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ORIGINAL PAPER

Improvement of yield and water productivity of Adama onion (*Allium cepa* L.) under deficit irrigation using furrow method in West Oromia, Ethiopia

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Abstract: Water scarcity is the most severe constraint for agricultural growth in arid and semi-arid areas. To overcome this, there is a need to use the scarce water efficiently and economically which is an important strategy to address present and future water need. This study was conducted from December 2017 to March 2018 in Ambo District, aiming to investigate the effect of deficit irrigation at different growth stages on yield and water productivity of onion. The experiment was laid out in randomized completed block design with three replications and nine treatments namely, T1: control (without deficit irrigation at any growth stage – 100% crop evapotranspiration, ETc); T2: 20% deficit irrigation in all growth stages – 80% ETc; T3: 40% deficit irrigation in all growth stages – 60% ETc; T4: 20% deficit irrigation in development and late stages – 80% ETc, and 40% deficit irrigation in mid stage – 60% ETc; T5: 20% deficit irrigation in development and late stages – 80% ETc, and 40% deficit irrigation in initial stage – 60% ETc; T6: 20% deficit irrigation in initial stage – 80% ETc; T7: 20% deficit irrigation in development stage – 80% ETc; T8: 20% deficit irrigation in mid stage – 80% ETc; T9: 20% deficit irrigation in late stage – 80% ETc. The results indicated that deficit irrigation levels at different growth stages had significantly ($p \leq 0.05$) affected the yield and water productivity of onion. The highest marketable yield (28.68 ton ha^{-1}) was obtained from 20% deficit irrigation at late stage (T9), whereas lowest yield (14.42 ton ha^{-1}) was recorded from 40% deficit irrigation in all growth stages (T3). The mean values of onion yield obtained in T2, T6, T8, and T9 no differ statistically. The highest water productivity (8.77 kg m^{-3}) was obtained in T2 (20% deficit in all growth stages), while the lowest water productivity (5.17 kg m^{-3}) was obtained in T4 (20% deficit irrigation at development and late stages, and 40% deficit irrigation at mid stage). These results confirmed that with deficit irrigation practice it is possible to increase water productivity by saving water and increase income from scarce water. Therefore, it was recommended that the application of deficit irrigation in 20% of crop water requirement throughout season in four days irrigation interval is beneficial for obtaining optimum onion yield and increases water productivity. To save scarce irrigation water and to gained better economic return as optional, farmers should also use 20% deficit irrigation at development and late stages, and 40% deficit irrigation at mid stage.

Keywords: Deficit irrigation, crop water requirement, water resources.

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Introduction

Ethiopia is the second most populous country in Africa next to Nigeria. Most of its populations were dependent on agriculture with a low level of productivity. Agricultural practice of the country is mostly on rain-fed depended and it accounts about 40% of the gross domestic products (Awulachew et al., 2010). Irrigated agriculture is the main focus for the food security strategy of the country by implementing small scale irrigation schemes which reduce dependency on rain-fed agriculture and increase food self-sufficiency of the rapidly increasing population (Awulachew and Ayana, 2011; Temesgen et al., 2022). Its continuous decreases in water availability coupled with an increasing demand for irrigation water use has forced farmers to seek water saving technologies. To achieve sustainable irrigated agriculture by using limited water resources, different water saving technologies and guidelines are advisable for irrigation water users (Geerts and Raes, 2009; Silva et al., 2021; Coelho et al., 2022).

In scarce water resource condition, deficit one of the ways to maximize irrigation water use efficiency. Deficit irrigation is a technology to improve water use efficiency by exposing crops to certain level of water stress either during a particular period or throughout the whole growing season. This technology has been widely investigated as a valuable and sustainable production strategy in arid and semi-arid regions to maximize water use efficiency for higher yields per unit of irrigation water applied (Fereres and Soriano, 2007; Abdelkhalik et al., 2019; Asres et al., 2022; Yang et al., 2022).

