtained for irrigation water amount on one hand, and fruit number, fruit mean weight, fruit length and diameter on the other, while the relationship between water applied and TSS (Brix) was negative.

Key words: cucumber, solar greenhouse, water amounts, fruit traits, quality

INTRODUCTION

Cucumber is one of the most produced, traded and consumed vegetable crops in Turkey, as well as in the entire Mediterranean region. Most of the yearly production in the country is obtained from farming activities in protected facilities such as heated glass or unheated solar greenhouses.

The type of structure primarily used in the study country is the so-called Mediterranean greenhouse; low-cost, unheated plastic-covered structures used with soil-grown crops [Ayas and Demirtas 2009]. According to Yuan et al. [2001] solar greenhouses rely on sunlight as the primary energy source and have a simple structure, which makes them inexpensive to build and cheap to maintain.

Cucumbers require plenty of water, especially during the flowering and fruit-bearing periods, and

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shortage of water at the root depth of the plant during mentioned periods may lead to flower and fruit dropping [Kaya et al. 2005]. On the other hand, irrigation is an important limiting factor for crop yield, because it is associated with many factors, which influence growth and development of the plant. Yaghi et al. [2013] stated that the availability of adequate amounts of moisture at critical stages of plant growth optimizes the metabolic process in plant cells and increases the effectiveness of the mineral nutrients applied to the crop.

Water application scheduling and irrigation programming are very effective and strong tools for increasing the yields and improving the quality of agricultural crops grown either in open fields or protected agriculture. The matter of effective water use is much more pronounced under greenhouse conditions than under conditions of open fields, since the roof of the structure prevents water vapor inside the solar greenhouse exchanging with the air system outside [Aubinet et al. 1989]. Fernández et al. [2007] reported that total volumes of irrigation water applied per crop were considerably lower than for the same species grown in open fields due to a lower evaporative demand inside the greenhouse structure. Nevertheless, in protected environments, irrigation is considered an essential technique; bad management of this technique may hamper production [Oliveira et al. 2011].

The influence of different elements of irrigation application on yield and quality parameters of various vegetable crops was studied by different researchers around the world. Some of them [Noguera et al. 1988, Granges et al. 2000] evaluated dry matter contents, while the others discussed the sugar [Massantini 1962] and acidity content [Thybo et al. 2005] or carotenoids and acidity characteristics of various vegetables grown in greenhouses [Noguera et al. 1988, Granges et al. 2000, Parks et al 2004]. Cimpreanu et al. [2013] evaluated the biochemical characteristics of dry matter, soluble carbohydrates, acidity and vitamin C contents of cucumber fruit under various irrigation and fertigation conditions. Several investigations have been carried out on the effect of irrigation frequency and/or irrigation water amount on yield, fruit number per plant, fruit length, diameter, and weight of greenhouse grown cucumbers recently [Hakkim and Ghand 2014, Abu-Zinada 2015, Arshad 2017]. Wang et al. [2017] determined that with respect to fruit quality, soluble sugar, soluble solids and free proline were generally increased by saline water irrigation.

Experiments carried out with Silyon hybrid cucumber plants grown in unheated plastic greenhouses in India showed that irrigation and boron levels influenced the total dry matter and ascorbic acid content, as well as total soluble solids (Brix) and the average firmness values of fruit, which varies in the range of 2.26–3.71 kg cm^{-1} [Bommesh et al. 2017].

In another investigation carried out under greenhouse conditions in Saudi Arabia, Alsadon et al. [2006] evaluated the effect of irrigation water quality on fruit dry matter, fruit length and diameter, fruit weight and firmness of three cucumber cultivars and determined that mentioned quality characteristics, as well as some vegetative traits, are influenced by the salinity levels of irrigation water applied.

The aim of this investigation was to evaluate the effects of irrigation frequency and irrigation water amounts on biometrical and biochemical properties of mini cucumber plants grown as a spring-summer culture in unheated conditions within plastic greenhouse environment.

MATERIAL AND METHODS

The field experiments were conducted during a 3-year period in an unheated greenhouse facility constructed on the fields of the Ataturk Soil Water and Agricultural Meteorology Research Institute in Kirklareli Turkey. Irrigation water analysis performed in laboratories at the Research Institute showed that irrigation water applied to experimental plants is in S_2 salinity and A_1 alkalinity class, containing relatively high levels of calcium and magnesium (3.35 me/l) and high concentration of bicarbonate (3.09 me/l). On the other hand, the soils of the research site were determined to be poor in organic matter and phosphorus but rich in potassium. More details related to soil and water sampling and analyzing procedures applied in the study were described in our previously published study [Çakir et al. 2017].

The naturally ventilated solar greenhouse with 2.5 m height and total area of 608 m^2 was oriented in north-south direction and covered with polythene film to prevent the excessive increase of temperature in the structure.

The Maraton F1 mini cucumber cultivar, characterized by seedless short fruit with thin dark-green skin and high quality of the fruits was used as material of the study. Cucumber plant seedlings were produced in nursery plots nearby the experimental greenhouse, sowing one seed in each small pot filled with peat. When the cucumber plants in the nursery reached 3–4 leaf stage, they were transplanted in the experimental plots with 0.8 m × 0.4 m space between the rows and between plants, respectively. In order to provide surviving of seedlings, all treatments and sub treatments were irrigated with equal amounts of 10 mm irrigation water at planting.

