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RESPONSE OF CUCUMBERS TO DIFFERENT IRRIGATION REGIMES APPLIED THROUGH DRIP-IRRIGATION SYSTEM

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ABSTRACT

In the future, irrigated crop production will be affected significantly with water scarcity. There is a pressing need to improve the irrigation water efficiency under insufficient water supply conditions. Therefore, the effects of different irrigation quantities on the fruit yield, yield components (fruit length, diameter, weight and number), irrigation water use efficiency (IWUE) andfruit quality (minerals,phenolic content and antioxidant activity) ofdrip-irrigated cucumberwere evaluated in open field conditions. Different irrigation levels were adjusted usingthree different ratios(T1: 1.0, T2: 0.85 and T3: 0.70)of cumulative evaporation from a Class A pan.The maximumtotal fruit yield, early fruit yield, fruit length, fruit number per plant were determined fromT1 irrigation level(64.13 Mg ha^{-1}, 2.76 Mg ha^{-1}, 15.95 cm and 19.94), respectively.Significant positive linear relations were obtained between total fruit yield, fruit length and fruit number with irrigation quantity.The highest IWUE was obtained fromT2 irrigation level(134.94 kg ha^{-1} mm^{-1}), however, there wasno significant difference among the treatments.The mineral content (N, K, Ca, Mg, S, Mn and Zn) and total antioxidant activity in cucumber fruits was higher in T2 irrigation level compared with the T1 irrigation level, the T1 irrigation level provided statistically higher total phenolic, Cu and B content compared withT2 and T3.In conclusion, the T1 treatment is recommended in semi-arid areas with acool climate for obtaining higher fruit yield. However, the T2 treatment is also recommended for obtaining higher IWUE and fruit quality if water is scarce.

Key words: Cucumber, water-yield relationship, irrigation water use efficiency, total phenolics, antioxidant activity, mineral content

INTRODUCTION

Improvementof water use efficiency in irrigated agriculture is anincreasing need,because agriculture is the largestconsumer of fresh water worldwide. A portion of 70-80% of the diverted total water in the arid and semi-arid regions is used in agriculture (FereresandSoriano, 2007).At the same time, the percentage of people living in water limited areas worldwide is predicted to rise to 67% by 2050 (Wallace, 2000).Turkey is a country inthe Mediterranean region. Stress on the water resources inthe Mediterranean and other some parts of the world will increase due to climate change (Arnell, 2004).There is an area of more than 20 million ha available for irrigated agriculture in Turkey. However, water resources potential of Turkey is insufficient to irrigate this area (Cakmak *et al.,* 2007).

Irrigation scheduling is very important in terms of water saving. Determining crop water requirements is one of main parameters of irrigation schedules.Crop water requirements are usually estimated using the Penman-Monteith or pan evaporation methodunder open field conditions (Zhang *et al.,* 2010). Evaporation pans are preferred mostly for irrigation schedules because data measurements are easy and their equipment is not expensive. Class A pan is the most common pan type.

Cucumber is one of the major vegetable crops produced and consumed in Turkey. The production area and amount according toTurkey Statistical Institute data were 310671 da and 1605319 t during 2011, respectively. Cucumber is sensitive to water stress due to its shallow fibrous root system (Kirnak and Demirtas, 2006; Hashem *et al.,* 2011). Sufficient water application is important for horticultural crops because water shortage in soil can cause flower and fruit drop in crops (Kaya *et al.,* 2005). In cucumber, water stress has caused yield losses and fruit yield was higher generally under higher water applied conditions (Ayas and Demirtaş, 2009; Wang *et al.,* 2009; Zhang *et al.,* 2011).However, excess water application for cucumber provided lower fruit yields (Şimşek*et al.,* 2005; Hashem *et al.,* 2011). Fruit parameters (length, diameter, number, weight etc.) were also positively affected with irrigation quantities (Ayas and Demirtaş, 2009; Wang *et al.,* 2009; Zhang *et al.,* 2011).

