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THE EFFECTS OF DIFFERENT REGIMES ON TOMATO (*LYCOPERSICON LYCOPERSICUM* L. VAR. HAZAL) YIELD AND QUALITY CHARACTERICTICS UNDER UNHEATED GREENHOUSE CONDITIONS

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Abstract

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The aim of this study was to determine the effect of deficit irrigation on yield for tomato grown under unheated greenhouse condition. The research was carried out at the Agricultural Research Station of Yenişehir High School of Uludag University in Bursa, Turkey, in 2007. In the study, water was applied to tomato as 1.00, 0.75, 0.50, 0.25 and 0.00% (as control) of evaporation from a Class A Pan corresponding to 2 day irrigation frequency. Irrigation water applied ranged from 65 to 564 mm, and water consumption ranged from 95 to 568 mm. The effect of irrigation water level on the yield, fruit height, fruit diameter, fruit weight and dry matter were found to be significant. The highest yield was 91.0 t ha^{-1}. Crop yield response factor (k_y) was found as 0.99 The highest values for water use efficiency (WUE) and irrigation water use efficiency (IWUE) were found to be 17.37 and 13.92 kg m^{-3} for the $K2_{cp}$ treatment. Under the conditions that water resources are scarce, it can be recommended that $K2_{cp}$ treatment is most suitable as a water application level for tomato irrigation by drip irrigation under unheated greenhouse condition.

Key words: Evapotranspiration, water use efficiency (WUE), yield and quality parameters, irrigation scheduling

Introduction

Greenhouse technology is a breakthrough in the agricultural production technology that integrates market driven quality parameters with the production system profits (Aldrich and Barto, 1989). In the present scenario of perpetual demand of vegetables and shrinking land holding drastically, protected cultivation or Greenhouse technology is the best alternative for using land and other resources more efficiently. Greenhouses are framed structures covered with transparent or translucent material and large enough to grow crops under partial or fully controlled environmental conditions to get maximum productivity and quality produce. Greenhouse cultivation is a steadily growing agricultural sector all over the world (Enoch and Enoch, 1999; Von Elsner et al., 2000). 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.

The Greenhouse tomato is amajor vegetable crop that has achieved tremendous popularity over the last century. Tomatoes, aside from being tasty are very useful for our heath as they are a good source of Vitamins A and C. Cooked tomatoes and tomato products are the best source of lycopene, which is very powerful antioxidant and helpful in preventing the development of many form of cancer. Hence, this crop is gaining its importance both in developing and developed countries and efforts are being made for the quality and quantity production of tomato. Greenhouse is the best alternative for quality and quantity production of tomato because in addition to higher yield; the production is also free from dust, insect, disease and pest. Moreover, due to favorable environment the size of the fruit remain uniform.

Water is an important input for Greenhouse tomato because irrigation is the only source for application of water to the plants in Greenhouse. The use of drip irrigation saves water and gives better plant yield and quality as it reduces

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the humidity build up inside Greenhouse after irrigation due to precise application of water to the root zone of the crop (Papadopoulos, 1992). 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. 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 (Bar-Yosef and Sagiv, 1982; McNeeish et al., 1985; Clough et al., 1990; Hartz, 1993), allowable soil-water depletion (Bogle et al., 1989). A widely adopted method for estimating crop consumptive water use (CWU) is the pan evaporation method, which relates evaporation from a Class A pan to CWU. These two quantities are related by what is called the pan coefficient *K*. Irrigation scheduling based on the pan 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 management (Yuan et al., 2003). Based on the US Weather Bureau Class A pan evaporation, many studies have been completed on the irrigation of cucumber (Ayas and Demirtas, 2009), onion (Ayas and Demirtas, 2009), pepper (Demirtas and Ayas, 2009), lettuce (Yazgan et al., 2008), tomato (Locascio and Smajstral, 1996), gren bean (Buyukcangaz et al., 2008), potato (Ayas and Korukcu, 2010; Ayas, 2013) and broccoli (Ayas et al., 2011).

The objectives of this study were to provide a guideline for tomato growers and to determine drip irrigated tomato response to different irrigation regimes.

