



## Deficit irrigation effects on onion (*Allium cepa* L. E.T. Grano 502) yield in unheated greenhouse condition

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### Abstract

The aim of this study was to determine the effect of deficit irrigation on yield of onion grown under unheated greenhouse condition. The research was carried out at the Agricultural Research Station of Yenişehir High School of Uludağ University in Bursa, Turkey, in 2007. In the study, water was applied to onion as 100, 75, 50, 25 and 0% (as control) of evaporation from a Class A Pan corresponding to 2-day irrigation frequency. Irrigation water applied to crops ranged from 65 to 362 mm, and water consumption ranged from 95 to 372 mm. The effect of irrigation water level on the yield, bulb height, bulb diameter, bulb weight and dry matter ratio were found to be significant. The highest yields were 51 and 39 t ha<sup>-1</sup> for the  $K1_{cp}$  and  $K2_{cp}$  treatments, respectively. Crop yield response factor ( $k_y$ ) was found as 1.060. The highest values for water use efficiency (WUE) and irrigation water use efficiency (IWUE) were found to be 13.84 and 12.71 kg mm<sup>-1</sup> for the  $K3_{cp}$  treatment. Under the conditions that water resources are scarce, it can be recommended that  $K3_{cp}$  treatment is most suitable as a water application level for cucumber irrigation by drip irrigation under unheated greenhouse condition.

**Key words:** Onion, deficit irrigation, irrigation water use efficiency.

### Introduction

Greenhouse cultivation, also known as protected cultivation, is one of the farming systems widely used to provide and maintain a controlled environment suitable for optimum crop production leading to maximum profits. This includes creating an environment suitable for working efficiency as well as for better crop growth<sup>2</sup>. Greenhouse cultivation is a steadily growing agricultural sector all over the world<sup>12,38</sup>. The type of structure primarily used in Turkey is the so-called Mediterranean greenhouse; low-cost, unheated plastic-covered structures and with soil-grown crops.

Irrigation scheduling involves preventing the soil water deficit from falling below some threshold level for a particular crop and soil condition. This may involve estimating the earliest date to permit efficient irrigation or the latest date to avoid the detrimental effects of water stress on the crop<sup>30</sup>. 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.

Approaches used to establish schedules for drip irrigation include estimates based on evapotranspiration<sup>5,8,14,24</sup>, allowable soil-water depletion<sup>6</sup>. A widely adopted method for estimating crop consumptive water use (CWU) is the evaporation pan method, which relates evaporation from a Class A evaporation pan to CWU. These two quantities are related by what is called the crop coefficient  $K$ . Irrigation scheduling based on the crop coefficient  $K$  is one of the simplest methods where no sophisticated instrument is required. Precise values for  $K$  are often difficult to establish, given regional and site-specification, soil characteristics, crop physiology and cultural practices. Any

recommended value of  $K$  for regional irrigation scheduling program must be high enough to prevent water stress arising from emergencies and specialized local situations, while remaining low enough for efficient water management<sup>40</sup>. Based on the US Weather Bureau Class A pan evaporation, many studies have been completed on the irrigation of cucumber<sup>10,29</sup>, tomato<sup>20</sup>, potato<sup>13,26</sup>, lettuce<sup>39</sup> and green bean<sup>7</sup>.

Onion (*Allium cepa* L.) is one of the chief horticultural crops of Turkey. Many studies have been reported on irrigation of onions<sup>1,15,18,22,28,31-34,37</sup>. These studies give clear proof that the bulb and dry matter production were highly dependent on appropriate water supply.

The objective of this study was to determine the effect of irrigation water level on the yield, bulb height, bulb diameter, bulb weight and dry matter ratio, daily and seasonal evapotranspiration, yield response factor ( $k_y$ ), irrigation water use efficiency (IWUE) and water use efficiency (WUE).

### Materials and Methods

Field experiment was carried out under unheated greenhouse condition in Yenişehir, Bursa (40°15'09"N latitude, 29°38'43"E longitude and altitude of 225 m above mean sea level). A high tunnel with the size of 8 m x 40 m using plastic coverage placed in north-south direction was used for the experiment. Summers are hot and dry; winters are cold and rainy in the region. Annual mean rainfall and temperature are 482.9 mm and 13.6°C, respectively. Average minimum temperature is 3.6°C in December; maximum temperature is 23.3°C in August<sup>4</sup>. 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. N 80 kg ha<sup>-1</sup>, DAP (18% N and 46% P<sub>2</sub>O<sub>5</sub>) 100 kg ha<sup>-1</sup> and KNO<sub>3</sub> (N 13% and K<sub>2</sub>O 46%) 120 kg ha<sup>-1</sup> as granular fertilizer were applied prior to planting, and pest control chemicals were added as required.

