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Response of onion *(Allium cepa l.)* to deficit irrigation under different furrow irrigation water management techniques in Raya Valley, Northern Ethiopia

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Scarcity of water is the most severe constraint for development of agriculture in arid and semi-arid areas. Under this condition, the need to use the available water economically and efficiently is unquestionable. Based on the actual crop need, irrigation management has to be improved so that the water supply to the crop can be reduced while still achieving high yield. A field experiment was carried out at Mehoni Agricultural Research Center, Raya Valley of Ethiopia, during 2016/17 season with objectives of determining the effect of deficit irrigation on Onion yield component and crop water productivity and the effect of Conventional, Alternate and Fixed furrow irrigation on yield and crop water productivity of onion. The treatment were five deficit irrigation levels (40, 55, 70, 85 and 100% ETc), and three furrow irrigation techniques (conventional, alternate and fixed furrow) were laid out in a random complete block design (RCBD) with three replications. The highest bulb yield was obtained at 100% ETc with conventional furrow method. In terms of irrigation and water use efficiency, 40% ETc deficit irrigation level application gave the highest irrigation water use efficiency and crop water use efficiency which was significantly superior to all other treatment. Among the irrigation water application methods, the highest water use efficiency was obtained with alternate furrow application method. On the other hand, the minimum water use efficiency was recorded with conventional furrow method. Alternative furrow irrigation (AFI) gave the highest crop water use efficiency and irrigation water use efficiency whereas conventional furrow irrigation (CFI) recorded the lowest. Better crop water use efficiency and irrigation water use efficiency were obtained in the AFI and fixed furrow irrigation (FFI), while the applied water in AFI was reduced by 50% of the CFI. Therefore, it can be concluded that increased water saving and associated water productivity can be achieved without significant reduction of yield in AFI with 100% ETc of irrigation level. AFI system appears to be a promising alternative.

Key words: Alternate furrow, conventional furrow, deficit irrigation, fixed furrow, onion.

INTRODUCTION

Irrigated agriculture is the primary user of diverted water globally, reaching a proportion that exceeds 70 to 80% of the total in the arid and semi-arid zones. It is therefore not surprising that irrigated agriculture is perceived in those areas as the primary source of water, especially in emergency drought situations.

Currently, irrigated agriculture is caught between two perceptions that are contradictory; some perceive that agriculture is highly inefficient by growing ‘water-guzzling crops’ (Postel et al., 1996), while others emphasize that irrigation is essential for the production of sufficient food in the future, given the anticipated increases in food demand due to world population growth and changes in diets (Dyson, 1999). Globally, food production from irrigation represents more than 40% of the total and uses only about 17% of the land area devoted to food production (Fereres and Connor, 2004).

Ethiopia is the second most populous country in sub-Saharan Africa and third on the continent with a population of about 100 million. Agriculture is the main stay of 80% of the Ethiopian people. Agriculture also accounts for 40% of the gross domestic product (GDP) of Ethiopia (IWMI, 2010).

However, most Ethiopian farmers depend on low productivity rain-fed small holder agriculture, even though rainfall is very erratic, and drought occurs very frequently. In Ethiopia, almost all food crops come from rain-fed agriculture with the irrigation sub sector accounting for only about 3% (FAO, 2005). This indicates that the water potential of the country is untouched, developing and utilizing efficiently this natural resource will rise the country to be food self sufficient within a short period of time.

Furrow irrigation water application system is the most popular surface irrigation, as it requires a smaller initial investment compared to other types of irrigation water application systems. This type of irrigation method is the most widely used in Ethiopia in almost all large and small irrigation schemes (FAO, 2002). It usually causes excessive deep percolation at the upper part of the furrow, insufficient irrigation at the lower part and considerable runoff, resulting in low application efficiencies and distribution uniformities. Therefore, proper furrow irrigation practices have to be devised to minimize water application and irrigation costs and to save water at the same time maintaining higher crop yields.

Therefore, these field experiments were conducted to determine the effect of alternate, conventional and fixed furrow irrigation techniques on onion yield and crop water productivity and to determine the effect of deficit irrigation on onion yield and crop water productivity. Of these, the crop which was selected for this experiment was onion which is wildly grown in the study area. Because onion was a cash crop in the study area.