Materıals 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 greenhouse with the size of 8 m x 40 m using plastic coverage placed in north-south direction was used for the experiment. Climate is hot and dry in summers cold and rainy in winters. 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 August (Anonymous, 2003). 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. 300 kg ha^{-1} N, 200 kg ha^{-1} DAP (18% N and 46% P_2O_5), and 250 kg ha^{-1} KNO_3 (13% N and 46% K_2O) as granular fertilizer were applied prior to sowing and a further 85 kg ha^{-1} N as urea was added three weeks later. The experimental area was chlorphtifos-ethyl sprayed 10 L ha^{-1} to the experimental area for insects.

The seed were sown in small pot on 01 March 2007 and seedlings were transplanted to the plots – 10 April 2007 – when the plants showed four to five permanent leaves. The plants were grown 0.50 m apart between the rows with 0.75 m spacing in each row. Each plot has contained 36 plants. In order to prevent the water in any one plot from affecting its neighboring plots, only the 10 plants of middle row were harvested. Fruit weight (g), fruit diameter (cm) (two repetition in both east-west and north-south directions) and fruit height (cm) were measured by caliper rule and calculated as the average of measured values. To determine dry matter content, the fruits (two samples for each plot) were separated and dried at 65°C in a forced – air oven. Dry matter of heads and leaves was determined by the Kjeldahl method (AOAC, 2000).

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 differ-

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.

ent pan coefficients ($K1_{cp}$:1.00, $K2_{cp}$:0.75, $K3_{cp}$:0.50, $K4_{cp}$:0.25, $K5_{cp}$:0.00-control). The amount of irrigation water was calculated by using the equation given below:

$$I = E_p \, x \, K_{cp} \, x \, P,$$

where E_p is the cumulative evaporation for the 2-day irrigation interval (mm) and K_{cp} is the coefficient of pan evaporation and P is the percentage of wetted area. 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 was supplied from a deep well (3 L s^{-1}) 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:

$$ET_c = (SWC_{t0} - SWC_{t1}) + IW - D,$$

where ($SWC_{t0} - SWC_{t1}$) 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 application and monitored in 30 cm depth increments to 0.90 m after irrigation for each irrigation treatments (Lorenz and Maynard, 1980). 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 (Doorenbos and Kassam, 1979):

$$(1 - Y_a / Y_m) = k_y (1 - ET_a / ET_m),$$

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 tomato 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 (kg m^{-3}). IWUE was estimated by fallowing equation:

$$IWUE(kg \, m^{-3}) = \frac{YLD - YLD_{rainfed}}{IRGA},$$

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

In the harvest time, 126 days after the seedlings – day of year (DOY) 126 – were transplanted; the plants were fully developed and had the size, height, weight, colour and the flavour characteristics of the species. Harvested plants from each plot were evaluated immediately according to yield, fruit height, fruit diameter, fruit weight and dry matter.

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 were determined at the 0.05 and 0.01 probability levels, by the F-test (Steel and Torrie, 1980).

Results

Water applied and water used

After planting, 65 mm irrigation water was applied to all 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 564 mm in the $K1_{cp}$ treatment while the minimum amount was 65 mm in the $K5_{cp}$ treatment during the experimental year. The amount of water applied to other treatments ranged between 129-431 mm values. Seasonal evapotranspiration (ET_c) was increased with the applied irrigation water. The actual evapotranspiration ranged between 95 to 568 mm values for $K5_{cp}$ and $K1_{cp}$ treatments, respectively (Table 3).

Table 2
Chemical composition of irrigation water used in the experiment

Water source	EC_{25}x10^6 µmhos cm^{-1}	Na^+	K^+	Ca^{++}	Mg^{++}	pH	Class	SAR
		(me L^{-1})						
Deep well	715	2.3	2.56	9.25	5.7	7.12	C_2S_1	0.85

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

Irrigation treatment	Yield, t ha^{-1}	Applied Water, mm	Eta, mm	ET_a/ET_m	Y_a/Y_m	$1-(ET_a/ET_m)$	$1-(Y_a/Y_m)$	k_y
$K1_{cp}$	91.0	564	542	1.000	1.000	0.000	0.000	0.000
$K2_{cp}$	74.0	431	410	0.750	0.813	0.250	0.187	0.747
$K3_{cp}$	45.0	275	295	0.500	0.495	0.500	0.505	1.011
$K4_{cp}$	22.0	129	176	0.250	0.242	0.750	0.758	1.011
$K5_{cp}$	14.0	65	88	0.167	0.154	0.833	0.846	1.016

