



Water-Yield Relationships in Deficit Irrigated Onion

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ABSTRACT

This trial was realized in the greenhouses of Uludağ University Yenişehir Vocational School between 2009 and 2010 to investigate effects of water deficit on yield and quality parameters of onion during four crop growth stages. In this trial, fourteen irrigation treatments in four growth periods (establishment, vegetative, yield formation and ripening) of onion (*Allium cepa* L E.T Grano.502) 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 436 mm in the first year, and between 0 and 448 mm in the second year. Water consumption of onion in the first year ranged between 205 and 496 mm and in the second year ranged between 210 and 502 mm. Yield, bulb weight, diameter, height and dry matter ratio were determined statistically significant. In 2009 and 2010 years, the maximum yield were found as 52.2 t ha⁻¹ and 52.4 t ha⁻¹ in E₁₀₀V₁₀₀Y₁₀₀R₁₀₀ treatments, while the minimum yield were found as 0.8 t ha⁻¹ and 0.5 t ha⁻¹ in the E₀V₀Y₀R₀ treatments, respectively. Water- yield relationship factors (k_y) in 2009 and 2010 years were found as 1.03 and 1.04, respectively. The maximum WUE and IWUE values were obtained from establishment and ripening periods. Establishment and ripening periods may be suggested as the maximum efficient irrigation periods for the onion applied with drip irrigation under unheated greenhouse conditions.

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Introduction

Decreases in water resources together with increasing impacts of global warming and climate changes and increasing demands of increasing population make effective utilization of water resources a must. Increasing demands of sectors also deplete the ground water resources, pollute water ecosystems and developing new water resources is getting more and more expensive each day. Since about 75% of water resources of Turkey is allocated for agricultural purposes, effective water utilization and water saving in irrigation are the most critical issues to be considered. Pressurized piped systems and especially drip irrigation should be widespread for effective water utilization in agriculture (Çakmak and Gökalp, 2011).

Van Straten et al. (2010), stated that the greenhouse is worldwide the fastest growing sector of all agricultural production activities. There are two essential causes for this. First, the plant grows in greenhouse differently from the external environment, in this way supplying some way

of abri from the direct effect of the external air conditions. This allows the production of crops at that specific place. Second, the greenhouse allows to be produced of many crops. This situation permits the grower to direct the farming in a desirable aspect. It causes to higher crop yield, extended 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 field agriculture.

According to 2016 FAO data, dry onions were produced in 144 countries around the world and world total onion production was 90 million tons in 2016 year. China, India and Egypt are the world's three biggest onion producers with 23.9, 19.4, 3.0 million tons, respectively. India is the largest onion exporting country with 1.62 million tons. Turkey is one of the significant onion producer with Turkey 2 120 581 tons (sixth in the world) in the world. The onion production of Bursa province was around 85 000 tons (Anonymous, 2016).

The onion plant is native to Asia. Although it is cultivated in almost every part of our country, production is done intensively in Thrace region and Balıkesir, Bursa, Bandırma, Amasya, Corum, Tokat, Kastamonu, Hatay and Denizli. Onion is one of our vegetables which is of high economic importance which adds flavour to almost every food and it is of utmost importance in the nutrition of our country (Vural et al., 2000). Cooking bulbs are grown and consumed worldwide. They are known as *Allium* species and belong to the Alliaceae family. In this family, bulb onion (*Allium cepa* L.) or onion is the most common one in terms of cultivation and consumption (Günay, 2005).

Sezen (2005) found that surface irrigation is not suggested due to low irrigation efficiency originated from salinity and drainage problems in irrigated areas. On the other hand, excess water inputs and poor drainage, accompanied by traditional irrigation systems, lead to environmental problems such as salinization and water logging. The problems of conventional irrigation methods can be eliminated through the use of pressurized irrigation methods designed to ensure the efficient use of irrigation water in the field scale (Büyükcangaz et al., 2007). Thus, the use of less water consuming irrigation methods is of great importance with regard to irrigation planning (Anonymous, 2005).

The objectives of irrigation planning is to prevent the soil moisture level falling below the critical level for a specific crop and soil 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 approaches based on evapotranspiration estimations (Bar-Yosef and Sagiv, 1982; McNeesh 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 effective water management (Yuan et al., 2003).

Some studies have been carried out to investigate the effect of deficit irrigation on onion (Orta and Şener, 2001; Kadayıfci et al., 2005; Ayas and Demirtas, 2009). The purposes of this experiment were to obtain a prospectus for onion growers and to determine drip irrigated onion response to deficit irrigation regimes in Bursa province of Turkey.

Material and Methods

The trial 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, winters are cold, and summers 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/m² and 335-139 W/m², respectively (Figure 4) (Anonymous, 2011b).

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.

