

Research article

Methods and Deficit level on Onion (*Allium cepa* L.) Yield and Water Productivity

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Accepted 30 April 2020

Onion is one of vegetable crops grown under irrigation. Furrow irrigation is most commonly used method of irrigation. Field study was carried out on clay soil at experimental site of Debre Zeit agricultural research center to investigate the effect of furrow irrigation methods and identify optimal deficit irrigation level on crop yield and water productivity of onion. Treatments include three furrow irrigation methods, viz., alternate, fixed and conventional furrow irrigations and three deficit irrigation levels of 85% ET_c, 70% ET_c and 55% ET_c and a control irrigation of 100%ET_c laid out in split plot design with three replications. A furrow irrigation method was assigned as main plots and the irrigation levels as sub plots. Irrigation water was applied at allowable soil moisture depletion ($p=0.25$) for onion. Analysis of variance indicate furrow irrigation methods and irrigation levels significantly ($P<0.01$) affected onion yield and water productivity. The highest total bulb yields were obtained from alternate furrow irrigation and control irrigation of 100%ET_c application. Among the deficit irrigation, 85%ET_c gave significantly higher yield. Although 55%ET_c application under alternate furrow irrigation gave the highest Crop Water Use Efficiency (CWUE) and Irrigation Water Use Efficiency (IWUE), yield penalty was significant compared to all other deficit irrigation. However, deficit irrigation of 70%ET_c under alternate furrow irrigation gave above the mean value of CWUE and IWUE and hence can be considered best practice in a water resources limited area.

Key words: Alternate furrow irrigation, Conventional furrow irrigation, fixed furrow irrigation

Cite this article as: Gebeyehu TM (2020). Methods and Deficit level on Onion (*Allium cepa* L.) Yield and Water Productivity. Acad. Res. J. Agri. Sci. Res. 8(3): 200-213

INTRODUCTION

Irrigated agriculture makes a major contribution to food security, producing nearly 40% of food and agricultural commodities on 17% of agricultural land in the World. Irrigated areas have almost doubled in recent decades and contributed much to the growth in agricultural productivity over the last 50 years. Agriculture accounts for about 70 % of the freshwater withdrawals in the world (FAO, 2013), while evaporative use of water in agriculture (water that is evaporated from irrigated fields) accounts for about 90 % of all of the water that is evaporated as a result of human intervention. Irrigated

agriculture is therefore the main reason for water demand and a driver of scarcity of fresh water in a number of regions.

In the 20th century, worldwide irrigated area experienced a huge expansion of more than 500% increase from 40 million to 270 million ha of irrigated land. Such numbers are part of the ability of humankind to produce food fast enough to meet population growth. But that remarkable ability, on the other hand, has its cost - a water crisis, characterized by water scarcity and competition, pollution and malnutrition (Molden, 2003).

Agriculture is the dominant sector in Ethiopian economy contributing about 45% to the gross domestic

product (GDP) and 85% to export earnings. The cultivated land in the country is mostly rain-fed and subsequently variability of rainfall during the cropping season affects crop production and productivity. To solve such problems irrigation is an important. Irrigation not only improves crop production and productivity, but also reduces reliance on rainfall, contribute towards food security, self-sufficiency and export market.

Water availability is considered the climatic factor with greatest effect on agricultural productivity (Falkenmark and Rockstrom, 2000). Aranus *et al.* (2003) reported that, among the environmental factors affecting crops, the water input, expressed as the sum of rainfall and irrigation during the growing period, explained the large part of the yield variability.

Irrigation development is increasingly implemented in Ethiopia more than ever to supplement the rain-fed agriculture. It aims to increase agricultural productivity and diversify the production of food and raw materials for agro-industry as well as to ensure that the agriculture to play a pivotal for driving the economic development of the country (Mekonen, 2011). But, the overall performance of the crop production is still hindered due to unsustainable water supply. The scope for further irrigation development to meet food requirements in future is, however, severely constrained by decreasing water resources and growing competition for clean water. While on a global scale, water resources are still ample. Serious water shortages are developing in the arid and semi-arid regions as existing water resources reach full exploitation. The situation is exacerbated by the declining quality of water and soil resources. The dependency on water has become a critical constraint on further progress and threatens to slow down development, endangering food supplies and aggravating rural poverty. The great challenge for the coming decades will therefore be the task of increasing food production with less water, particularly in countries with limited water and land resources.