The split plot design experimental layout in 3 replications was used in the study. Four different plant–pan coefficients (0.75, 1.00, 1.25 and 1.50) and two irrigation intervals (2 and 4 days) were applied as subplots and main plots of the study, respectively. The layout of the experimental study with main plots and subplots is presented on Fig. 1.

The experimental treatments applied in the study were designed as follow:

D_1I_1 – irrigation at 2-day intervals with water amount calculated using Kcp 0.75,

D_1I_2 – irrigation at 2-day intervals with water amount calculated using Kcp 1.00,

D_1I_3 – irrigation at 2-day intervals with water amount calculated using Kcp 1.25,

D_1I_4 – irrigation at 2-day intervals with water amount calculated using Kcp 1.50,

D_2I_1 – irrigation at 4-day intervals with water amount calculated using Kcp 0.75,

D_2I_2 – irrigation at 4-day intervals with water amount calculated using Kcp 1.00,

D_2I_3 – irrigation at 4-day intervals with water amount calculated using Kcp 1.25,

D_2I_4 – irrigation at 4-day intervals with water amount calculated using Kcp 1.50.

In order to ensure rooting and establishment of plants in the experimental plots, all the treatments and sub treatments were irrigated with equal amounts of 10 mm irrigation water at planting and during the first 7–8 days after the establishment of each experimental year. Following the establishment period, all the plots and sub plots of the experiment were irrigated according to requirements of the experimental treatments.

Evaporation within the structure was measured using a stainless steel circular pan of 121 cm diameter and 25.5 cm in height (Class – A pan), located in the central part of the greenhouse.

Irrigation water amounts to be applied to different treatments and sub treatments of the experiment were determined using the procedure of Doorenbos and Pruitt [1977] given below as:

$$Ir = Ep \times Kcp$$

where, Ir is irrigation water amount (mm), Ep is evaporation from a standard pan (mm), and Kcp is crop pan coefficients.

Irrigation water was applied using drip irrigation system consisting of laterals, laid at a distance of 0.8 m parallel to each plant row and equipped with in-line emitters of 2 L h^{-1} discharge.

In addition to farmyard manure estimated on the bases of 25 t ha^{-1} and applied each experimental year prior to soil tillage, mineral fertilizers determined on the base of soil analysis results were used at weekly or 10-day intervals, *via* the fertigation system. The fertigation applications were terminated approximately two weeks before the last harvest.

In order to avoid variations in the amount of applied fertilizers due to different irrigation intervals and/or evapotranspiration coefficients used in the study, the fertigation was preferably applied when all the experimental treatments and sub treatments were irrigated. In order to assure equal fertilizer application to all irrigation programs, the fertilizer application was scheduled on the base of the sub treatment with least applied water amounts and the shortest irrigation duration. The procedure consisted of irrigation during the first ¼ of the application, followed by fertigation (water + fertilizer) during ½ of the irrigation application and again irrigation during the last ¼ of the application time. The fertigation solution was prepared using relatively easily soluble forms of fertilizers such as ammonium nitrate and NPK containing composite fertilizers known as 6–18–24 and 18–6–24. The composition of the fertilizing solution prepared on the basis of recommendations by [Papadopoulos 1998] and used during the years of the study is given in Tab. 1.

Plots of the trial were harvested when cucumber fruits reached 10–13 cm length accepted as normal size for the cultivar. The harvesting was repeated at 2 or 3-day intervals (3 harvests per week) and fruits obtained from the harvested 5.12 m^2 area of the total 11.52 m^2 of each experimental plot were weighed and the number of fruit per plant and per m^2 was determined. Fruit length (cm), fruit diameter (cm), fruit weight (g) and fruit firmness values (lb cm^{-1}), as well as analysis for total soluble solids (Brix) and pH, were determined in samples taken from one of the harvests in each week.