The competition for water resources is increasing dramatically. Therefore, determining of water use efficiency is essential to obtaining optimal irrigation level. Generally irrigation water use efficiency (IWUE) for cucumber was the lowest under unstressed conditions (Şimşek *et al.,* 2005; Kirnak and Demirtas, 2006; Hashem *et al.,* 2011). Conversely, Wang *et al.* (2009) and Zhang *et al.* (2011) determined that IWUE was the lowest under the lowest water application conditions. Similarly, Ayas and Demirtaş, 2009 found that IWUE increased with the increase of irrigation water applied to cucumbers.

Vegetables aresources of manyvitamins, mineralsandothernaturalsubstances.Many researchers have reported that the irrigation amount applied to cucumber had a significant effect on leaf nutrients and fruit quality (Kaya *et al.,* 2005; Kirnak and Demirtas, 2006; Wang *et al.,* 2009; Zhang *et al.,* 2011). Macronutrient concentration in leaves of cucumbers grown in water stress is significantly reduced.However, soluble sugar, vitamin C and free amino acidin cucumber fruits were higher in lowest irrigated conditions.Phenolic compounds are present in plant foods such as cereals, legumes and vegetables. These compounds have antioxidant, antimicrobial, anticancer, anti-obesity, anti-diabetic, anti-hypertensive and anti-mutagenic properties (Kunyanga *et al.,* 2012).

One of the most important climatic factors that influence photosynthesis, respiration, growth and phenological development in plants is atmospheric temperature. Phenologicalchanges are especially important in cooler regions and at the higher altitudes (White and Howden, 2010). In addition, plant water use is also significantly affected by air temperature.

The purpose of the study was to evaluate fruit yield, yield components, fruit mineral content, total phenolic content and antioxidant activityand irrigation water use efficiency (IWUE) of drip-irrigated cucumber with different irrigation quantities and was to suggest the most suitable irrigation level for adequate and inadequate water conditions in a semi-arid region with acool climate under high altitude conditions.

MATERIALS AND METHODS

Experimental area: The experiment was conducted at the Agricultural Research Station of Ataturk University, Erzurum, Turkey (39.933º N and 41.237º E, 1793 m above mean sea level) from June to September 2011.The climate in experimental region is semi-arid. During the growing season (12 June-18 September), the mean temperature, relative humidity, wind speed and daily sunshine values respectively were 17.9 ºC, 52.2%, 3.50 m s^{-1} and 7.7 hours according to data supplied from the Erzurum meteorology station at 5 km distance to the experimental area. Also, the total evaporation and precipitation values measured by a Class A pan and a pluviometer in the experimental area were 688 mm and 41 mm, respectively.

The soils of the experimental region are Aridisol considering the US Soil Taxonomy. Some physical and chemical properties of experimental field soil for the soil layers of 0-30, 30-60 and 60-90 cm are given in table 1. The soil of the experimental field was classified as medium textured and water-holding capacity for a soil depth of 90 cm was 127.1 mm.

Experimental Design, Planting and Irrigation: Different irrigation quantities were investigated in a completelyrandomizedblockdesignwith three replicates. Serena F1 type (*Cucumbissativus* L.)cucumberseedlings were planted to each plot with 50 cm between plants and 70 cm between rows on 12^{th} June. Each treatment plot contained 4 crop rows and 56 cucumber plants. There was space of 1.5 m between the plots and blocks to prevent the passage of water from each other.Manure at the rate of 30 Mg ha^{-1} was applied over the whole experimental area before planting, during soil preparation.

Good quality groundwater stored in a pool was used as irrigation water.The pH, electrical conductivity and sodium adsorption ratio of irrigation water were 7.45, 0.310dS m^{-1}, and0.46, respectively. Irrigation water was applied using the drip irrigation method. Four driplines were placed to each plot. Polyethylene driplines of 16 mm in diameter had in-line type emitters with distance of 0.50 m. Driplines were connected PE manifolds of 50 mm in diameter placed along the edge of each plot. Mean flow rate of emitters on driplines was 4 $Lhour^{-1}$ under an operation pressure of 0.1 MPa.Required pressure was provided using a centrifugal pump. Also, drip irrigation system had a control unit (a screen filter, a flow meter, a pressure gauge and valves). Irrigations were manually controlled with valves on the manifolds.