Onion (*Allium cepa* L.) is one of a popular vegetable crop in Ethiopia and area coverage is increasing from time to time mainly due to its high profitability per unit area, ease of production and important in the daily diet. The country has high potential to benefit from onion production and contributes significant value to the national economy. This indicates that Ethiopia has high potential to benefit from onion production. Higher yield potential, availability of desirable cultivars for various uses, ease of production by seed, high domestic and export marketing were making onion increasingly important in Ethiopia (Belay et al., 2015; Gessesew et al., 2015; Mugoro et al., 2020). Onion is the most potential crop in the study area for income generation and household consumption. Therefore, people in the area highly compete for water to produce this potential crop. Even though crops response to soil moisture level depends on growth stage and crop variety, there has been no investigation was identified (Temesgen et al., 2018; Tolossa, 2020).

A Huluka small scale irrigation scheme at Ambo district is one of major sources of income to the rural communities in western Showa. The scheme is facing with high water scarcity during the dry season (October to April); during this season crop water supply is low while its demand is high and the scarce irrigation water application is practiced based on farmers' judgment but not based on scientific principle which resulting in competition among the farmers (Tolossa, 2021). The assessment done, despite the significance of the problem of water scarcity and inefficient irrigation water use, the studies which could improve water use efficiency was not done almost for all crops.

Given the context, the objective of the present study was to investigate the effect of deficit irrigation on yield and water productivity of onion under furrow irrigation system in West Oromia, Ethiopia.

Material and Methods

Description of the study area

The study was conducted at Ambo District in West Showa Zone, Oromia, Ethiopia (08° 57' N, 37° 52' E, and at an altitude of 2225 m above mean sea level), as shown in Figure 1. The site is located at about 115 km west of Addis Ababa. The area has a warm humid climate with mean minimum and maximum monthly temperatures of about 10.3 and 26.4°C, respectively. The mean total annual rainfall is 1036 mm.

The soil physical and chemical properties of experimental area are presented in Table 1. The composite soil samples were collected using auger from experimental field diagonally from five locations before starting of field operation. Collected samples were at 30 cm soil depth interval up to 60 cm (0-30 and 30-60 cm) to characterization of texture, pH, electrical conductivity (EC), bulk density (BD), gravimetric water content at field capacity (GWC_{FC}), and gravimetric water content at permanent wilting point (GWC_{PWP}).