Onion seedlings were transplanted to the plots (18 May 2007). The plants were grown 0.20 m apart between the rows with 0.10 m spacing in each row. Each plot has contained 600 plants. In order to prevent the water in any one plot from affecting its neighboring plots, only the 50 plants of middle row were harvested. Bulb length (cm), bulb diameter (cm), and bulb weight (g) were measured by caliper rule and calculated as the average of measured values. The dry matter amount was found after drying at 85°C in 48 hours.

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

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

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

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

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

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

where ( $SWC_{i0} - SWC_{i1}$ ) is the change in volumetric soil water content between two measurement dates;  $IW$  and  $D$  are respectively the total volumes of applied irrigation water and

collected drainage for the period under consideration. The water content of plant root depth (0.60 m) was determined by gravimetric method before irrigation water application<sup>21</sup> and monitored in 30 cm depth increments to 0.90 m after irrigation for each irrigation treatments. Monitoring the soil water content in the plots revealed that deep percolation below 0.60 m depth was negligible.

In this study, the Stewart model has contributed to define the relationships between yield and  $ET$ <sup>9</sup>:

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

where  $Y_a$  is the actual yield (t ha<sup>-1</sup>),  $Y_m$  is the maximum yield (t ha<sup>-1</sup>),  $ET_a$  is the actual evapotranspiration (mm) and  $ET_m$  is the maximum evapotranspiration (mm). Values of  $k_y$  indicate the response factor of onion 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  $WUE = YLD/ET_a$  (t ha<sup>-1</sup> mm<sup>-1</sup>). IWUE was estimated by following equation:

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

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

In the harvesting time, 104 days after the onion bulbs were transplanted; the onion plants were fully developed and had the diameter, length, weight, colour and the flavour characteristics of the species. Harvested bulbs from each plot were evaluated immediately according to yield, bulb height, bulb diameter, bulb weight and dry matter ratio.

Analysis of variance was performed on yield and yield component data using the MSTAT-C (version 2.1-Michigan State University 1991) and MINITAB (University of Texas at Austin) software. The significance of irrigation treatments were determined at the 0.05 and 0.01 probability levels, by the F-test<sup>36</sup>.

## Results and Discussion

**Water applied and water used:** After planting, 65 mm irrigation water was applied to some treatments to bring the soil water content in 0–60 cm soil depth up to level of field capacity. Irrigation treatments were started measuring of evaporation from Class A

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

Soil depth (cm)	$\gamma$ (g cm <sup>-3</sup> )	Soil type	Field capacity (%)	Wilting point (%)	pH	Total salt (%)	CaCO <sub>3</sub> (%)	Organic matter (%)	Available (kg da <sup>-1</sup> )	
									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

$\gamma$  Unit weight of soil, SL Sandy loam, P Phosphorus, K Potassium.

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

Water source	EC <sub>25x</sub> (10 <sup>6</sup> )	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	pH	Class	SAR
Deep well	715	2.3	2.56	9.25	5.7	7.12	C <sub>2</sub> S <sub>1</sub>	0.85

pan after the first irrigation application. The maximum amount of water applied to the crop was 362 mm in the  $K1_{cp}$  treatments 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 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  $K5_{cp}$  and  $K1_{cp}$  treatments, respectively (Table 3).