The irrigations were done when evaporation amount in the Class A pan located in experiment field was approximately 30 mm. Irrigation water amountwas calculated below pan evapotranspiration equation (Ertek, 2011).

$$I = E_{pan} \times K_{cp} \times P$$

$$P = (W_p/W_b)$$

whereIis the irrigation water amount(mm), E_{pan} is the cumulative evaporation amount (mm), K_{cp} is the plant-pan coefficient, P is the wetting factor, W_p is plant cover width (m), and W_b is plant row interval (m). Three different plant-pan coefficients (1.0, 0.85 and 0.70) wereused. Therefore, different irrigation quantities were adjusted according to 100, 85 and 70% of cumulative evaporation from the Class A pan for T1, T2 and T3 treatments, respectively.

Harvesting, Measurements and Fruit Quality Analysis: During the harvesting period, cucumber fruits from twenty-four plants on the two rows in the middle of each plot were harvested by hand. In each harvest time, fruits numbers, weights, diameters and lengths were determined.

The mineral content, total phenolics and antioxidant activities of cucumber fruits as quality parameters were analysed on fruits collected in the middle of harvesting period.Cucumber fruit tissues dried for 48 hours at 68°C and powdered were analysed for determining the macro- and micro-minerals (N, P, K, Ca, Mg, Na, S, Fe, Cu, Mn, Zn and B). Nitrogen content in the fruit tissues was determined by the Micro-Kjeldahl method (Bremner and Mulvaney, 1982). The P, K, Ca, Mg, Na, S, Fe, Cu, Mn, Zn and B were found by wet digestion using a HNO_3-H_2O_2 acid mixture (2:3 v/v) in a microwave unit (Speedwave MWS-2 Berghof products + Instruments Harresstr.1. 72800 Enien Germany) according to the following sequence: 145°C, 75% RF, 5 minutes; 180°C, 90% RF, 10 minutes and 100°C, 40% RF, 10 minutes (Mertens, 2005a). Macro- and micro-minerals were determined using an ICP-OES spectrophotometer (Inductively Couple Plasma spectrophotometer Perkin-Elmer, Optima 2100 DV, ICP/OES, Shelton, CT 06484-4794, USA) (Mertens, 2005b).

For the analysis of antioxidant activity and phenolic compounds, 10 g of the cucumber pulp was mixed with 10 ml ethanol and stirred for six hours with a magnetic stirrer, after than suspension was filtered through Whatman No. l filter paper (Sengul *et al.*, 2011).Extracts were stored in a freezer at -20 °C until analysis.

Total phenolics content in extracts was evaluated by using the Folin–Ciocalteau colorimetric method (Gulcin*et al.*, 2002) with analytical grade gallic acid as a standard, and the values were expressed as µg of gallic acid equivalents per milligram of fresh sample (µgGAE/mg fresh sample) (Sengul *et al.*, 2011).The antioxidant activity was evaluatedby using the β-carotene bleaching method (Kaur and Kapoor, 2002) with some modifications (Sengul *et al.*, 2011).

Irrigation Water Use Efficiency (IWUE): The IWUE iseconomic yield from per unit irrigation water (Howell, 2001). It was calculated using the following equation:

$$IWUE = \frac{Y}{IW}$$

where IWUE is the irrigation water use efficiency (kg ha^{-1} mm^{-1}), Y is the total marketable fruit yield (kg ha^{-1}), and IW is the amount of seasonal irrigation water (mm).

Statistical Analysis: The variance analysis (ANOVA) by using MINITAB software was applied to determine the effects of the different irrigation quantities on yield, yield components,irrigation water use efficiency and fruit quality.The treatment means were compared and ranked by the Duncan's multiple range test.

RESULTS AND DISCUSSION

Evaporation, PrecipitationandIrrigationQuantity: The monthly evaporation and precipitation values measured in the experiment areausing a Class A pan and a standard pluviometer, respectively,are shown in Figure 1.Total Class A pan evaporation and precipitation values during the growing period (12 June-18 September) of cucumber were 688 mm and 41 mm, respectively.The highest evaporation values were measured in August (Figure 1). The dailymean evaporation value was5.7, 7.6, 8.1 and 5.1 mm in June, July, August and September, respectively. In contrast to evaporation, the precipitation values during growing period were very low (Figure 1).Therefore, irrigation requirement of cucumber was high.

