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Research Article

Effect of Deficit Irrigation on Yield and Water Productivity of Onion *(Allium cepa l.)* under Conventional Furrow Irrigation System, in Bennatsemay Woreda, Southern Ethiopia

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The field experiment was conducted in Bennatsemay Woreda, Enchete kebele during 2018 season with objective of investigating the effect of deficit irrigation on yield and water productivity of onion under conventional furrow irrigation system. Six treatments (T1=100% ETc, T2=85% ETc, T3=70% ETc, T4=50% ETc, T5=100% ETc Is, 85% ETc Ds, 70% ETc Ms, 50% ETc Ls and T6=85% ETc Is, 70% ETc Ds, 50% ETc Ms, 0% ETc Ls) were imposed on onion (Allium cepa L.) and laid out in randomized complete block design (RCBD) with four replications. Results indicated that the different deficit irrigation levels had highly significant ($p < 0.01$) effect on vegetative growth, yield, yield components and water use efficiency of onion. The highest bulb yield of 21.3 t/ha were obtained from T1 which was significantly different to all other treatments while yield from T6 (12.86 t/ha) was recorded as the lowest one. Similarly, the highest IWUE (2.41 kg/m^3) and CWUE (4.02 kg/m^3) were obtained from T6. However, at T4 and T6 high yield reduction was recorded which may not be attractive for producers. Therefore, it could be concluded that increased water saving and water productivity through irrigation at 70% ETc deficit irrigation level under conventional furrow irrigation system can solve the problem of water shortage and would ensure the opportunity of further irrigation development in the study area and similar agro-ecology.

Key words: Deficit irrigation, Water productivity, Conventional furrow irrigation system, Onion

INTRODUCTION

In Ethiopia, irrigated agricultures becoming main concern and strongly recognized to ensure the food security, which is taken as a means to increase food production and self-sufficiency of the rapidly increasing population of the country. Accordingly, Ethiopia has planned to irrigate over 5 million hectares of the land with existing water resources (Awulachew *et al.*, 2010). This expansion of irrigated agriculture to feed the ever-increasing population on one hand and the increasing competition for water due to the development of other water use sectors on the other hand necessitated the improvement of water use efficiencies in irrigated agriculture to ensure sustained production and conservation of this limited resource (Mekonen, 2011).

Improving water use efficiencies are an important strategy for addressing future water scarcity problem particularly in arid and semi-arid regions (Mdemu *et al.* 2008). As argued by the Geerts and Raes (2009), and FAO (2010), increasing crop water productivity can be an important pathway for poverty reduction. This would enable growing more food and hence feeding the ever-increasing population of Ethiopia or gaining more benefits with less water thus enhancing the household income. Moreover, more water will be available for other natural and human uses. In this context, deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield (Mermoud *et al.*, 2005).

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Accordingly, deficit irrigation (DI) is believed to improve water productivity without causing severe yield reductions; which the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season with the expectation that any yield reduction will be insignificant compared with the benefits gained through diverting the saved water to irrigate other fields.

The target crop, onion, is becoming more widely grown in recent years in Ethiopia. Currently, the crop is produced in different parts of the country for local consumption and export. During the 2013/2014 cropping season, the total area under onion production was estimated to be 24, 375.7 ha with an average yield of about 9.02 tons per hectare and estimated a total production of greater than 2, 19, 735.27 tons (CSA, 2014). This indicates that Ethiopia has high potential to benefit from onion production. To utilize the genetic yield of onion and achieve high economic performance, it is necessary to gain knowledge of the onion response to different deficit irrigation levels and application methods.

Therefore, practically investigating the effect of deficit irrigation on yield and water productivity of irrigated onion was found to be important to utilize the limited water resource of the area without severely affecting the crop yield. The objective of this study is to investigate deficit irrigation effect on yield and water productivity of onion under conventional furrow irrigation system and to identify the level of deficit irrigation, which allows achieving optimum onion yield and water productivity.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted at Weyito experimental site of Jinka Agricultural Research Center in Southern Agricultural Research Institute. The site is situated in the eastern part of Bennatsemay Woreda at Enchete kebele a distance of 82 km away from Jinka town, capital of South Omo Zone, Southern Ethiopia. Geographically, the experimental site is located at 5˚18'0'' to 5˚31'33'' N latitude and 36˚52'30'' to 37˚5'0'' E longitude, and at an altitude of 550 m above sea level. Likewise, it is found 668 km south west of Addis Ababa and about 438 km west of Hawassa, the capital of Southern Nations Nationalities and Peoples Regional State (EPaRDA, 2005).

