Turkish Journal of Agriculture - Food Science and Technology, 7(9): 1328-1338, 2019
DOI: https://doi.org/10.24925/turjaf.v7i9.1328-1338.2553

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology

Water-Yield Relationships of Deficit Irrigated Pepper (*Capsicum Annuum L. Demre*)

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ARTICLE INFO

Research Article

Received : 23/03/2019
Accepted : 27/08/2019

Keywords:
Evapotranspiration
Crop yield response factor (ky)
WUE and IWUE values
Yield and quality parameters,
Irrigation planning

ABSTRACT

This trial was realized in the greenhouses of Uludag University Yenisehir Vocational School between 2009 and 2010 to investigate effects of water deficit on yield and quality parameters of pepper during four crop growth stages. In this study, fourteen irrigation treatments in four growth periods (vegetative, flowering, yield formation and ripening) of pepper (*Capsicum annuum l. Demre*) were constituted and the yield and quality parameters found from these treatments were evaluated. The layout of the experiment was a completely randomized block design with three replications for each of the fourteen irrigation treatments tested. According to the content of the treatments, the irrigation amount water applied to the plants varied between 0 and 744 mm in the first year, and between 0 and 750 mm in the second year. Water consumption of pepper in the first year ranged between 320 and 760 mm and in the second year ranged between 330 and 770 mm. Yield, fruit weight, diameter, length and dry matter ratio were determined statistically significant. In 2009 and 2010 years, the maximum yield were found as 26.2 t ha^{-1} and 27.8 t ha^{-1} in $V_{100}F_{100}Y_{100}R_{100}$ treatments, while the minimum yield were found as 0.2 t ha^{-1} and 0.3 ha^{-1} in the $V_0F_0Y_0R_0$ treatments, respectively. Water- yield relationship factors (k_y) in 2009 and 2010 years were found as 1.29 and 1.24, respectively. The maximum WUE and IWUE values were obtained from vegetative and ripening periods. Vegetative and ripening periods may be suggested as the maximum efficient irrigation periods for the pepper applied with drip irrigation under unheated greenhouse conditions.

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Introduction

As water demand of growing population continues to rise rapidly and new sources of supply become scarcer, the efficient use of water is increasingly important. As water demand increases in all sectors, ground water is depleted, water ecosystems are polluted, and water resources development is becoming more costly. Since agriculture accounts for 75% of water consumption in our country, even small improvements in irrigation water use efficiency may contribute significant quantities of water available to further irrigation or to other users (Çakmak and Gökalp, 2011).

Van Straten et al. (2010), stated that protected is worldwide the fastest growing sector of all agricultural production activities. There are two essential causes for this. First, the plants are grown in greenhouse differently from the open field, in this way supplying in a sort of way of abri from the flat-out effect of the exterior air conditions. This allows the production of crops at that specific place. Second, the greenhouse allows to be produced of many crops. Thus, grower allows the farming to come true as desired. It also offers advantages such as higher yield, longer production period, better quality and less use of chemicals. The value added per unit surface area in greenhouse crops is much higher than that in open field.

According to 2017 FAOSTAT; the US, Germany are the United Kingdom are the world's three biggest pepper importers with 1.0, 0.4, 0.2 million tons, respectively. Mexico is the largest pepper exporting country with 0.95 million tons. Turkey is one of the significant pepper exporters with Turkey 97 312 tons in the world (FAOSTAT, 2017). According to TUIK 2018 data, the pepper production of Bursa province was 163 347 tons (Anonymous, 2016).

Pepper as a member of genus Capsicum of Solanaceae family is known as an annual plant in temperate climates and perennial plant in tropical climates. Researchers and botanists acknowledge that the main homeland of pepper is tropical America (Brazil) and spread from there to the world. Before America's discovery, pepper was not recognized in other continents, especially in Europe. A limited amount of peppers produced in our country are exported as fresh, pickles, pepper paste, dried or as red chili powder, roasted pepper (Vural et al., 2000).

Sezen (2005) found that surface irrigation is not suggested due to low irrigation efficiency originated from salinity and drainage problems in irrigated areas. From a different viewpoint, traditional irrigation systems where excess water inputs and poor drainage occur, cause environmental problems such as salinity and water logging. In irrigation methods where irrigation water is used efficiently don't have the problems of conventional irrigation methods (Buyukcangaz et al., 2007). Thus, the use of less water consuming irrigation methods is importance with regard to irrigation planning (Anonymous, 2005). The objectives of irrigation planning is to prevent the soil moisture level falling below the critical line for a specific soil and crop condition. This may enable to avoid the harmful effect of water stress by means of estimating the earliest date (Ritchie and Johnson, 1990).

Irrigation planning with drip irrigation relies on approachments connected with evapotranspiration estimations (Bar-Yosef and Sagiv, 1982; McNeeish et al., 1985; Clough et al., 1990; Hartz, 1993) and permissible soil-water depletion (Bogle et al., 1989). *Ky* represents the declines in the yield as a result of each deficit level in water consumption. *Ky* values usually difficult to create accurately. *Ky* values are affected by regional conditions, soil properties, crop physiology and cultural practices. A suggested *Ky* value for irrigation planning must be high enough to avoid the water stress caused by the needs and specific local situations. It remains low enough for water management (Yuan et al., 2003). Some studies have been realized to investigate the effect of deficient irrigation on pepper (Gencoglan et al., 2006; Sezen et al., 2006; Demirtas and Ayas, 2009). The purposes of this experiment were to obtain a prospectus for pepper growers and to determine drip irrigated pepper response to deficit irrigation regimes in Bursa conditions.

Material and Methods

The study was realized in Yenisehir Vocational School, Bursa in 2009 and 2010 years. For practical purposes, plastic greenhouse (8 m × 40 m) was used. In the study place, wintertime's are cold and summertime's are hot. The average annual rainfall and temperature values for the region where the greenhouse experiments were made in 2009 and 2010 were 531.3-804.4 mm and 13.3-14.6°C, respectively. While the average minimum temperature for 2009 and 2010 were -3.6 - (5.9)°C between January and December, the average maximum temperature in August was measured as 30.6 and 34.6°C (Anonymous, 2011a). Maximum and minimum temperature values in greenhouse during the plant growing period (91 days) were 38-38°C and 0.9-1.3°C, respectively in 2009-2010 years (Figure 1 and 2). The highest and lowest relative humidity values in greenhouse in 2009 and 2010 years were found as 88-87% and 39-39%, respectively (Figure 3). In addition, the highest and lowest radiation values in greenhouse in 2009-2010 years were measured as 1974-1542 W/m^2 and 335-139 W/m^2, respectively (Figure 4) (Anonymous, 2011b).