Throughout irrigation period (19 June-15 September), total 22 irrigations were treated to all plots. The plots were irrigated according to 100% of evaporated water from the Class A pan in first two irrigations. In subsequent irrigations, different irrigation quantities adjusted according to 100, 85 and 70% of Class A pan evaporation were applied to the T1, T2 and T3 treatments, respectively. Therefore, seasonally the highest irrigation quantity was applied to the T1 treatment as 479.9 mm. The seasonal irrigation quantities were 404.5 mm in the T2 treatment and 330.3 mm in the T3 treatment. Seasonally water amounts applied to the T2 and T3 treatments were 15.7% and 31.2%, lower than the T1 treatment, respectively.Increasing of cumulative irrigation quantities throughout irrigation period was linear for all treatments (Figure 2). Mean irrigation interval was 4 days during irrigation period. Also, mean irrigation water amount applied each irrigation was 21.8 mm, 18.4 mm and 15.0 mm in the T1, T2 and T3 treatments, respectively.

Fruit Yield and Yield Components: Harvesting period started from 18^{th} July and finished on 18^{th} September. Total 27 harvestings were done during this period. The highest total fruit yield was obtained from T1 treatment as 64.13 Mg ha^{-1}(Table 2). Total fruit yields obtained from T2 and T3 treatments were 14.9% and 33.4% lower than the T1 treatment, respectively.There was a significant ($P < 0.05$) difference between the T1 and T3 treatment's total fruit yields (Table 2). Numerous researches indicated that effect of irrigation quantity on fruit yield of cucumber was very important (Hashem *et al.*, 2011; Zhang *et al.*, 2011). Cucumber fruit yields decreased linearly with decreasing irrigation quantity (Figure 3).The determination factor (R^2) of irrigation quantity-yield relationship equation was significantlyhigh ($P<0.01$).Similarly, some researchers (Zhang *et al.*, 2011) also determined positive linear relations between cucumber fruit yield and irrigation water. However, Şimşek *et al.* (2005) indicated that irrigation water-yield relationship was polynomial.

The mean harvest interval was 2.3 days during the cucumber harvesting period. Mean yields in each harvest for the T1, T2 and T3 treatments were 2.38 Mg ha^{-1}, 2.02 Mg $ha^{-1}$and 1.58 Mg ha^{-1}, respectively. However, themean yields from 13^{th} to 25^{th} harvesting were higher than other harvestings. Mean yields per harvest in this period was 3.88 Mg ha^{-1} for the T1 treatment, 3.40 Mg ha^{-1} for the T2 treatment and 2.65 Mg ha^{-1} for the T3 treatment. Therefore, increasing cumulative fruit yields throughoutthe harvesting period was significantly polynomial (Figure4).

The first four harvests were considered as the early fruit yield. The T1 treatment the most irrigated had the highest early fruit yield (2.76 Mg ha^{-1}) (Table 2). Early fruit yield of the T1 treatment was significantly ($P<0.05$) higher than the T3 treatment as 110.7%. At the same time, higher water applying to cucumber plants increased fruit length, fruit diameter, fruit weight and fruit number (Table 2). However, cucumber fruit diameter and average fruit weight wasnot affected significantly with different irrigation quantity.Whereas fruit number per plant and fruit length values obtained from the T1 treatment was significantly ($P<0.05$) higher than values of the T3 treatment as 45.7% and 6.3%, respectively. Relationships betweenfruit number per plant or fruit length with irrigation quantity were positive linearand significant ($P<0.01$) (Figure3). Many researchers indicated that there were positive effects of irrigation quantity on cucumber fruit parameters (Ayas and Demirtaş, 2009; Wang *et al.,* 2009; Zhang *et al.,* 2011).