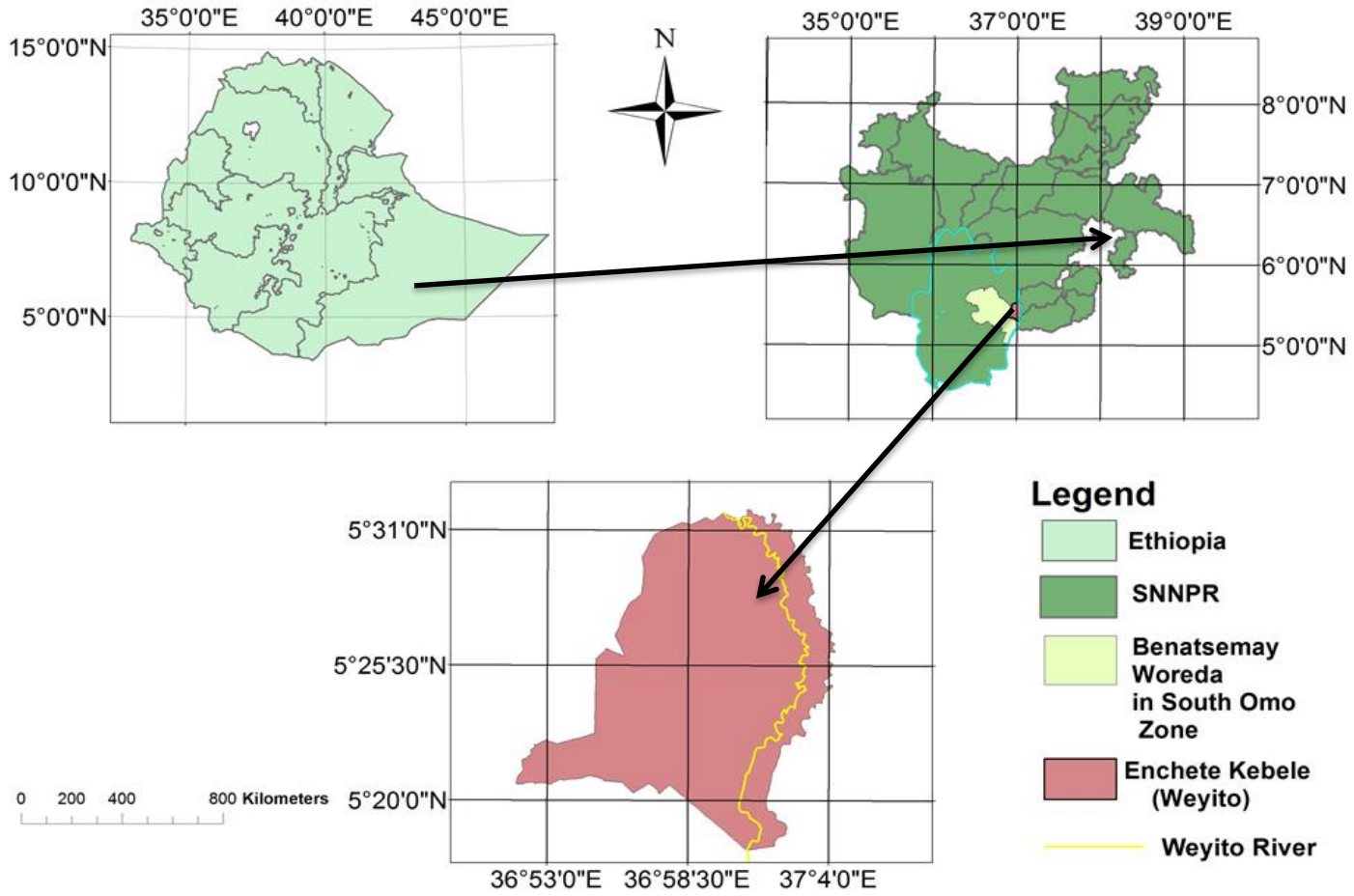

Figure 1. Map of Study Area

Experimental Procedures

ETo and ETc Determination

Primarily 20 years (1997-2016) climatic data includes monthly maximum and minimum temperature relative humidity, wind speed, sunshine hour's data was collected. Daily ETo (mm/day) values were computed from the collected data using FAO CropWat 8.0 windows model. The Kc-values was obtained from FAO Irrigation and Drainage Paper No. 56 (Allen *et al.*, 1998). Then, crop water requirement was calculated from (FAO, 2009):
ETc (mm/day) = ETo x Kc

Soil Sampling and Analysis

For soil textural analysis and bulk density determination, disturbed and undisturbed soil samples were collected from 0 cm – 20 cm, 20 cm – 40 cm and 40 cm – 60 cm depth along the diagonal of the experimental field before planting respectively. Hydrometer method was employed for soil textural class analysis (Basu, 2011). The soil bulk density was determined by Oven dry method in the laboratory and calculated as the ratio of dry weight of the soil to known cylindrical core sampler volume (ICARDA, 2013).

$$\mathrm{BD} = \frac{\mathrm{Ms}}{\mathrm{Vs}} \quad \text{...2.1}$$

Where Ms is the weight of oven dry soil in gram, and Vs is the volume of the same soil in cm^3.

For the determination of moisture content at field capacity (FC) and Permanent wilting Point (PWP) soil samples was collected from 0 – 20 cm, 20 cm – 40 cm and 40 cm – 60 cm depth from the experimental field and determined in Ethiopian Construction, Design and Supervision Works Corporation soil laboratory in Addis Ababa. Then, calculated by using equation (Jaiswal, 2003).

$$\theta m\ (\%) = \frac{(\mathrm{Wws} - \mathrm{Wds})}{Wds}\ x\ 100 \quad \text{....2.2}$$

Where θm is mass based soil moisture content at FC or PWP (%), Wws is weight of wet soil (gm) and Wds is weight of dry soil (gm). Soil infiltration rate was measured by using double ring infiltrometer in the field (Amreeta, 2014).

Selected soil chemical properties like pH, electrical conductivity (EC), organic carbon (OC) and organic matter (OM) content were analyzed in Hawassa Agricultural Research Center soil laboratory. The organic carbon was analyzed with colorimetric method by the help of Spectrophotometer device in the laboratory and organic matter (OM) content was determined by multiplying organic carbon (OC) by constant factor 1.724 (Basu, 2011).

Hence, the total available water (TAW), stored in a unit volume of soil, is approximated by taking the difference between the water content at field capacity (FC) and at permanent wilting point (PWP). Therefore, the total available water was expressed by (Jaiswal, 2003):

$$TAW = \frac{(\mathrm{FC}-\mathrm{PWP})}{100}\ x\ BD\ x\ Dz \quad \text{.....2.3}$$

Where, TAW is total available water in mm/m, FC is field capacity and PWP is permanent welting point in percent (%) on weight basis, BD is the bulk density of the soil in gm/cm^3 and Dz is the maximum effective root zone depth of onion in mm. Then, RAW (mm) was computed from the expression (Allen *et al.*, 1998):

$$RAW = \mathrm{P}\ x\ TAW \quad \text{...2.4}$$

Where P is in fraction for allowable soil moisture depletion for no stress (p = 0.25 for onion) and TAW is total available water in mm. Then, irrigation interval was computed from the expression (FAO, 2009):

$$\text{Interval (days)} = \frac{\mathrm{RAW}}{\mathrm{ETc}} \quad \text{....2.5}$$

Where, RAW in mm which is equal to net irrigation depth (d_{net}) and ETc in mm/day.
Then, gross irrigation requirement (dg):

$$\mathrm{dg} = \frac{\mathrm{dnet}}{\mathrm{Ea}} \quad \text{...2.6}$$

Where, d_g in mm and E_a is the field irrigation application efficiency of a short, end diked furrow was taken as 60% (Brouwer and Prins, 1989).