The objective of the study was to determine the effect of alternate, conventional and fixed furrow irrigation techniques on onion yield and crop water productivity, and to determine the effect of deficit irrigation on onion yield and crop water productivity.

MATERIALS AND METHODS

Description of the experimental site

This study was conducted at the research station of Mehoni Agricultural Research Centre (MehARC) in the Raya Valley, Northern Ethiopia, located 668 Km from the capital Addis Ababa and about 120 Km south of Mekelle, the capital city of Tigray regional state. Geographically, the experimental site is located at 12° 51'50'' North Latitude and 39° 68'08'' East Longitude with an altitude of 1578 m.a.s.l. The site receives a mean annual rainfall of 300 mm with an average minimum and maximum temperature of 18 and 32°C, respectively. The soil textural class of the experimental area is clay with pH of 7.1 to 8.1(MehARC, 2015).

Climatic characteristics

The average climatic data (Maximum and minimum temperature, relative humidity, wind speed, and sun shine hours) on monthly basis of the study area were collected from the near meteorological station. The potential evapotranspiration ETo was estimated using CROPWAT software version 8 (Tables 1 and 2).

Experimental treatments

The experiment included three furrow irrigation systems, that is, CFI (Conventional furrow irrigation), AFI (Alternate furrow irrigation) and FFI (Fixed furrow irrigation) and four deficit irrigation levels, viz., 40ETc, 55ETc ,70ETc, 85ETc and a control irrigation of 100%ETc making a total of fifteen treatments. The treatment combination was given in Table 3. Control irrigation implies the amount of irrigation water applied in accordance with the computed crop water requirement with the aid of CROPWAT program. The treatments were replicated three times resulting in a total of 45 plots. Hence, the design was factorial experiment in randomized complete block (RCBD) design.

Statistical analysis

The collected data were analyzed using SAS 9.1 statistical software Mean separation was carried out using least significance difference (LSD) test at 5% probability level.

RESULTS AND DISCUSSION

Onion water and irrigation demand

The reference evapotraspiration (ETo) value of the site ranged between 3.9 mm/day in January to 4.8 mm/day

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Table 1. Long term monthly average climatic data of the experimental area.

Month	T_{min}	T_{max}	RH	Wind	Sun	Rad	ETo
	°C	°C	Percentage (%)	km/hr	Hours	MJ/m²/day	Mm/day
January	11.5	27.2	73	69	7.9	18.4	3.33
February	12.8	27.1	70	86	9.4	22.0	4.02
March	13.5	29.5	68	86	8.7	22.4	4.44
April	13.8	29.7	67	95	8.7	22.9	4.65
May	15.3	32.5	58	52	9.1	23.3	4.69
June	15.8	35.0	60	43	8.6	22.2	4.70
July	15.6	31.5	90	52	6.5	19.1	4.04
August	15.0	29.7	95	43	6.5	19.3	3.89
September	14.3	30.8	74	52	6.6	19.2	3.96
October	13.1	29.8	69	86	9.2	22.0	4.36
November	12.1	28.6	67	69	9.0	20.1	3.77
December	11.3	27.1	69	69	8.8	19.0	3.40

Table 2. Physical characteristics of soil at the experimental site.

Soil texture	Bulk density (g/cm^3)	Field capacity (%)	Permanent wilting point (%)	Total water holding capacity (mm)
Clay	1.1	45.47	28.47	170.02

Table 3. Treatment used in the experiment.

Irrigation level	Furrow irrigation techniques		
100%ET_c	AF1	FF1	CF2
85%ET_c	AF2	FF5	CF5
70%ET_c	AF3	FF3	CF1
55%ET_c	AF4	FF4	CF4
40%ET_c	AF5	FF2	CF3

Where; AF1, AF2, AF3, AF4 and AF5 means irrigated at alternate furrow with 100, 85, 70, 55 and 40%Etc irrigation level respectively; FF1, FF2, FF3, FF4 and FF5 means irrigated at fixed furrow with 100, 85, 70, 55 and 40%Etc irrigation level respectively; CF1, CF2, CF3, CF4 and CF5 means irrigated at convectional furrow with 100, 85, 70, 55 and 40%Etc irrigation level respectively.