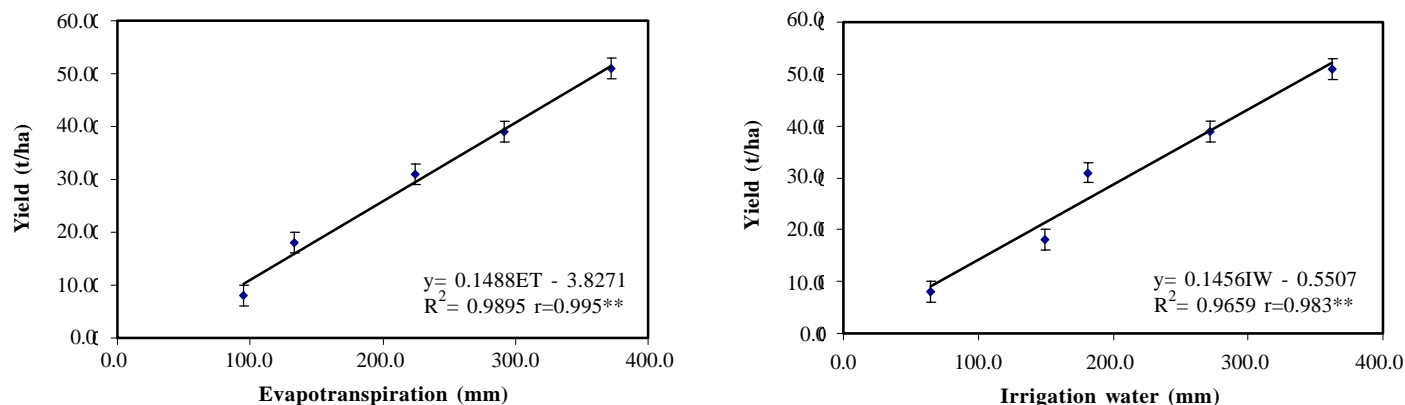
Water requirements for onions varies with location and irrigation system<sup>3</sup>. Onion irrigation quantities applied to the treatments varied from 135 to 620.3 mm and seasonal evapotranspiration ranged from 350 to 450 mm in Isparta<sup>17</sup>. The water requirements in Albacete (Spain) for optimum yield were 662 mm when using drip irrigation<sup>23</sup>. 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<sup>19</sup>. Seasonal evapotranspiration for optimum onion yield ranged from 350 mm to 450 mm, depending on the irrigation of each year<sup>25</sup>. Irrigation requirements of onion ranged between 350 and 550 mm<sup>9</sup>. The seasonal crop water consumption was between 286 and 389 mm<sup>11</sup>. Linear relationships were observed between the crop evapotranspiration ( $ET_c$ ) with yield ( $Y_a$ ) and irrigation water (IW) with yield ( $Y_a$ ). The equation for the relationship was  $Y_a = 0.1488ET_c - 3.8271$  with  $R^2 = 0.99$  and  $Y_a = 0.1456IW - 0.5507$  with  $R^2 = 97$  (Fig. 1).

In our study, treatment  $K1_{cp}$  had the highest yield (51 t ha<sup>-1</sup>) followed by  $K2_{cp}$ ,  $K3_{cp}$  and  $K4_{cp}$  irrigation treatments with 39, 31 and 18 t ha<sup>-1</sup>, respectively. As expected, non-irrigated control  $K5_{cp}$  had the lowest yield (8 t ha<sup>-1</sup>). The non-irrigated treatment ( $K5_{cp}$ ) produced 537.5% lower yield than the  $K1_{cp}$  treatment. However,  $K2_{cp}$ ,  $K3_{cp}$  and  $K4_{cp}$  had 30.8, 64.5 and 183.3% less yield compared with treatment  $K1_{cp}$  (Table 4).

Deficit irrigation had a significant effect on bulb height, the value of  $K1_{cp}$  was in the first group,  $K2_{cp}$ ,  $K3_{cp}$  and  $K4_{cp}$  treatments were in the second group and  $K5_{cp}$  was placed in last group. It can be concluded that the deficit of applied irrigation water (25%) is not compatible with the reduction in bulb height. According to results, there was no effect of deficit irrigation on bulb height in terms of marketable value. These results are in agreement with earlier studies<sup>16, 17, 19, 23, 25</sup>.

The bulb diameter and bulb weight had a similar response to deficit irrigation like yield. All irrigation treatments had higher values than the non-irrigated ( $K5_{cp}$ ) treatment.

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 bulb weight observed from  $K1_{cp}$  treatment than those of deficit irrigation treatments. These results are similar to those of other authors<sup>16, 25, 27</sup>.



**Figure 1.** The relationship between crop evapotranspiration with yield and water irrigation with yield. (The error bars are SE of 50 plants).