The amount of water applied to the experimental field was measured by 3-inch Parshall flume. The time required to deliver the desired depth of water into each plot was calculated using the equation (Kandiah, 1981):

$$\mathrm{t} = \frac{\mathrm{dg}\times\mathrm{A}}{6\times\mathrm{Q}} \quad \text{...2.7}$$

Where: d_g = gross depth of water applied (cm)
t = application time (min)
A = Area of experimental plot (m^2) and
Q = flow rate (discharge) (l/s)
The irrigation depth was converted to volume of water by multiplying it with area of the plot (Valipour, 2012).

$$V = A\ x\ dg \quad \text{...2.8}$$

Where: V = Volume of water in (m^3)
A = Area of plot (m^2)
d_g = Gross irrigation water applied (m)

Experimental Design and Treatments

The experiment was designed with five deficit irrigation level treatments (T) and one control irrigation of 100% ETc, under conventional furrow irrigation methods. The experiment was laid out in a Randomized Complete Block Design (RCBD) with four replications of six level treatments.

- T1 = Irrigation water application of 100% ETc (Control)
- T2 = Irrigation water application of 85% ETc
- T3 = Irrigation water application of 70% ETc
- T4 = Irrigation water application of 50% ETc
- T5 = Irrigation water application of 100% ETc initial stage (Is), 85% ETc development stage (Ds), 70% ETc mid stage (Ms) and 50% ETc late season (Ls)
- T6 = Irrigation water application of 85% ETc initial stage, 70% ETc development stage, 50% ETc mid stage and 0% ETc late season.

Collected Crop Data

Date of onion seed sowing, transplanting and date of harvesting was recorded. Data on vegetative growth (plant height, leave number per plant, leave length and leaf dry matter), yield and yield components such as average bulb weight, bulb and neck diameter, bulb length and dry matter of bulb was recorded from five randomly selected plants from two middle rows of each experimental plot as reported by David *et al.*, (2016).

Crop Water Use Efficiency (CWUE)

CWUE is the yield harvested in kilogram per ha-mm of total water used. It was calculated using formula as the ratio of crop yield to the amount of water consumptively used by the crop (Ibragimov *et al.*, 2007):

$$\mathrm{CWUE} = \frac{\mathrm{Y}}{\mathrm{ET_C}} \quad \text{....2.9}$$

Where: CWUE = crop water use efficiency (kg/m^3)
Y = yield in kg ha^{-1} and
ETc = is crop evapotranspiration (mm)

Irrigation Water Use Efficiency (IWUE)

IWUE is usually defined as the ratio of yield per unit of total irrigation water applied and calculated by the formula (Ofori, 1994).

$$\mathrm{IWUE} = \frac{\mathrm{Y}}{\mathrm{IW}} \quad \text{...2.10}$$

Where: IWUE is irrigation water use efficiency of onion (kg/m^3), Y is yield of onion in kg/ha and IW is total amount irrigation water applied in m^3/ha.

Yield Response Factor

The yield response factor (K_y) defined as the decrease in yield with respect to the deficit in water consumptive use (ET) and was calculated according to the procedure mentioned by Doorenbos and Kassam (1979) as follows:

$$1 - \frac{\mathrm{Ya}}{\mathrm{Ym}} = \mathrm{K_y}\left(1 - \frac{\mathrm{ETa}}{\mathrm{ETm}}\right) \quad \text{...2.11}$$

Where: K_y is yield response factor, Y_a is actual bulb yield obtained from each deficit treatments (t/ha), Y_m is maximum bulb yield obtained from the control treatment with full irrigation (t/ha), ET_a is the net depth of irrigation applied for each deficit treatments (mm), ET_m is the net depth of irrigation water applied for the control treatment with full irrigation (mm), $\left(1 - \frac{\mathrm{Ya}}{\mathrm{Ym}}\right)$ is the decrease in relative yield due to deficit water application and $\left(1 - \frac{\mathrm{ETa}}{\mathrm{ETm}}\right)$ is the relative water saved (decrease in relative crop water consumptive) due to deficit irrigation.

Economic Water Productivity

Economic analysis was done using the prevailing market prices during experimentation and at the time the crop was harvested. All costs and benefits were calculated on hectare basis in Ethiopian Birr (Birr/ha). The adjusted yield was obtained by reducing the average yield by 10% as indicated in CIMMYT (1988). The average cost the local people were paying for daily labor was 60.00 Birr per day. Thus, for computing the analysis labor cost of 60.00 Birr per day was used. The farm gate price of onion during the harvesting time was 12.00 Birr/kg and the price of irrigation water was taken as 1.00 Birr per 0.5 m^3 of water. Net income (NI) in Birr/ha, generated from onion crop was computed by subtracting the total variable cost (TVC) in Birr/ha from the total return (TR) in Birr/ha obtained from onion sale as:

$$\mathrm{NI} = \mathrm{TR} - \mathrm{TVC} \quad \text{.....2.12}$$

Fixed costs (FC) are those that do not vary between irrigation treatments, i.e. onion seeds, pesticides, land rent and farm implements. Variable costs (VC), on the other hand, are those that do vary between irrigation treatments, i.e. irrigation water and labor.
Percent marginal rate of return (MRR) was calculated by the following formula:

$$\mathrm{MRR} = \frac{\Delta \mathrm{NI}}{\Delta \mathrm{VC}} * 100\% \quad \text{.....2.13}$$

Where; ΔNI is the difference of the net income in Birr and ΔVC is additional unit of expense in Birr, between two consecutive undominated treatments.

Statistical Analysis

Data analysis was under taken according to the data collected by using SAS software 9.1 for windows. Whenever treatment effects were found significant, treatment means were compared using the least significant difference (LSD) at 5% probability level (Steel *et al.,* 1997).

RESULTS AND DISCUSSION

Soil Physical and Chemical Properties

The result of the soil textural analysis from the experimental site was presented in Table 3. The texture (40.8% sand, 32% silt, 27.2% clay), (38% sand, 38% silt, 24% clay), (45.6% sand, 30.8% silt, 23.6% clay) at a depth of 0 – 20 cm, 20 – 40 cm, 40 – 60 cm, respectively. Thus, according to USDA soil textural classification system, the soil of the experimental field could be classified as loam at all depths.

Table 1. Particle size distribution of the experimental site

Depth (cm)	Particle size distribution (%)			Textural class
	Sand	Clay	Silt	
0 – 20	40.8	27.2	32.0	Loam
20 – 40	38.0	24.0	38.0	Loam
40 – 60	45.6	23.6	30.8	Loam
Average	41.5	24.9	33.6	Loam

(**Source**: Laboratory Result, 2010).