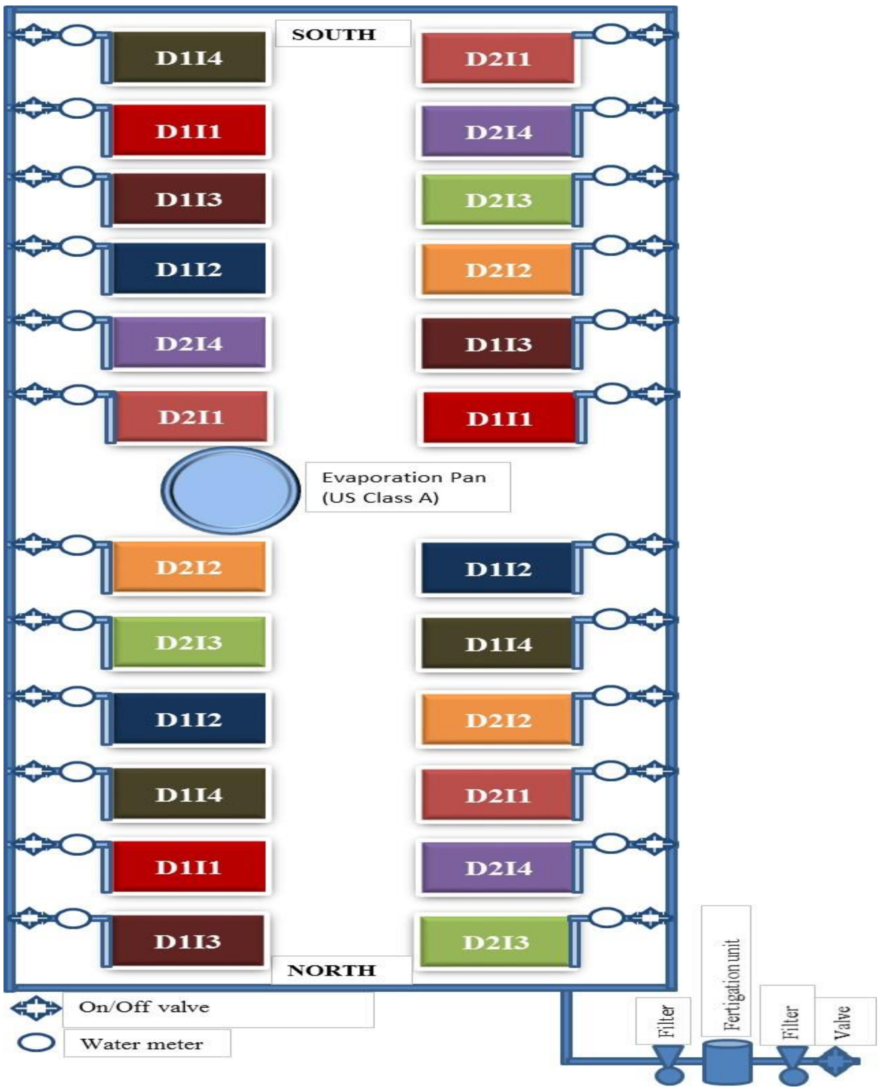

Fig. 1. Layout of the experimental plots in the greenhouse (not scaled)

Table 1. Fertilization program applied to experimental plots of the study (ppm)

Application date	2009			Application date	2010			Application date	2011		
	N	P	K		N	P	K		N	P	K
13.05.09	100	5.6	22	26.04.10	100	24	64	07.05.11	100	30	71
18.05.09	100	5.6	22	06.05.10	100	24	64	12.05.11	100	30	71
28.05.09	100	5.6	22	16.05.10	100	24	64	22.05.11	100	30	71
02.06.09	100	5.6	22	21.05.10	100	24	64	27.05.11	100	30	71
12.06.09	100	5,6	22	26.05.10	100	24	64	01.06.11	100	30	71
17.06.09	90	30	120	31.05.10	100	24	64	06.06.11	100	30	71
22.06.09	90	30	120	10.06.10	100	24	64	16.06.11	100	30	71
02.07.09	90	30	120	15.06.10	100	24	64	26.06.11	100	30	71
07.07.09	90	30	120	25.06.10	100	24	64	01.07.11	100	30	71

(Experimental year spans 2009, 2010, 2011.)

All the data obtained from the investigation were subjected to statistical analysis using SAS statistical software (SAS Systems for Windows 2002), and the Duncan mean separation test was applied. Experimental results obtained from the years of the study were subjected to ANOVA test and year × treatment interactions were also evaluated.

RESULTS

Effects of irrigation frequency and irrigation water amounts on yield and yield components. The average cucumber yields obtained from the experimental plots during the 3-year study are plotted on Fig. 2. Data on the figure show that the yields obtained from the experimental treatments were significantly ($p < 0.01$) affected by the irrigation scheduling and in general, the cucumber fruit yields increased with the increase of plant-pan coefficient or irrigation water amount applied. As it is evident from the mentioned figure, the highest average yields in the range of 12.8 and 12.7 kg m^{-2} were obtained from D_1I_4 and D_2I_4 treatments, both of which include the highest Kcp coefficient of 1.50 and irrigation frequency of 2 or 4 days, respectively. More detailed results related to cucumber yields obtained during the years of the study were presented in our paper discussing the matters of effective water use and crop response factor (k_y) published earlier [Çakir et al. 2017].

Similar to cucumber yield per ha, the studied parameters of fruit number per m^{-2} and per plant (Tab. 2), average fruit weight (g), fruit length and diameter (cm) were also closely dependent on irrigation frequency as well as on water application rate (Tab. 3). Data included in Tab. 2 show that average fruit number per unit area and per plant were closely ($p < 0.01$ or $p < 0.05$) affected by irrigation water amounts during the years of the experiment, though the effect of the irrigation intervals was not statistically proven. The average fruit number obtained per m^2 and per plant were determined to increase with the increase in the applied plant-pan coefficient and varied from 112 to 163 and from 28 to 41 fruit per m^2 and per plant, respectively. As it was expected, the lowest fruit numbers were provided from plots with the lowest plant–pan coefficient applied Kcp of 0.75, while the highest values were obtained from the treatments with highest applied Kcp of 1.50. The significant effects of irrigation scheduling and irrigation water amounts were established also in terms of the fruit biometrical parameters as fruit weight, fruit length and fruit diameter. As it can be concluded from data in Tab. 3, mean values of the mentioned parameters increased with increasing water amounts applied to plants at 2 or 4 day irrigation intervals. The highest overall average fruit weight values were determined to increase with the increase in Kcp in the ranges of 76.0 to 85.6 g and 75.1– 86.9 g, respectively for 2 and 4-day irrigation intervals. Similar influences were recorded for overall fruit length and fruit diameter, increasing from 11.7 to 12.9 cm and from 11.7 to 13.1 cm (fruit length), and from 3.03 to 3.22 cm and 3.11 to 3.25 cm (diameter), respectively under irrigation at 2 and 4 day intervals.

