



Deficit irrigation effects on cucumber (*Cucumis sativus* L. Maraton) yield in unheated greenhouse condition

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Abstract

The aim of this study was to determine effect of deficit irrigation on yield for cucumber grown under unheated greenhouse condition. The research was carried out at the Agricultural Research Station of Yenişehir High School of Uludağ University in Bursa, Turkey, in 2007. In the study, water was applied to cucumber as 100, 75, 50, 25 and 0% (as control) of evaporation from a Class A Pan corresponding to 2-day irrigation frequency. Irrigation water applied to crops ranged from 75 to 420 mm, and water consumption ranged from 84 to 424 mm. The effect of irrigation water level on the yield, fruit length, fruit diameter, fruit weight and dry matter ratio were found to be significant. The highest yields were 148 and 108 t ha⁻¹ for the KI_{cp} and $K2_{cp}$ treatments, respectively. Crop yield response factor (k_y) was 1.213. The highest values for water use efficiency (WUE) and irrigation water use efficiency (IWUE) were found to be 34.91 and 31.90 kg mm⁻¹ for the KI_{cp} treatment. Under the conditions that water resources are scarce, it can be recommended that KI_{cp} treatment is most suitable as a water application level for cucumber irrigation by drip irrigation under unheated greenhouse condition.

Key words: Cucumber, deficit irrigation, irrigation water use efficiency.

Introduction

Greenhouse cultivation, also known as protected cultivation, is one of the farming systems widely used to provide and maintain a controlled environment suitable for optimum crop production leading to maximum profits. This includes creating an environment suitable for working efficiency as well as for better crop growth¹. Greenhouse cultivation is a steadily growing agricultural sector all over the world⁸. The type of structure primarily used in Turkey is the so-called Mediterranean greenhouse; low-cost, unheated plastic-covered structures and with soil-grown crops.

Irrigation scheduling involves preventing the soil water deficit from falling below some threshold level for a particular crop and soil condition. This may involve estimating the earliest date to permit efficient irrigation or the latest date to avoid the detrimental effects of water stress on the crop¹⁷. Scheduling water application is very critical to make the most efficient use of drip irrigation system, as excessive irrigation reduces yield, while inadequate irrigation causes water stress and reduces production. The optimum use of irrigation can be characterized as the rooting area, and at the same time, avoiding the leaching of nutrients into deeper soil layers¹¹. High frequency water management by drip irrigation minimizes soil as a storage reservoir for water, provides at least daily requirements of water to a portion of the root zone of each plant and maintains a high soil matric potential in the rhizosphere to reduce plant water stress. On the other hand, the intensity of the operation requires that the water supply is kept at the optimum to maximize returns to the farmer.

Approaches used to establish schedules for drip irrigation include estimates based on evapotranspiration^{3,5,10,14}, allowable

soil-water depletion⁴. A widely adopted method for estimating crop consumptive water use (CWU) is the evaporation pan method, which relates evaporation from a Class A evaporation pan to CWU. These two quantities are related by what is called the crop coefficient K . Irrigation scheduling based on the crop coefficient K is one of the simplest methods where no sophisticated instrument is required. Precise values for K are often difficult to establish, given regional and site-specification, soil characteristics, crop physiology and cultural practices. Any recommended value of K for regional irrigation scheduling program must be high enough to prevent water stress arising from emergencies and specialized local situations, while remaining low enough for efficient water management²¹. Based on the US Weather Bureau Class A pan evaporation, many studies have been completed on the irrigation of cucumber^{7,16}, tomato¹² and potato^{10,15}.

Materials and Methods

Field experiment was carried out under unheated greenhouse condition in Yenişehir-Bursa (40°15'09"N latitude, 29°38'43"E longitude and altitude of 225 m above mean sea level). A high tunnel with the size of 8 m x 40 m using plastic coverage placed in north-south direction was used for the experiment. Summers are hot and dry; winters are cold and rainy in the region. Annual mean rainfall and temperature are 482.9 mm and 13.6°C, respectively. Average minimum temperature is 3.6°C in December; maximum temperature is 23.3°C in August². The soil of the experimental plot can be classified as sandy loam and the soil pH was 7.99-8.04.

Some physical and chemical soil properties are given in Table 1.