Table 2. Bulk densities, field capacity, permanent welting point and TAW of the soil

Depth (cm)	BD (g/cm^3)	FC (%)	PWP (%)	TAW (mm/depth)	TAW (mm/m)
0 – 20	1.26	29.31	12.78	41.66	208.28
20 – 40	1.28	28.13	12.46	40.11	200.55
40 – 60	1.31	26.04	10.72	40.15	200.74
Average	1.28	27.83	11.98	40.64	203.18

The basic infiltration rate of the soil was about 27.3 mm/hr. (**Source**: Laboratory Result, 2010).

Table 3. Soil chemical properties of the experimental site

Depth (cm)	pH	ECe (dS/m)	OC (%)	OM (%)
0 – 20	7.69	0.210	1.43	2.46
20 – 40	7.93	0.173	1.65	2.85
40 – 60	7.87	0.178	1.58	2.72
Average	7.83	0.182	1.55	2.67

(**Source**: Laboratory Result, 2010).

Crop Water Requirement of Onion

The calculated daily reference evapotranspiration (ETo) from long-term (20 years) climatic data was calculated. The result showed that the minimum (6.0 mm/day) and maximum (7.15 mm/day) ETo value was occurred in June and February months respectively. Generally, the evaporative power of the atmosphere was under arid and semi-arid ranges (6 - 8 mm/day) (Brouwer and Heibloem, 1986).

Table 4. Seasonal net and gross irrigation water depth applied for each treatment

Treatments (T)	Net irrigation water depth (mm)	Gross irrigation water depth (mm)
T1	826.4	1377.5
T2	702.4	1170.9
T3	578.5	964.3
T4	413.2	688.8
T5	563.2	938.9
T6	320.1	533.6
Total	**3403.8**	**5673.8**

Effect of Deficit Irrigation on Vegetative Growth and Yield Components

Plant Height

As shown in Table 5 below, there was statistically significant ($P < 0.01$) difference among all the deficit levels except between the T5 and T3 application levels has no significant variation. The highest plant height was recorded from control treatment which is 59.33 cm while the minimum plant height (48.48 cm) was observed from T6 and this was significantly inferior to all other treatments. Generally, the mean table showed that, onion plant height was decreased as the stress level increased through the whole crop growing season and its phenological stages. On the other hand, higher plant height was associated with higher irrigation water application and shorter plant height was resulted because of application of minimum irrigation water (Figure 4). This finding is in agreement with the finding of Dirirsa *et al.* (2017) and Mebrahtu *et al.* (2018) who reported that the plant height of onion increased with increased irrigation water application levels and also decrease with the decrease of irrigation water application level.

Number of Leaves per Plant

The analysis of variance has indicated that there was highly significant leaf number variation due to different deficit irrigation application level ($P < 0.01$). As indicated in Table 5 below, the highest leaf number per plant was observed from T1 where as the lowest leaf number per plant was recorded from T6 and had no significant difference ($P < 0.01$) with T4. Moreover, there was no significant difference of leaf number per plant between T3 and T5. This result is in line with other experiment carried out by Metwally (2011) showed that larger amount of water was associated with more onion leaves per plant. Gebregwergis *et al.* (2016) also reported that the leaf number of onion plants was significantly affected ($P < 0.01$) by irrigation depth. Therefore, this shows irrigation water application level had significant effect on vegetative growth of onion and subsequent variations on yield.

Leaf Length

According to analysis of variance the effect of irrigation level on leaf length of onion plants was highly significant ($P < 0.01$). As shown in the Table 5 below, highly significant differences were observed between the T1 and other treatments. In such a way that the T1 gave the longest (49.83 cm) Onion leaves where as the shortest leaf length (40.6 cm) was obtained under T6 which had no significant differences with T4. Similarly, between treatments T2 and T5 as well as T3 and T5 there was no significant difference on leaf length. This result is supported by Smith *et al.* (2011) quoted that the rate of transpiration, photosynthesis and growth are lowered by even mild water stresses. In general, based on this observation it is obvious that onion leaf length increased with increasing irrigation water application level and which is further visualized on the Figure 2 below.

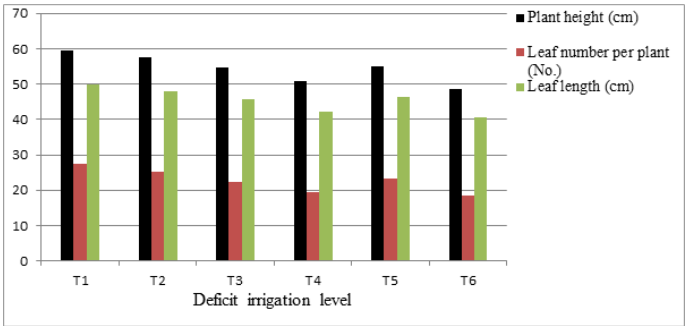

Figure 2. Effect of deficit irrigation on plant height, leaf number per plant and leaf length

Bulb Diameter

As indicated in Table 5 below, the largest bulb diameter (7.67 cm) was observed at T1 which was significantly ($P < 0.01$) different to all other treatments. In similar way, the least bulb size was (4.84 cm) recorded at T6 then followed by T4 which was significantly ($P < 0.01$) different to all other irrigation application levels. The second largest bulb size (6.63 cm) was recorded from treatment T2 this was not significantly different to treatment receiving 70% ETc (T3). This implies application of 15% ETc deficit at development stage, 30% ETc deficit at mid stage and 50% ETc deficit at maturity (late) stage gave comparable bulb diameter with 30% ETc deficit at whole the growing season. However, the 15% ETc, 30% ETc, 50% ETc and 100% ETc deficit irrigation water applied at initial, development, mid and late stage respectively, resulted significantly smaller bulb diameter than the control and other treatments of deficit irrigation application. This result is in agreement with that of a study conducted by Al-Moshileh (2007) who reported that high amount of soil moisture application leads to large photosynthesis area, results to large bulb diameter. The same study by Serhat and Demirtaş (2009) indicated that bulb diameter has increasing trend with the level of irrigation application. Also, the obtained data by Abd El-Hady *et al.* (2015) revealed that increasing ETc level could increase bulb diameter value by 0.04 and 0.03% over control. From this, it is evident that larger onion bulb sizes were observed for larger irrigation water application levels. The result also more specifically presented on Figure 3 below.