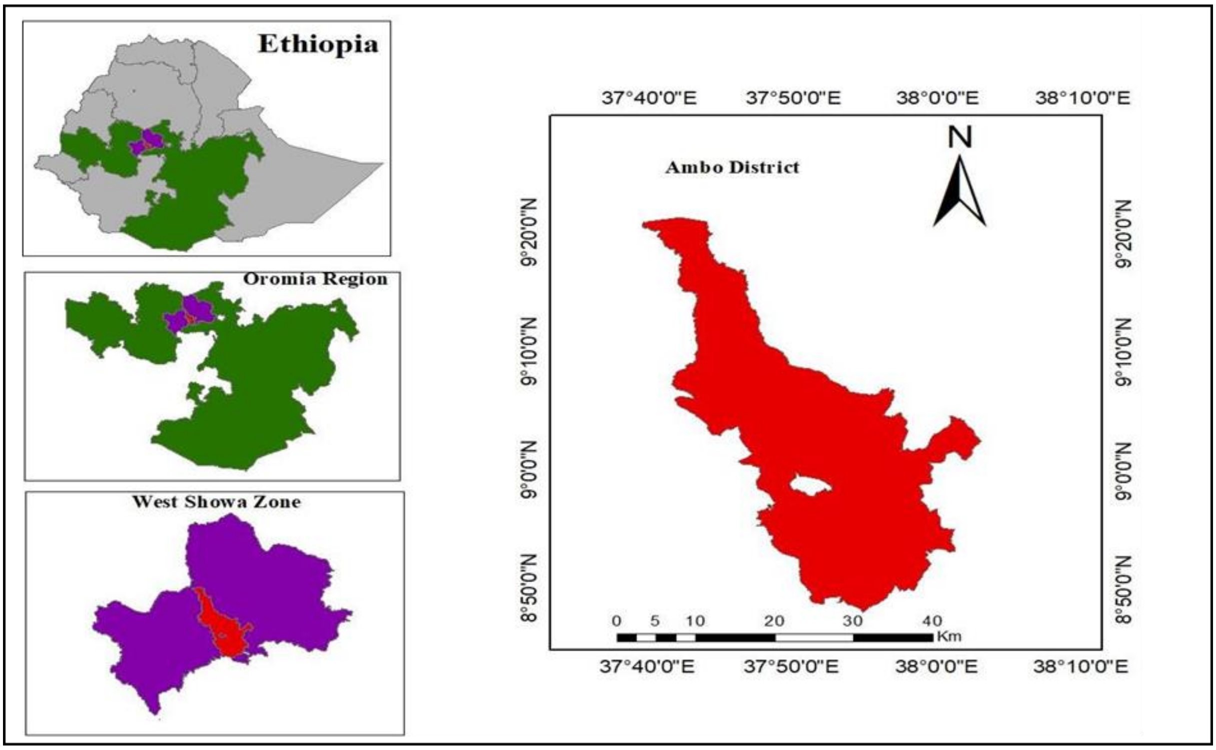

Figure 1: Location map of the study area.

Table 1: Soil physical and chemical properties of the experimental site

Soil properties		Soil depth (cm)		
		(0-30)	(30-60)	Average
Particle size distribution	Sand (%)	35.23	34.50	34.87
	Silt (%)	28.54	26.50	27.52
	Clay (%)	36.23	39.00	37.62
Textural class		Clay loam	Clay loam	--
Bulk density – BD (g cm^{-3})		1.05	1.20	1.13
GWC_{FC} (%)		28.93	26.50	27.72
GWC_{PWP} (%)		14.02	13.80	13.91
TAW (mm m^{-1})		156.56	152.40	154.48
pH		7.20	7.50	7.35

TAW – Total available water [$TAW = (GWC_{FC} – GWC_{PWP}) \times BD \times 10$]; GWC_{FC} – gravimetric water content at field capacity; GWC_{PWP} – gravimetric water content at permanent wilting point.

Experimental design and growing conditions

The experiment was laid out in randomized completed block design with three replications and nine treatments namely, T1: control (without deficit irrigation at any growth stage – 100% crop evapotranspiration, ETc), T2: (20% deficit irrigation in all growth stages – 80% ETc), T3: (40% deficit irrigation in all growth stages – 60% ETc), T4: (20% deficit irrigation in development and late stages – 80% ETc; 40% deficit irrigation in mid stage – 60% ETc; initial stage without deficit irrigation – 100% ETc), T5: (20% deficit irrigation in development and late stages – 80% ETc; 40% deficit irrigation in initial stage – 60% ETc; mid stage without deficit irrigation – 100% ETc), T6: (20% deficit irrigation in initial stage – 80% ETc), T7: (20% deficit irrigation in development stage – 80% ETc), T8: (20% deficit irrigation in mid stage – 80% ETc), and T9: (20% deficit irrigation in late stage – 80% ETc).

The size of experimental site was 20.0 m × 43.8 m (876 m^2), each plot with 3.2 m × 4.0 m size. The spacing between plots and replications were 1.5 and 2.0 m, respectively. Surface drainage system was provided to protected excess flow of water to other plots. Onion was planted in ridges with spacing of 40 × 20 × 10 cm (40 cm between furrow, 20 cm between row on furrow bed, and 10 cm between plants, respectively). Plants were grown in both ridges of furrow and each plot had eight rows (80 plants per row), a total of 640 plants per plot.

Adama onion variety was used in the present study. This variety takes 110-120 days for bulb maturity; it has light red bulb skin color, dark green leaf color, flat globe bulb shape and reddish white bulb flesh color. The seeds were sown in bed in beginning November and transplanted to the field on December 10, 2017. The 40-day-old seedlings had from 12 to 15 cm height, with 3-4 true leaves. The experimental area was kept weed free by ploughing before transplanting. One day before transplanting, the nursery beds were provided light irrigation for the safe uprooting of onion safely. During planting only healthy, vigorous and uniform seedlings were transplanted. To ensure the plant establishment full irrigation was applied to all plots at two days interval with 7.76 mm of water for total of 8 days before beginning of the differential irrigation.