Linear relationships were observed between the crop evapotranspiration (ET_c) and yield (Y_a). The equation for the relationship was:

$Y_a = 0.1673ET_c - 1.4787$ with, $R^2 = 0.99$ (Figure 1)

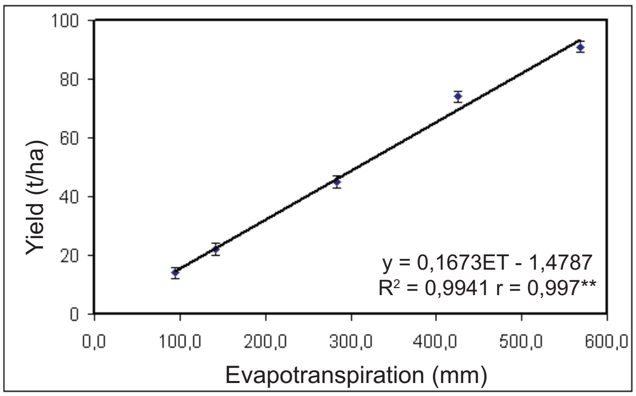

Fig. 1. The relationship between crop evapotranspiration and yield. (The errors bars are SE of 10 plants)

In our study, treatment $K1_{cp}$ had the highest yield 91.0 t ha^{-1} followed by $K2_{cp}$, $K3_{cp}$, and $K4_{cp}$ irrigation treatments with 74.0 t ha^{-1}, 45.0 t ha^{-1} and 22.0 t ha^{-1}, respectively. As expected, non-irrigated treatment control $K5_{cp}$ had the lowest yield. The non irrigated treatment ($K5_{cp}$) produced 550 % lower yield than the $K1_{cp}$ treatment. However $K2_{cp}$, $K3_{cp}$, and $K4_{cp}$ had 23 – 313.6% less yield compared with treatment $K1_{cp}$ (Table 4).

Water deficits, particulary in the three or four week prior to harvest, lower crop yields and quality. Deficit irrigation had a significant effect on fruit height but, the values of $K1_{cp}$, $K2_{cp}$, $K3_{cp}$, $K4_{cp}$ and $K5_{cp}$ treatments were placed in the same group. It can be concluded that the deficit of applied irrigation water (25%) is not compatible with the reduction in fruit diameter. Positive linear relation was found among fruit height, fruit diameter and fruit weight, negative linear relation was found between dry matter and amount of water applied (IW). The equation for the relationship was: fruit height = $0.0061IW + 3.2085$ with $R^2 = 0.99$ (Figure 2a), fruit diameter = $0.0099IW + 2.5999$ with $R^2 = 0.99$ (Figure 2b), fruit weight = $0.2041IW - 98.242$ with $R^2 = 0.93$ (Figure 2c),

Table 4
Effects of irrigation treatments on tomato marketable parameters

Irrigation treatment	Fruit Height, cm	Fruit Diameter, cm	Fruit Weight, g	Dry matter, %	Yield, t ha^{-1}
$K1_{CP}$	6.5a	8.0a	202.0a	6.0e	91.0a
$K2_{CP}$	6.0ab	7.0ab	196.0a	7.4d	74.0b
$K3_{CP}$	5.0bc	5.5bc	162.0b	10.1c	45.0c
$K4_{CP}$	4.0cd	4.0cd	132.0c	12.3b	22.0d
$K5_{CP}$	3.5d	3.0d	98.0d	14.0a	14.0e
Treatments	**	**	**	**	**
Blocks	ns	ns	ns	ns	ns

** Significant at the P<0.01, * Significant at the P<0.05, ns: Not significant and dry matter = - 0.0159IW + 14.62 with R^2 = 0.99 (Figure 2d.), treatment.

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 (Stewart et al., 1975; Doorenbos and Kassam, 1979). Seasonal yield response factor was determined as 0.99 for irrigation treatments (Figure 3). Values of k_y increased with increasing water deficit except in $K5_{cp}$.