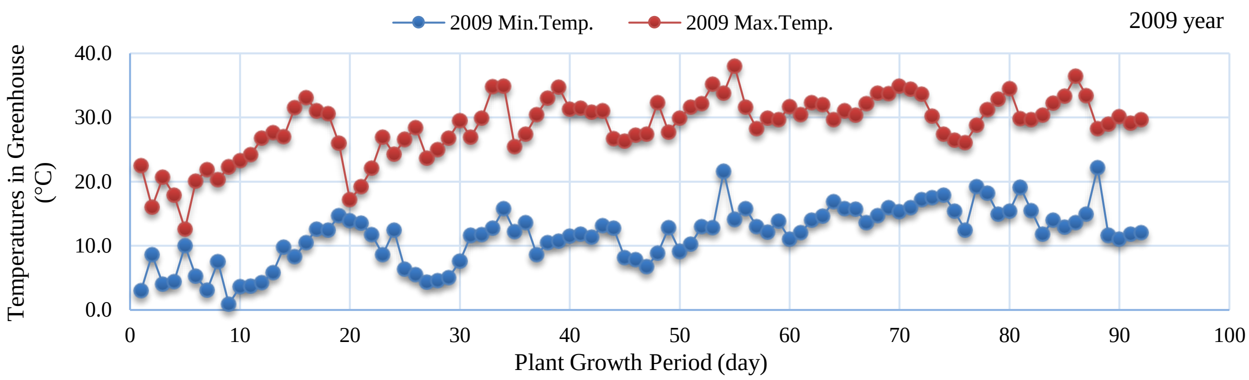


Figure 1 Temperatures in greenhouse during the plant growth period in 2009 year

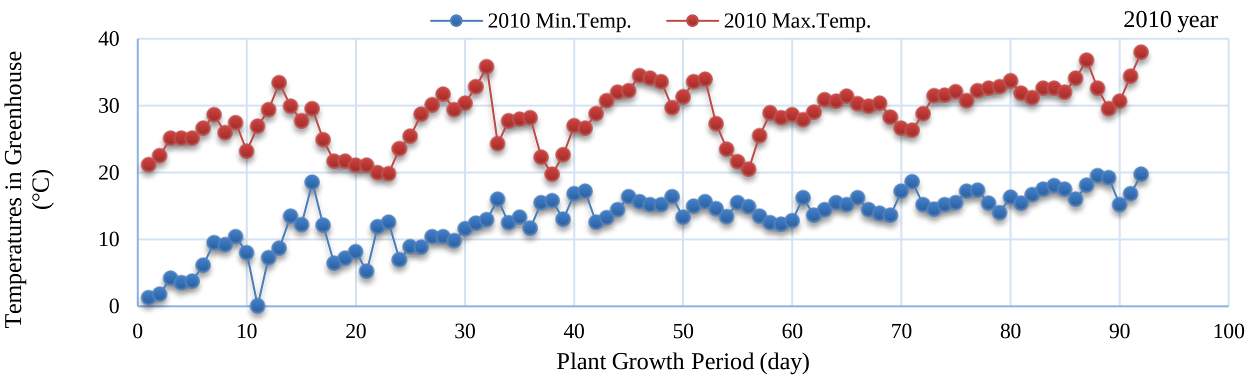


Figure 2 Temperatures in greenhouse during the plant growth period in 2010 year

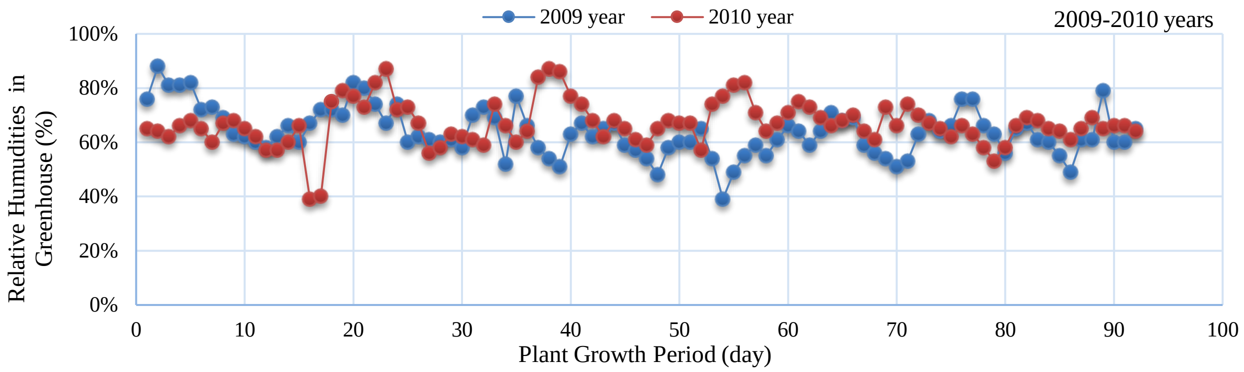


Figure 3 Relative humidities in greenhouse during the plant growth period in 2009-2010 years

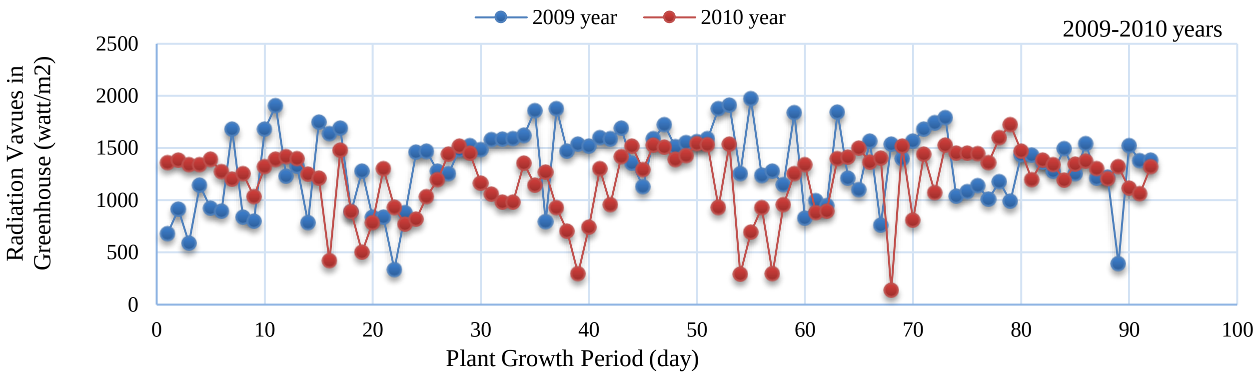


Figure 4 Radiation values in greenhouse during the plant growth period in 2009-2010 years

Table 1 Some specific properties of the experimental soil

Soil Depth (cm)	Soil Type	Unit Weight (gr cm^{-3})	Field Capacity (%)	Wilting Point (%)	pH	Total Salt (%)	$CaCO_3$ (%)	Organic Matter (%)
0-30	SL	1.34	29.73	21.74	7.99	0.037	16.5	2.92
30-60	SL	1.37	27.26	19.37	8.04	0.031	29.5	1.39
60-90	SL	1.58	33.92	23.72	7.86	0.034	31.5	1.08
90-120	SL	1.50	36.30	27.73	8.05	0.032	33.0	0.94

SL: Sandy Loam

The soil of study place was sandy clay and pH value of soil ranged between 7.86 and 8.05. The specific features of the soil are given in Table 1.