Agronomic management practices such as hand digging, pulling of weeds and chemical applications were done in cropping season starting from December to February, practices similar to those adopted in the study area. According to recommendations of the Ethiopian Agricultural Transformation Agency, before transplanting 200 kg ha^{-1} of NPS (nitrogen, phosphorus and sulfur) fertilizer were applied. Urea 100 kg ha^{-1} during planting and other 100 kg ha^{-1} six weeks after transplanting were applied. Rodomel Gold (3 L ha^{-1}) was used to control against fungus.

Crop evapotranspiration

First, reference evapotranspiration (ET_o) was calculated by the modified FAO Penman-Monteith method using FAO CROPWAT 8.0 software's (Allen et al., 1998), based on the data collected (minimum and maximum air temperature, relative humidity, wind speed, and solar radiation) from the Ethiopian Meteorological Agency. From the ET_o (mm day^{-1}), the crop evapotranspiration (ETc, mm day^{-1}) was calculated according to Equation 1.

$$ETc = Kc \times ET_o \quad (1)$$

Where: Kc – crop coefficient (0.7 used in initial stage, 17 days; 0.7 < Kc < 1.05 used in development stage, 29 days; 1.05 used in mid stage, 37 days; 0.95 < Kc < 1.05 used in late stage, 21 days).

The net irrigation requirement (NIR, in mm) was then calculated by Equation 2.

$$NIR = ETc - Pe \text{ (mm)} \quad (2)$$

Where: Pe – effective rainfall, calculated from the Equations 3 or 4 (Brouwer and Heibloem, 1986):
For P > 75 mm month^{-1}

$$Pe = 0.8 \times P - 25 \quad (3)$$

For P < 75 mm month^{-1}

$$Pe = 0.6 \times P - 10 \quad (4)$$

Gross irrigation requirement (GIR, in mm) is the ratio of net irrigation considering application efficiency (Ea) of furrow irrigation. By taking application efficiency of a short, end diked furrow as 60% (Brouwer et al., 1989), the GIR was calculated according to Equation 5.

$$GIR = \frac{NIR}{Ea} \quad (5)$$

Finally, the application time (Ta) of the irrigation depth was calculated using Equation 6, described by Dirirsa et al. (2022). The amount of irrigation water applied to the plots was measured using a Parshall flume.

$$Ta \text{ (min)} = \frac{GIR \times A}{60 \times q} \quad (6)$$

Where: A – plot area, in m^2; q – flow rate, in L s^{-1}.

Data collection

At the end of the experiment (104 days), the plant height (PH, in cm), number of leaves (all completely developed leaf were counted and recorded per plant), and bulb diameter (BD, in mm) were measured. The data were collected from 12 random tagged plants of six central rows, excluding two border rows. The PH was taken by measuring the main stem height from the ground level up to the tip of the leaf with the ruler. BD was measured middle portion of the mature bulb using a slide caliper. The harvested yield data from each plot was then expressed in ton ha^{-1}.

The crop water productivity (CWP) was calculated using Equation 7. The CWP (kg m^{-3}) in this study was determined by dividing the onion bulb yield to the irrigation water used by the crop, as described by other authors (Simões et al., 2022; Veimrober Júnior et al., 2022; Akbar et al., 2023).

$$CWP = \frac{\text{Onion bulb yield (kg)}}{\text{Irrigation requirement (m}^{-3}\text{)}} \quad (7)$$

Statistical analysis

The collected data were subjected to statistical analysis of variance (ANOVA) using SAS software version 9.1. Whenever treatment effects were found significant, treatment means were compared using the least significant difference (LSD) method.

Results and Discussion

Climatic conditions and irrigation water requirement during the experiment

The ET_o values varied from 3.6 to 4.2 mm day^{-1} for January and March, respectively (Table 2). A low ETc at the beginning of the growing season was observed, increasing gradually, and attained a maximum during mid-season crop growth stage, and subsequently decreased in late-season (Table 3). The result indicated that the maximum amount of crop water requirement was applied at the mid stage.