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,

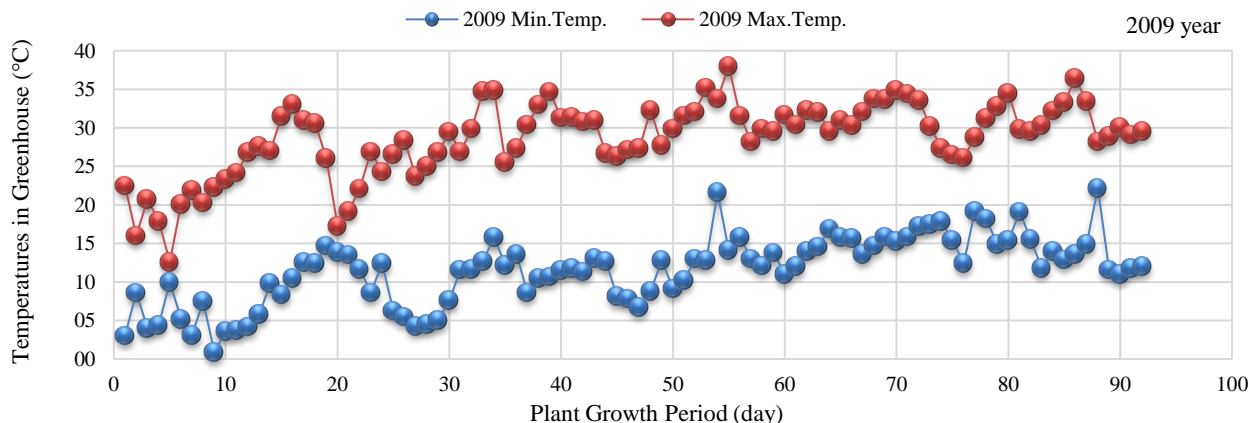


Figure 1 Temperatures in greenhouse during the plant growth period in 2009 year

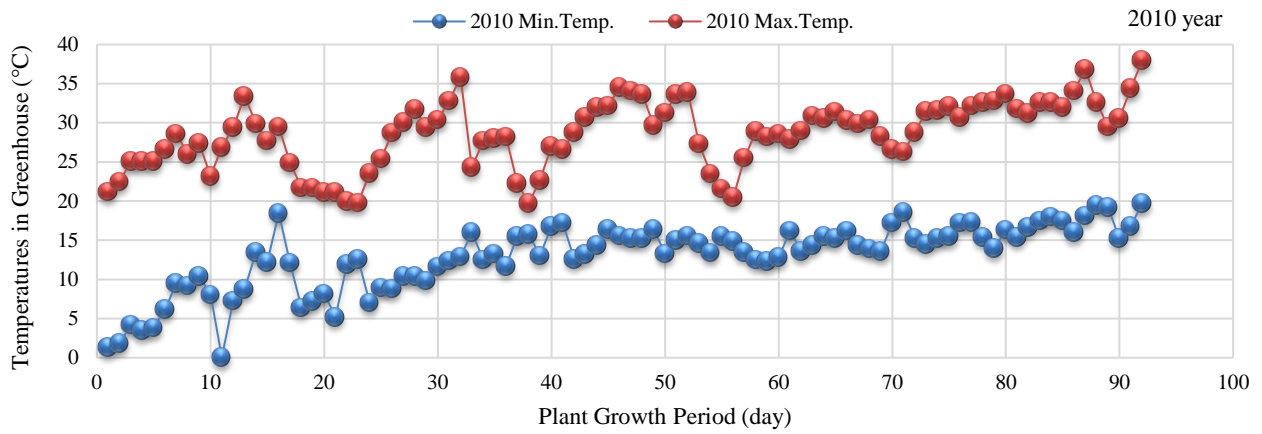


Figure 2 Temperatures in greenhouse during the plant growth period in 2010 year

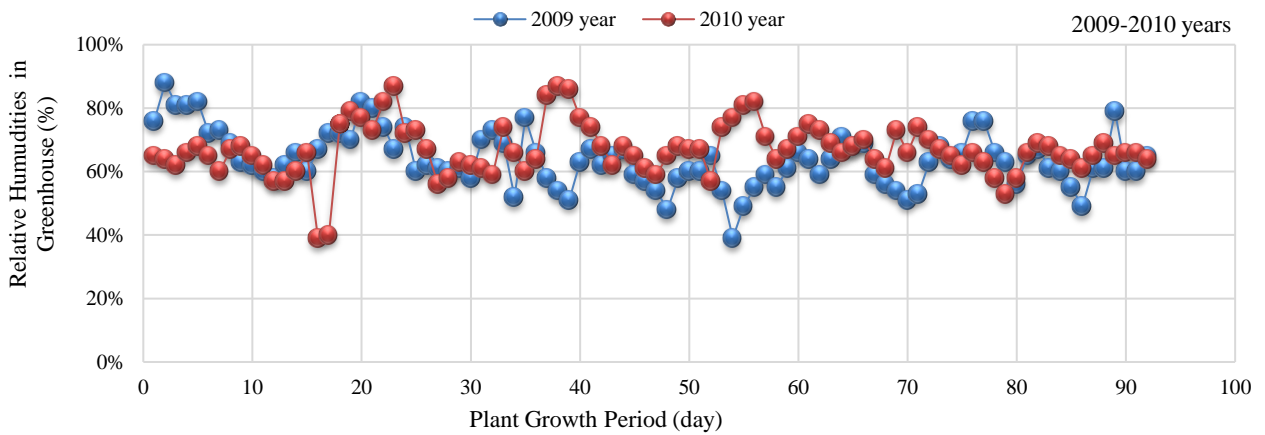


Figure 3 Relative humidity's in greenhouse during the plant growth period in 2009-2010 years

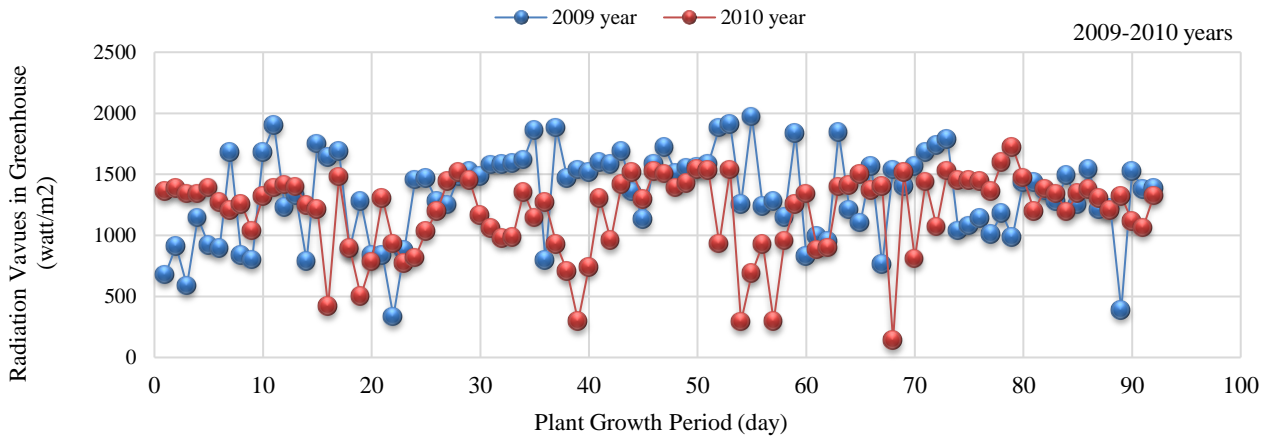


Figure 4 Radiation values in greenhouse during the plant growth period in 2009-2010 years

Yalova-15 variety was used in the study. This onion variety is white fleshy and its flavour is slightly bitter. Soluble solids content of onion is on average 14%. The storage property is very good and its production happens with bulbs. The head shape of onion is long, the number of onionskin is 3-4 pieces and the colour of the onionskin is pink-brown. In the experimental area, an irrigation well was utilized as the source and the water was classified as C₁S₁ 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 onions 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 sprayed 10 L ha⁻¹ chlorphtifos-ethyl to the onions for insects.