Demre F1 variety was used in the study. Demre F1 is a mid-early type and its fruits are around 15-22 cm. The fruit flesh of Demre F1 is thick and the fruits are bright. The plant of Demre F1 has many branches and its development is very good. In the first harvest of the Demre F1 variety, the fruits are sweet and in the later harvests fruits are bitter. This variety has a wide adaptability and high efficiency. In addition, this variety is tolerant to diseases and insects. In the experimental area, an irrigation well was utilized as the source and the water was of the class C_1S_1 after the analysis done. NPK 15-15-15 fertilizer was sprinkled on the soil by hand before planting the seedlings as bottom fertilizer. The application depth of the fertilizer ranged from 15 to 20 cm depending on the soil structure and the root depth of the plant grown. NPK 15-15-15 fertilizer was utilized to trial plots while the peppers were being planted, and 750 kg of NPK 15-15-15 fertilizer per hectares were utilized. The urea form of the nitrogen was applied to the plots together with the irrigation water. The first manure was applied as 250 kg/ha (% 46 N) in the flowering stage and the second fertilizer was utilized as 250 kg/ha in yield formation stage together with the irrigation water. Furthermore, in 2009 and 2010 years, 250 kg of magnesium nitrate manure per hectares (11 – 0 – 0 + 16 MgO - Nitrogen 11% and MgO 16%) were used in the flowering and early yield formation stages to support the generative development. In the greenhouse was chlorphtifos-ethyl sprayed 10 L ha^{-1} to the peppers for insects.

The plots of the randomized experimental design were formed with three replications and 14 trial treatments were randomly scattered. The size of the experimental plots was 4 m^2 (2.0 m × 2.0 m). The distances between the plots were 0.80 m and blocks were placed with 1.5 m distances. The pepper seeds (Demre F1) were sown in viyols on 10 April 2009 and on 06 April 2010 in the experimental years. The pepper seedlings were transplanted to the plots on 10 May 2009 and on 07 May 2010. The seedlings were grown with 20 cm intervals on the same row and with 10 cm intervals between the plant lines. Into each plot, 126 plants were planted.

Some quality parameters of pepper are yield, fruit weight, diameter, length and dry matter ratio. The fruit weight was determined by weighting 36 plants in the harvest part and fruit diameter and height were calculated by gauging the weighted fruit with a ruler and by taking the average of these values. The dry matter ratio was obtained after they were dried at 65°C in a drying oven for 48 h and fruit dry matter ratio was calculated. The detail of the experimental plot is shown in Figure 5.

In different growth periods of pepper (Vegetative (V), flowering (F), yield formation (Y) and ripening (R)) fourteen deficit irrigation treatments were formed depending on full or deficit irrigation treatments. 75-50-25% of the deficit irrigations were applied in different growth stages of the plant, while 100% of irrigation water was used in full irrigation treatment. In line with this planning, irrigation treatments were planned like this: $V_{100}F_{100}Y_{100}R_{100}$, $V_{75}FYR$, $V_{50}FYR$, $V_{25}FYR$, $VF_{75}YR$, $VF_{50}YR$, $VF_{25}YR$, $VFY_{75}R$, $VFY_{50}R$, $VFY_{25}R$, $VFYR_{75}$, $VFYR_{50}$, $VFYR_{25}$, $V_0F_0Y_0R_0$ (Table 2.).

The drip irrigation equipment in greenhouse used in the study was given in Figure 6.

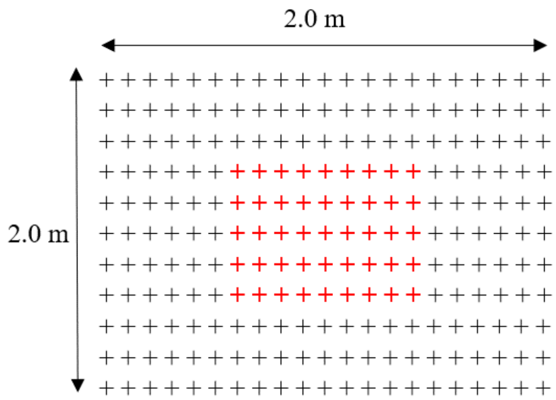
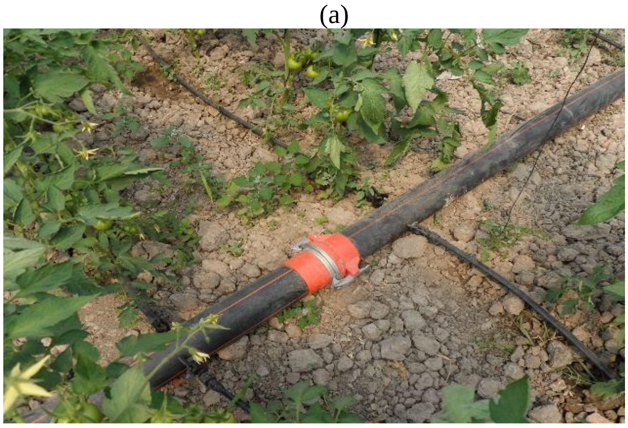


Figure 5 The detail of a plot

(a)



(b)

Figure 6 (a) Drip irrigation system, (b) Main and lateral pipes

In the trial, the plants were irrigated by drip irrigation method and water was used an irrigation well. Some features of the irrigation water were given in Table 3. The irrigation water has low-sodium risk and medium EC and its class in C_2S_1 class. C2S1 irrigation water quality class has low sodium and medium electrical conductivity (salinity). Water in the C2S1 quality class can be used for be irrigated medium and highly resistant plants to salinity. In addition, C1S1 quality class water can be used in all plants and soil without creating harmful alkalinity. A study has been conducted on irrigating pepper by using C2S1 quality class water (Ashraf and Ewees, 2008).

In four growth stages the soil moisture contains of the soil was followed before and after irrigation with a gravimetric method in every 30 cm up to 120 cm depth. The water balance equation was used to calculate evapotranspiration (ET), (Eq. 1) (Howell et al., 1995).

$$ET = I + P - R_f - D_p \pm \Delta S \tag{1}$$

Where, ET represents the evapotranspiration, I shows the irrigation water amount during the period (mm), P is the total precipitation, R_f is the amount of the surface flow (mm), D_p indicates the deep drainage (mm) and ΔS is the soil water content at the beginning and end of the period (mm/120 cm). Before planting seedlings, water was given to the crop by the drip irrigation method. Total precipitation (P) and surface flow (R_f) were omitted due to the plant production in the greenhouse. The soil water in the deeper than 120 cm was taken as the deep drainage (D_p) and the deep drainage (Dp) was neglected. The intervals of lateral were equal to the plant row intervals in the trial. Therefore the percentage of wetted area was calculated by the equation as follows (Eq. 2) (Güngör and Yıldırım, 1989).

$$P = \frac{Sd}{Sl} 100 \tag{2}$$

Where P is the percentage of wetted area, Sd and Sl are the interval of dripper and the intervals of lateral, respectively. The amount of irrigation water to be applied in each irrigation (Eq.3) was found by the equation given below.