in March, with an average of 4.3 mm/day for the whole growth period. Based on this output, the seasonal irrigation requirement was found to be 362.45 mm (Table 3). This amount was needed for full irrigation level treatments. Accordingly, the 85, 70, 55, and 40% of irrigation level with the furrow irrigation techniques of CFI were applied 308.1, 253.7, 199.4 and 145 mm, with AFI 210.8, 183.7, 156.6, 129.4 and 102.2 mm, and with FFI 210.8, 183.7, 156.6, 129.4 and 102.2 mm, respectively. This amount of seasonal ETc for AFI and FFI and the effective rainfall with 29.65 mm added showed the three furrows which does not irrigate at that time due to the rainfall. Crop water requirement (ETc) values were low at the beginning of the growing season, increased gradually to attain a maximum during March and April and subsequently decreased (Table 8). This result indicates that, the maximum amount of water was applied around bulb formation of the onion. This was also confirmed by Boyhan and Granberry (2001), that peak use of water generally occurs during the latter stages of bulb enlargement especially during periods of warm weather (Table 4).

Onion response to deficit Irrigation

Plant height

Plant height of onion was highly significantly ($P \leq 0.01$)

Table 4. Onion irrigation requirement in the study area.

Date	ETo	Crop	ETc	Total Rain	Effective rain	IRn	IRg
	mm/period	Kc	mm/period	mm/period	mm/period	mm/period	mm/period
13 Jan	23.4	0.5	11.7	-	-	11.7	16.71
19 Jan	22.62	0.5	11.31	-	-	11.31	16.16
25 Jan	24.3	0.5	12.15	-	-	12.15	17.36
31 Jan	23.7	0.5	11.85	-	-	11.85	16.93
6 Feb	25.62	0.56	14.3472	-	-	14.3472	20.50
13 Feb	27.93	0.67	18.7131	12	3.9	14.8131	21.16
20 Feb	29.96	0.78	23.3688	36.5	18.8	4.5688	6.53
27 Feb	30.38	0.92	27.9496	17.3	7	20.9496	29.93
6 Mar	30.17	1.05	31.6785	-	-	31.6785	45.26
13 Mar	34.16	1.05	35.868	-	-	35.868	51.24
20 Mar	32.34	1.05	33.957	-	-	33.957	48.51
27 Mar	31.01	1.05	32.5605	32	16	16.5605	23.66
3 April	33.11	1.05	34.7655	-	-	34.7655	49.67
10 April	32.27	1.02	32.9154	-	-	32.9154	47.02
17 April	31.08	0.94	29.2152	28	13.6	15.6152	22.31
Total	432.05		362.45	125.8	59.3	303.05	432.93

affected by the main effects of furrow irrigation techniques and irrigation level, but not significantly ($P < 0.05$) affected by the interaction effects of the treatments. Irrigation system, in its main effect, increased plant height significantly ($P < 0.01$), Conventional furrow irrigation techniques result in 43.99 cm height followed by 42.26 cm AFI and 41.62 cm on FFI system.

The irrigation levels were highly significantly different from each other in plant height at *($P \leq 0.01$)*. Significantly higher plant height of 46.68 cm was recorded for 100%ETc (full irrigation) of irrigation depth of water applied while 85, 70, and 50% irrigation water levels got 43.49 cm, 42.21 cm, and 40.99 cm plant heights respectively. 40%ETc of irrigation depth of water applied recorded the lowest plant height of 39.46 cm. Among the irrigation level between 70 and 55% there were no significances difference in plant height. Full irrigation level (100%) got 6.92 cm, which was greater than plant heights recorded in treatments that received 40%, irrigation level.

Plant height is a good indicator for determining the water stress. Sammis et al. (1988) reported that plant height could change at different level of water deficiency. Some authors emphasized that deficit irrigation shortens plant height (Otegui et al., 1995; Stone et al., 2001a; Pandey et al., 2000).

This finding is in agreement with the result of Aklilu (2009) and Takele (2009) who reported that the plant height of pepper decreased with decreased irrigation levels and also increase with the irrigation level. Wien (1997) indicated that plant height had a linear correlation with the availability of soil moisture. The present result was also in agreement with the work of Al-Moshileh (2007) who reported that with increasing soil water supply, plant growth parameters (plant height) were significantly increased.