The total effective rainfall during the experimental period was 136.9 mm (Table 3). The irrigation water depths applied in each treatment is shown in Table 4. The irrigation depth throughout the entire period of onion cultivation was 366 mm for the treatment control (without deficit irrigation at any growth stage – 100% ETc). This value is within the range of stated by Doorenbos and Kassam (1979) for an optimum onion yield production, that requires from 350 to 550 mm of water.

Table 2: Average monthly of the climatic data during the experimental period (from January to March 2018)

Month	T_{min} (°C)	T_{max} (°C)	RH (%)	Wind speed (km h^{-1})	Rs (MJ m^{-2} day^{-1})	ET_o (mm day^{-1})
January	7.8	25.5	81.3	121.3	19.9	3.6
February	8.9	26.4	77.3	124.0	20.5	3.9
March	10.2	26.4	80.0	130.0	21.7	4.2

T_{min} – minimum air temperature; T_{max} – maximum air temperature; RH – relative humidity; Rs – solar radiation; ET_o – reference evapotranspiration.

Table 3: Onion crop water requirement with irrigations performed every four days

Growth stage	Irrigations	ET_o (mm)	Kc	ETc (mm)	Pe (mm)	NIR (mm)	GIR (mm)
Initial 17-days	18-Dec	14.8	0.6	8.88	0	8.88	14.8
	22-Dec	14.8	0.6	8.88	0	8.88	14.8
	26-Dec	14.8	0.6	8.88	0	8.88	14.8
	30-Dec	14.8	0.6	8.88	0	8.88	14.8
	3-Jan	14.4	0.6	8.64	0	8.64	14.4
Development 29-days	7-Jan	14.4	0.8	11.52	0	11.52	19.2
	11-Jan	14.4	0.8	11.52	0	11.52	19.2
	15-Jan	14.4	0.8	11.52	0	11.52	19.2
	19-Jan	14.4	0.8	11.52	0	11.52	19.2
	23-Jan	14.4	0.8	11.52	0	11.52	19.2
	27-Jan	14.4	0.8	11.52	0	11.52	19.2
	31-Jan	14.4	1.1	15.84	8	7.84	13.07
	4-Feb	15.6	1.1	17.16	8.4	9.16	15.27
Mid 37-days	8-Feb	15.6	1.1	17.16	14	3.16	5.27
	12-Feb	15.6	1.1	17.16	12	5.16	8.6
	16-Feb	15.6	1.1	17.16	0	17.16	28.6
	20-Feb	15.6	1.1	17.16	15	2.16	3.6
	24-Feb	15.6	1.1	17.16	13	4.16	6.93
	28-Feb	15.6	1.1	17.16	0	17.16	28.6
	4-Mar	16.8	1.1	18.48	15	3.48	5.8
	8-Mar	16.8	1.1	18.48	10	8.48	14.13
Late 21-days	12-Mar	16.8	0.9	15.12	9.5	5.62	9.37
	16-Mar	16.8	0.9	15.12	9	6.12	10.2
	20-Mar	16.8	0.9	15.12	12	3.12	5.2
	24-Mar	16.8	0.9	15.12	11	4.12	6.87
	28-Mar	16.8	0.9	15.12	0	15.12	25.2
	1-Apr	4.2	0.9	3.78	0	3.78	6.3
104-days	Total			365.58	136.9	229.08	381.8

ET_o – reference evapotranspiration; Kc – crop coefficient; ETc – crop evapotranspiration; Pe – effective rainfall; NIR – net irrigation requirement; GIR – gross irrigation requirement.