$$dn = \frac{(FC\text{-}WP)Ry}{100}\, ɣt\, D\, \frac{P}{100} \tag{3}$$

Where dn is the amount of irrigation water to be applied in each irrigation, FC and WP are the field capacity and wilting point, respectively. ɣt is the soil bulk density, D is wetted soil depth, P is the percentage of wetted area. In this study, the relationships between yield and ET was described by Steward Model (Eq.4) (Stewart et al., 1975; Doorenbos and Kassam, 1979). The equation can be given as;

$$\left(1 - \frac{Ya}{Ym}\right) = ky\left(1 - \frac{ETa}{ETm}\right) \tag{4}$$

Where Y_m (t/ha) and Y_a (t/ha) are maximum and actual yield, respectively, ET_m (mm) and ET_a (mm) are maximum and actual evapotranspiration, respectively. The yield response factor is shown as k_y. WUE values were determined to assess irrigation efficiency in treatments. WUE and IWUE terms refer to contribution of irrigation water to effective use of plant production stages (Bos, 1980). WUE was calculated by dividing the fruit yield by seasonal evapotranspiration (ET). (ET). IWUE was predicted as (Eq.5) (Zhang et al., 1999):

$$IWUE=\frac{(Y1-YNI)}{I} \quad (5)$$

Where Y_1 is fruit yield of irrigated treatments (t ha $^{-1}$) and Y_{NI} is the fruit yield of non-irrigated treatment (t ha $^{-1}$) and I is the amount of irrigation water (mm). The water content of the soil up to 120 cm depth was calculated before the seedlings were planted into the soil. Before starting irrigations, moisture level of the soil was completed to the level of field capacity in all treatments. Irrigation was begun on May 10 in 2009 and May 07 in 2010 and it was repeated every 7 days. Because of the moisture level in the soil was fulfilled to the field capacity before planting the seedlings, there was no need to apply sap after planting. The irrigation water amounts for the four growth periods of pepper were given in Table 4. Crop evapotranspiration for growth periods of pepper were given in Table 5.

Yield and quality parameters were evaluated. Variance analysis of yield and quality parameters were evaluated according to LSD multiple comparison test (P<0.05). Variance analysis was done with the values of yield productivity and quality parameters by using MSTAT-C and MINITAB software (Steel and Torrie, 1980).

Table 2 The experimental treatments

Treatments	Growth Stages			
	Establishment	Vegetative	Yield Formation	Ripening
$E_{100}V_{100}Y_{100}R_{100}$	+	+	+	+
$E_{75}VYR$	%25 deficit irrigation	+	+	+
$E_{50}VYR$	%50 deficit irrigation	+	+	+
$E_{25}VYR$	%75 deficit irrigation	+	+	+
$EV_{75}YR$	+	%25 deficit irrigation	+	+
$EV_{50}YR$	+	%50 deficit irrigation	+	+
$EV_{25}YR$	+	%75 deficit irrigation	+	+
$EVY_{75}R$	+	+	%25 deficit irrigation	+
$EVY_{50}R$	+	+	%50 deficit irrigation	+
$EVY_{25}R$	+	+	%75 deficit irrigation	+
$EVYR_{75}$	+	+	+	%25 deficit irrigation
$EVYR_{50}$	+	+	+	%50 deficit irrigation
$EVYR_{25}$	+	+	+	%75 deficit irrigation
$E_0V_0Y_0R_0$	-	-	-	-

+: Water application in the specified period, -: Without irrigation

Table 3 Specific properties of irrigation water used in the trial

Water Source	$EC_{25} \times (10^6)$	Na^+ (me L^{-1})	K^+ (me L^{-1})	Ca^{2+} (me L^{-1})	Mg^{2+} (me L^{-1})	pH	Class	SAR
Deep well	715	2.3	2.56	9.25	5.7	7.12	C_2S_1	0.85

Table 4 The irrigation water applied for four growth stages

Treatments	Irrigation Water (mm)									
	Vegetative		Flowering		Yield Formation		Ripening		Total	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
$V_{100}F_{100}Y_{100}R_{100}$	180	178	220	220	240	248	104	104	744.0	750.0
$V_{75}FYR$	135	134	220	220	240	248	104	104	699.0	706.0
$V_{50}FYR$	90	89	220	220	240	248	104	104	654.0	661.0
$V_{25}FYR$	45	44	220	220	240	248	104	104	609.0	616.0
$VF_{75}YR$	180	178	165	165	240	248	104	104	689.0	695.0
$VF_{50}YR$	180	178	110	110	240	248	104	104	634.0	640.0
$VF_{25}YR$	180	178	55	55	240	248	104	104	579.0	585.0
$VFY_{75}R$	180	178	220	220	180	186	104	104	684.0	688.0
$VFY_{50}R$	180	178	220	220	120	124	104	104	624.0	626.0
$VFY_{25}R$	180	178	220	220	60	62	104	104	564.0	564.0
$VFYR_{75}$	180	178	220	220	240	248	78	78	718.0	724.0
$VFYR_{50}$	180	178	220	220	240	248	52	52	692.0	698.0
VFYR25	180	178	220	220	240	248	26	26	666.0	672.0
$V_0F_0Y_0R_0$	0	0	0	0	0	0	0	0	0.0	0.0

Table 5 Crop evapotranspiration for different growth stages

Treatments	Crop Evapotranspiration (mm)									
	Vegetative		Flowering		Yield Formation		Ripening		Total	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
V100F100Y100R100	160	164	220	220	240	246	140	140	760	770
V75FYR	155	162	210	215	232	220	128	127	725	724
V50FYR	136	142	214	215	214	216	116	107	680	680
V25FYR	126	130	212	212	188	190	116	114	642	646
VF75YR	147	145	218	216	226	238	133	135	724	734
VF50YR	148	148	220	218	208	203	104	112	680	681
VF25YR	136	135	190	195	196	184	102	114	624	628
VFY75R	149	147	216	212	230	236	125	127	720	722
VFY50R	129	132	215	226	200	208	112	92	656	658
VFY25R	120	125	186	180	205	208	93	95	604	608
VFYR75	155	157	220	218	236	243	139	133	750	751
VFYR50	152	158	218	216	236	232	130	136	736	742
VFYR25	154	160	220	220	235	242	93	89	702	711
V0F0Y0R0	70	70	90	90	100	100	60	70	320	330

Table 6 Relationship between yield and yield response factor (ky) with the decrease in water use, for pepper in 2009 and 2010 years.

Treatment	Y	AW	E	E/E	Y/Y	1-E/E	1-Y/Y	ky	ky
V100F100Y100R100	26.2	744.0	760.0	1.000	1.000	0.000	0.000	0.000	0.000
V75FYR	25.5	699.0	725.0	0.954	0.973	0.046	0.027	0.580	
V50FYR	24.1	654.0	680.0	0.895	0.920	0.105	0.080	0.761	0.652
V25FYR	23.7	609.0	642.0	0.845	0.905	0.155	0.095	0.615	
VF75YR	23.3	689.0	724.0	0.953	0.889	0.047	0.111	2.337	
VF50YR	22.9	634.0	680.0	0.895	0.874	0.105	0.126	1.197	1.469
VF25YR	22.4	579.0	634.0	0.834	0.855	0.166	0.145	0.875	
VFY75R	21.8	684.0	720.0	0.947	0.832	0.053	0.168	3.191	
VFY50R	21.0	624.0	656.0	0.863	0.802	0.137	0.198	1.450	1.925
VFY25R	20.1	564.0	604.0	0.795	0.767	0.205	0.233	1.134	
VFYR75	26.0	718.0	740.0	0.974	0.992	0.026	0.008	0.290	
VFYR50	25.8	692.0	736.0	0.968	0.985	0.032	0.015	0.483	0.375
VFYR25	25.5	666.0	702.0	0.924	0.973	0.076	0.027	0.350	
V0F0Y0R0	0.2	0.0	320.0	0.421	0.008	0.579	0.992	1.714	1.669
									1.29
Treatment	Y	AW	E	E/E	Y/Y	1-E/E	1-Y/Y	ky	ky
V100F100Y100R100	27.8	750.0	770.0	1.000	1.000	0.000	0.000	0.000	0.000
V75FYR	25.9	706.0	724.0	0.940	0.932	0.060	0.068	1.144	
V50FYR	25.5	661.0	680.0	0.883	0.917	0.117	0.083	0.708	0.826
V25FYR	25.0	616.0	646.0	0.839	0.899	0.161	0.101	0.625	
VF75YR	24.2	695.0	734.0	0.953	0.871	0.047	0.129	2.770	
VF50YR	24.0	640.0	681.0	0.884	0.863	0.116	0.137	1.183	1.591
VF25YR	23.6	585.0	628.0	0.816	0.849	0.184	0.151	0.819	
VFY75R	23.5	688.0	722.0	0.938	0.845	0.062	0.155	2.481	
VFY50R	22.9	626.0	658.0	0.855	0.824	0.145	0.176	1.212	1.550
VFY25R	22.2	564.0	608.0	0.790	0.799	0.210	0.201	0.957	
VFYR75	27.5	724.0	751.0	0.975	0.989	0.025	0.011	0.437	
VFYR50	27.2	698.0	742.0	0.975	0.978	0.025	0.022	0.875	0.563
VFYR25	27.0	672.0	711.0	0.923	0.971	0.077	0.029	0.376	
V0F0Y0R0	0.3	0.0	330.0	0.429	0.011	0.571	0.989	1.731	1.759
									1.24