Number of leaf per plant

Furrow irrigation techniques were significantly different from each other in number of leaf per plant. Significantly, higher number of leaf per plant was recorded at 9.21 (100%) followed by 85, 70 and 55%, irrigation level with the value of 8.89, 8.44, and 8.43 respectively. There were no significant difference between 70 and 55% of irrigation level. The lower number of leaf per plant was observed at 40% irrigation level with 7.82 leaves per plant.

The furrow irrigation techniques were significantly different from each other in number of leaf per plant. Significantly higher number of leaf per plant of 9.31 was recorded with convection furrow irrigation technique followed by 8.32 of AFI and 8.05 of FFI (Table 5). There were no significance difference between AFI and FFI of irrigation.

This result seems closely related to that of Biswas et al. (2003), who reported that onion bulbs of irrigated treatments gave highest leaves number per plant than the non irrigated one, whereas onion grown without supplemental irrigation gave lower number of leaves. This indicated that when plants respond to water stress by closing their stomata to slow down water loss by transpiration, gas exchange within the leaf is limited, consequently, photosynthesis and growth was slow down (Currah and Proctor, 1990). The obtained result was

Table 5. Effect of furrow irrigation techniques and irrigation levels on (PH, cm), number of leaves (NL) and bulb diameter (BD) of onion.

Furrow techniques	PH (cm)	NL	BD (mm)
CFI	43.99	9.31	55.00
AFI	42.26	8.32	53.17
FFI	41.62	8.05	49.30
LSD (P=0.05)	1.76	1.03	3.34
Irrigation level			
100%	46.68	9.21	57.1
85%	43.49	8.89	53.42
70%	42.21	8.43	53.4
55%	40.99	8.44	51.2
40%	39.76	7.82	47.3
LSD (P=0.05)	2.69	1.19	5.05
CV (%)	4.6	8.96	10.64

At P ≤ 0.05; LSD= least significant difference; CV = Coefficient of variation.

also in agreement with the findings of Wien (1997) who recorded that leaf number had a linear correlation with the availability of soil moisture.

Bulb diameter

The analysis of variance revealed that the interaction effect of furrow irrigation techniques and irrigation level showed no significant difference (P < 0.05) on bulb diameter, but furrow irrigation techniques and irrigation level indicated significant (P ≤ 0.05) differences (Table 5).

The analysis of variance for the furrow irrigation techniques has shown that there was significant difference on bulb diameter due to irrigation systems. As shown in Table 5, the furrow technique shows that the largest and lowest bulb diameter was recorded. 55 mm and 53.17 mm were observed for CFI and FFI respectively. However, the least bulb diameter (49.3mm) was recorded for fixed furrow irrigation. .

In this study, the irrigation level and largest onion bulbs (57.1 mm diameter) were recorded for 100%ETc (full irrigation) amount of irrigation water applied. On the other hand, the smallest bulb diameter (47.3 mm) was recorded from irrigation level treated with 40% irrigation depth. Bulb diameter was not significantly different between 85, 70 and 55% irrigation level. The result might be because of the reason that high irrigation levels increased photosynthetic area of the plant (height of plants and number of leaves), which increased the amount of assimilate partitioned to the bulbs and increased bulb diameter.

This result is closely related to that of Kumar et al. (2007a) who observed that irrigation at 1.20 Ep produced higher mean bulb size, which decreased with the decrease reduction of irrigation amount. In the same way, Al-Harbi (2002) and Biswas et al. (2003) indicated that bulb diameter of onions were increased at higher levels of irrigation.

Similarly, Olalla et al. (2004) reported that plots which received the greatest volumes of water yielded harvests with higher percentages of large-size bulbs whereas water shortages led to higher percentages of small-size bulbs. This indicates that transpiration, photosynthesis and growth rates were lowered by water stress as stressed plant produces smaller sized bulbs (Table 5).

Marketable bulb yield

Furrow irrigation techniques showed significant effect in interaction with irrigation level on bulb yield (P ≤ 0.05) (Table 6). Conventional furrow irrigation system produced 15738 kg ha^{-1} bulb yield with CFI 40% of irrigation water applied, which increased to 26802 kg ha^{-1} with CFI 100% (full irrigation). Fixed furrow irrigation techniques produced bulb yield of 14.326 tons ha^{-1} with 40% which increased to 20.865 tons ha^{-1} 100%, and alternate furrow irrigation system, on the other hand, produced bulb yield of 23.640 tons ha^{-1} with 100%, and 15.137 tons ha^{-1} with 40%.