Neck Diameter

The analysis of variance indicates, the different deficit irrigation levels had a highly significant ($P < 0.01$) effect on onion neck diameter. As indicated in Table 5 below, the highest neck diameter (3.58 cm) was obtained from control treatment which was significantly ($P < 0.01$) different to all other treatments. The neck diameters of T2, T3 and T5 were 3.05 cm, 2.85 cm and 2.97 cm respectively, and had no statistically significant difference with each other while 2.51cm was recorded from treatment T4 (50% ETc) and had statistically high significant ($P < 0.01$) difference to all other treatments. The lowest neck diameter (2.06 cm) was recorded from T6 and inferior to all other treatments. This result is consistent with findings of Al-Moshileh (2007) and Metwally (2011) who reported that higher level of applied water resulted in a significantly thicker neck. In general, the result shows decreasing irrigation water application level caused significant effect on onion neck diameter (see Figure 3 below).

Bulb Length

As indicated in Table 5 below, the first and the second longest bulb length of 8.09 cm and 7.35 cm was recorded from the plots received 100% ETc (T1) and 85% ETc (T2) respectively; in such a way that had highly significant ($p < 0.01$) difference between each other and to all other treatments. The bulb lengths of T3 and T5 were 6.79 cm and 6.85 cm respectively, and had no statistically significant difference with each other. This result is in line with that of Olalla *et al.* (2004) who observed smaller sized bulbs in mild water stressed onion plants. Also, Kamble *et al.* (2009) reported significant increase in bulb yield and yield components is attributed to adequate moisture in the root zone which did not show any visual stress on various physiological processes resulting in better uptake of nutrients and finally increased plant growth, yield and yield components (like bulb length and bulb diameter).This indicates that higher level of irrigation water resulted in maximum onion bulb length (see Figure 3 below).

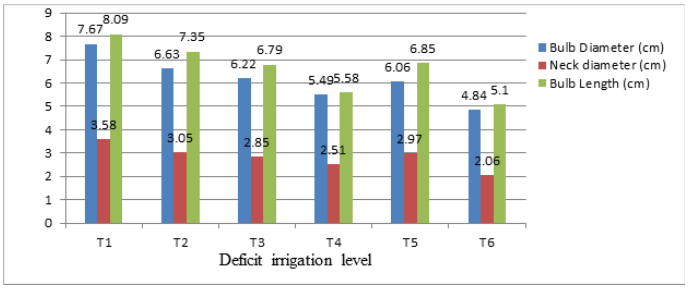

Figure 3. Effect of deficit irrigation on bulb diameter, neck diameter and bulb length

Average Bulb Weight

The analysis of variance indicates average bulb weights differed significantly due to the level of deficit irrigation water applied ($P < 0.01$). As shown in Table 5 above, the highest bulb weight (0.20 kg) was obtained at T1 irrigation water application level which was significantly different ($P < 0.01$) and superior to all other treatments. Similarly, the lowest bulb weight (0.12 kg) was recorded at T6 and was not significantly different to that recorded at T4 irrigation water application level. There was a bulb weight reduction of 40%, 35%, 20%, 20% and 10% observed under the T6, T4, T3, T5 and T2, respectively, when compared with the T1(100% ETc) irrigation water application level. This fact reveals, there was an increasing trend in bulb weight for an increase in water application level whether throughout whole growing season or in a specific growth

Table 5. Deficit irrigation effect on vegetative growth and yield components

Treatments (T)	Plant height (cm)	Leaf number per plant (No.)	Leaf length (cm)	Bulb Diameter (cm)	Neck diameter (cm)	Bulb Length (cm)	Average bulb weight (kg)	Bulb dry matter (%)	Leaf dry matter (%)
T1	59.33^{a}	27.35^{a}	49.83^{a}	7.67^{a}	3.58^{a}	8.09^{a}	0.20^{a}	20.58^{a}	18.80^{a}
T2	57.53^{b}	25.35^{b}	47.80^{b}	6.63^{b}	3.05^{b}	7.35^{b}	0.18^{b}	19.75^{ab}	16.43^{b}
T3	54.78^{c}	22.20^{c}	45.73^{c}	6.22^{bc}	2.85^{b}	6.79^{c}	0.16^{c}	18.80^{bc}	14.95^{bc}
T4	50.68^{d}	19.30^{d}	42.30^{d}	5.49^{d}	2.51^{c}	5.58^{d}	0.13^{d}	17.00^{d}	12.40^{d}
T5	54.85^{c}	23.13^{c}	46.25^{bc}	6.06^{c}	2.97^{b}	6.85^{c}	0.16^{c}	17.90^{cd}	14.48^{c}
T6	48.48^{e}	18.36^{d}	40.60^{d}	4.84^{e}	2.06^{d}	5.10^{e}	0.12^{d}	15.08^{e}	10.03^{e}
LSD (0.05)	1.79	1.31	1.81	0.29	0.45	0.56	0.01	1.07	1.55
CV (%)	2.2	3.86	2.64	6.01	6.83	4.46	4.92	3.92	7.07

Note: *The letters indicate the significance relation of treatments. Treatment values within a column followed by the same letter are not significantly different (P < 0.01). LSD = least significant difference; CV = Coefficient of variation. T1 = 100% ETc, T2 = 85% ETc, T3 = 70% ETc, T4 = 50% ETc, T5 = 100% ETc Is, 85% ETc Ds, 70% ETc Ms and 50% ETc Ls, T6 = 85% ETc Is, 70% ETc Ds, 50% ETc Ms and 0% ETc Ls*

stages and indicating that irrigation water application level positively influenced bulb weight (Figure 4). This means that water stress affects negatively the weight of individual bulbs. In agreement with the present result, David *et al.* (2016) reported that the highest mean weight of onion bulb was obtained from treatment with the highest supply of water while the treatment with the lowest quantity produced the least mean onion bulb weight and there is a positive linear relationship between water stress and onion bulb mass. Likewise, Kandila *et al.* (2011) reported increasing the soil water tension, significantly decreased the mean onion bulb weight.