Y: Yield (t ha^{-1}), AW: Applied Water (mm), E: ETa (mm), E/E: ETa/ETm, Y/Y: Ya/Ym,

Results

In 2009 and 2010 years, the highest irrigation water was found in $V_{100}F_{100}Y_{100}R_{100}$ treatment as 744 – 750 mm and minimal irrigation water was found in $V_0F_0Y_0R_0$ treatment as 0 – 0 mm respectively. Crop water use of pepper (ET_c) increased with the increment in the water amount. ET was found as 320 – 760 mm in 2009 and as 330 – 770 mm in 2010 in $V_{100}F_{100}Y_{100}R_{100}$ and $V_0F_0Y_0R_0$ treatments, respectively. The irrigation water and yields are presented in Table 6.

Crop water production functions (k_y and R^2 values) obtained for each growth stage (vegetative, flowering, yield formation, ripening) and total growing season in 2009 and 2010 were given in Table 7.

Linear relationships between ET_c with Y_a, and IW with Y_a were observed for 2009 year. The relationship equation is as follows; $Y_a = 0.0572ET_c - 16.045$ with $R^2 = 0.9201$ and $Y_a = 0.352IW + 0.5366$ with $R^2 = 0.9615$ (Figure 7.a and

7.b). Linear relationships between ET_c with (Y_a), and IW with Y_a were observed for 2010 year. The relationship equation is as follows; $Y_a = 0.0599ET_c - 16.819$ with $R^2 = 0.9085$ and $Y_a = 0.0365IW + 0.8495$ with $R^2 = 0.9660$ (Figure 7.a and 7.b).

When the results were taken into consideration, yield was substantially affected by irrigation applications (Figure 7.a and 7.b) the maximum values of yield were found as 26.2 t ha^{-1} and 27.8 t ha^{-1} in $V_{100}F_{100}Y_{100}R_{100}$ treatment for 2009 and 2010 years, respectively (Table 8 and 9).

When $V_{100}F_{100}Y_{100}R_{100}$ treatment was made comparison with the other irrigation treatments, yield losses were determined as 2.8%, 8.7%, 10.6%, 12.5%, 14.4%, 19.1%, 20.2%, 24.8%, 30.4%, 0.8%, 1.6%, 2.8%, and 13000.0% in 2009 and 7.3%, 9.0%, 11.2%, 14.9%, 15.8%, 17.8%, 18.3%, 21.4%, 25.2%, 1.1%, 2.2%, 3.0% and 9166.7% in 2010. In the study, it was observed that at P<0.05 level has a significant effect on the yield and quality parameters of deficit irrigation.

While a positive straight line relationship was obtained between the water amount and the yield, fruit weight, diameter, length; a negative straight line relationship was obtained between the irrigation amount and dry matter ratio. As for that the relationship, these results were determined: fruit weight (2009)= 0.0108IW + 3.8022, $R^2 = 0.9078$ and fruit weight (2010)= 0.0118IW + 3.2647, $R^2 = 0.9044$ (Fig. 8.a.); fruit diameter (2009)= 0.0033IW + 0.3341, $R^2 = 0.9231$ and fruit diameter (2010)= 0.0031 + 0.3293, R^2= 0.9056 (Fig. 8.b).

Table 7 Crop water production functions obtained for each growth period and total growing season in 2009 and 2010 years

Year	Period	Production Functions
2009	E	ky=0.652, R^2= 0.9330
	V	ky=1.469, R^2= 0.9999
	Y	ky=1.925, R^2= 0.9913
	R	ky=0.375, R^2= 0.9854
	Seasonal	ky=1.290, R^2= 0.9201
2010	E	ky=0.826, R^2= 0.9811
	V	ky=1.591, R^2= 0.9643
	Y	ky=1.550, R^2= 0.9868
	R	ky=0.563, R^2= 0.8319
	Seasonal	ky=1.240, R^2= 0.9085

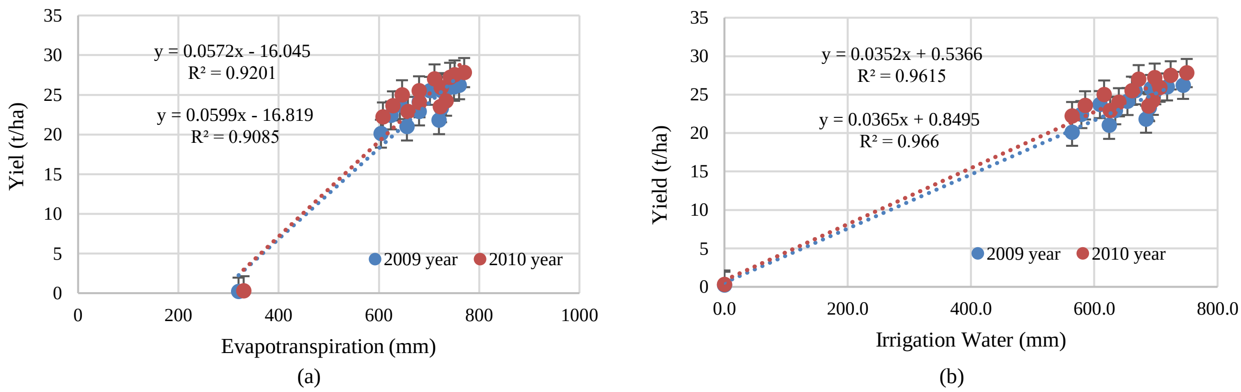


Figure 7a The relationship between crop water consumption and yield. 7b The relationship between irrigation water and yield

Table 8 Effects of irrigation treatments on yield and quality parameters of pepper in 2009 year.