Table 4: Irrigation water depths applied in each growth stage of the Adama onion

Treatments	Growth stages: Initial	Development	Mid	Late	NIR_{total} (mm)	Pe (mm)	IR (NIR_{total} + Pe) (mm)
	NIR_{stage} (mm)						
T1	44.20	77.00	70.10	37.90	229.1	136.5	366
T2	35.33	61.568	56.06	30.34	183.3	136.5	320
T3	26.49	46.176	42.05	22.73	137.4	136.5	274
T4	44.16	61.568	42.05	30.31	178.1	136.5	315
T5	26.49	61.568	70.08	30.30	188.4	136.5	325
T6	35.33	76.96	70.08	37.88	220.2	136.5	357
T7	44.16	61.568	70.08	37.88	213.7	136.5	350
T8	44.16	76.96	56.06	37.88	215.1	136.5	352
T9	44.16	76.96	70.08	30.30	221.5	136.5	358

T1 – control (without deficit irrigation at any growth stage – 100% crop evapotranspiration, ETc); T2 – (20% deficit irrigation in all growth stages – 80% ETc); T3 – (40% deficit irrigation in all growth stages – 60% ETc); T4 – (20% deficit irrigation in development and late stages – 80% ETc; 40% deficit irrigation in mid stage – 60% ETc; initial stage without deficit irrigation – 100% ETc); T5 – (20% deficit irrigation in development and late stages – 80% ETc; 40% deficit irrigation in initial stage – 60% ETc; mid stage without deficit irrigation – 100% ETc); T6 – (20% deficit irrigation in initial stage – 80% ETc); T7 – (20% deficit irrigation in development stage – 80% ETc); T8 – (20% deficit irrigation in mid stage – 80% ETc); T9 – (20% deficit irrigation in late stage – 80% ETc); NIR_{stage} – net irrigation requirement in each growth stage; NIR_{total} – total net irrigation requirement in all growth stages; Pe – effective rainfall; IR – irrigation requirement per treatment.

Effects of deficit irrigation on yield and water productivity of onion

Table 5 shows the statistical analysis of the evaluated variables, such as plant height (PH), number of leaves per plant (NLP), bulb diameter (BD), bulb yield, and water productivity (WP) of the onion. The treatments imposed with irrigation deficit in different growth stages promoted significant changes ($p \leq 0.05$) on the PH, NLP, BD, bulb yield, and WP of the onion.

For PH (Table 5), only in T3 (40% deficit irrigation in all growth stages – 60% ETc), T4 (20% deficit irrigation in development and late stages – 80% ETc; 40% deficit irrigation in mid stage – 60% ETc; initial stage without deficit irrigation – 100% ETc), and T5 (20% deficit irrigation in development and late stages – 80% ETc; 40% deficit irrigation in initial stage – 60% ETc; mid stage without deficit irrigation – 100% ETc) the lowest means were reported.

With regard to number of leaves per plant (Table 5), the highest means of 9.7 and 8.8 leaves were obtained in the treatments T1 and T9, respectively. The highest 40% deficit irrigation applied in all growth stages (T3) produced fewer leaves of the onion; however, this treatment was not significantly different of the treatments T4, T5, and T6. These results they are in agreement with those reported by Tolossa (2021), where the number of leaves of the onion varied according to irrigation levels.

Similar to the number of leaves, a smaller bulb diameter was recorded for T3 (5.10 cm); however, this mean was not significantly different of those obtained in treatments T4 (5.34 cm) and T5 (5.47 cm). The means of the other treatments are statistically equal (Table 5). Therefore, as well as the number of leaves, the application of 40% deficit irrigation throughout all growth stages had significantly reduced the bulb diameter of the onion. This result was similar with conclusion made by Rop et al. (2016), where the bulb size of the onion varied proportionally with the quantity of irrigation water applied.