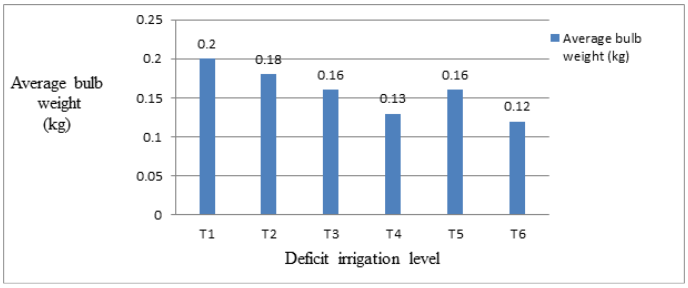

Figure 4. Effect of deficit irrigation on average bulb weight

Bulb and Leaf Dry Matter

According to the analysis of variance, the effect of irrigation level on dry matter content of onion bulb and leaf was highly significant (P < 0.01). As Table 5 above indicates, the highest bulb and leaf dry matters were 20.58% and 18.80% respectively, obtained from T1 (at 100% ETc irrigation application level) while the lowest bulb and leaf dry matter contents were 15.08% and 10.03% respectively, obtained from T6, which is inferior to all other treatments. The bulb dry matter obtained at 100% ETc (T1) and 85% ETc (T2) irrigation levels were not significantly different (P < 0.01). Similarly, the bulb dry matter content obtained between at T2 and T3, T3 and T5, T4 and T5 were not significantly different (Table 5). Also, leaf dry matter content recorded between at T2 and T3, T3 and T5 were not significantly different (P < 0.01). This result is in line with Kumar *et al.* (2007) studied the effect of water application and fertigation on onion dry matter production and reported that irrigation at high water supply and nutrient level onion produced higher dry matter yield. Accordingly, the dry matter content both bulbs and leaves decreased with increasing water deficit level (Figure 5).

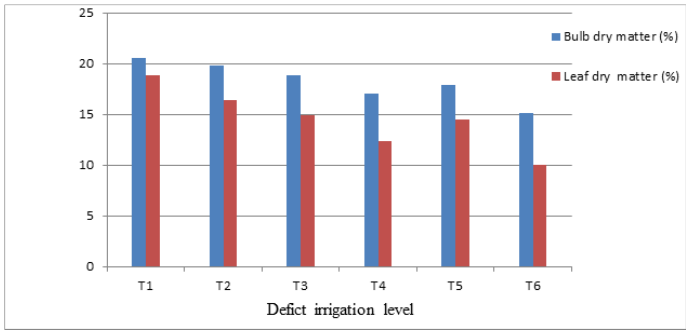

Figure 5. Effect of deficit irrigation on bulb and leaf dry matter

Effect of Deficit Irrigation on Yield of Onion

Marketable Bulb Yield

As the mean yield values in Table 6 below shows, the yield obtained from all deficit levels were significantly different from each other except yield from T3 and T5. Highest marketable bulb yield (21.3 t/ha) was recorded from the control treatment (T1) and the lowest marketable bulb yield (12.85 t/ha) was observed from treatment T6.This indicates that the highest marketable yield reduction was occurred when the water stress was imposed at the plant phenological stages as well as whole growing season. In other way, while the stress level increase through plant phenological stages as well as whole growing season and the amount of water applied reduced then marketable bulb yield was reduced gradually. The current result is in agreement with Dirirsa *et al.* (2017) indicated, bulb formation stage was observed to be the most sensitive stage to water stress and in addition, the deficit irrigations applied at the bulb formation stage resulted in lower yield than the other stages. Similar to the present observation Patel and Rajput (2013) also reported that water application with no deficit (100% ETc) at any stage of plant growth gave highest marketable yield.

Unmarketable Bulb Yield

The analysis of variance indicated that unmarketable bulb yield of onion was significantly ($P < 0.01$) affected by different deficit irrigation levels. As shown in Table 6 below, highest unmarketable bulb yield was recorded from T6, whereas the lowest unmarketable yield was obtained from T1 and had no significant difference ($P < 0.01$) with T2. Similarly, the result observed from T2 had no statically significant difference with T3. The result recorded from the plots which received 50% ETc irrigation application level (T4) had statically high significant ($p < 0.01$) difference with all other treatments. This shows that increasing soil moistures stress (deficit level) through the whole growing season constantly and at phenological stages of plant results increasing of unmarketable bulb yield. The result presented in this study is inclusive and similar with previous research done by Casey and Garisson, (2003) who indicated that onion plant stressed prior to bulb formation, result in reduced bulb sizes that are not acceptable for market grades and those plants stressed after bulb formation are prone to re-growth problems such as thick necks and scallions, which reduce marketable grades and increase storage problems.

Table 6. Deficit irrigation effect on yield of onion

Treatments (T)	Marketable Yield (t/ha)	Unmarketable Yield (t/ha)	Total Bulb Yield (t/ha)
T1	21.299^{a}	2.95E-03^{e}	21.300^{a}
T2	19.133^{b}	3.23E-03de	19.135^{b}
T3	17.363^{c}	3.37E-03^{d}	17.363^{c}
T4	15.175^{d}	4.63E-03^{b}	15.177^{d}
T5	17.125^{c}	3.75E-03^{c}	17.130^{c}
T6	12.847^{e}	5.50E-03^{a}	12.855^{e}
LSD (0.05)	1.1359	2.93E-04	1.136
CV (%)	4.39	4.98	4.39

Total Bulb Yield

The sum of unmarketable and marketable bulb yield gives total bulb yield which was highly influenced by different deficit irrigation levels. A highly significant variation ($P < 0.01$) in total bulb yield was observed due to the effect of deficit irrigation levels. As shown in Table 6 above, the yield obtained from all deficit levels were significantly different from each other except at T3 and T5. This could be because the yield components like bulb diameter, neck diameter, bulb length, average bulb weight and dry matter at T3 and T5 deficit levels were all not statistically different. The highest bulb yield was 21.3 t/ha obtained under T1 and contrary to this; the lowest bulb yield was 12.86 t/ha obtained under T6 which was statistically inferior to all other treatments (Table 6). This shows that the bulb yield decreased as the deficit level was increased either constantly throughout the whole crop growing season or at plant phenological stages and also the relation was visualized in detail in the Figure 6 below. This result agrees with previous research study by Mekonen (2011) who observed that water stress during different growth stages affected crop water productivity differently. According to David *et al.,* (2016) when crop is subjected to water stress at development and late growth stages at varying levels, soil moisture is depleted through absorption by the roots leading to reduced physiological activities which in turn affect root developments.