Irrigation Treatments	Yield (t ha^{-1})	Fruit Weight (g)	Fruit Diameter (cm)	Fruit Length (cm)	Dry Matter Ratio (%)
$V_{100}F_{100}Y_{100}R_{100}$	26.2^{a}	12.2^{a}	3.2^{a}	19.5^{a}	8.1^{i}
$V_{75}FYR$	25.5^{a}	11.5^{bcd}	2.5^{bcd}	$17.5d^{e}$	8.2^{hi}
$V_{50}FYR$	24.1^{b}	11.3^{cde}	2.4^{bcd}	17.2^{ef}	8.3^{hi}
$V_{25}FYR$	23.7^{bc}	11.0^{def}	2.3^{cd}	16.8^{fg}	$8.6g^{hi}$
$VF_{75}YR$	23.3^{bcd}	10.8^{ef}	2.5^{bcd}	16.5^{gh}	$8.7f^{gh}$
$VF_{50}YR$	22.9^{cde}	10.5^{fg}	2.4^{bcd}	16.1^{hi}	9.0^{efg}
$VF_{25}YR$	22.4^{de}	10.1^{gh}	2.3^{cd}	15.8^{ij}	9.7^{bc}
$VFY_{75}R$	21.8^{ef}	10.0^{gh}	2.3^{cd}	15.5^{j}	9.1^{defg}
$VFY_{50}R$	21.0^{fg}	9.6^{hi}	2.2^{d}	14.9^{k}	9.2^{cdef}
$VFY_{25}R$	20.1^{g}	9.0^{i}	2.1^{d}	14.2^{l}	9.8^{b}
$VFYR_{75}$	26.0^{a}	12.0^{ab}	2.8^{ab}	18.5^{b}	9.3^{bcde}
$VFYR_{50}$	25.8^{a}	11.9^{abc}	2.7^{bc}	18.2^{bc}	9.6^{bcd}
$VFYR_{25}$	25.5^{a}	11.7^{abc}	2.7^{bc}	17.9^{cd}	9.7^{bc}
$V_0F_0Y_0R_0$	0.2^{h}	4.0^{j}	0.4^{e}	6.5^{m}	15.1^{a}
Treatments	*	*	*	*	*
Blocks	ns	ns	ns	ns	ns

* means correlation is significant at the 0.005 level. ns shows non-significant correlation.

Table 9 Effects of irrigation treatments on yield and quality parameters of pepper in 2010 year.

Irrigation Treatment	Yield (t ha^{-1})	Fruit Weight (kg)	Fruit Diameter (cm)	Fruit Length (cm)	Dry Matter Ratio (%)
$V_{100}F_{100}Y_{100}R_{100}$	27.8^{a}	12.4^{a}	3.1^{a}	20.0^{a}	7.7^{g}
$V_{75}FYR$	25.9^{bcd}	11.7^{bcd}	2.5^{bc}	18.0^{bcd}	8.1^{fg}
$V_{50}FYR$	25.5^{cde}	11.5^{cde}	2.4^{bcd}	17.7^{bcde}	8.3^{ef}
$V_{25}FYR$	25.0^{def}	11.2^{def}	2.3^{bcd}	17.5^{cde}	8.7^{de}
$VF_{75}YR$	24.2^{defg}	11.0^{ef}	2.3^{bcd}	17.0^{def}	8.5^{ef}
$VF_{50}YR$	24.0^{efg}	10.7^{fg}	2.2^{bcd}	16.7^{def}	8.6^{e}
$VF_{25}YR$	23.6^{fgh}	10.3^{gh}	2.1^{cd}	16.4^{efg}	9.4^{bc}
$VFY_{75}R$	23.5^{fgh}	10.1^{h}	2.1^{cd}	15.9^{fgh}	8.4^{ef}
$VFY_{50}R$	22.9^{gh}	9.5^{i}	2.1^{cd}	15.3^{gh}	9.1^{cd}
$VFY_{25}R$	22.2^{h}	8.8^{j}	2.0^{a}	14.6^{h}	9.7^{b}
$VFYR_{75}$	27.5^{ab}	12.3^{a}	2.6^{b}	19.0^{ab}	9.5^{bc}
$VFYR_{50}$	27.2^{abc}	12.1^{ab}	2.6^{b}	18.8^{abc}	9.5^{bc}
$VFYR_{25}$	27.0^{abc}	12.0^{abc}	2.5b^{c}	18.5^{abc}	9.6^{b}
$V_0F_0Y_0R_0$	0.3^{i}	3.5^{k}	0.4^{e}	6.0^{i}	15.5^{a}
Treatments	*	*	*	*	*

*means correlation is significant at the 0.005 level. ns shows non-significant correlation

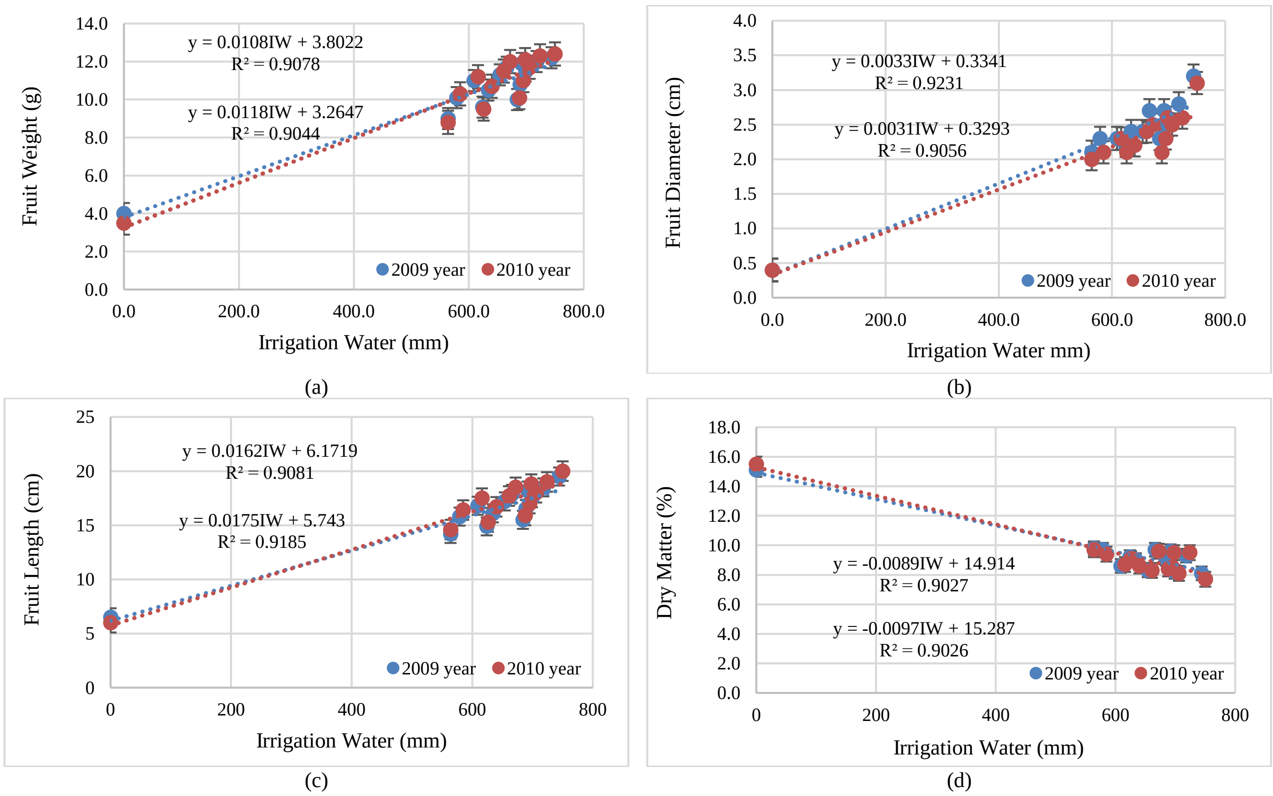


Figure 8 Relationship between irrigation water and fruit weight, diameter, length and dry matter ratio

Fruit length (2009)= 0.0162IW + 6.1719, R^2 = 0.9081 and fruit length (2010)= 0.0175IW + 5.743, R^2 = 0.9185 (Fig. 8.c.); dry matter ratio (2009)= -0.0089IW + 14.914, R^2 = 0.9027 and dry matter ratio (2010)= -0.0097IW + 15.287, R^2= 0.9026 (Fig. 8.d.).