Water use efficiencies

WUE and IWUE values decreased when irrigation water amount decreased. The highest WUE and IWUE was obtained from treatment $K2_{cp}$, 17.37 and 13.92 kg m^{-3} respectively. When considering IWUE values of $K1_{cp}$ and $K2_{cp}$ treatments, IWUE values of $K2_{cp}$ treatments was found higher than that of $K1_{cp}$ treatment and followed by $K3_{cp}$ (Table 5).

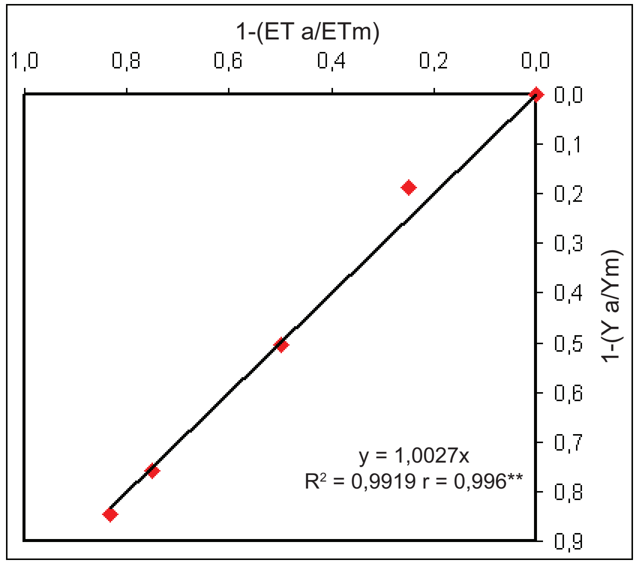

Fig. 3. Relationship between relaative yield decrease and relative crop evapotranspiration for tomato throughout the total growing season