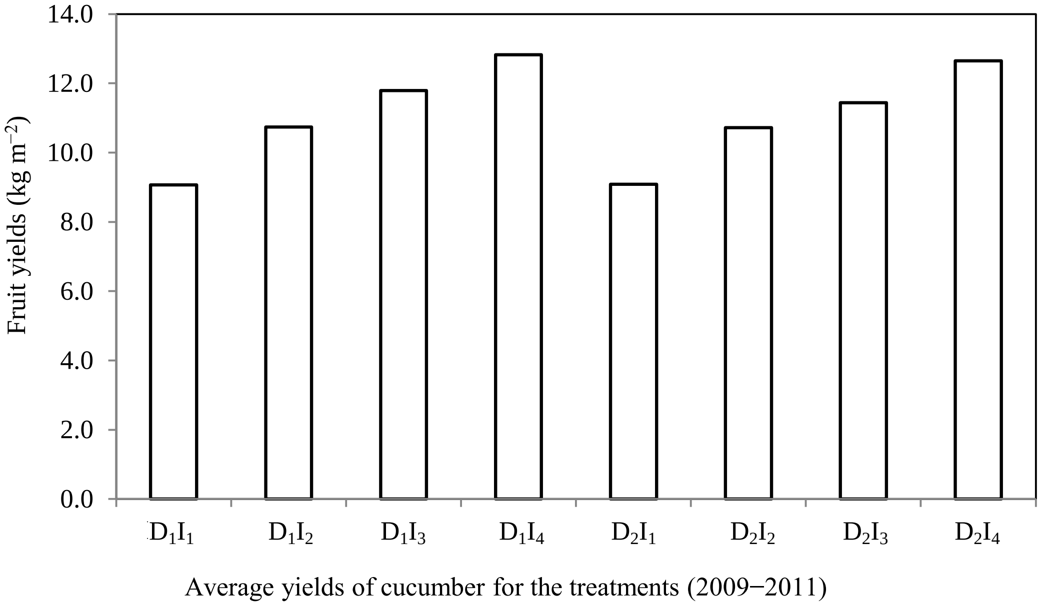

Fig. 2. Effect of irrigation intervals and Kcp coefficient on greenhouse grown yields ($P < 0.01$)

Table 2. Effect of irrigation applications on cucumber fruit number per m^2 and per plant

Studied parameters Experimental years Treatments	Fruit number per m^2			Fruit number per plant		
	2010	2011	avg.	2010	2011	avg.
D_1I_1	117^d	107^d	112^d	29^d	27^d	28^d
D_1I_2	135^c	133^c	134^c	34^d	33^c	34^c
D_1I_3	158^b	143^b	151^b	39^b	36^b	38^b
D_1I_4	169^a	156^a	163^a	42^a	39^a	41^a
D_2I_1	121^d	111^d	116^c	30^d	28^d	29^d
D_2I_2	151^b	132^c	142^b	38^b	33^c	35^c
D_2I_3	152^b	140^b	146^b	38^b	35^b	37^b
D_2I_4	167^a	158^a	163^a	42^a	40^a	41^a
Statistical evidence, p						
Irrigation intervals	ns	ns	ns	ns	ns	ns
Irrigation coefficients	0.01	0.01	0.05	0.01	0.01	0.05

Table 3. Influence of water scheduling on biometrical characteristics of fresh cucumber fruit

Studied parameters	Average fruit weight (g)				Average fruit length (cm)				Average fruit diameter (cm)			
Experimental years / Treatments	2009	2010	2011	avg.	2009	2010	2011	avg.	2009	2010	2011	avg.
D_1I_1	85.0^{b}	62.0^{g}	81.1^{d}	76.0^{b}	11.4^{c}	11.6^{e}	12.1^{e}	11.7^{c}	3.27^{f}	2.78^{e}	3.03^{c}	3.03^{b}
D_1I_2	101.1^{a}	68.5^{e}	87.3^{c}	85.6^{a}	12.9^{b}	12.2^{d}	12.2^{d}	12.4^{b}	3.58^{bc}	2.86^{d}	3.09^{b}	3.17^{a}
D_1I_3	98.2^{a}	70.6^{d}	87.9^{b}	85.6^{a}	13.3^{a}	12.8^{c}	12.6^{b}	12.9^{ab}	3.55^{d}	2.92^{c}	3.15^{a}	3.21^{a}
D_1I_4	93.8^{a}	70.8^{d}	88.3^{a}	84.3^{a}	13.4^{a}	13.0^{b}	12.4^{b}	12.9^{a}	3.51^{e}	2.98^{b}	3.13^{a}	3.22^{a}
D_2I_1	85.8^{b}	66.6^{f}	72.8^{g}	75.1^{b}	11.4^{c}	12.1^{d}	11.5^{f}	11.7^{c}	3.54^{d}	2.86^{d}	2.93^{d}	3.11^{b}
D_2I_2	94.8^{a}	71.7^{c}	78.5^{f}	81.7^{a}	12.6^{b}	12.7^{c}	12.2^{d}	12.5^{b}	3.63^{a}	2.93^{c}	3.13^{a}	3.23^{a}
D_2I_3	98.1^{a}	74.2^{b}	79.4^{e}	83.9^{a}	13.1^{a}	13.1^{b}	12.3^{c}	12.8^{ab}	3.57^{c}	2.93^{c}	3.15^{a}	3.22^{a}
D_2I_4	102.1^{a}	77.3^{a}	81.2^{d}	86.9^{a}	13.7^{a}	13.4^{a}	12.4^{b}	13.1^{a}	3.60^{b}	3.03^{a}	3.13^{a}	3.25^{a}
Statistical evidence, p												
Irr. intervals	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Irr. coefficients	0.05	0.01	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table 4. Some quality properties of cucumber fruits as affected of irrigation frequency and water amounts