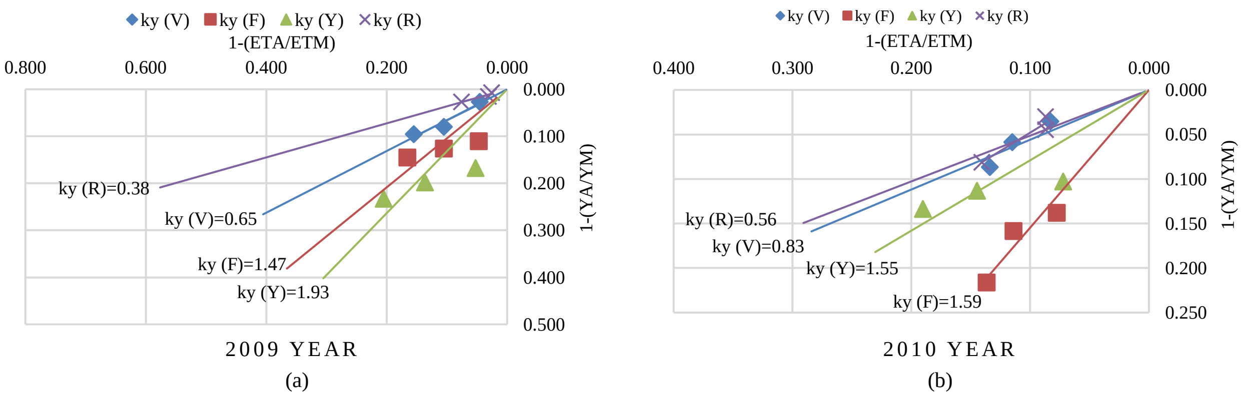


Figure 9 The relationship between relative yield decrease and relative evapotranspiration deficit for the experimental years

Crop Yield Response Factor (k_y)

The linear relationship between relative crop evapotranspiration and relative yield decrease is given the ky value. It is regarded as the yield response to the relative crop evapotranspiration. In another saying, it represents the declines in the yield as a result of each deficient level in water depletion. Seasonal ky values were determined as 1.29 (2009 year) and 1.24 (2010 year) (Fig.9). Ky value increased with the increase in the water deficit. This result was relatively small with regard to seasonal crop yield response factors in four different crop growth periods of the peppers, while it was consistent with the crop yield response factors in each growth factors given in literature. The difference between these two results may refer to the differences between the empirical, climatic and seedling quality.

Water Use Efficiencies

WUE and IWUE values of the 2009 and 2010 years appeared differently in different treatments (Table 10). The maximum WUE values for 2009 year were found as 0.4, 0.4, 0.4 – 0.4, 0.4, 0.4 kg mm^{-1} and were found 0.4, 0.4, 0.4 - 0.4, 0.4, 0.4 kg mm^{-1} from V75FYR, V50FYR, V25FYR and $VFYR_{75}$, $VFYR_{50}$, $VFYR_{25}$ treatments for 2010 year, respectively.

IWUE values for 2009 year were found as 0.4, 0.4, 0.4 – 0.4, 0.4, 0.4 kg.mm^{-1} and were found 0.4, 0.4, 0.4 – 0.4, 0.4, 0.4 kg mm^{-1} from V75FYR, V50FYR, V25FYR and $VFYR_{75}$, $VFYR_{50}$, $VFYR_{25}$ treatments for 2010 year, respectively. When WUE and IWUE values were taken into consideration, the maximum WUE and IWUE values were obtained in vegetative and ripening periods and the lowest value was obtained from flowering and yield formation periods. In other words, the maximum yields were obtained from vegetative and ripening periods and the most water saving was supplied with deficit irrigation only in the vegetative and ripening periods of the pepper.

Table 10 WUE and IWUE values for the pepper at fourteen irrigation treatments.

2009				2010			
Irrigation Treatment	Yield (t ha^{-1})	WUE (kg/m^3)	IWUE (kg/m^3)	Irrigation Treatment	Yield (t ha^{-1})	WUE (kg/m^3)	IWUE (kg/m^3)
V100F100Y100R100	26.2	0.03	0.04	V100F100Y100R100	27.8	0.04	0.04
V75FYR	25.5	0.04	0.04	V75FYR	25.9	0.04	0.04
V50FYR	24.1	0.04	0.04	V50FYR	25,5	0.04	0.04
V25FYR	23.7	0.04	0.04	V25FYR	25.0	0.04	0.04
VF75YR	23.3	0.03	0.03	VF75YR	24,2	0.03	0.03
VF50YR	22.9	0.03	0.04	VF50YR	24.0	0.04	0.04
VF25YR	22.0	0.03	0.04	VF25YR	23.6	0.04	0.04
VFY75R	21.8	0.03	0.03	VFY75R	23.5	0.03	0.03
VFY50R	21.0	0.03	0.03	VFY50R	22.9	0.03	0.04
VFY25R	20.1	0.03	0.04	VFY25R	22.2	0.04	0.04
VFYR75	26.0	0.04	0.04	VFYR75	27.5	0.04	0.04
VFYR50	25.8	0.04	0.04	VFYR50	27.2	0.04	0.04
VFYR25	25.5	0.04	0.04	VFYR25	27.0	0.04	0.04
V0F0Y0R0	0.2	0.00	0.00	V0F0Y0R0	0.3	0.00	0.00

Discussion

In this experiment, irrigation treatments considerably influenced yield, fruit weight, diameter, length and dry matter. In both experimental years, the maximum amounts of water applied to the crop were 744-750 mm for from $V_{100}F_{100}Y_{100}R_{100}$ while the seasonal evapotranspiration (ETa) values were changed between 760-320 mm and 770-330 mm for $V_0F_0Y_0R_0$ treatment. Total water requirements was 600 to 900 mm and up to 1250 mm for long growing periods and several pickings (Doorenbos and Kassam, 1979). In a study conducted by Goldberg and Shmueli (1971) in Israel, they applied 1340 mm irrigation water during the plant growing season. Demirtas and Ayas (2009) stated that irrigation water amount applied for 65-724 mm in different treatments in the province of Bursa of Turkey. In a study conducted in Hungary by Posgay (1972), the water consumption of the pepper was 719 mm in furrow irrigation and 625 mm in porous pipe irrigation. Sezen et al. (2006) determined that crop evapotranspiration (ET) values varied from 365 mm to 528 mm in the first experimental year and 309 mm to 511 mm in the second experimental year. Smittle et al. (1994) also reported that the water applied of pepper changed from 207 mm to 396 mm. Plant water consumption in this study changed from 425 mm to 656 mm. Chartzoulakis and Drosos (1999) indicated that the seasonal irrigation water of pepper changed from 132 to 329 mm in first year and from 147-366 mm in second year. Gencoglan et al., (2006) specified that the most economical irrigation levels, in terms of both net income from per unit of land and water, were 815 mm and 752 mm, respectively.