The seed were sown in small pot on 24 April 2007 and seedlings were transplanted to the plots (18 May 2007) when the plants showed four to five permanent leaves. The plants were grown 0.50 m apart between the rows with 0.50 m spacing in each row. Each plot contained 52 plants. In order to prevent the water in any one plot from affecting its neighboring plots, only 10 plants of middle row were harvested. fruit weight (g), fruit diameter (cm) and fruit length (cm) were measured by caliper rule and calculated as the average of measured values. The dry matter amount was found after drying at 85°C in 48 hours.

The layout of the experiment was a completely randomized block design with three replications for each of the five irrigation treatments tested. However, replications have been distributed to the random blocks in such a way that following same range in three blocks not to disturb the existing irrigation system. Irrigation treatments consist of five different plant-pan coefficients ($K1_{cp}$ 1.00, $K2_{cp}$ 0.75, $K3_{cp}$ 0.50, $K4_{cp}$ 0.25, $K5_{cp}$ 0.00-control). Pan evaporation method was used for calculation of applied water amount:

$$IW = E_{pan} \times K_{cp}$$

where IW is the amount of applied irrigation water (mm), E_{pan} the cumulative evaporation between each irrigation interval (mm) and K_{cp} is the plant-pan coefficient. Evaporation between the irrigation intervals was measured with US Weather Bureau Class A pan located in the center of greenhouse. Irrigation water was applied in the 2-day frequency and drip irrigation method was used. Required irrigation water was measured by flow meter device at the head of each plot.

Irrigation water (3 l s^{-1}) was supplied from a deep well drilled in the area. Quality properties of irrigation water are given in Table 2. The water is placed in C_2S_1 class with low sodium risk, medium EC value. Since there is no recorded problem with water quality, it is well suited for irrigation.

Crop evapotranspiration (ET_c) was estimated using the following form of the water balance equation:

$$ET_c = (SWC_{i0} - SWC_{i1}) + IW - D$$

where $(SWC_{i0} - SWC_{i1})$ is the change in volumetric soil water content between two measurement dates; IW and D are respectively the total volumes of applied irrigation water and collected drainage for the period under consideration. The water content of plant root depth (0.60 m) was determined by gravimetric method before irrigation water application¹³ and monitored in

30 cm depth increments to 0.90 m after irrigation for each irrigation treatments. Monitoring the soil water content in the plots revealed that deep percolation below 0.60 m depth was negligible.

In this study, the Stewart model has contributed to define the relationships between yield and ET ⁶:

$$(1 - Y_a \cdot Y_m^{-1}) = k_y (1 - ET_a \cdot ET_m^{-1})$$

where Y_a is the actual yield (t ha^{-1}), Y_m is the maximum yield (t ha^{-1}), ET_a is the actual evapotranspiration (mm) and ET_m is the maximum evapotranspiration (mm). Values of k_y indicate the response factor of cucumber to deficit irrigation. The water use efficiency (WUE) was determined to evaluate the productivity of irrigation in the treatments. WUE and irrigation water use efficiency (IWUE) are two terms used to promote the efficient use of irrigation water at the crop production level.

WUE was calculated as the ratio of yield (YLD) to ET_a , given as $WUE = YLD/ET_a$ ($\text{t ha}^{-1} \text{ mm}^{-1}$). IWUE was estimated by following equation:

$$IWUE(\text{t ha}^{-1} \text{ mm}^{-1}) = \frac{YLD - YLD_{rainfed}}{IRGA}$$

where $YLD_{rainfed}$ is the yield obtained from the rainfed treatment or dryland yield and IRGA is the seasonal irrigation amount used in mm

In the harvesting time, 55 days after the seedlings were transplanted, the plants were fully developed and had the diameter, length, weight, colour and the flavour characteristics of the species. Harvested plants from each plot were evaluated immediately according to yield, fruit length, fruit diameter, fruit weight and dry matter ratio.

Analysis of variance was performed on yield and yield component data using the MSTAT-C (Version 2.1-Michigan State University 1991) and MINITAB (University of Texas at Austin) software. The significance of irrigation treatments was determined at the 0.05 and 0.01 probability levels, by the F-test¹⁹.

Results and Discussion

Water applied and water used: After planting, 75 mm irrigation water was applied to some treatments to bring the soil water content in 0–60 cm soil depth up to level of field capacity. Irrigation treatments were started measuring of evaporation from Class A pan after the first irrigation application. The maximum amount of water applied to the crop was 420 mm in the $K1_{cp}$ treatments while the minimum amount was 75 mm in the $K5_{cp}$ treatment during the

Table 1. Some of chemical and physical properties of experimental field soil.