In this study, the bulb yield response to fixed furrow irrigation and alternate furrow irrigation was higher at 100% than at 85% of irrigation water applied. Yet, CFI showed significantly higher yield at 100% of irrigation level. It showed that conventional furrow irrigation system gave more yield with irrigation water amount of 100%, and CFI with 85% gave optimum yield followed by AFI with 100%.

Irrigation level, in its main effect, increased bulb yield significantly (P < 0.01), producing higher marketable bulb yield of onion 23.769 tons ha^{-1} with full irrigation (100%) and followed by 85, 70 and 55% irrigation level with the value of 21.680 tons ha^{-1} , 19.708 tons ha^{-1} and 17.414 tons ha^{-1}, respectively. Significantly, lower bulb yield of 15.067 tons ha^{-1} was recorded with 40% of irrigation level. Among the irrigation furrow treatments, conventional furrow irrigation produced the highest bulb yield of 21.156 tons ha^{-1}, alternate furrow irrigation system (19.566 tons ha^{-1}) while fixed furrow irrigation system gave the lowest bulb yield of 17.860 tons ha.$^{-1}$

Furthermore FFI and AFI all showed a substantial decrease in bulb yield (7.51 and 15.5%, respectively). Bakker et al. (1997) and Sepaskhah and Ghasemi (2008), reported that small amount of applied water reduced yield in every other furrow irrigation (AFI and FFI) as compared to CFI due to water stress, when the same irrigation frequency was applied which supported the result of this research.

Table 6. Effect of furrow irrigation techniques and irrigation levels on Marketable bulb yield of onion (tons ha^{-1}).

Furrow techniques	Irrigation level					
	100%	85%	70%	55%	40%	Mean
CFI	26.802	23.712	20.364	19.165	15.738	21.156.2
AFI	23.640	21.939	20.033	17.084	15.137	19.566.6
FFI	20865	19.390	18.729	15.994	14.326	17.860.8
Mean	23.769	21.680.3	19.708.67	17.414.33	15.067	
LSD (0.5)	4053.4					
Cv (%)	6.8					

At P ≤ 0.05; LSD= least significant difference; CV = Coefficient of variation.

Table 7. Effect of furrow irrigation techniques and irrigation levels on unmarketable bulb yield and total bulb yield of onion (tons ha^{-1}).

Furrow techniques	UMBY	TBY
CFI	17.436	22.8999
AFI	18.381	21.4047
FFI	19.298	19.7906
LSD (P=0.05)	**148.1**	**1307.1**
Irrigation level		
100%	16.636	25.4327
85%	18.037	23.4839
70%	18.43	21.5517
55%	18.903	19.3048
40%	19.8526	17.0522
LSD (P=0.05)	225.2	-
CV (%)	8.92	6.77

At P ≤ 0.05; LSD= least significant difference; CV = Coefficient of variation.

The present result agreed with the general principle that the response of crop to full irrigation is generally higher under irrigated conditions than none irrigated one (Michael, 1978). The increment in marketable bulb yield due to application of irrigation water could be attributed to the increment in vegetative growth and increased production, which is associated with increment in leaf area index, bulb diameter and average bulb weight (Neeraja et al., 2007).

Similarly, Shoke et al. (1998) and Shock et al. (2000) indicated that the bulb and dry matter production of onion is highly dependent on appropriate water supply. Similar results were also reported by Kloss et al. (2012) who showed that dealing with improvement of water productivity is closely related to the irrigation practice of regulated deficit irrigation and has a direct effect on yield that is, if the amount of water applied decreases intentionally the crop yield will drop (Table 6).

Unmarketable bulb yield

Significantly higher unmarketable onion bulb yield was recorded when fixed irrigation furrow technique was applied with 19.29 tons ha^{-1} and followed by alternative furrow irrigation techniques, while the lowest unmarketable bulb yield of 18.38 tons ha^{-1} were recorded when convection furrow irrigation system applied with the value of 17.43 tons ha^{-} (Table 7).