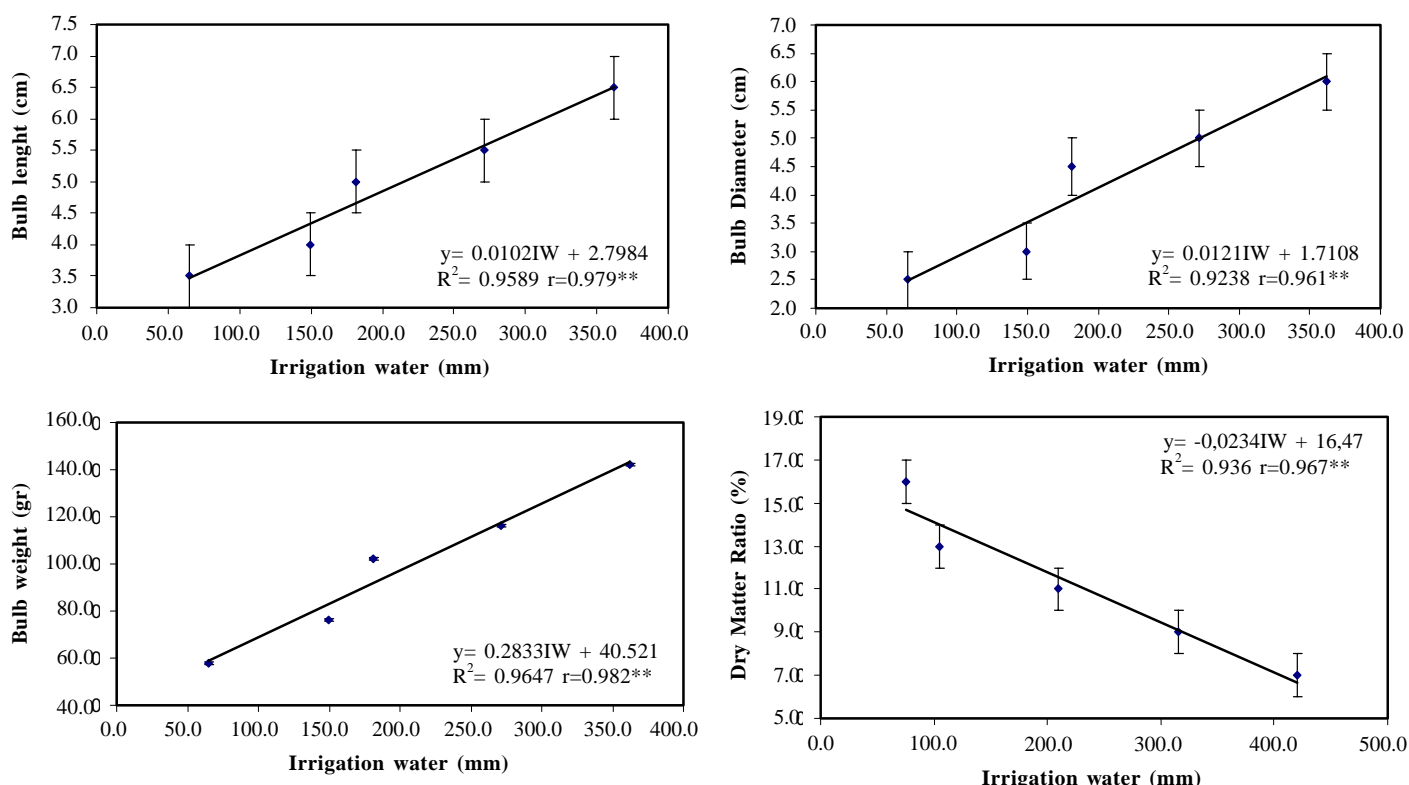
**Table 3.** Relationship between the decrease in relative water use and decrease in relative yield and yield response factor for onion irrigated by a drip system.

Irrigation treatment	Yield (t ha <sup>-1</sup> )	Applied Water (mm)	ET <sub>a</sub> (mm)	ET <sub>a</sub> /ET <sub>m</sub>	Y <sub>a</sub> /Y <sub>m</sub>	1-(ET <sub>a</sub> /ET <sub>m</sub> )	1-(Y <sub>a</sub> /Y <sub>m</sub> )	k <sub>y</sub>
$K1_{cp}$	51	362	372	1.000	1.000	0.000	0.000	0.000
$K2_{cp}$	39	272	292	0.785	0.765	0.215	0.235	1.094
$K3_{cp}$	31	181	224	0.602	0.608	0.398	0.392	0.986
$K4_{cp}$	18	149	134	0.359	0.353	0.641	0.647	1.009
$K5_{cp}$	8	65	95	0.255	0.157	0.745	0.843	1.132