Soil depth (cm)	γ (g cm^{-3})	Soil type	Field capacity (%)	Wilting point (%)	pH	Total salt (%)	CaCO ₃ (%)	Organic matter (%)	Available (kg da ⁻¹)	
									P	K
0-30	1.34	SL	19.66	11.94	7.99	0.058	5.67	2.94	1.53	38.35
30-60	1.37	SL	17.26	9.98	8.04	0.051	8.49	1.39	1.24	19.52

γ Unit weight of soil, SL Sandy loam, P Phosphorus, K Potassium.

Table 2. Chemical composition of irrigation water used in the experiment.

Water source	EC _{25x} (10 ⁶)	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	pH	Class	SAR
		(me L ⁻¹)						
Deep well	715	2.3	2.56	9.25	5.7	7.12	C ₂ S ₁	0.85

experimental year. The amount of water applied to other treatments ranged between 315 and 105 mm. Seasonal evapotranspiration (ET_c) was increased with the applied irrigation water and ranged from 84 mm to 424 for $K5_{cp}$ and $K1_{cp}$ treatments, respectively (Table 3).

Cucumber irrigation quantities applied to the treatments varied from 320 to 509 mm and seasonal plant water consumption or evapotranspiration varied from 391 to 597 mm in central Van ⁹. Linear relationships were observed between the crop evapotranspiration (ET_c) and yield (Y_a). The equation for the relationship was $Y_a = 0.4152ET_c - 29.548$ with $R^2 = 0.99$ (Fig. 1).

Vittum and Flocker ²⁰ stressed the importance of maintaining adequate, uniform soil moisture throughout the crop cycle. Water deficits, particularly in the three or four week prior to harvest, lower crop yields and quality. In our study, treatment $K1_{cp}$ had the highest yield (148 t ha⁻¹) followed by $K2_{cp}$, $K3_{cp}$ and $K4_{cp}$ irrigation treatments with 108, 64 and 24 t ha⁻¹, respectively. As expected, non-irrigated control $K5_{cp}$ had the lowest yield. The non-irrigated treatment ($K5_{cp}$) produced 957.1% lower yield than the $K1_{cp}$ treatment. However $K2_{cp}$, $K3_{cp}$ and $K4_{cp}$ had 37-516.7% less yield compared with treatment $K1_{cp}$ (Table 4).

Deficit irrigation had a significant effect on fruit weight, but the values of $K1_{cp}$ and $K2_{cp}$ were in the same group, $K3_{cp}$ and $K4_{cp}$ treatments in the second group and $K5_{cp}$ was placed in the last group. It can be concluded that the deficit of applied irrigation water (25%) is not compatible with the reduction in fruit diameter. According to results, there was no effect of deficit irrigation fruit weight in terms of marketable value.

The significant increases in dry matter were found as parallel to irrigation water deficit and the highest and lowest dry matter were found at $K5_{cp}$ and $K1_{cp}$, respectively. This may be attributed to higher head weight observed from $K1_{cp}$ treatment than those of deficit irrigation treatments.

Positive linear relation was found among fruit length, fruit diameter and fruit weight and negative linear relation between dry matter ratio and amount of water applied (IW). The equation for

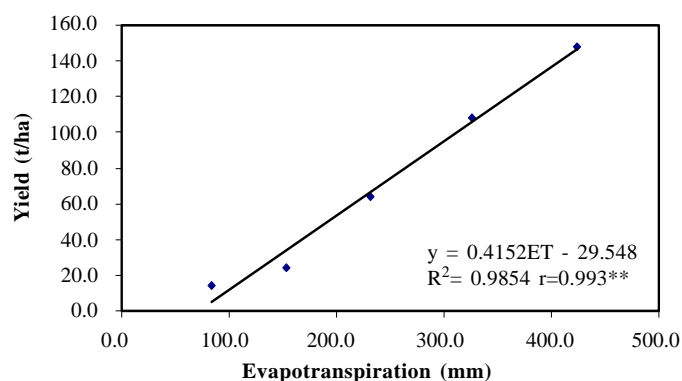


Figure 1. The relationship between crop evapotranspiration and yield. (The error bars are SE of 10 plants).

the relationship was $Fruit\ length = 0.0188IW + 4.3635$ with $R^2 = 0.93$ (Fig. 2a), $Fruit\ diameter = 0.0076IW + 0.8451$ with $R^2 = 0.96$ (Fig. 2b), $Fruit\ weight = 0.1095IW - 58.551$ with $R^2 = 0.95$ (Fig. 2c), and $Dry\ matter\ ratio = -0.0234IW + 16.47$ with $R^2 = 0.94$ (Fig. 2d).