Studied parameters	Fruit penetration (lb cm^{-1})				TSS (Brix)				Fruit pH			
Experimental years / Treatments	2009	2010	2011	avg.	2009	2010	2011	avg.	2009	2010	2011	avg.
D_1I_1	10.7^{bc}	11.5^{d}	9.8^{d}	10.7	4.2^{a}	5.7^{a}	5.0	5.0	5.7^{a}	5.6	5.5^{b}	5.6
D_1I_2	10.6^{c}	11.9^{c}	10.0^{c}	10.8	4.1^{a}	5.1^{b}	5.0	4.7	5.7^{a}	5.5	5.4^{c}	5.5
D_1I_3	10.8^{bc}	12.3^{b}	10.0^{c}	11.0	3.8^{a}	4.7^{d}	4.0	4.2	5.7^{a}	5.5	5.6^{a}	5.6
D_1I_4	11.5^{ab}	12.8^{a}	10.5^{b}	11.6	4.1^{a}	4.3^{e}	4.0	4.1	5.6^{b}	5.5	5.5^{b}	5.5
D_2I_1	11.5^{ab}	11.2^{e}	9.5^{e}	10.7	3.9^{b}	5.1^{b}	5.0	4.7	5.6^{a}	5.5	5.5^{b}	5.5
D_2I_2	11.9^{a}	11.5^{d}	10.0^{c}	11.1	3.8^{b}	4.8^{cd}	5.0	4.5	5.6^{a}	5.5	5.5^{b}	5.5
D_2I_3	11.6^{ab}	11.9^{c}	10.5^{b}	11.3	3.4^{b}	4.7^{d}	4.0	4.0	5.6^{a}	5.5	5.6^{a}	5.6
D_2I_4	10.7^{bc}	12.3^{b}	10.8^{a}	11.3	3.5^{b}	4.9^{c}	4.0	4.1	5.6^{b}	5.5	5.6^{a}	5.6
Statistical evidence, p												
Irr. intervals	ns	0.01	0.01	ns	0.05	0.05	ns	ns	0.05	ns	0.01	ns
Irr. coefficients	0.05	0.01	0.01	ns	ns	0.01	ns	0.05	ns	ns	0.01	ns

Table 5. Seasonal evaporation, total irrigation water amount and seasonal water consumptive use during the years of the study

Hydraulic parameters	Evaporation amount (mm)				Irrigation water use (mm)				Water consumptive use (mm)			
Experimental years Treatments	2009	2010	2011	avg.	2009	2010	2011	avg.	2009	2010	2011	avg.
D_1I_1	189	187	200	192	152.3	166.5	168.0	162.3	205.8	199.3	251.2	219.0
D_1I_2	189	187	200	192	191.0	213.2	218.0	207.4	246.6	249.6	293.4	263.0
D_1I_3	189	187	200	192	230.0	260.0	268.0	252.7	287.8	285.8	335.4	303.0
D_1I_4	189	187	200	192	268.5	306.7	318.0	297.8	320.3	326.8	404.8	350.0
D_2I_1	189	185	200	192	152.3	165.0	168.0	161.8	205.7	195.8	252.7	218.0
D_2I_2	189	185	200	192	191.0	211.2	218.0	206.7	247.5	243.5	300.8	264.0
D_2I_3	189	185	200	192	230.0	257.5	268.0	212.8	275.6	280.1	342.0	299.0
D_2I_4	189	185	200	192	268.5	303.7	318.0	296.7	306.1	330.6	405.7	347.0

Irrigation frequency and irrigation water amounts applied to the experimental plots also influenced fruit firmness (penetration), fruit total soluble solids (Brix) and pH values during the experimental years (Tab. 4). As a general rule, fruit penetration (firmness) values increased with increase in the irrigation water amount under conditions of higher applied Kcp values of 1.25 and 1.50. While the lowest average fruit penetration values of 10.7 and 10.8 lb cm^{-1}, equivalent to 4.85 and 4.90 kg cm^{-1}, were measured for fruits of the plants grown under Kcp applications of 0.75 and 1.0; the highest fruit firmness values of 11.0 and 11.6 lb cm^{-1} or 4.99 and 5.26 kg cm^{-1} were identified for sub treatments (I_3 and I_4) with highest water amounts applied at 2-day intervals. Similar mean penetration values were recorded for the applications made at 4 day irrigation intervals**.**

Both irrigation interval and water amount, or water stress, significantly ($p < 0.05$ and $p < 0.01$) affected the fruit TSS (Brix) in the second experimental year, while only irrigation interval was identified to have significant effect ($p < 0.05$) during the first (2009) year of the experiment. However, no statistically proven effects of both irrigation scheduling factors were available during the third year. The evaluations of overall average values for TSS (Brix) showed that only the effect of irrigation water amount had statistically significant effect at $p < 0.05$ level and the highest TSS (Brix) values were measured in the conditions of most severe water stress imposed in the plots with the lowest water application rates of Kcp 0.75. TSS values decreased to 4.0–4.1 (Brix) for the plants grown under more favorable moisture conditions in plots with Kcp applications of 1.25 and 1.50 at 2 or 4-day intervals.

On the other hand, data for pH included in the table indicate that the effect of irrigation time and irrigation water quantity on pH was much less and uncertain with very limited fluctuations in the range of 5.5–5.7 between treatments compared to the other evaluated parameters.