The pepper yield ranged between 26.2-0.2 and 27.8-0.3 t ha^{-1} for 2009 and 2010 years, respectively. Yield was decreased as the irrigation water amount reduced. As a result, the effect of deficit irrigation was found significant on total yield. This result was compatible with those of (Doorenbos and Kassam, 1979; Chartzoulakis and Drosos, 1999; Demirtas and Ayas, 2009; Gencoglan et al., 2006). As in yield, some quality parameters of pepper (fruit weight, diameter, length and dry matter) showed a similar response to deficit irrigation.

As for fruit weight, there was influence of deficiency irrigation on single fruit weight with respect to quality parameters. As observed in yield, the fruit diameter and weight gave similar response to deficit irrigation. The highest quality parameters were obtained from $V_{100}F_{100}Y_{100}R_{100}$ treatments every two experiment years. The non-irrigated ($V_0F_0Y_0R_0$) treatment had lower values than all irrigation treatments. The result of study were in conformance with (Chartzoulakis and Drosos, 1999; Braga and Klar, 2003; Sezen et al., 2006; Demirtas and Ayas, 2009; Gul et al., 2011). Since $V_{100}F_{100}Y_{100}R_{100}$ treatments had higher fruit weight than the other treatments, the lowest dry matters have been found at $V_{100}F_{100}Y_{100}R_{100}$ treatments when the highest dry matter values were observed at $V_0F_0Y_0R_0$ treatments in both years of the experiment. As a result, we may say that as the amount of irrigation water decrease, the number of dry matter increases. These values are similar to those of previous studies (Chartzoulakis and Drosos, 1999; Gencoglan et al., 2006; Sezen et al., 2006; Demirtas and Ayas, 2009; Gul et al., 2011). The maximum WUE values for 2009 year were found as 0.04, 0.04, 0.04 – 0.04, 0.04, 0.04 kg mm^{-1} and were found as 0.04, 0.04, 004 - 0.04, 0.04, 0.04 kg mm^{-1} from V75FYR, V50FYR, V25FYR and $VFYR_{75}$, $VFYR_{50}$, $VFYR_{25}$ treatments for 2010 year, respectively. IWUE values for 2009 year were found as 0.04, 0.04, 0.04 – 0.04, 0.04, 0.04 kg.mm^{-1} and were found as 0.04, 0.04, 0.04 – 0.04, 0.04, 0.04 kg mm^{-1} for 2010 year from V75FYR, V50FYR, V25FYR and $VFYR_{75}$, $VFYR_{50}$, $VFYR_{25}$ treatments, respectively. When WUE and IWUE values were taken into consideration, the maximum WUE and IWUE values were obtained in vegetative and ripening periods and the lowest value was obtained from flowering and yield formation periods. When the results concerning WUE values were in comparison to the findings of different researchers, they were in agreement with those of the other studies (Doorenbos and Kassam, 1979; Chartzoulakis and Drosos, 1999; Gencoglan et al., 2006; Sezen et al., 2006; Demirtas and Ayas, 2009).

The variety of pepper, climate of the region, soil properties and effective use of water also influence yield and quality parameters of pepper. As explained by Davis et al. (2008), it may be attributed to the variety and applied cultural practices handling under different climate and geographical conditions. Crop yield response factor (k_y) for 2009 and 2010 year were calculated as 1.29 and 1.24 for pepper, respectively. The specified values of k_y (1.29-1.24) which is bigger than 1.00 shows that pepper is responsive to the water. The factor of k_y also matches up with the values obtained by researchers who studied on similar issues (Doorenbos and Kassam, 1979; Sezen et al., 2006; Demirtas and Ayas, 2009).

Conclusion

According to the results of the study, irrigation water were applied 744 and 750 mm in $V_{100}F_{100}Y_{100}R_{100}$ treatment applied of full irrigation in 2009 and 2010 years. The plant water consumption of pepper was determined as 320-760 mm and 330-770 mm for $V_0F_0Y_0R_0$ treatment 2009 and 2010 years.

The factors of k_y for the different irrigation levels ($V_{100}F_{100}Y_{100}R_{100}$, $V_{75}FYR$, $V_{50}FYR$, $V_{25}FYR$, $VF_{75}YR$, $VF_{50}YR$, $VF_{25}YR$, $VFY_{75}R$, $VFY_{50}R$, $VFY_{25}R$, $VFYR_{75}$, $VFYR_{50}$, $VFYR_{25}$, $V_0F_0Y_0R_0$ treatments) in 2009 and 2010 years were calculated as 1.29 and 1.24 for pepper, respectively. The factors of k_y (1,29 and 1.24) values are bigger than 1,00 showed that the pepper was susceptible to water. The crop yield response factors (k_y) were close to each other in both years of the study. The highest yield decreases in all treatments were in $V_0F_0Y_0R_0$ treatments, while the lowest yield decreases were in $V_{100}F_{100}Y_{100}R_{100}$ treatments. In our trial, it was studied out that irrigation treatments considerable influences yield, fruit diameter, weight, length and dry matter ratio.

In this study, it was studied out that irrigation applications considerably influences yield, fruit weight, diameter, length and dry matter. In both years of the study, the highest yield were 26.2 t h^{-1} and 27.8 t h^{-1} and it was observed in $V_{100}F_{100}Y_{100}R_{100}$ treatment. The lowest yield were observed as 0.2 t h^{-1} and 0.3 t h^{-1} in $V_0F_0Y_0R_0$ treatment. Yield decreased considerably as a result of the diminishment in the water amount. Relative yield decreases in the irrigation treatments in 2009 and 2010 were 2.8%, 8.7%, 10.6%, 12.5%, 14.4%, 19.1%, 20.2%, 24.8%, 30.4%, 0.8%, 1.6%, 2.8%, 13000.0% and 7.3%, 9.0%, 11.2%, 14.9%, 15.8%, 17.8%, 18.3%, 21.4%, 25.2%, 1.1%, 2.2%, 3.0%, 9166.7%, respectively. WUE and IWUE values of vegetative and ripening periods were the maximum of all the treatments.

As a result, of a possible deficit irrigation in a semi-humid climate condition, it is necessary to plan carefully and it is possible to say that the levels and times of the deficit irrigation were significantly effective on pepper yield. It is very important to give sap after planting seedlings. Because of the moisture level in the soil was fulfilled to the field capacity before planting the seedlings, there was no need to apply sap after planting. If deficit irrigation treatment is obligatory, water deficiency should be planned only for vegetative and ripening periods of pepper. The deficit irrigation should not be applied in flowering and yield formation periods and full irrigations should be exactly applied during these periods. In addition, in the irrigation planning to be applied in similar climatic conditions may be benefited from crop yield response factor (ky) values. The results used to determine the amount of reduction in yield in response to the water deficiency applied to the plant may be used in studies related to pepper. It can be recommended that ripening and vegetative periods is most suitable periods for the deficit irrigation practices for pepper irrigation by drip irrigation.

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