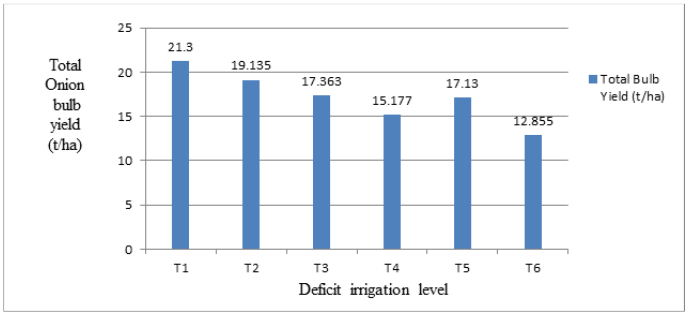

Figure 6. Effect of deficit irrigation on yield of onion

Effect of Deficit Irrigation on Water Productivity

Crop Water Use Efficiency (CWUE)

The analysis of variance on irrigation water application levels throughout whole growing season and at growth stages showed that the variability among irrigation level treatments were statistically high significant ($P < 0.01$) on the mean CWUE values. In this experiment, the crop water use efficiency of onion varied from 2.578 kg/m^3 to 4.02 kg /m^3 (Table and Figure 7). The highest CWUE (4.02 kg/m^3) was obtained at T6. The lowest mean value of CWUE (2.578 kg/m^3) was obtained under full irrigation water application (T1) and this was not significantly different with T2. In this experiment, even if the T6 and T4 plots seem to result highest crop water productivity due to high water savings, the yield reduction is also high. Here, it is clearly understood that higher water productivity for lower yield and the saved water may not compensate this severe yield reduction.

In general, the result revealed that with decreasing the amount of water supply through whole growing season or at growth stages, the crop water use efficiency increases (Figure 7). This result is in line with the result of Samson and Ketema (2007) reported that deficit irrigation increased the water use efficiency of onion. According to, a review of reduced water supplies effect on crop yield by FAO (2002) deficit irrigation maximizes CWUE in a way that crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season and any yield reduction will be insignificant compared with the benefits gained from the saved water to irrigate other crops.

Irrigation Water Use Efficiency (IWUE)

The analysis of variance revealed that the different deficit irrigation levels throughout and at growth stages had

highly significant ($p < 0.01$) effect on irrigation water use efficiency of onion. As presented in mean Table 7 below, the highest irrigation water use efficiency (2.41 kg/m^3) was obtained under T6 and statistically had highly significant difference ($p < 0.01$) to all other treatments. This shows that treatments with lower yield due to less water application had higher irrigation water use efficiency. The lowest irrigation water use efficiency (1.55 kg/m^3) was obtained from T1 and had no statistically significant variation with T2 (1.64 kg/m^3). The IWUE obtained under T3 and T5 had no statistically significant variation between them. This means IWUE obtained at T1 is similar with T2 and T3 is similar with T5. On the other hand, under T5 the relative yield reduction was greater when compared to T3. So, instead of T5, using T3 is advisable. Accordingly, made T5 out of the role, compared T1, T2, T3, T4 and T6, high IWUE was observed under T6 and T4 with high yield reduction penalty. From resources conservation point of view, maximum water productivity may be of interest, which could be obtained under this severe deficit irrigation. However, such consequences on yield may not be tolerable from producers view point (at T4 and T6).

Table 7. Deficit irrigation effect on crop and irrigation water use efficiency

Treatments (T)	Irrigation Water Applied (m^3/ha)	CWUE (kg/m^3)	IWUE (kg/m^3)	Water Saved (m^3/ha)
T1	13775.0	2.578^{d}	1.545^{d}	-
T2	11708.8	2.725^{d}	1.635^{d}	2066.25
T3	9642.5	3.040^{c}	1.825^{c}	4132.50
T4	6887.5	3.673^{b}	2.205^{b}	6887.50
T5	9388.7	3.030^{c}	1.803^{c}	4386.35
T6	5335.7	4.015^{a}	2.408^{a}	8439.35
LSD (0.05)		0.2164	0.1283	
CV (%)		4.53	4.47	

Note: *CWUE is crop water use efficiency; IWUE is irrigation water use efficiency.*

This result is in agreement with Kebede (2003) and Sarkar *et al.* (2008) reported that irrigation water use efficiency was higher at lower levels of available soil moisture. Among all irrigation treatments 70% ETc deficit irrigation level applied through whole growing season under conventional furrow irrigation system was efficient in conserving significant irrigation water at the same time attaining acceptable level of yield. Also, it is believed that, the advantages from increased crop water use efficiency and use of saved water to irrigate other additional areas would compensate the yield reduction as a result of imposed water stress.

Clearly, as observed in the Figure 7 below showed that there was a direct relationship between water productivity and water deficit level. On the other hand, water productivity associated positively with stress levels, where as negatively associated with irrigation amount. So, it is confirmed that deficit irrigation had positive effect on water productivity of onion under conventional furrow irrigation system.

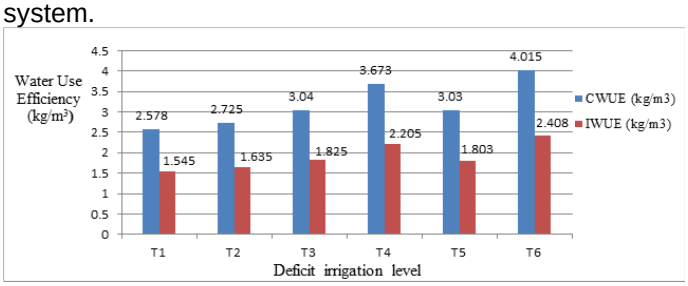

Figure 7. Effect of deficit irrigation on water productivity

The result related to the efficiencies showed that in area where irrigation water is limited, T3 deficit irrigation levels can be applied by increasing the water use efficiencies with significant and tolerable yield reduction. Therefore, for this particular onion variety (Bombay red) it could be concluded that increased water saving and water productivity through irrigation at 70% ETc deficit level under conventional furrow irrigation system can solve the problem of water shortage and would ensure the opportunity of further irrigation development in the study area and similar agro-ecology.

Yield Response Factor (K_y)

The relationship between relative yield reduction and relative evapotranspiration deficit for onion yield was estimated. As shown in the Table 8 below, the relative yield reduction increased with increasing relative evapotranspiration deficit. Observed yield response factors (K_y) of T2, T3, T4, T5 and T6 were 0.68, 0.62, 0.57, 0.61 and 0.65 respectively which is less than one (Table 8).This shows that deficit levels distributed during whole growing season and at growth stages could tolerate yield reduction ($K_y < 1$) during cropping season in the area. Results obtained were in agreement with those reported by Doorenbos and Kassam (1979). They reported, $K_y < 1.0$ indicates that the decrease in yield is proportionally less with increase in water deficit, while yield decrease in proportionally greater when $K_y > 1.0$.