Irrigation water amounts and water use of the experimental treatments. The hydrologic parameters of yearly and average evaporation values, irrigation water amounts and seasonal water consumption use are summarized in Tab. 5. The highest evaporation amounts and irrigation water totals were determined in 2011 with the longest growing season of 95 days, while lower amounts were determined for 2009, the year with the shortest growing period of 80 days. In general, the amount of seasonal water used for the purposes of irrigation increased with the increase in plant-pan coefficient (Kcp) and reached maximum values of 268.5, 306.7 and 318.0 mm

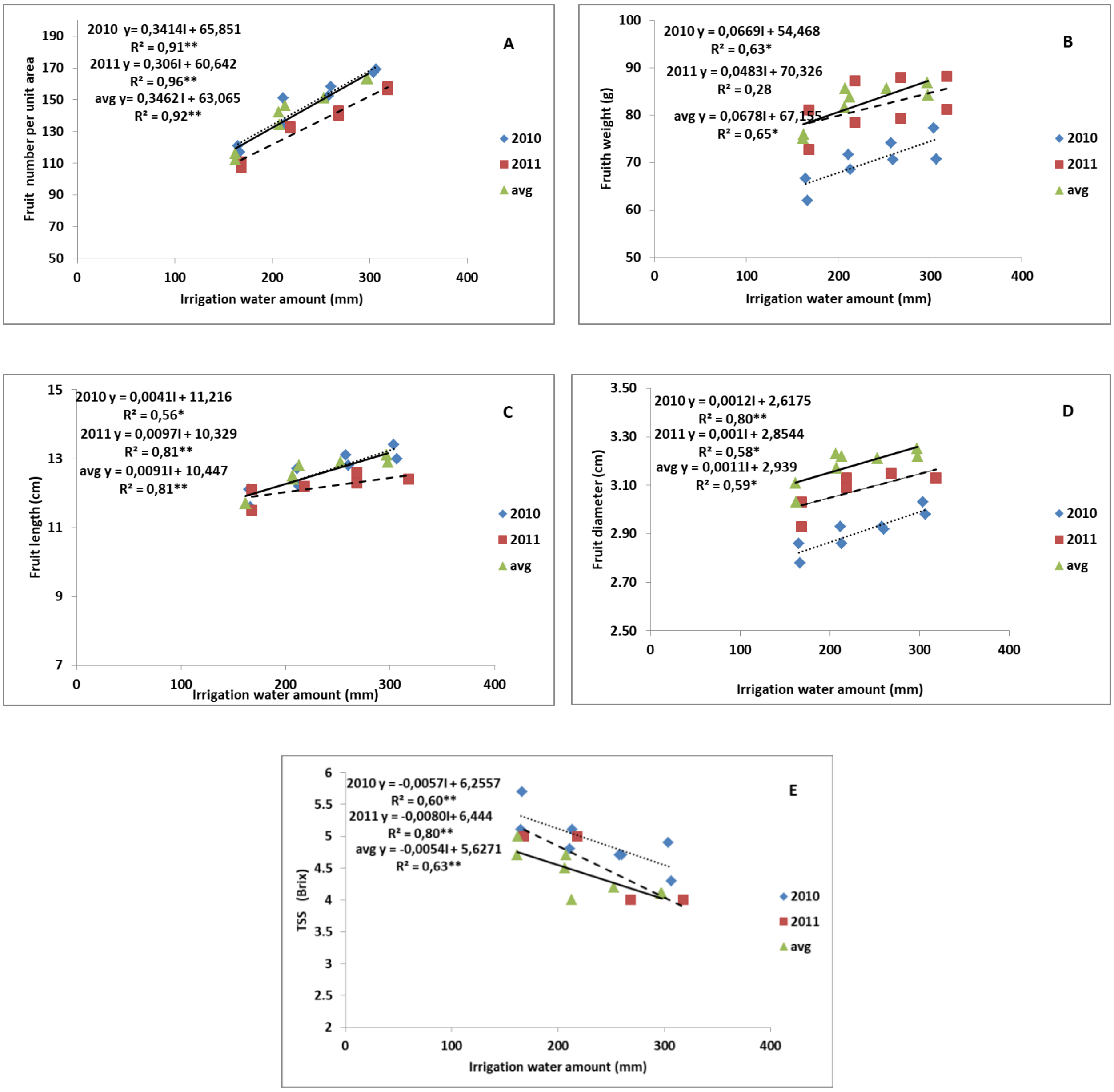

Fig. 3. Relationships between seasonal irrigation water and some biometrical and/or biochemical traits of cucumber fruit. A. Total irrigation water amount − fruit number per m^2 relationship. B. Relationship between irrigation water amount (mm) and fruit weight (g). C. Seasonal irrigation water amount-fruit mean length (cm) relationships for the years of the study and overall averages. D. Relation between total irrigation water and fruit diameter. E. Irrigation water amount (mm) – TSS (Brix) relations for the experimental treatment

(avg. 297.8 mm), and 268.5, 303.7 and 318.0 mm (avg. 296.7 mm) for the experiments during the 1st, 2nd and 3rd years of the investigation, and for the subplots with the highest Kcp of 1.50 (I_4), irrigated at 2 or 4-day intervals, respectively. In a similar manner, seasonal water consumption use was estimated to increase with the prolongation of the cropping season and increasing rates of the applied Kcp coefficient. The highest seasonal consumption use of 404.8 mm and 405.7 mm was determined for plants growing under most favorable conditions of Kcp 1.5 during the longest cropping season of 2011, while the least water consumption of 199.3 mm and 165.0 mm was estimated for plants growing under conditions of plots irrigated using water quantities determined on the base of Kcp 0.75 and applied respectively at 2 or 4 days intervals during 2010.