In Adaa wereda, Bishoftu (Debrezeit) 5,441ha of land has been studied and identified as potential developable (prioritized area). The recorded land area of 3,561.9ha is already under irrigation by farmers and benefits a total of 5,600 households. That shows an average land holding size of about 0.5ha irrigated area. However, in the wereda there are certain unaccounted private commercial and state/regional government owned schemes, which are already in place. Particularly, irrigated agriculture through development of ground water for horticulture and floriculture are emerging quite strongly. The exact extent of exploitation of the ground water resources and the developed area is not known, particularly those associated to commercial farming. A total of 1087 hand dug wells are also available irrigating 55ha of irrigation land (Seleshi *et al.*, 2006).

Water stress affects yield productivity in many ways.

Most of the responses have a negative effect on production. But crops have different and often complex mechanisms to react to shortages of water. Several crops and genotypes have developed different degrees of drought tolerance, drought resistance or compensatory growth to deal with periods of stress. The highest crop productivity is achieved for high-yielding varieties with optimal water supply and high soil fertility levels, but under conditions of limited water supply crops will adapt to water stress and can produce well with less water (FAO, 2002).

The use of fixed and alternate furrow irrigation methods allows for a reduction in volume irrigation water and completion of irrigation application in shorter time, thus reducing labor use when compared to conventional furrow irrigation method. Scientist observed a highly significant crop yield differences from alternate furrow relative to conventional furrow method Kang *et al.* (1999).

Onion is one of the most cultivated vegetable crops in the world. It is produced in many countries both under rain fed and irrigation conditions. According to World Bank (2004) report in 2001 the crop shared one fourth of the vegetable export quantities and stood third following green beans and peas contributing about 20% of the total vegetable export value which is about 244,000 US dollar of export earnings.

Global production of onions in 2008 was second only to tomatoes among horticultural crops: more than 73 million metric tons harvested from 3.6 million hectares. China alone produced more than 20 million metric tons; other leading producers were India, Australia, the United States, Pakistan, and Turkey (FAOSTAT, 2011). In Africa Egypt, Algeria, Morocco, Nigeria, South Africa and Niger are the leading producers of the crop in Africa (FAOSTAT, 2008). In Ethiopia, the crop is one of the most important vegetables produced by smallholder farmers mainly as a source of cash income and for flavoring the local stew 'wot' (Lemma and Shemelis, 2003; Fekadu *et al.*, 2006). In 2016/17, the total area under onion production in Ethiopia is estimated to be 33603.39 ha with an average yield of about 97.45 Qt per ha (CSA, 2015/16).

The country has high potential to benefit from onion production. To attain the genetic potential yield and achieve high economic growth from onion production and productivity, it is necessary to study the response onion to different deficit irrigation levels and different furrow irrigation application methods. The experimental treatments had three furrow irrigation methods, viz., alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI) and three deficit irrigation levels of application, viz., 85 % ETc, 70 % ETc and 55% ETc, and a control irrigation of 100%ETc. Crop water requirement or crop evapotranspiration (ETc).

The objective of the study was to investigate the effect of furrow irrigation methods and identify optimal deficit

irrigation level on crop yield and water productivity of onion under central highland environment condition.

MATERIALS AND METHODS

Description of the Study Area

The Experiment was conducted in 2017/18 cropping season at Debre Zeit Agricultural Research Center, main station which about 47 km Southeastern of Addis Ababa. The geographical location extent ranges to 08° 44' 15" to

08° 46' 45" N Northern latitude and from 38° 59' 45" to 39° 01' 00" E Eastern longitude. The research center is located on a nearly level of a very gently sloping topography with a gradient of zero to 2 % slope. It has low relief difference with altitude ranging from 1610 to 1908 meters above the sea level. The site is situated in the Central high land area of the country having Tepid to cool sub-moist highlands type climate. The area receives an annual mean rainfall of 851 mm. The mean maximum and minimum temperature are 28.3°C and 8.9°C, respectively with the average value of 19°C. The experimental fields are dominated by heavy soils (Vertisol) (WRB, 2014).