There was highly significance difference among irrigation level on unmarketable bulb yield at P ≤ 0.001. The highest unmarketable bulb yield 19.85 tons ha^{-1} was recorded on irrigation level of 40% and the lowest value 1663.69 kg ha^{-1} was observed in 100% of water applied. 100% irrigation level produced 16.2, 14.07 and 9.73% lower unmarketable bulb yield of 40, 55 and 70%, respectively. In the treatments of 40 and 55% of irrigation levels, there was no observed significant difference. Similarly, there was no significant effect on unmarketable bulb between irrigation levels of 85 and 70% (Table 7).

The result revealed that, yield of very small bulbs increased with deficit irrigation. Stressed onion plants may bulb too early, produce small-sized bulbs and bulb splits and, thus, produce high amount of unmarketable yield (Kebede, 2003). This could be due to low rate of transpiration caused by stomata closer under moisture stress condition which brought about reduced photosynthesis and poor bulb growth and developments.

Corresponding to this, de Santa Olalla et al. (1994), de Santa Olalla et al. (2004) and Zayton (2007) reported that plots which received the lowest volumes of water during the development and ripening stages produced higher percentage of small size bulbs. From present result, increasing water deficit had a positive relationship with the production of high yield of under size bulbs.

Total bulb yield

Higher total onion bulb yield was recorded when convectional furrow irrigation system was applied that gave 22.899 tons ha^{-1}, and 21.404 tons ha^{-1} was recorded under alternative furrow irrigation system. The lowest total bulb yield of 19.790 tons $ha^{-1}$was recorded when fixed furrow irrigation system was applied (Table 7).

Irrigation level as the main effect is shown in Table 6 there was highly significance difference among irrigation level on total bulb yield ($P \leq 0.01$). The highest total bulb yield of 25.432 tons ha^{-1} was recorded on irrigation level of 100%ETc and followed by 23.483 tons ha^{-1}, 21.553 tons ha^{-1} 19.304 tons ha^{-1} for 85, 70 and 55% respectively. The lowest value of 17.052 tons ha^{-1} was observed in 40%ETc of water applied.

The increment in onion total bulb yield might be attributed to large size of onion bulb due to application of high level of irrigation. This is because it encourages cell elongation, above ground vegetative growth and imparts dark green colour of leaves, which is important for more assimilate production and partition that favours onion bulb growth (Brady, 1985).

The increased total bulb yield by applying full (no deficit) irrigation could have better performance on vegetative growth like plant height, number of leaves and leaf length which increase photosynthetic capacity of the plant, which in turn can improve bulb weight and contribute to increment in total bulb yield. As the irrigation level increased from 40% ETc to 100% ETc, the total bulb yield increased. This result was also in agreement with the findings of Ferreira and Carr, (2002) (Table 7).

Effects of irrigation level and furrow irrigation techniques on water use efficiency and crop water use efficiency

Irrigation level and furrow irrigation techniques had highly significant influence on water use efficiency of onion.

Crop water use efficiency (CWUE)

CWUE values with the furrow irrigation techniques ranged from 8.72 kg m^{-3} for convectional furrow irrigation while AFI and FFI had higher values of 11.76 kg m^{-3} and 10.8 kg m^{-3} respectively. The highest CWUE was recorded from alternate furrow irrigation system with value of 11.76 kg $m.^{-3}$ (Table 7). Irrigation level, in its main effect, increased CWUE ($P < 0.01$) to a higher CWUE value of 13.44 with 40% whereas 55, 70, 85 and 100% ETc irrigation levels got 11.22 kg $m,^{-3}$ 10.06 kg m^{-3}, and 9.05 kg $m^{-3}$and 8.4 kg m^{-3}, respectively. The results of this research are in agreement with Gençoglan and Yazar (1999), who reported that WUE values decreased with increasing

Table 8. Effect of furrow irrigation techniques and irrigation levels on crop water use efficiency and irrigation water use efficiency of onion (kg m^{-3}).

Furrow technique	CWUE	IWUE
CFI	8.72	6.1
AFI	11.76	8.23
FFI	10.82	7.58
LSD (P=0.05)	0.55	0.39
Irrigation level		
100%	8.4	5.88
85%	9.05	6.33
70%	10.06	7.04
55%	11.22	7.86
40%	13.44	9.41
LSD (P=0.05)	0.84	0.59
CV (%)	5.85	5.85

At $P \leq 0.05$; LSD= least significant difference; CV = Coefficient of variation.

irrigation level. In line with this result, Samson and Ketema (2007) reported that deficit irrigations increased the water use efficiency of onion. Similarly, Shock et al., (1998), Fabeiro et al. (2001), Kebede (2003), Kirnak et al. (2005) and Sarkar et al. (2008) reported that irrigation water use efficiency was higher at lower levels of available soil moisture.