Irrigation water use efficiency (IWUE): According to the in table 2 values, IWUE was the highest at the T2 treatment as 134.94 kg ha^{-1} mm^{-1}. However, there were no significant differences among the treatments. Also, linear relationship between irrigation quantity and IWUE was not significant (Figure 3). IWUE obtained from the T1 and T3 treatments were 1.0% and 4.1% lower than the T2 treatment, respectively. The lowest irrigated treatment provided the lowest IWUE value. Similarly, some researchers obtainedthe lowest IWUE values for cucumber inthe lowest irrigation conditions (Wang *et al.*, 2009; Zhang *et al.*, 2011). Conversely, Şimşek *et al.*(2005), Kirnak and Demirtas (2006) and Hashem *et al.* (2011) indicated that maximum IWUE values were obtained from lower irrigated cucumber. In addition, the IWUE values determined in this study were higher than values of previous some studies (Ertek *et al.*, 2006; Kirnak and Demirtas, 2006). However, the IWUE values of this study were close to the values obtained by Wang *et al.* (2009) and Zhang *et al.*, 2011).

Fruit Mineral Contents,Total Phenolic Content and Antioxidant Activity: The irrigation quantity significantly ($P<0.01$) affected all analyzedmineral contents (N, P, K, Ca, Mg, Na, S, Fe, Cu, Mn, Zn, and B) in fruits of cucumber (Table 3).The highest fruit mineral contents except P, Na, Fe, Cu and B contents were determined in the T2 treatment. While the P, Na and Fe contents were the highest in the T3 treatment, only Cu and B contents were the highest in the T1 treatment (Table 3). It could be said that lower water applications to cucumber are better for human nutrition due to lower water treatments provided higher fruit mineral contents.

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

Properties	Soil depth (cm)		
	0-30	30-60	60-90
Texture	**Clay loam**	**Loam**	**Loam**
Clay	29.7	25.8	21.4
Silt	34.8	33.7	31.7
Sand	35.5	40.5	46.9
Bulk density (g cm^{-3})	1.33	1.39	1.42
Field capacity (%)	30.5	27.6	24.4
Wilting point (%)	18.9	17.1	15.7
pH	7.68	7.37	7.49
Electrical conductivity (dS m^{-1})	1.36	1.48	1.21
Carbonates (%)	2.39	2.06	2.17
Organic C (g kg^{-1})	1.53	0.97	0.42

Normally, the decrease in soil water content negatively affects nutrients uptake of plants. Also, Kaya *et al.* (2005) and Kirnak and Demirtas (2006) determined that macronutrient concentrations (N, P, K, Ca and Mg) in leaves of cucumber was significantly reduced by water stress. However, we obtained generally higher fruit mineral contents under lower irrigation conditions. It could be explained that the changing soil solution chemistry due to variation of soil moisture regime can change the uptake of minerals by plants (Misra and Tyler, 1999).

The total phenolic content in fruit extracts of cucumber reduced with decreasing irrigation quantity (Table 3). T1 treatment provided significantly ($P<0.05$) higher phenolic content (19.27 µg GAE/mg fresh sample) compared with the T2 and T3 treatment values. The lowest phenolic content (17.60 µg GAE/mg fresh sample) was obtained from the T3 treatment. However, there was no statistically significant difference between the phenolic contents of T2 and T3 treatments. The highest and lowest total antioxidant activities in fruit extract of cucumber were 38.81% (T2) and 37.09% (T1), respectively. While the T1 and T3 treatment values were statistically similar, the T2 treatment value was significantly ($P<0.05$) different from the T1 value. However, our study results showed that there was a non-significant linear relationship ($R^2=0.432$) between antioxidant activity with phenolic content. Although basic secondary metabolites with antioxidant activity are phenolic compounds, antioxidant activity also may be due to the presence of other antioxidant secondary metabolites (Javanmardi *et al.* 2003).

Table 2. Fruit yield, yield components and irrigation water use efficiencies (mean±SEM) of cucumber under different irrigation levels.

Parameters	Irrigation treatments		
	T1	**T2**	**T3**
Total fruit yield (Mg ha^{-1})	64.13±5.02 a	54.59±3.07 ab	42.74±2.79 b
Early fruit yield (Mg ha^{-1})	2.76±0.08 a	1.88±0.21 b	1.31±0.25 b
Fruit number per plant	19.94±1.69 a	17.64±0.70 ab	13.69±1.11 b
Fruit diameter (cm)	3.81±0.05	3.73±0.05	3.61±0.07
Fruit length (cm)	15.95±0.09 a	15.36±0.18 ab	15.0±0.28 b
Average fruit weight (g)	112.7±0.70	108.2±1.90	109.6±1.64
IWUE (kg ha^{-1} mm^{-1})	133.65±10.45	134.94±7.59	129.41±8.46

Between the means marked with the same letter in rows do not differ significantly (P < 0.05).