Crop yield response factor (k_y): Crop yield response factor (k_y) indicates a linear relationship between the decrease in relative water consumption and the decrease in relative yield. It shows the response of yield with respect to the decrease in water consumption. In other words, it explains the decrease in yield caused by the per unit decrease in water consumption ^{6,18}. Seasonal crop response factor was 1.213 for irrigation treatments (Fig. 3). Values of k_y increased with increasing water deficit except in $k_{5_{cp}}$.

Water use efficiencies: WUE and IWUE values decreased when irrigation water amount decreased. The highest WUE and IWUE were obtained from treatment $K1_{cp}$, 34.91 and 31.90 kg mm⁻¹, respectively. When considering IWUE values of $K1_{cp}$ and $K2_{cp}$ treatments, IWUE values of $K1_{cp}$ treatments was found higher than that of $K2_{cp}$ treatment followed by $K3_{cp}$ (Table 5).

Table 3. Relationship between the decrease in relative water use and decrease in relative yield and yield response factor for cucumber irrigated by a drip system.

Irrigation treatment	Yield (t ha ⁻¹)	Applied Water (mm)	ET _a (mm)	ET _a /ET _m	Y _a /Y _m	1-(ET _a /ET _m)	1-(Y _a /Y _m)	k_y
$K1_{cp}$	148	420	424	1.000	1.000	0.000	0.000	0.000
$K2_{cp}$	108	315	326	0.769	0.730	0.231	0.270	0.169
$K3_{cp}$	64	210	231	0.545	0.432	0.455	0.568	1.247
$K4_{cp}$	24	105	153	0.361	0.162	0.639	0.838	1.311
$K5_{cp}$	14	75	84	0.198	0.095	0.802	0.905	1.129

Table 4. Effects of irrigation treatments on cucumber marketable parameters.

Irrigation treatment	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (g)	Dry matter (%)	Yield (t ha ⁻¹)
$K1_{CP}$	11.5a	4.0a	102.0a	7.0d	148a
$K2_{CP}$	11.0a	3.5ab	96.0a	9.0cd	108b
$K3_{CP}$	9.0ab	2.1bc	82.0b	11.0bc	64c
$K4_{CP}$	6.5bc	1.7bc	74.0b	13.0ab	24d
$K5_{CP}$	5.0c	1.5c	62.0c	16.0a	14e
Treatments	**	**	**	**	**
Blocks	ns	ns	ns	ns	ns

** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level, ns non-significant.

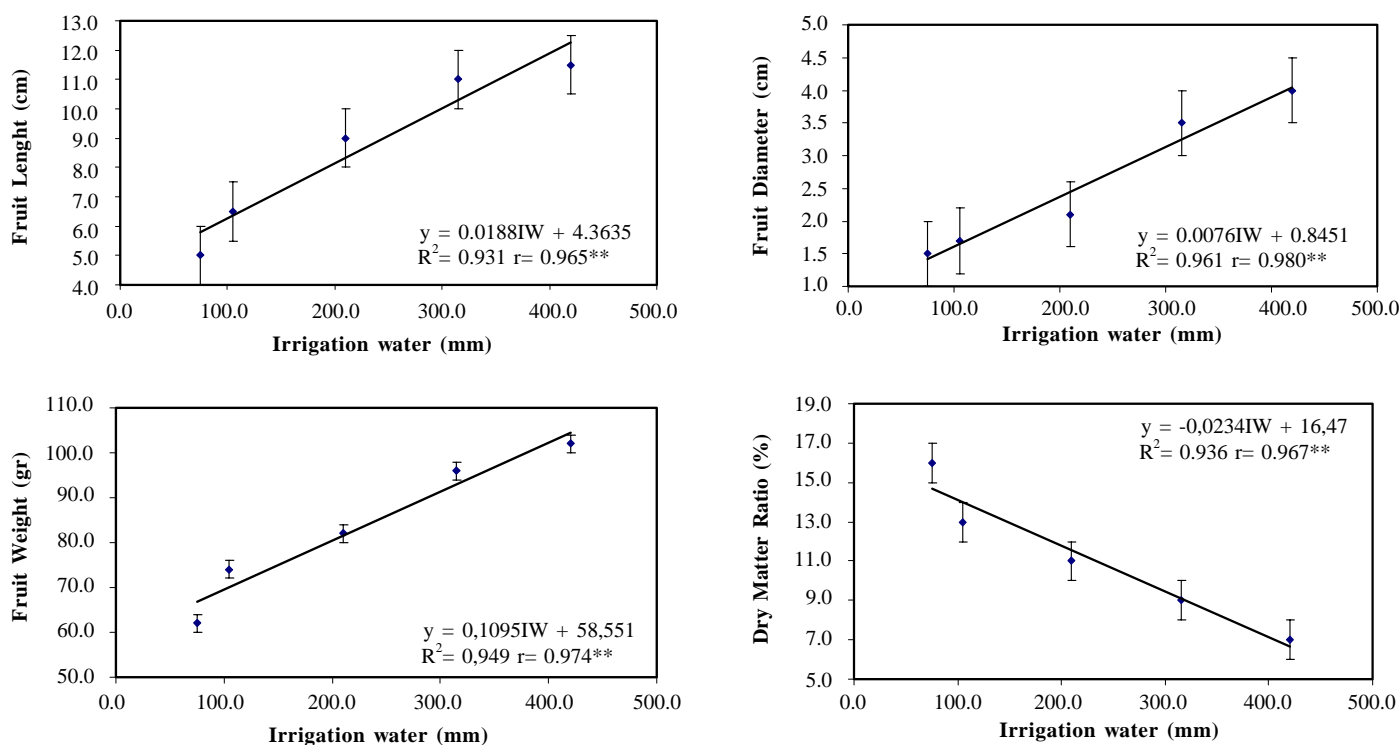


Figure 2. Relationship between applied of irrigation water and fruit length, fruit diameter, fruit weight and dry matter ratio. (The error bars are SE of 10 plants).

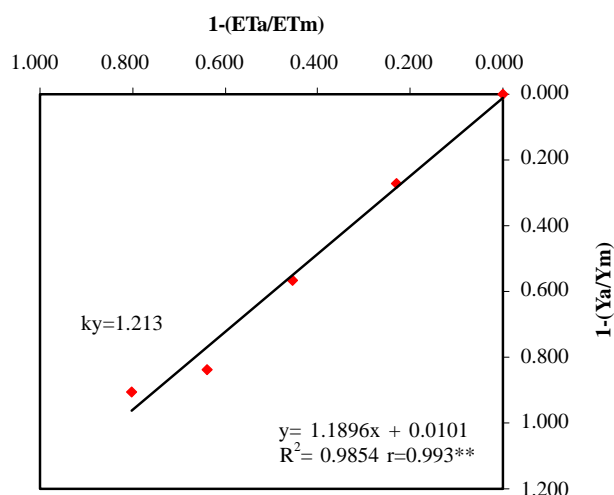


Figure 3. Relationship between relative yield decrease and relative crop evapotranspiration for cucumber throughout the total growing season.

Conclusions

In this study, irrigation treatments significantly affected yield, fruit length, fruit diameter, fruit weight and dry matter ratio. The highest yield was obtained from the $K1_{cp}$ treatment as 29.2 t ha^{-1} and the minimum yield was obtained from the $K5_{cp}$ treatment as 148 t ha^{-1} . Yield was significantly reduced as the amount of irrigation water decreased. The rates of reduction in relative yield were 37.0, 131.3, 516.7 and 957.1% at the irrigation treatments, respectively. IWUE value in the $K1_{cp}$ treatment was higher than in the $K2_{cp}$ and $K3_{cp}$ treatments. Under the conditions that water resources are scarce, it can be recommended that $K1_{cp}$ treatment is most suitable as a water application level for cucumber irrigation by drip irrigation under the unheated greenhouse condition.

Table 5. Total water use efficiency (WUE) and irrigation water use efficiency (IWUE) values for cucumber irrigated by a drip system at different irrigation treatments.

Irrigation treatment	Yield (t ha^{-1})	WUE (kg mm^{-1})	IWUE (kg mm^{-1})
$K1_{cp}$	148	34.91	31.90
$K2_{cp}$	108	33.13	29.84
$K3_{cp}$	64	27.71	23.81
$K4_{cp}$	24	15.69	9.52
$K5_{cp}$	14	16.67	0.00

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