Irrigation water use efficiency

The analysis of variance showed that furrow irrigation techniques as main effect was influenced by irrigation water use efficiency. The highest value of 8.23 kg/m^3 of IWUE were recorded on alternate furrow irrigation technique and 7.58 kg/m^3, 6.1 kg/m^3 obtained in FFI and CFI, respectively. In alternate furrow irrigation technique, higher value of 7.9% of WUE was obtained as compared to that of FFI and 26% of conventional furrow irrigation technique (Table 8).

IWUE significantly changed when irrigation level amount increased. However, IWUE values ranged from 5.88 kg m^{-3} for 100% irrigation level of water applied to 9.41 kg m^{-3} 40% of irrigation level of water applied. Higher IWUE values of 7.86 kg m^{-3} and 9.41 kg m^{-3}were obtained from 55 and 40%, respectively. There was no significance difference between 100% and 85% of irrigation level in IWUE.

Generally, CWUE and IWUE are influenced by crop yield potential, irrigation method, estimation and measurement of ET, crop environment, and climatic characteristics of the region. The results related to the efficiencies showed that when irrigation water is limited, 55 and 40% deficit irrigation can be applied by increasing the water use efficiencies. Mansouri-Far et al. (2010) reported that irrigation water can be conserved and yields maintained (as sensitive crop to drought stress) under water limited conditions (Table 8).

Conclusions

The most important result arisen from this investigation was that when less irrigation was applied, the conventional furrow irrigation techniques had the smallest bulb yield reduction. The highest values of plant height (46.7 cm), bulb diameter (49.9mm), leaf number per plant (9 leaves), average bulb weight per plant (64.6g) and total bulb yield (25.437 tons ha^{-}) were recorded at treatment of 100% irrigation level.

Unmarketable bulb yield was reduced as the amount of irrigation level increased. The highest unmarketable bulb yield was recorded at 40% irrigation level with the value of 19.853 tons ha^{-1} and the lowest (16.636 tons ha^{-1}) was recorded at 100% irrigation level. Both plant height and leaf number per plant showed decreases with reduction in the amount of irrigation water applied.

Smallest bulb height (42mm), lower in maturity (96days), small leaf length (28.9cm) and lower marketable bulb yield (14.326 tons ha^{-1}) were recorded at treatment combination of 40% irrigation depth with FFI. On the other hand, the bulb height (55.4mm), delay in maturity (106days), highest leaf length (40.8 cm) and higher marketable bulb yield (26.802 tons m^{3}) were recorded at treatment combination of 100% irrigation level with CFI.

The highest CWUE (9.41 kg mm^{-3}) of onion was obtained from 40% irrigation level and the lowest recorded from 100%ETc irrigation level with the valve (5.88 kg m^{3}). CWUE values of 8.23 kg ha^{-1} m^{3}, 7.58 kg m^{3}, and 6.1 kg m^{3} were obtained for AFI, FFI, and CFI, respectively. Based on the results of this study, the following conclusions can be drawn:

(1) Onion bulb yield increased when irrigation level increased from 40% deficit irrigation to full application of 100%;
(2) CFI with 100% gave the highest bulb yield as compared to fixed furrow irrigation techniques and AFI gives an equivalent bulb yield at 100% with AFI and with 85% CFI. But in terms of CWUE, AFI was much better than CFI.
(3) In the study areas, water was a limiting factor, it was possible to get equivalent bulb yield and higher CWUE and IWUE when we applied 100% of irrigation level with AFI.
(4) In areas under no limitation of irrigation water, yield of Bombay Red onion variety could be improved substantially by applying 100% irrigation amount with CFI.

In conclusion, AFI can allow saving a substantial amount of water and labour without highly reduction of onion yield in the study area. This also demonstrates that crop water use efficiency will be increased by using AFI which may result in substantial benefits, under limited water condition, labour saving and improved flexibility in farm irrigation management are also expected to be achieved using AFI. This result should be of significant value in this area to irrigate additional land. However, under scarce water condition, 100% irrigation level with alternative furrow irrigation can be practiced. .

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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