Table 3. Mineral substance, antioxidant activities (β-Carotene Bleaching Assay) and total phenolic contents (mean±SEM) of cucumber fruits under different irrigation levels

Parameters	Irrigation treatments		
	T1	**T2**	**T3**
Minerals[&]			
N (g kg^{-1})	18.67±0.09 b	19.57±0.12 a	17.93±0.12 c
P (g kg^{-1})	1.23±0.01 c	1.32±0.01 b	1.43±0.01 a
K (g kg^{-1})	24.34±0.01 c	25.41±0.00 a	24.43±0.02 b
Ca (g kg^{-1})	8.75±0.01 b	9.25±0.02 a	8.66±0.01c
Mg (g kg^{-1})	4.17±0.01 a	4.21±0.01 a	4.03±0.01 b
Na (g kg^{-1})	1.23±0.01 c	1.32±0.00 b	1.38±0.00 a
S (g kg^{-1})	2.33±0.01 b	2.45±0.02 a	2.31±0.01 b
Fe (mg kg^{-1})	124.2±1.94 b	104.0±2.37 c	144.2±0.96 a
Cu (mg kg^{-1})	20.44±0.32 a	18.39±0.16 b	19.72±0.09 a
Mn (mg kg^{-1})	35.29±0.64 c	43.51±0.86 a	40.31±0.27 b
Zn (mg kg^{-1})	24.91±0.44 b	30.90±0.44 a	21.39±0.38 c
B (mg kg^{-1})	8.26±0.09 a	7.90±0.02 b	7.41±0.06 c
Total antioxidant activity[£] (%)	37.09±0.38 b	38.81±0.35 a	37.91±0.25 ab
Total phenolic content[£] (µg GAE/mg fresh sample)	19.27±0.38 a	18.11±0.19 b	17.60±0.22 b

[&]Between the means marked with the same letter in rows do not differ significantly (P < 0.01)
[£] Between the means marked with the same letter in rows do not differ significantly (P < 0.05)

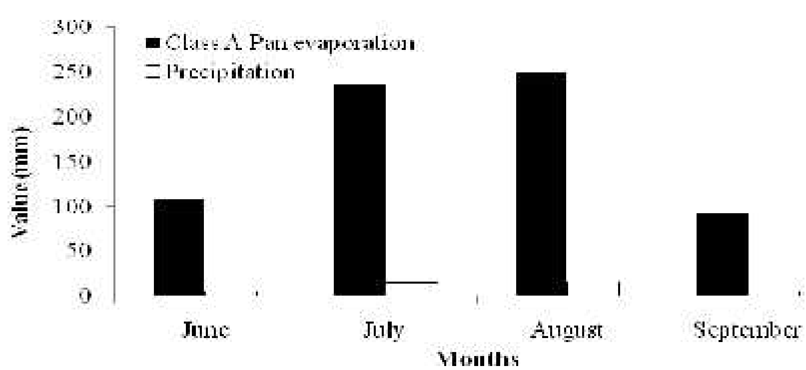

Figure 1. Montly Class A pan evaporation and precipitation values during growing period (12 June-18 September) of cucumber