The plots of the randomized experimental design were formed with three repetitions and 14 trial treatments were randomly scattered. The size of the trial plots was 4 m² (2.0 m x 2.0 m). The distances between the plots were 0.80 m and blocks were placed with 1.5 m distances. The seeds were sown in small pot on 15 May 2009 and on 12 May 2010 in the experimental years. The onion seedlings were transplanted to the plots on 10 April 2009 and on 17 April 2010. The seedlings were grown with 10 cm intervals on the same line and with 20 cm intervals between the plant lines. Into each plot, 231 plants were planted.

The yield and quality parameters of onion are yield, fruit weight, diameter, height and dry matter ratio. The fruit weight was determined by weighting 45 plants in the harvest part and bulb diameter and height were calculated by gauging the weighted fruit with a scale/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 hours and fruit dry matter ratio was calculated. The detail of the experimental plot is shown in Figure 5.

In different growth periods of the onion (Establishment (E), vegetative (V), yield formation (Y) and ripening (R)) fourteen deficit irrigation treatments were formed depending on full or deficit irrigation applications. 75-50-25% of the deficit irrigations were applied in different growth stages of the plant (establishment, vegetative, yield formation and ripening), while 100% of irrigation water was used in full irrigation treatment. In line with this planning, irrigation treatments were planned like this: E₁₀₀V₁₀₀Y₁₀₀R₁₀₀, E₇₅V_{YR}, E₅₀V_{YR}, E₂₅V_{YR}, EV₇₅Y_R, EV₅₀Y_R, EV₂₅Y_R, EVY₇₅R, EVY₅₀R, EVY₂₅R, EVYR₇₅, EVYR₅₀, EVYR₂₅, E₀V₀Y₀R₀ (Table 2.).

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

In the trial, the plants were irrigated by drip irrigation method and water was provided from 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 C₂S₁ 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 period, 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.

Evapotranspiration (ET), was calculated with water balance equation (Eq. 1) (Howell et al., 1995).

$$ET = I + P - R_f - D_p \pm \Delta S \quad (1)$$

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 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 (D_p) 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 (2) (Güngör and Yıldırım, 1989).

$$P = \frac{S_d}{S_l} 100 \quad (2)$$

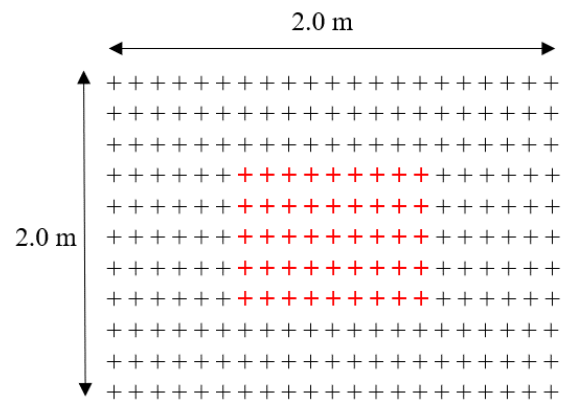


Figure 5 The detail of a plot



(a)



(b)

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

Table 2 The experimental treatments

Irrigation 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 ₀ V ₀ Y ₀ R ₀	-	-	-	-

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

Table 3 Specific properties of irrigation water used in the trial

Water Source	EC ₂₅ × (10 ⁶)	Cations (me L ⁻¹)				pH	Class	SAR
		Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺			
Deep well	715	2.3	2.56	9.25	5.7	7.12	C ₂ S ₁	0.85

Table 4 The irrigation water applied for four growth stages

Treatments	Irrigation Water (mm)									
	Establishment		Vegetative		Yield Formation		Ripening		Total	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
E100V100Y100R100	80	80	140	148	160	160	56	60	436	448
E75VYR	60	60	140	148	160	160	56	60	416	428
E50VYR	40	40	140	148	160	160	56	60	396	408
E25VYR	20	20	140	148	160	160	56	60	376	388
EV75YR	80	80	105	111	160	160	56	60	401	411
EV50YR	80	80	70	74	160	160	56	60	366	374
EV25YR	80	80	35	37	160	160	56	60	331	337
EVY75R	80	80	140	148	120	120	56	60	396	408
EVY50R	80	80	140	148	80	80	56	60	356	368
EVY25R	80	80	140	148	40	40	56	60	316	328
EVYR75	80	80	140	148	160	160	42	45	422	433
EVYR50	80	80	140	148	160	160	28	30	408	418
EVYR25	80	80	140	148	160	160	14	15	394	403
E0V0Y0R0	0	0	0	0	0	0	0	0	0	0

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.

$$dn = \frac{(FC-WP)Ry}{100} \gamma t D \frac{P}{100} \quad (3)$$

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. γt is the soil bulk density, D is wetted soil depth, P is the percentage of wetted area. In this trial, 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;

$$\left(1 - \frac{Y_a}{Y_m}\right) = ky \left(1 - \frac{ET_a}{ET_m}\right) \quad (4)$$

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). Water use efficiency (WUE) for each treatment was calculated as fruit yield divided by seasonal evapotranspiration (ET). Irrigation water use efficiency (IWUE) was predicted as (Zhang et al., 1999):

$$IWUE = \frac{(Y_1 - Y_{NI})}{I} \quad (5)$$

Where Y₁ is bulb yield of irrigation treatments (t ha⁻¹) and Y_{NI} is the bulb yield of non-irrigation treatment (t ha⁻¹) and I is the amount of irrigation water (mm). The water content of the soil till 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 started on May 15 in 2009 and May 12 in 2010 and it was repeated every 7 days. The irrigation water amounts for the four growth periods of onion were given in Table 4. Crop evapotranspiration for growth periods of onion 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 5 Crop evapotranspiration for different growth stages