Stressed treatments with irrigation application under T2, T3, T4, T5 and T6 showed a yield reduction of 10%, 18%, 29%, 20% and 40% respectively compared with the 100% ETc (T1) irrigation water application. This indicates a linear relationship between the decrease in relative water use and the decrease in relative yield (Figure 8). It also, clearly shows the effect of water deficit on crop yield. In other words, it describes the decrease in yield caused by the per unit decrease in water consumption. This relation is closely in line with Bhagyawant *et al.* (2015) who reported that there is a linear relationship between the decrease in relative water consumption and the decrease in relative yield.

Table 8. Deficit irrigation effect on yield response factor of Onion

Treatments (T)	Yield (t/ha)	ET_a (mm)	$\frac{ETa}{ETm}$	$\frac{Ya}{Ym}$	$1-\frac{ETa}{ETm}$	$1-\frac{Ya}{Ym}$	K_y
T1	21.30	826.4	1.00	1.00	0.00	0.00	-
T2	19.14	702.4	0.85	0.90	0.15	0.10	0.68
T3	17.36	578.5	0.70	0.82	0.30	0.18	0.62
T4	15.18	413.2	0.50	0.71	0.50	0.29	0.57
T5	17.13	563.2	0.68	0.80	0.32	0.20	0.61
T6	12.86	320.1	0.39	0.60	0.61	0.40	0.65

$1-\frac{ETa}{ETm}$ *= Relative evapotranspiration deficit,* $1-\frac{Ya}{Ym}$ *= Relative yield reduction,* ET_a *= the net depth of irrigation applied for each deficit treatments (mm),* ET_m *= the net depth of irrigation water applied for the control treatment with full irrigation (mm),* K_y *= Yield response factor.*

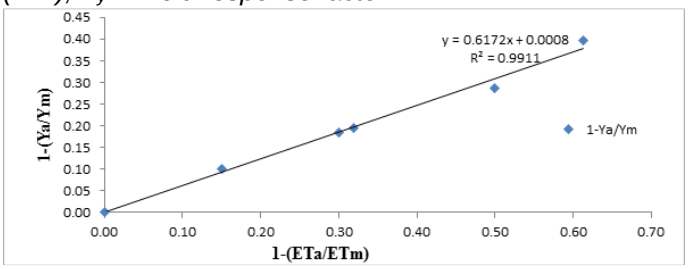

Figure 8. The relationship between relative yield reduction and relative evapotranspiration deficit for onion.

In general, the results of this study reveal, increasing water deficit throughout the whole growing season caused decreasing of K_y values, but increasing water deficit during a specific growth stages (initial, development, mid and late stages) caused increasing of K_y values.

Economic Analysis

The partial budget analysis revealed that the highest net benefit of Birr 191368.09 per hectare with higher cost was recorded from T1 with marginal rate of return 290.91% which was followed by net benefit of Birr 173959.54 per hectare from T2 with marginal rate of return 246.21%. However, the highest net benefit of Birr 160365.03 per hectare with least cost production of about Birr 27155.37 per hectare was obtained from T3 with its marginal rate of return 271.02 %. This means that for every Birr 1.00 invested in T3, growers can expect to recover the Birr 1.00 and obtain an additional Birr 2.7102. The minimum acceptable marginal rate of return (MRR %) should be between 50% and 100% CIMMYT (1988). Thus, the current study indicated that marginal rate of return is higher than 100% (Table 9). This showed that all the treatments are economically important as per the MRR is greater than 100%. Hence, the most economically attractive for small-scale farmers with low cost of production and higher net benefit was obtained by application of T3 under conventional furrow irrigation system. However, for resource full producers (investors) and in areas where water is not limiting factor for crop production, application of 100% (T1) is highly profitable with higher cost which is recommended as a second option.

Table 9. Economic analysis of onion production under different deficit irrigation treatments

Treatments (T)	Irrigation Water Applied (m^3/ha)	Marketable Bulb Yield (t/ha)	Adjusted bulb yield (t/ha)	Total Return (Birr/ha)	Variable cost (Birr/ha)	Net Income (Birr/ha)	MRR (%)
T1	13775.0	21.30	19.17	230029.20	38661.11	191368.09	290.91
T2	11708.8	19.13	17.22	206636.40	32676.86	173959.54	246.21
T3	9642.5	17.36	15.63	187520.40	27155.37	160365.03	271.02
T4	6887.5	15.18	13.66	163890.00	19423.15	144466.85	471.43
T5	9388.7	17.13	15.41	184950.00	26462.59	158487.42	199.17
T6	5335.7	12.85	11.56	138747.60	15023.25	123724.35	-

MRR = Marginal Return Rate

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study was proposed to investigate the deficit irrigation effect on yield and water productivity of onion under conventional furrow irrigation system. The field experiment consist of six treatments with different level of deficit irrigation water application throughout crop growth season and at different growth stages (T1 = 100% ETc, T2 = 85% ETc, T3 = 70% ETc, T4 = 50% ETc, T5 = 100% ETc Is 85% ETc Ds 70% ETc Ms 50% ETc Ls and T6 = 85% ETc Is 70% ETc Ds 50% ETc Ms 0% ETc Ls irrigation water application levels).The treatments were assigned in Randomized Complete Block Design with four replications.

As result revealed that, all DI treatments had highly significant effect ($p < 0.01$) on vegetative growth, yield, yield components and water use efficiency of onion. Thus, total onion bulb yield and WUE was varied under different deficit irrigation levels. The highest and the lowest bulb yield were recorded from T1 and T6 respectively. Similarly, the highest IWUE and CWUE were obtained from T6 while the lowest one recorded from T1. But, at T6, T4 and T5

high yield reduction was recorded which may not be attractive for producers. Therefore, it could be concluded that 70% ETc can solve the problem of water shortage and would ensure the opportunity of further irrigation development in the study area and similar agro-ecology.

Recommendations

Based on the study and the results obtained on yield, yield components and water productivity of onion, the following important recommendations were made:

- In the study area, water scarcity is the major limiting factor for crop production. So, it is possible to get better yield and water productivity of onion when we apply 70% ETc irrigation water application throughout growing season under conventional furrow irrigation system.
- To achieve maximum onion bulb yield in areas where water is not scarce, applying 100% ETc irrigation water application level throughout whole growing season under conventional furrow irrigation system is recommended.
- Since this experiment is a one-season study in a single location, further research over locations and seasons is necessary to confirm the present results.

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