Relationships between seasonal irrigation water amounts and some traits of mini cucumber fruits. The effect of various irrigation programs and water amounts applied to experimental treatments and subtreatments in this study on fruit traits and some biochemical properties of cucumber fruit, was supported by the results of statistical regression analysis between seasonal irrigation water amounts and the values measured in the field or obtained in the laboratory (Figs. 3A, B, C, D and E). The regression line curves and equations presented in the figures showed that seasonal irrigation water amounts, or Kcp values, had significant effect on the number, mean weight, length and diameter of the fruit, as well as on total soluble solids (TSS) of the fruit.

The type of regression curves and equations presented in Figs. 3A and B show that seasonal irrigation water amounts had a significant positive effect at the $p < .01$ level on the number of cucumber fruit recorded during each of the experimental years, as well as for overall averages for the study years. The equations defining these relationships and the curves of lines were determined as $Y = 0.3414I + 65.851$ ($R^2 = 0.91^{**}$); $Y = 0.3060I + 60.642$ ($R^2 = 0.96^{**}$) and $Y = 0.3462I + 63.065$ ($R^2 = 0.92^{**}$), respectively, for the evaluated years and for the averages. However, relationships identified for irrigation water amount and mean fruit weight appeared to be proven at lower ($p < .05$) significance level and only for one of the experimental years and for the average values.

Results of the regression analysis between the applied seasonal irrigation water quantities and mean fruit length and diameter are summarized in Figs. 3C and D. The positive linear relationships determined between irrigation water amount and fruit length quantified for the experimental years and on the basis of overall averages were identified as $Y = 0.0041I + 11.216$ ($R^2 = 0.56^{*}$); $Y = 0.00971I + 10.329$ ($R^2 = 0.81^{**}$) and $Y = 0.0091I + 10.447$ ($R^2 = 0.81^{**}$), respectively. A similar situation was recorded for relationships between total irrigation water amounts and fruit diameter proven at $p < .01$, $p < .05$ and $p < .05$ significance levels for the results obtained in 2010, 2011 and overall averages, respectively.

Unlike the positive relationships given above, the relationships defined between seasonal irrigation water and total soluble solids (Brix) were negative and TSS (Brix) decreased with increasing amounts of water applied (Fig. 3E). The linear decrease in TSS estimated in both of the evaluated years and for the averages was statistically proven at a high level of significance ($p < 0.01$) and the type of the regression equations were estimated as $Y = -0.0057I + 6.256$; $Y = -0.0080I + 6.444$ and $Y = -0.0054I + 5.627$, respectively for 2010, 2011 and the average values for the evaluated years.

DISCUSSION

The increasing effects of irrigation amounts on fruit number per m^2 or per plant determined in our study probably occurred due to the stimulating effect of water availability on fruit setting and the limited rate of flower and fruit set drop under favorable moisture conditions; a phenomenon also reported by other research [Kaya et al. 2005]. Arshad [2017] determined that the highest fruit number of 33.75 fruits per plant was provided by the most irrigated treatment, while the lowest number of 23.29 was recorded for the least irrigated plots. The author concluded that the proper amount of water application boosts the vigorous growth of cucumber, which eventually increases the number of fruit per plant. In a similar way, Hakkim and Chand [2014] recorded the maximum fruit number of 49 was obtainable from salad cucumber hybrid Hilton F1 plants drip irrigated with the highest water amounts (1.3 liter plant day^{-1}), while the minimum number of 35 was obtained from the treatment with the least applied water amount of 1.0 liter plant day^{-1}. Papadopoulos [1986] determined much higher fruit number (43–65) per plant over harvesting period of 93 days from Pepita cucumber cultivars grown in a greenhouse. Much lower number of fruits per plant (11–21) compared to 28–41 obtained in our study were published for Master Green Japanese cucumber cultivar with long fruits grown under greenhouse conditions in Brazil [Oliveira et al. 2011].

Abu-Zinada [2015] claimed that fruit number on the cucumber plant decreases not only due to decreased water amount, but that salinity of irrigation water also significantly decreases the number of early and total fruits on cucumber hybrid 3785 plants, which are reported to reach the ranges of 28–29 and 76–77 for fresh water applied in higher amounts. Some authors obtained much lower number of cucumbers than those determined in the evaluated study. Guler et al. [2006] reported lower mean numbers of 51.9 and 54.6 per m^2 for Seyhan and Afrodit cucumber cultivars vs. averages of 112–163 recorded in our study. With high probability, the difference occurred as a result of the specific fruiting characteristics and higher weight of the fruits of the two mentioned cultivars. In another study, the number of cucumber fruits per m^2 was recorded to be lower than those in our study and varied in the ranges of 92–110 and 63–76 for the first and second experimental years, respectively [Tuzel et al. 2013].