Treatments	Crop Evapotranspiration (mm)									
	Establishment		Vegetative		Yield Formation		Ripening		Total	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
E100V100Y100R100	70	70	176	172	180	182	70	78	496	502
E75VYR	50	55	154	155	178	180	46	45	428	435
E50VYR	56	53	151	152	175	176	43	51	425	432
E25VYR	50	50	155	155	176	178	40	45	421	428
EV75YR	53	57	165	165	173	179	49	47	440	448
EV50YR	50	55	161	165	177	170	47	53	435	443
EV25YR	48	52	156	158	174	174	51	52	429	436
EVY75R	55	62	170	167	174	175	53	56	452	460
EVY50R	55	53	164	167	170	175	55	58	444	453
EVY25R	53	52	165	167	165	166	51	58	434	443
EVYR75	53	51	165	169	170	177	44	42	432	439
EVYR50	50	53	167	173	172	174	41	37	430	437
EVYR25	50	58	168	171	171	173	38	32	427	434
E0V0Y0R0	50	50	55	55	60	60	40	45	205	210

Results

In both of the years, maximal irrigation water was found in E₁₀₀V₁₀₀Y₁₀₀R₁₀₀ treatment as 436 – 448 mm and minimal irrigation water was found in E₀V₀Y₀R₀ treatment as 0 – 0 mm respectively. Crop water use of onion (ET_c) increased with the increment in the water amount. ET was found as 205 – 496 mm in 2009 and 210 – 502 mm in 2010 in E₁₀₀V₁₀₀Y₁₀₀R₁₀₀ and E₀V₀Y₀R₀ treatments, respectively. The irrigation water and yield values are given in Table 6.

Crop water production functions (k_y and R^2 values) obtained for each growth stage (Establishment (E), flowering (F), yield formation (Y), ripening (R)) 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; $Y_a = 0.1861ET_c - 34.488$ with $R^2 = 0.91$ and $Y_a = 0.1143IW + 2.9695$ with $R^2 = 0.96$ (Figure 7a and 7b). Linear relationships between ET_c with (Y_a), and IW with Y_a were observed for 2010 year. The relationship equation is as follows; $Y_a = 0.1874ET_c - 36.138$ with $R^2 = 0.93$ and $Y_a = 0.1121IW + 2.9147$ with $R^2 = 0.96$ (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 52.2 t ha⁻¹ and 52.4 t ha⁻¹ in E₁₀₀V₁₀₀Y₁₀₀R₁₀₀ treatment for 2009 and 2010 years, respectively (Table 8 and 9).

When E₁₀₀V₁₀₀Y₁₀₀R₁₀₀ treatment was made comparison with the other irrigation treatments, yield losses were determined as 6.5%, 7.2%, 7.6%, 12.5%, 13.5%, 14.2%, 17.3%, 19.2%, 21.4%, 6.5%, 7.2%, 7.9%, and 6425.0% in 2009 and 7.4%, 8.0%, 8.7%, 12.7%, 13.4%, 14.4%, 14.2%, 16.4%, 18.6%, 6.5%, 7.4%, 8.3% and 10380.0% in 2010. In the trial, it was observed that deficit irrigation has a significant effect on yield and quality parameters at $P < 0.05$ level.

Linear relationships between ET_c with Y_a, and IW with Y_a were observed for 2009 year. The relationship equation is as follows; $Y_a = 0.1861ET_c - 34.488$ with $R^2 = 0.91$ and $Y_a = 0.1143IW + 2.9695$ with $R^2 = 0.96$ (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; $Y_a = 0.1874ET_c - 36.138$ with $R^2 = 0.93$ and $Y_a = 0.1121IW + 2.9147$ with $R^2 = 0.96$ (Figure 7.a and 7.b).

While a positive straight line relationship was obtained between the water amount and the yield, bulb weight, diameter, height; a negative straight line relationship was obtained between the irrigation amount and dry matter ratio. As for that the relationship, these results were determined: bulb weight (2009)= $0.239IW + 18.457$, $R^2 = 0.89$ and bulb weight (2010)= $0.2508IW + 17.78$, $R^2 = 0.92$ (Figure 8.a.); bulb diameter (2009)= $0.0121IW + 0.8005$, $R^2 = 0.89$ and bulb diameter (2010)= $0.0126IW + 0.6794$, $R^2 = 0.92$ (Figure 8.b).

Crop Yield Response Factor (k_y)

A straight line between relative crop evapotranspiration and relative yield decrease represents crop yield response factor (k_y). It indicates the response of the yield to the relative crop evapotranspiration. In another saying, it represents the declines in the yield as a result of each deficit level in water consumption. Seasonal crop yield response factors (k_y) were determined as 1.03 (2009 year) and 1.04 (2010 year) (Figure 9). K_y 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 stages of the onions, 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 bulb quality conditions.

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

Irrigation Treatment	Y	AW	E	E/E	Y/Y	1-E/E	1-Y/Y	ky	ky
E100V100Y100R100	52.2	436	496	1.000	1.000	0.000	0.000	0.000	0.000
E75VYR	49.0	416	428	0.863	0.939	0.137	0.061	0.447	
E50VYR	48.7	396	425	0.857	0.933	0.143	0.067	0.468	0.461
E25VYR	48.5	376	421	0.849	0.929	0.151	0.071	0.469	
EV75YR	46.4	401	440	0.887	0.889	0.113	0.111	0.984	
EV50YR	46.0	366	435	0.877	0.881	0.123	0.119	0.966	0.957
EV25YR	45.7	331	429	0.865	0.875	0.135	0.125	0.922	
EVY75R	44.5	396	452	0.911	0.852	0.089	0.148	1.663	
EVY50R	43.8	356	444	0.895	0.839	0.105	0.161	1.535	1.536
EVY25R	43.0	316	434	0.875	0.824	0.125	0.176	1.410	
EVYR75	49.0	422	432	0.871	0.939	0.129	0.061	0.475	
EVYR50	48.7	408	430	0.867	0.933	0.133	0.067	0.504	0.501
EVYR25	48.4	394	427	0.861	0.927	0.139	0.073	0.523	
E0V0Y0R0	0.8	0	205	0.413	0.015	0.587	0.985	1.678	1.678
									1.03
Irrigation Treatment	Y	AW	E	E/E	Y/Y	1-E/E	1-Y/Y	ky	ky
E100V100Y100R100	52.4	448	502	1.000	1.000	0.000	0.000	0.000	0.000
E75VYR	48.8	428	435	0.867	0.931	0.133	0.069	0.515	
E50VYR	48.5	408	432	0.861	0.926	0.139	0.074	0.534	0.531
E25VYR	48.2	388	428	0.853	0.920	0.147	0.080	0.544	
EV75YR	46.5	411	448	0.892	0.887	0.108	0.113	1.047	
EV50YR	46.2	374	443	0.882	0.882	0.118	0.118	1.007	1.004
EV25YR	45.8	337	436	0.869	0.874	0.131	0.126	0.958	
EVY75R	45.9	408	460	0.916	0.876	0.084	0.124	1.483	
EVY50R	45	368	453	0.902	0.859	0.098	0.141	1.447	1.420
EVY25R	44.2	328	443	0.882	0.844	0.118	0.156	1.331	
EVYR75	49.2	433	439	0.875	0.939	0.125	0.061	0.487	
EVYR50	48.8	418	437	0.875	0.931	0.125	0.069	0.547	0.533
EVYR25	48.4	403	434	0.865	0.924	0.135	0.076	0.564	
E0V0Y0R0	0.5	0	210	0.418	0.010	0.582	0.990	1.703	1.703
									1.04