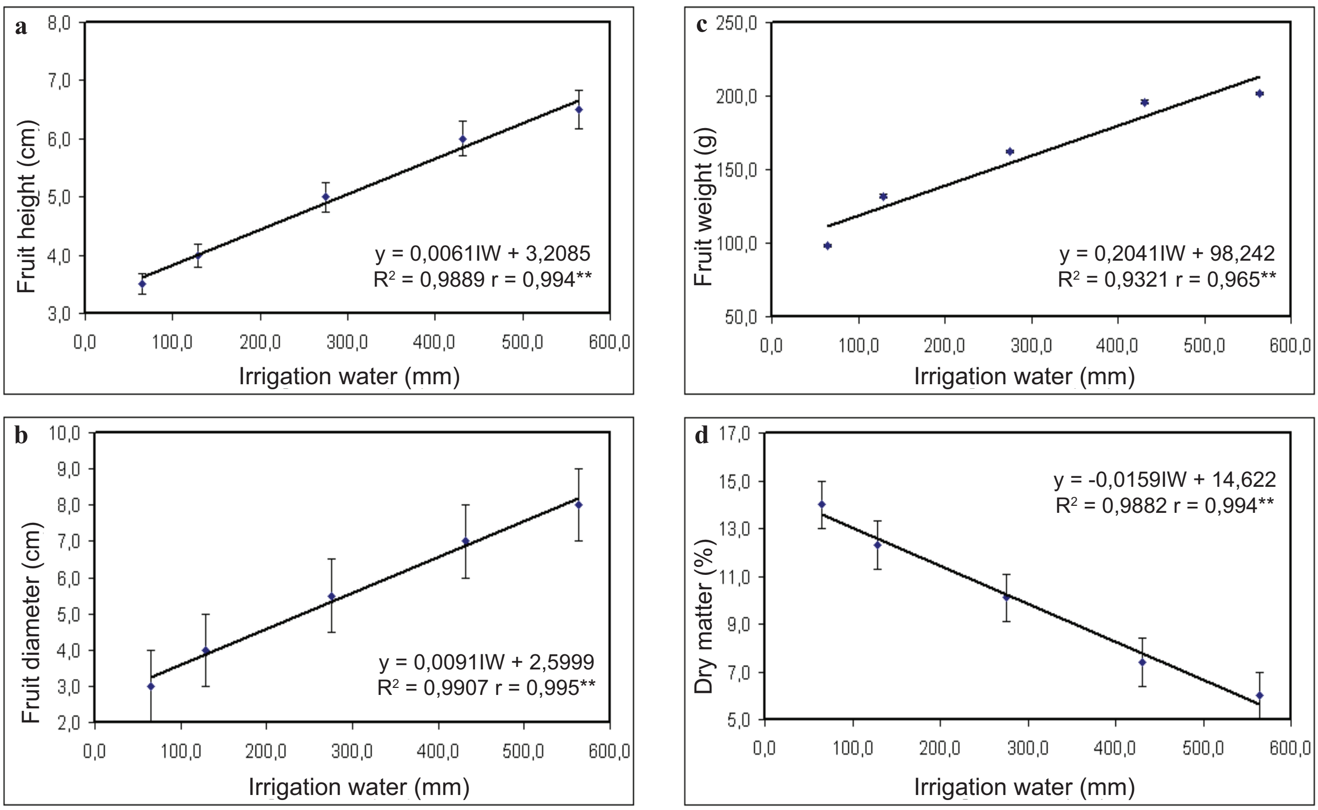

Fig. 2. Relationship between applied of irrigation water and fruit height (2a), fruit diameter (2b), fruit weight (2c) and dry matter (2d). (The errors bars are SE of 10 plants)

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

Irrigation treatment	Yield, t ha^{-1}	WUE, kg m^{-3}	IWUE, kg m^{-3}
$K1_{cp}$	91.0	16.02	13.65
$K2_{cp}$	74.0	17.37	13.92
$K3_{cp}$	45.0	15.85	11.27
$K4_{cp}$	22.0	15.49	6.20
$K5_{cp}$	14.0	14.74	0.00

Dıscussion

In this study, irrigation treatments significantly affected yield, fruit height, fruit diameter, fruit weight and dry matter. Water applied for tomato ranged from 415 to 800 mm under different controling sistems (Mahajan and Singh, 2006). Total seasonal evapotranspiration by tomato for spring and fall planted varied from 274 - 447 mm and irrigation water applied varied from 173 - 456 mm (Kirda et al., 2004). Hanson and May (2004) reported that for three years and under drip and sprinkler methods avarage of cumulative crop ET values varied from 516 - 676 and applied water values varied from 406 - 737 mm in the San Joaquin Valley of California, USA. Yohannes and Tadesse (1998) also reported that water consumptive use was 670 mm in Dire Dawa Ethiopia. Wan et al. (2007) reported that for three years, avarage of evapotranspiration of tomato was 607 mm/season for drip irrigation with saline water. Seasonal evapotranspiration varied from 405 mm to 946 mm and irrigation water applied from 271 mm to 832 mm in Eskişehir between 1998 and 2000 years (Çetin et al., 2002). Cumulative ET was found to be in the range of 451 to 626 mm as soil water tension increased from 300 kPa to 500 kPa, corresponding to 5.22 and 3.76 mm/day, respectively (Nuruddin, 2001). Our results are in harmony with these earlier researches.

According to results, there was effect of deficit irrigation on single fruit weight in terms of marketable value. This result was in agreement with İmtiyaz et al. (2000) and Topcu et al. (2007). The fruit diameter and fruit weight had a similar response to deficit irrigation like yield. All irrigation treatments had higher values than the non-irrigated ($K5_{cp}$) treatment. Our result are in agreement with Sezen et al. (2010), Favati et al. (2009), Chartzoulakis and Drosos (1999).

The yield ranged from 14 t ha^{-1} to 91 t ha^{-1}. Similar results under different irrigation regimes have been obtained in the previous research (Vazquez et al., 2006; Gajc-Wolska, 2002; Singandhupe et al., 2003; Patane and Cosentino, 2010; Wang et al., 2007).

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 fruit weight observed from $K1_{cp}$ treatment than those of deficit irrigation treatments. These results are similar to Birhanu and Tilahun (2010), Nurzynski (2006), Wuzhong (2002).

Conclusions

Under the conditions that water resources are scarce, it can be recommended that $K2_{cp}$ treatment is most suitable as a water application level for tomato irrigation by drip irrigation under the unheated greenhouse condition.

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