**Table 4.** Effects of irrigation treatments on onion marketable parameters.

Irrigation treatment	Bulb height (cm)	Bulb diameter (cm)	Bulb weight (g)	Dry matter (%)	Yield (t ha <sup>-1</sup> )
$K1_{cp}$	6.5a	6.0a	142.0a	9.8d	51a
$K2_{cp}$	5.5ab	5.0a	116.0b	11.4cd	39b
$K3_{cp}$	5.0ab	4.5ab	102.0c	12.1bc	31c
$K4_{cp}$	4.0ab	3.0bc	76.0d	13.3ab	18d
$K5_{cp}$	3.5b	2.5c	58.0e	14.4a	8e
Treatments	**	**	**	**	**
Blocks	ns	ns	ns	ns	ns

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

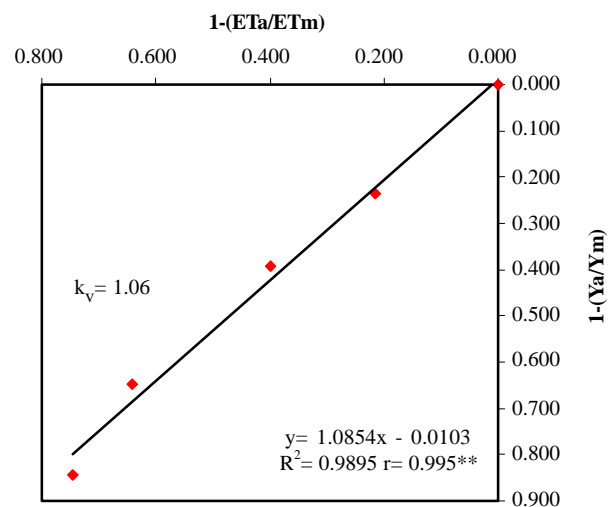


**Figure 2.** Relationship between applied of irrigation water and bulb length, bulb diameter, bulb weight and dry matter ratio. (The errors bars are SE of 50 plants).

Positive linear relation was found among bulb height, bulb diameter and bulb weight, negative linear relation was found between dry matter ratio and amount of water applied (IW). The equation for the relationship was *Bulb height* = 0.0102IW + 2.7984 with  $R^2 = 0.96$  (Fig. 2a), *Bulb diameter* = 0.0121IW + 1.7108 with  $R^2 = 0.92$  (Fig. 2b), *Bulb weight* = 0.2833IW + 40.521 with  $R^2 = 0.96$  (Fig. 2c) and *Dry matter ratio* = -0.0234IW + 16.47 with  $R^2 = 0.94$  (Fig. 2d).

**Crop yield response factor ( $k_y$ ):** Crop yield response factor ( $k_y$ ) indicates a linear relationship between the decrease in relative water consumption and the decrease in relative yield. It shows the response of yield with respect to the decrease in water consumption. In other words, it explains the decrease in yield caused by the per unit decrease in water consumption<sup>9,35</sup>. Seasonal crop response factor was determined as 1.060 for irrigation treatments (Fig. 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  $K3_{cp}$ , 13.84 and 12.71 kg mm<sup>-1</sup> respectively. When considering IWUE values of  $K1_{cp}$ ,  $K2_{cp}$  and  $K3_{cp}$  treatments, IWUE values of  $K3_{cp}$  treatment was found higher than that of  $K1_{cp}$  treatment followed by  $K2_{cp}$  (Table 5).



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

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

Irrigation treatment	Yield (t ha <sup>-1</sup> )	WUE kg mm <sup>-1</sup>	IWUE kg mm <sup>-1</sup>
$K1_{cp}$	51	13.71	11.88
$K2_{cp}$	39	13.36	11.42
$K3_{cp}$	31	13.84	12.71
$K4_{cp}$	18	13.48	6.71
$K5_{cp}$	8	8.42	0.00

### Conclusions

In this study, irrigation treatments significantly affected yield, bulb height, bulb diameter, bulb weight and dry matter ratio. The

highest yield was obtained from  $K1_{cp}$  treatment as  $51 \text{ t ha}^{-1}$  and the minimum yield was obtained from  $K5_{cp}$  treatment as  $8 \text{ t ha}^{-1}$ . Yield was significantly reduced as the amount of irrigation water decreased. The rates of reduction in relative yield were 30.8, 64.5, 183.3 and 537.5% at the irrigation treatments, respectively. IWUE value in  $K3_{cp}$  treatment was higher than in  $K1_{cp}$  and  $K2_{cp}$  treatments. Under the conditions that water resources are scarce, it can be recommended that  $K3_{cp}$  treatment is most suitable as a water application level for onion irrigation by drip irrigation under the unheated greenhouse condition.

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