Y: Yield (t ha⁻¹), AW: Applied Water (mm), E: ETa (mm), E/E: ETa/ETm, Y/Y: Ya/Ym,

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

Year	Period	Production Functions
2009	E	(1-Ya/Ym)= 0.46, R ² = 0.9616
	V	1-(Ya/Ym)= 0.96, R ² = 0.9820
	Y	1-(Ya/Ym)= 1.54, R ² = 0.9993
	R	1-(Ya/Ym)= 0.50, R ² = 0.9868
	Seasonal	1-(Ya/Ym)= 1.03, R ² = 0.9129
2010	E	(1-Ya/Ym)= 0.53, R ² = 0.9932
	V	1-(Ya/Ym)= 1.00, R ² = 0.9998
	Y	1-(Ya/Ym)= 1.42, R ² = 0.9818
	R	1-(Ya/Ym)= 0.53, R ² = 0.9868
	Seasonal	1-(Ya/Ym)= 1.04, R ² = 0.9289

Table 8 Effects of irrigation treatments on yield parameters of onion in 2009 year.

Irrigation Treatment	Yield (t ha ⁻¹)	Bulb Weight (g)	Bulb Diameter (cm)	Bulb Height (cm)	Dry Matter (%)
E100V100Y100R100	52.2 ^a	134.0 ^a	6.6 ^a	7.0 ^a	9.8 ^f
E75VYR	49.0 ^b	120.0 ^{bc}	6.1 ^{abc}	6.4 ^b	10.0 ^f
E50VYR	48.7 ^b	117.0 ^{cd}	5.9 ^{bc}	6.3 ^b	10.3 ^{ef}
E25VYR	48.5 ^b	113.0 ^{ef}	5.6 ^{cde}	6.1 ^b	10.6 ^{def}
EV75YR	46.4 ^c	96.0 ^h	4.7 ^{ghi}	5.2 ^{de}	10.8 ^{def}
EV50YR	46.0 ^{cd}	90.0 ⁱ	4.5 ^{hi}	4.9 ^{ef}	11.2 ^{cdef}
EV25YR	45.7 ^d	85.0 ^j	4.2 ⁱ	4.5 ^f	11.6 ^{bcde}
EVY75R	44.5 ^e	120.0 ^{bc}	5.3 ^{def}	5.5 ^{cd}	12.0 ^{bcd}
EVY50R	43.8 ^f	112.0 ^{ef}	5.1 ^{efg}	5.2 ^{de}	12.5 ^{bc}
EVY25R	43.0 ^g	103.0 ^g	4.8 ^{fgh}	5.0 ^{def}	13.0 ^b
EVYR75	49.0 ^b	122.0 ^b	6.3 ^{ab}	6.5 ^{ab}	10.6 ^{def}
EVYR50	48.7 ^b	115.0 ^{de}	6.1 ^{abc}	6.3 ^b	10.9 ^{def}
EVYR25	48.4 ^b	110.0 ^f	5.8 ^{bcd}	6.0 ^{bc}	11.0 ^{cdef}
E0V0Y0R0	0.8 ^h	20.0 ^k	1.0 ^j	1.0 ^g	16.0 ^a
Treatments	*	*	*	*	*
Blocks	ns	ns	ns	ns	ns

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

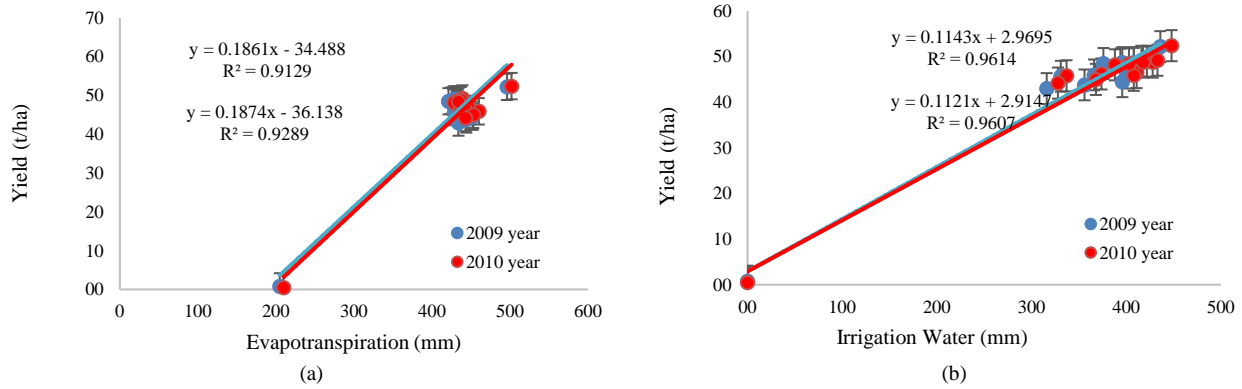


Figure 7a The relationship between crop water consumption and yield. 7b The relationship between irrigation water and yield