The highest bulb yield was obtained in the treatments T1 (control, without deficit irrigation at any growth stage – 100% ETc), T2 (20% deficit irrigation in all growth stages – 80% ETc), T6 (20% deficit irrigation in initial stage – 80% ETc), T8 (20% deficit irrigation in mid stage – 80% ETc), and T9 (20% deficit irrigation in late stage – 80% ETc), respectively, of 28.47, 28.03, 28.34, 28.46, and 28.68 ton ha^{-1}. Lowest bulb yield of 14.42 and 16.23 ton ha^{-1} were recorded with T3 (40% deficit irrigation in all growth stages – 60% ETc) and T4 (20% deficit irrigation in development and late stages – 80% ETc; 40% deficit irrigation in mid stage – 60% ETc; initial stage without deficit irrigation – 100% ETc), followed by T5 (20% deficit irrigation in development and late stages – 80% ETc; 40% deficit irrigation in initial stage – 60% ETc; mid stage without deficit irrigation – 100% ETc) with 16.83 ton ha^{-1}. This revealed that the decrease in irrigation depth (60% ETc) at specific stage or throughout growth stages significantly affected yield when compared to treatments T1, T2, T6, T8, and T9 (Table 5). These results are in agreement with the finding by Samson and Ketema (2007), that applying deficit irrigation at first and fourth growth stages of onion did not significantly reduce bulb yield.

Table 5: Plant height (PH), number of leaves per plant (NLP), bulb diameter (BD), bulb yield, and water productivity (WP) of the onion grown under irrigation deficit

Treatments	PH (cm)	NLP	BD (cm)	Yield (ton ha^{-1})	WP (kg m^{-3})
T1	71.3a	9.7a	6.10a	28.47a	7.79b
T2	68.7a	8.3bc	5.98ab	28.03ab	8.77a
T3	53.7b	6.7e	5.10d	14.42d	5.26c
T4	56.3b	7.7bcde	5.34cd	16.23cd	5.17c
T5	55.7b	7.0de	5.47bcd	16.83c	5.18c
T6	68.0a	7.4cde	5.67abc	28.34ab	7.95b
T7	68.7a	8.3bc	5.77abc	27.55b	7.87b
T8	69.3a	8.0bcd	6.05a	28.46ab	8.09b
T9	69.3a	8.8ab	5.85abc	28.68ab	8.01b
CV (%)	4.00	1.30	5.49	2.87	1.67
LSD (0.05)	3.60	9.50	0.54	1.19	0.65

T1 – control (without deficit irrigation at any growth stage – 100% crop evapotranspiration, ETc); T2 – (20% deficit irrigation in all growth stages – 80% ETc); T3 – (40% deficit irrigation in all growth stages – 60% ETc); T4 – (20% deficit irrigation in development and late stages – 80% ETc; 40% deficit irrigation in mid stage – 60% ETc; initial stage without deficit irrigation – 100% ETc); T5 – (20% deficit irrigation in development and late stages – 80% ETc; 40% deficit irrigation in initial stage – 60% ETc; mid stage without deficit irrigation – 100% ETc); T6 – (20% deficit irrigation in initial stage – 80% ETc); T7 – (20% deficit irrigation in development stage – 80% ETc); T8 – (20% deficit irrigation in mid stage – 80% ETc); T9 – (20% deficit irrigation in late stage – 80% ETc); CV – coefficient of variation; means within a column followed by the same letter(s) are not significantly different by the least significant difference (LSD) method at $p \leq 0.05$.

Under 20% deficit irrigation (T2) throughout the whole growth season resulted highest water use efficiency (8.77 kg m^{-3}) (Table 5). This shows that the onion was more efficient using 20% less water (80% ETc) compared to plants grown under full irrigation (T1); therefore, saving water and obtain optimum yield. This behavior results from the fact that bulbs are part of the root system, and therefore their growth when plants are water stressed is a consequence of their surviving strategy for developing the root system and creating water reserves in the bulb. This indicates that the onion plants have the ability to develop the bulbs with reduced water but not high-quality bulbs as analyzed before relative to bulb sizes.

The lowest WP values of 5.26, 5.17, and 5.18 kg m^{-3} was obtained in treatments T3, T4, and T5, respectively (Table 5).

Conclusions

Water scarcity remains the major limiting factor in intensifying agricultural production. Efficient use of irrigation water using appropriate irrigation systems and management is an important consideration in the drought prone season of the region for improved crop production. Therefore, to obtain higher yield and water productivity of the onion is recommended for the farmers of the study area using 20% less water throughout the season, that is, apply 80% of the required water (crop evapotranspiration).

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