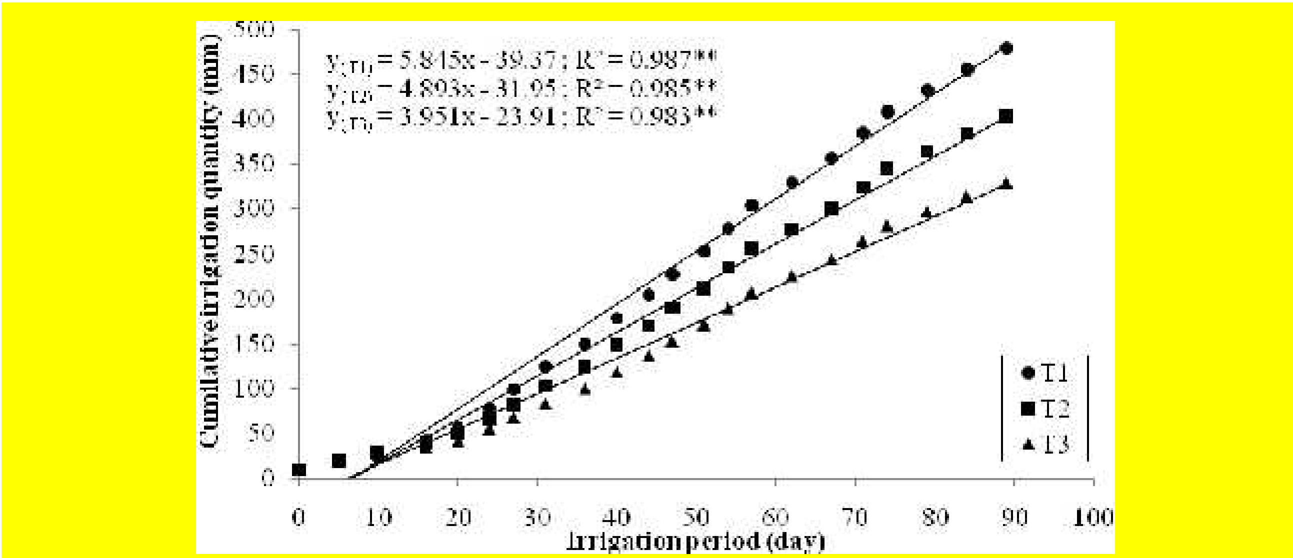

Figure 2. The change in cumulative irrigation quantities applied in different irrigation levels throughout the irrigation period (19 June-15 September) of cucumbers