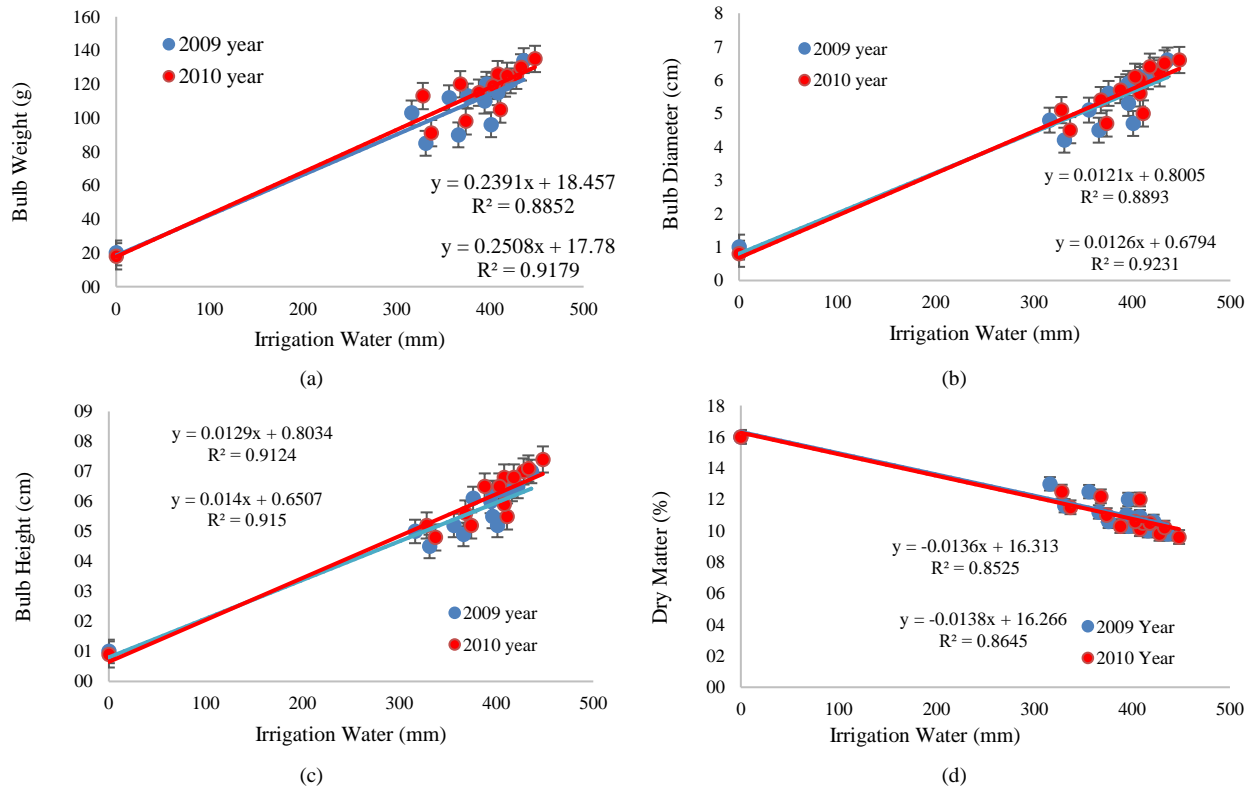


Figure 8 Relationship between irrigation water and fruit weight, diameter, height and dry matter ratio.

Bulb height (2009)= 0.0129IW + 0.8034, $R^2 = 0.91$ and bulb height (2010)= 0.014IW + 0.6507, $R^2 = 0.92$ (Figure 8c.); dry matter ratio (2009)= - 0.0138IW + 16.266, $R^2 = 0.85$ and dry matter ratio (2010)= -0.0136IW + 16.313, $R^2 = 0.85$ and dry matter ratio (2010)= -0.0138IW + 16.266, $R^2 = 0.86$ (Figure 8d.).

Table 9 Effects of irrigation treatments on yield parameters of onion in 2010 year.

Irrigation Treatment	Yield (t ha ⁻¹)	Bulb Weight (g)	Bulb Diameter (cm)	Bulb Height (cm)	Dry Matter (%)
E100V100Y100R100	52.4 ^a	135.0 ^a	6.6 ^a	7.4 ^a	9.6 ^f
E75VYR	48.8 ^{bc}	125.0 ^{bcd}	6.2 ^{ab}	7.0 ^{abc}	9.8 ^{ef}
E50VYR	48.5 ^{bc}	121.0 ^{cde}	6.0 ^{abc}	6.8 ^{bc}	10.1 ^{ef}
E25VYR	48.2 ^c	115.0 ^{ef}	5.7 ^{bcd}	6.5 ^c	10.3 ^{def}
EV75YR	46.5 ^d	105.0 ^g	5.0 ^{ef}	5.5 ^{de}	10.5 ^{def}
EV50YR	46.2 ^d	98.0 ^h	4.7 ^f	5.2 ^{ef}	11.0 ^{cde}
EV25YR	45.8 ^{de}	91.0 ⁱ	4.5 ^f	4.8 ^f	11.5 ^{bcd}
EVY75R	45.9 ^d	126.0 ^{bc}	5.6 ^{bcde}	5.9 ^d	12.0 ^{bc}
EVY50R	45.0 ^{ef}	120.0 ^{cde}	5.4 ^{cde}	5.6 ^{de}	12.2 ^{bc}
EVY25R	44.2 ^f	113.0 ^f	5.1 ^{def}	5.2 ^{ef}	12.5 ^b
EVYR75	49.2 ^b	130.0 ^{ab}	6.5 ^a	7.1 ^{ab}	10.2 ^{ef}
EVYR50	48.8 ^{bc}	125.0 ^{bcd}	6.4 ^a	6.8 ^{bc}	10.5 ^{def}
EVYR25	48.4 ^{bc}	119.0 ^{def}	6.1 ^{ab}	6.5 ^c	10.6 ^{def}
E0V0Y0R0	0.5 ^g	18.0 ^j	0.8 ^g	0.9 ^g	16.0 ^a
Treatments	*	*	*	*	*
Blocks	ns	ns	ns	ns	ns