Results for average fruit weights detected in our study in the ranges of 76.0 to 85.6 g and 75.1–86.9 g respectively for 2 and 4-day irrigation intervals, are close to the ranges of 62 and 102 g published for the same (Matador) cucumber cultivar grown in greenhouse conditions in the Marmara region of the country [Ayas and Demirtas 2009]. However, the minimum values of 5.0 cm and 1.5 cm reported for mean fruit length and diameter respectively in the later study appear to be much lower than minimum values of 11.7 cm and 3.03 cm recorded in our experiment. The obvious reason for this contradictory situation is extremely low Kcp value accepted as the minimum value in the research carried out by these authors. Moreover, maximum values of 11.5 cm and 4.0 cm noted for fruit of the plants growing in plots with high applied Kcp are very close to our results discussed above. Results obtained from our investigation confirm fruit weight values in the range of 60–80 g obtained by Abu-Zinada [2015] and those in the limits of 52–70 g determined for Alasil, Alia and Copra cucumber cultivars published by Alsadon et al. [2006]. Lower weights of 50–57 g were reported for fruits of Triumf and Mirabelle cucumber cultivars grown under conditions of classic and fertigation applications [Cimpreanu et al. 2013], while higher fruit weights of 117.4–121.6 g were found for Seyhan and Afrodit cultivars grown in glasshouses [Guler et al. 2006]. The differences among fruit average weights obtained from different studies, to a large extent, appear to be due to the characteristics of cultivars used as plant material in the studies. Moreover, values of the parameters of fruit weight, length and diameter also depend on fruit harvesting frequency.

In our study, it was also detected that fruit penetration (firmness) values increased with the increase in the irrigation water amount, especially under conditions of higher applied Kcp of 1.25 and 1.50, where the max fruit firmness values reached up to 11.0–11.06 lb cm^{-1} or 4.99 and 5.26 kg cm^{-1}. Lower but comparable fruit firmness values of 3.5–4.2 kg cm^{-1} (7.78–9.3 lb cm^{-1}) and 2.26–3.71 kg cm^{-1} (5.02–8.25 lb cm^{-1}) were reported earlier by Alsadon et al. [2006] and Shahin et al. [2016], for conditions of water application of various salinity and boron levels, respectively.

The limited effect of irrigation scheduling on pH determined in the study supports findings for pH varying between 5.45–5.47 and 5.73–5.78 determined for a 2-year experiment for cucumbers under organic farming conditions in an unheated greenhouse [Tuzel et al. 2013].

Data related to some of the biochemical parameters obtained in our study differ to some extent from those reported earlier by other authors. Cimpreanu et al. [2013] declared that dry matter accumulation in the fruits of Triumf and Mirabelle cucumber cultivars was between 2.75% and 3.25% depending on the cultivar and/or applications. Higher dry matter content values between 3.0–3.5% were reported for the fruits of Alasil, Alia and Copra cucumber cultivars grown in greenhouses with irrigation scheduling based on different growth stages [Alsadon et al. 2006]. Wang et al. [2017] estimated that soluble solid contents of cucumber fruits varied from 2.74 to 3.37 mg 100 g^{-1} fresh weight, and from 3.08 to 3.53 mg 100 g^{-1} fresh weight for various applications and autumn-winter or winter-spring cropping cycles, respectively. Even lower total soluble solids (Brix) between 2.00–3.00 were reported in India for fruits of Silyon hybrid cucumber fruits under conditions of different boron concentrations [Bommesh et al. 2017]. Higher TSS contents varying between 3.49–3.64% were reported for plants grown in greenhouses under various fertilization and irrigation scheduling conditions [Tuzel et al. 2005].

Results related to seasonal water application and consumption water use amounts determined in the ranges of 160–297 mm and 220–350 mm in our study are close to data published earlier [Tuzel et al. 2005, Wang et al. 2009, Zhang et al. 2011].

The phenomena of the increase in the number of fruit per unit area with increasing irrigation water levels observed in our study and the significance level of the relationship, as well as the curve of lines, imply that favorable moisture regimes in the root zone improve the fruit formation and elongation under greenhouse conditions through less flower and fruit set drop [Kaya et al. 2005], better optimization of the metabolic processes in plant cells and increasing the effectiveness of the mineral nutrients applied to the crop [Yaghi et al. 2013]. Since the mean weight of the fruit is influenced not only by the soil moisture but also by the harvesting frequency, the relationships obtained during the experimental years and for averages of the years are not always obvious and are proven at the lower level of significance.

Our results for existing significant relationships between seasonal water amounts on fruit number per m^2, and some of the fruit traits and TSS (Brix) are in agreement with those obtained earlier by other researchers. Ayas and Demirtas [2009] reported that positive linear correlations were present between fruit length, fruit diameter and fruit weight, while negative linear correlation existed between dry matter content and amount of water applied to mini cucumber plants. Recently, Kumar et al. [2017] also reported that the total soluble solids (Brix) of fruits of Hilton cultivar cucumber plants grown in a naturally ventilated greenhouse were numerically higher for lower irrigation level I_2 than for I_4 with more water applied.

CONCLUSIONS

Results of the 3-year long study show that all the yield parameters discussed in this study are significantly affected by the amount of applied irrigation water or the value of the plant-pan coefficient (Kcp) used for the purposes of irrigation scheduling.

Yields of mini cucumber grown in an unheated greenhouse are higher under applications of higher Kcp values such as 1.25 and 1.50.

The average fruit number per unit area and per plant increased with the increase in the applied plant-pan coefficient (water amount) and varied in the ranges of 112–163 and 28–41 fruit per m^2 and per plant. Similar situation is observed in terms of mean fruit weight, fruit length and diameter. Obviously, more favorable moisture conditions under applications of higher plant-pan coefficients promote formation and development of the parthenocarpic cucumber fruit, decreasing flower and fruit dropping in greenhouse conditions.

Close positive linear relationships exist between total seasonal water used for irrigation on one hand, and the evaluated parameters of fruit number, fruit average weight, fruit length and diameter on the other. The relationship between irrigation water amount and TSS (Brix) is negative due to the decreasing value of dry matter under conditions of higher plant-pan coefficients applied.

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