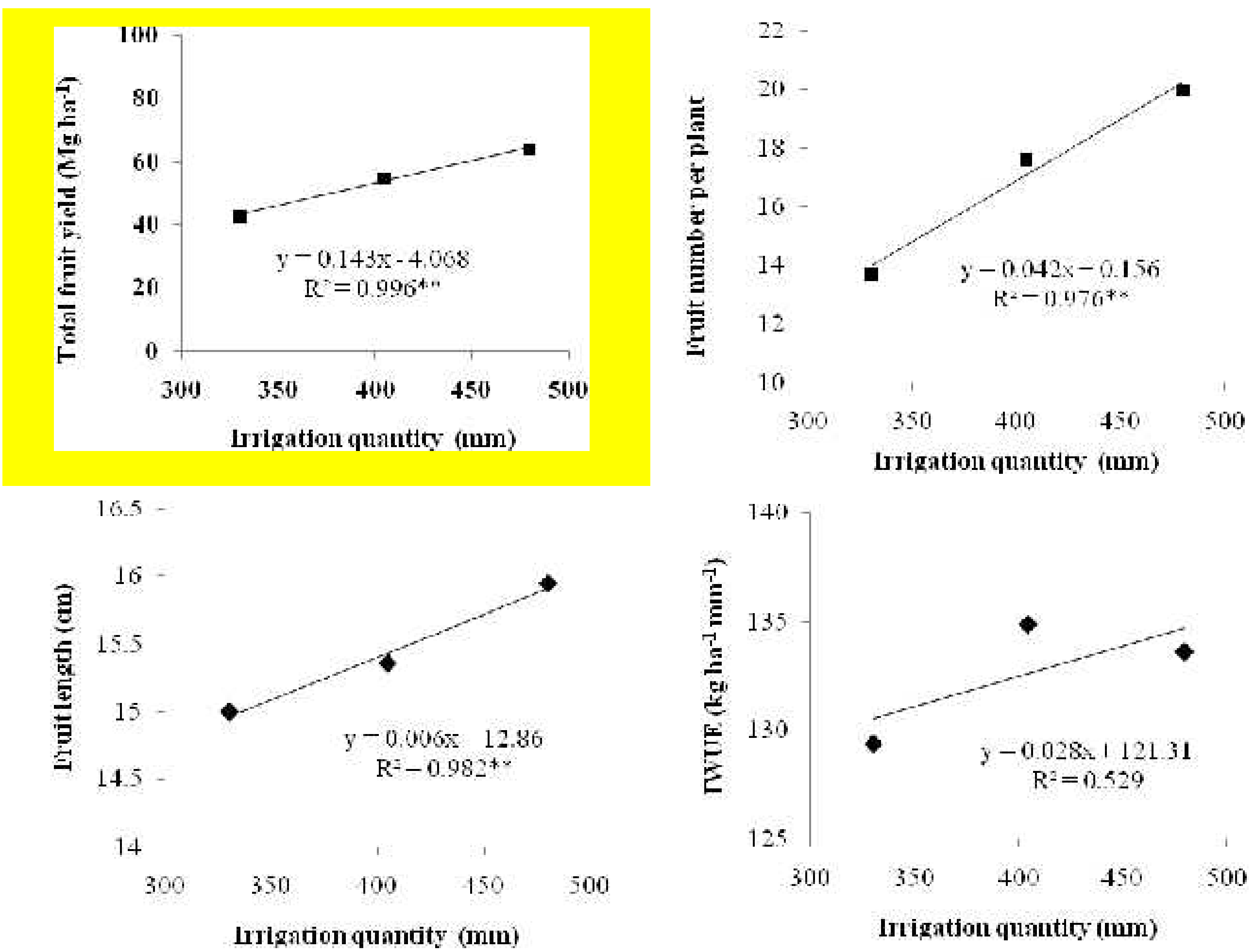

Figure 3. The relationships between total fruit yield, fruit number and length and irrigation water use efficiency of cucumber with irrigation quantity

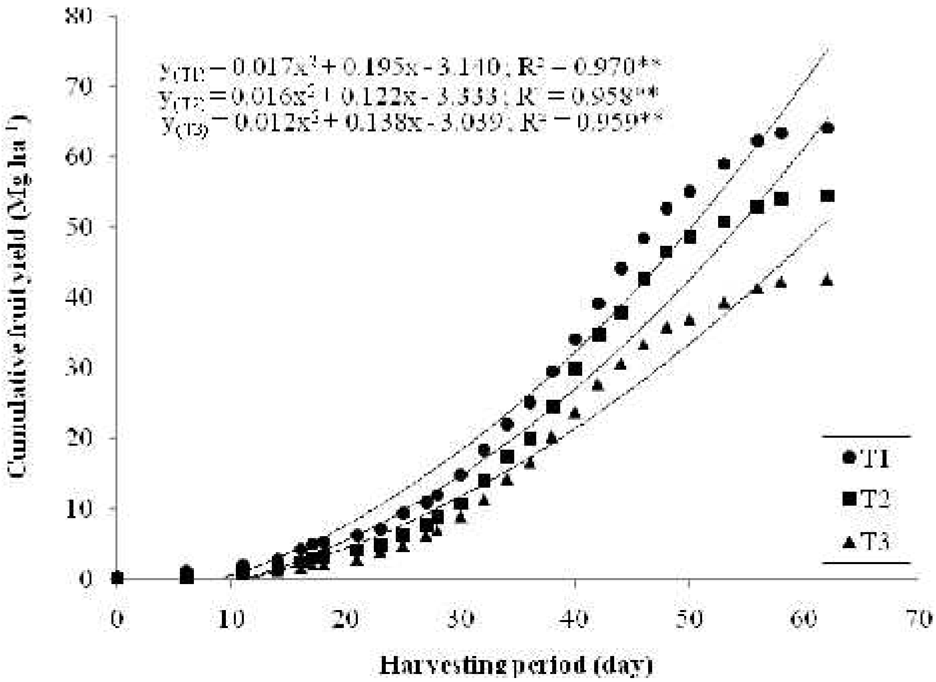

Figure 4. The change of cumulative fruit yields in different irrigation levels throughout the harvesting period (18 July–18 September) of cucumbers

Conclusions: Results of the study indicate that cucumber plants are sensitive to irrigation quantity. Therefore, water applications equal to Class A Pan evaporation by a drip system in semi-arid areas with cool climatewould be optimal for obtaining higher fruit yields. As a second result, water applications equal to 75% of the Class A Pan evaporation would be optimal for obtaining higher irrigation water use efficiency and fruit quality.

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