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

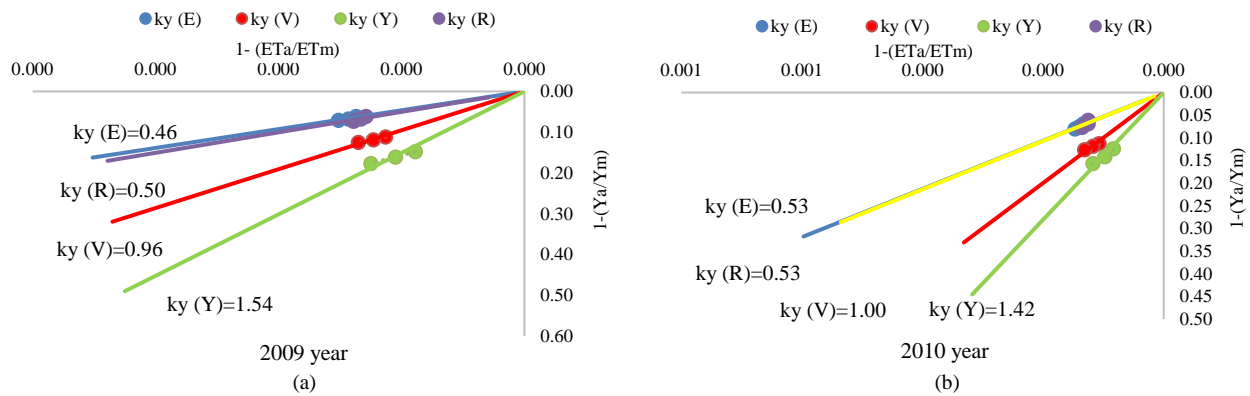


Figure 9 The relationship between relative yield decrease and relative evapotranspiration deficit for the experimental years

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

Irrigation Treatment	2009			Irrigation Treatment	2010		
	Yield (t ha ⁻¹)	WUE (kg/m ³)	IWUE (kg/m ³)		Yield (t ha ⁻¹)	WUE (kg/m ³)	IWUE (kg/m ³)
E ₁₀₀ V ₁₀₀ Y ₁₀₀ R ₁₀₀	52.2	0.11	0.12	E ₁₀₀ V ₁₀₀ Y ₁₀₀ R ₁₀₀	52.4	0.10	0.12
E ₇₅ VYR	49.0	0.11	0.12	E ₇₅ VYR	48.8	0.11	0.13
E ₅₀ VYR	48.7	0.11	0.12	E ₅₀ VYR	48.5	0.11	0.12
E ₂₅ VYR	48.5	0.12	0.13	E ₂₅ VYR	48.2	0.11	0.12
EV ₇₅ YR	46.4	0.11	0.12	EV ₇₅ YR	46.5	0.10	0.11
EV ₅₀ YR	46.0	0.11	0.13	EV ₅₀ YR	46.2	0.10	0.12
EV ₂₅ YR	45.7	0.11	0.14	EV ₂₅ YR	45.8	0.11	0.11
EVY ₇₅ R	44.5	0.10	0.11	EVY ₇₅ R	45.9	0.10	0.11
EVY ₅₀ R	43.8	0.10	0.12	EVY ₅₀ R	45	0.10	0.12
EVY ₂₅ R	43.0	0.10	0.14	EVY ₂₅ R	44.2	0.10	0.13
EVYR ₇₅	49.0	0.11	0.14	EVYR ₇₅	49.2	0.11	0.13
EVYR ₅₀	48.7	0.11	0.12	EVYR ₅₀	48.8	0.11	0.12
EVYR ₂₅	48.4	0.11	0.13	EVYR ₂₅	48.4	0.11	0.12
E ₀ V ₀ Y ₀ R ₀	0.8	0.00	0.00	E ₀ V ₀ Y ₀ R ₀	0.5	0.00	0.00

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 0.11, 0.11, 0.12 – 0.11, 0.11, 0.11 kg mm⁻¹ and were found as 0.13, 0.12, 0.12 - 0.11, 0.11, 0.11 kg mm⁻¹ from E75VYR, E50VYR, E25VYR and EVYR₇₅, EVYR₅₀, EVYR₂₅ treatments for 2010 year, respectively. IWUE values for 2009 year were found as 0.12, 0.12, 0.13 – 0.14, 0.12, 0.13 kg.mm⁻¹ and 0.13, 0.12, 0.12 – 0.13, 0.12, 0.12 kg mm⁻¹ from E75VYR, E50VYR, E25VYR and EVYR₇₅, EVYR₅₀, EVYR₂₅ treatments, respectively. When WUE and IWUE values were taken into consideration, the maximum WUE and IWUE values were obtained in establishment and ripening periods and the lowest value was obtained from vegetative and yield formation periods. In other words, the maximum yields were obtained from establishment and ripening periods and the most water was saved with deficit irrigation only in the establishment and ripening periods of the onion.

Discussion

In this experiment, irrigation treatments considerably influenced yield, bulb weight, diameter, height and dry matter. In both experimental years, the maximum amounts of water applied to the crop were 436-448 mm for from E₁₀₀V₁₀₀Y₁₀₀R₁₀₀ while the seasonal evapotranspiration (ET_a) values were changed between 496-205 mm and 502-

210 mm for E₀V₀Y₀R₀ treatment. Total water amounts varied from 350 to 550 mm for optimum yield (Doorenbos and Kassam, 1979). Ayas and Demirtas, (2009) reported that the maximum amounts of water applied to the crop was 362 mm in the K_{1cp} treatment while the minimum amount was 65 mm in the K_{5cp} treatment during the experimental year. The amount of water applied to other treatments ranged between 272 and 149 mm values. Seasonal evapotranspiration (ET_a) was increased with the applied irrigation water and ranged from 95 mm to 372 mm for K_{5cp} and K_{1cp} treatments, respectively. Onion irrigation quantities applied to the treatments varied from 135.0 to 620.3 mm and seasonal evapotranspiration ranged from 350 to 450 mm in Isparta (Kadayifci et al., 2005). Orta and Şener, (2001) stated that the maintenance of soil moisture depletion level at 0.30 required 339.4 mm and 227.2 mm of irrigation water in 1997 and 1998, respectively. The seasonal evapotranspiration of onion was 420.0 mm in 1997 and 351.2 mm in 1998. The water requirements in Albacete (Spain) for optimum yield were 662 mm when using drip irrigation (Martin de Santa Olalla et al., 2004). Kumar et al., (2007) specified that microsprinkler-irrigated onions in India required between 257 and 468 mm of applied water and the crop evapotranspiration (ET_c) were between 234-380 mm during the growing period. Ensico et al., (2009) reported that the seasonal crop water consumption was between 286 and 389 mm.

The onion yield ranged between 52.2-0.8 and 52.4-0.5 t ha⁻¹ for 2009 and 2010 years, respectively. Yield was

decreased as the irrigation water amount reduced. According to the results of this experiment, the effect of deficit irrigation was founded significant on total yield. This result was compatible with those of studies (Doorenbos and Kassam, 1979; Orta and Şener, 2001; Kadayifci et al. 2005, Ayas and Demirtas, 2009).

Quality parameters such as fruit weight, diameter, height and dry matter have showed a similar response to deficit irrigation as determined at yield. As for bulb weight, there was influence of deficit irrigation on single bulb weight with respect to quality parameters. The bulb diameter and height have given similar response to deficit irrigation as it was observed in yield.

The highest quality parameters were obtained from $E_{100}V_{100}Y_{100}R_{100}$ treatments every two experiment years. The non-irrigated ($E_0V_0Y_0R_0$) treatment had lower values than all irrigation treatments. The result of study were agreement with (Doorenbos and Kassam, 1979; Chung, 1989; İmtiyaz and Singh, 1990; İmtiyaz et al., 1999; Orta and Şener, 2000; Kumar et al., 2007). Since $E_{100}V_{100}Y_{100}R_{100}$ treatments have higher bulb weight than the other treatments, the lowest dry matters were found at $E_{100}V_{100}Y_{100}R_{100}$ treatments when the highest dry matter values were observed at $E_0V_0Y_0R_0$ 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 (İmtiyaz et al., 1999; Orta and Şener, 2001; Pelter et al., 2004; Kadayifci et al., 2004; Ayas and Demirtas, 2009).

The maximum WUE values for 2009 year were found as 0.11, 0.11, 0.12 – 0.11, 0.11, 0.11 kg mm⁻¹ and were found as 0.13, 0.12, 0.12 – 0.11, 0.11, 0.11 kg mm⁻¹ from $E_{75}V_{75}Y_{75}R_{75}$, $E_{50}V_{50}Y_{50}R_{50}$, $E_{25}V_{25}Y_{25}R_{25}$ and $E_{VYR_{75}}$, $E_{VYR_{50}}$, $E_{VYR_{25}}$ treatments for 2010 year, respectively. IWUE values for 2009 year were found as 0.12, 0.12, 0.13 – 0.14, 0.12, 0.13 kg.mm⁻¹ and 0.13, 0.12, 0.12 – 0.13, 0.12, 0.12 kg mm⁻¹ from $E_{75}V_{75}Y_{75}R_{75}$, $E_{50}V_{50}Y_{50}R_{50}$, $E_{25}V_{25}Y_{25}R_{25}$ and $E_{VYR_{75}}$, $E_{VYR_{50}}$, $E_{VYR_{25}}$ treatments, respectively. When WUE and IWUE values were taken into consideration, the maximum WUE and IWUE values were obtained in establishment and ripening periods and the lowest value was obtained from vegetative and yield formation periods.

When the results concerning WUE values compared with the findings of different researchers, they were in agreement with those of the other studies (Doorenbos and Kassam, 1979; Orta and Şener, 2001; Kadayifci et al., 2005; Bekele and Tilahun, 2007; Ayas and Demirtas, 2009; Bagali et al., 2012).

Water requirements for onions varies with location and irrigation system (Al-Jamal et al., 2001). 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 1.03 and 1.04 for onion, respectively. The specified values of k_y (1.03-1.04) which is bigger than 1.00 shows that onion is susceptible to the water. Crop yield response factor (k_y) also matches up with the values obtained by researchers who studied on similar issues (Doorenbos and Kassam, 1979; Orta and Şener, 2001; Kadayifci et al., 2005; Ayas and Demirtas, 2009; Bagali et al., 2012).

Conclusion

According to the results of the study, irrigation water were applied 436 and 448 mm in $E_{100}V_{100}Y_{100}R_{100}$ treatment applied of full irrigation in 2009 and 2010 years. The plant water consumption of onion was determined as 205-496 mm and 210-502 mm for $E_0V_0Y_0R_0$ treatment 2009 and 2010 years.

Crop yield response factors (k_y) for the different irrigation levels ($E_{100}V_{100}Y_{100}R_{100}$, $E_{75}V_{75}Y_{75}R_{75}$, $E_{50}V_{50}Y_{50}R_{50}$, $E_{25}V_{25}Y_{25}R_{25}$, $E_{VYR_{75}}$, $E_{VYR_{50}}$, $E_{VYR_{25}}$, $E_0V_0Y_0R_0$ treatments) in 2009 and 2010 years were calculated as 1.03 and 1.04 for onion, respectively. The factors of k_y (1,03 and 1.04) values are bigger than 1,00 showed that the onion 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 $E_0V_0Y_0R_0$ treatments, while the lowest yield decreases were in $E_{100}V_{100}Y_{100}R_{100}$ treatments. In our experiment, it was studied out that irrigation treatments considerable influences yield, bulb diameter, weight, height and dry matter ratio.

In this study, it was studied out that irrigation applications considerably influences yield, bulb weight, diameter, height and dry matter. In both years of the study, the highest yield were 52.2 t h⁻¹ and 52.4 t h⁻¹ and it was observed in $E_{100}V_{100}Y_{100}R_{100}$ treatment. The lowest yield were observed as 0.8 t h⁻¹ and 0.5 t h⁻¹ in $E_0V_0Y_0R_0$ treatment. Yield decreased considerably as a result of the diminishment in the irrigation water. Relative yield decreases in the irrigation treatments in 2009 and 2010 were 6.5%, 7.2%, 7.6%, 12.5%, 13.5%, 14.2%, 17.3%, 19.2%, 21.4%, 6.5%, 7.2%, 7.9%, 6.425.0% and 7.4%, 8.0%, 8.7%, 12.7%, 13.4%, 14.4%, 14.2%, 16.4%, 18.6%, 6.5%, 7.4%, 8.3%, 10380.0%, respectively. WUE and IWUE values of establishment 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 onion yield. If deficit irrigation treatment is obligatory, water deficiency should be planned only for establishment and ripening periods of onion. The water deficiency shouldn't be applied in vegetative and yield formation periods and irrigations in these periods should be exactly applied. In addition, in the irrigation planning to be applied in similar climatic conditions may be benefited from crop yield response factor (k_y) 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 onion. It can be recommended that establishment and ripening periods is most suitable periods for the deficit irrigation practices for onion irrigation by drip irrigation.

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