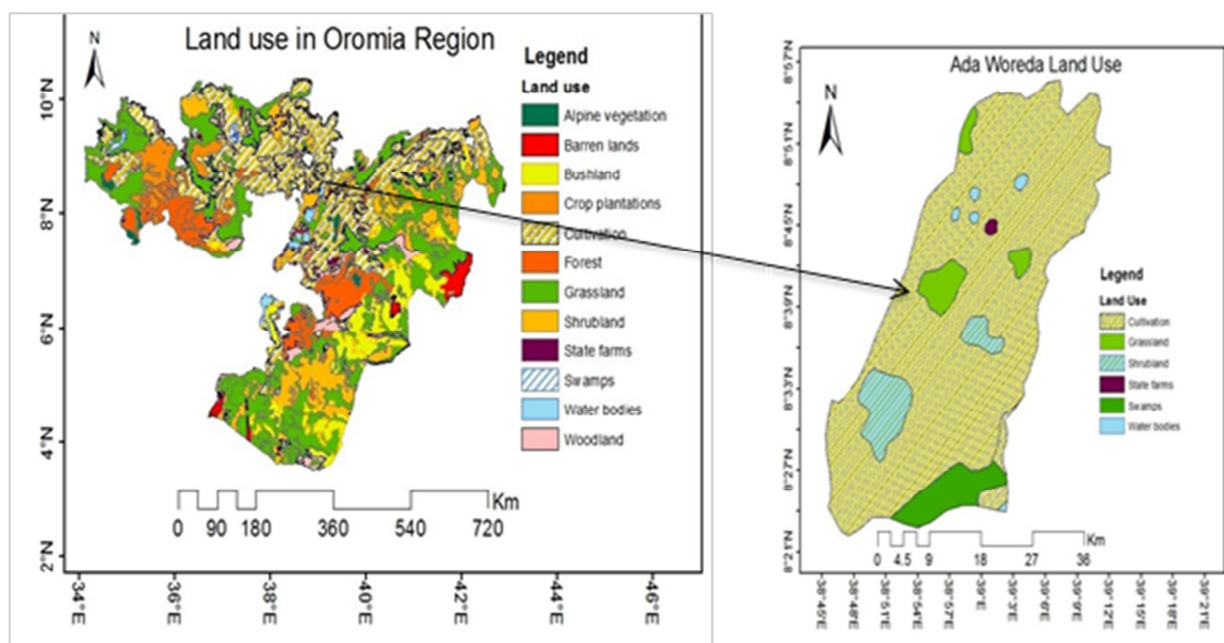


Figure 1. Location map of study area

Soil samples were collected from experimental plots after irrigation for gravimetric soil moisture determination from different depths Physical and Chemical properties of soil data Soil texture, Bulk density, Field capacity(FC), permanent wilting point(PWP), electrical conductivity of soil (ECe),cat ion exchange capacity of soil (CEC),organic matter and soil pH. Chemical properties of irrigation water Electrical conductivity of irrigation water (ECw) and irrigation water PH.

The soil samples were analyzed at Debre Zeit Agricultural research center's soil laboratory for physical (texture, Field Capacity (FC), Permanent wilting Point (PWP)) and chemical quality (pH, Organic Matter (OM), Electrical Conductivity (EC) and Cat ion Exchange Capacity (CEC) parameters at laboratory following standard test procedures. The FC and PWP were determined using pressure plate and membrane

apparatus by applying a pressure of 0.33 bars and 15 bars, respectively, on saturate soil paste until no change in moisture is detected. The soil texture was analyzed using hydrometer method. The soil pH was determined by measuring soil solution of 1:2.5 ratios (soil to water) using a pH meter. The Organic carbon (%) was determined following the wet digestion method as described by Walkley and Black (1934). OM content was then determined by multiplying OC by 1.724 (Nelson and Sommers, 1996). The ECe was determined by measuring the conductivity of saturated soil extract using electrical conductivity meter.

Onion seeds variety Nafis was used as seed material. The selected seed variety was sown in Oct 2017 on nursery bed. The seedlings were then transplanted in Dec 2017 on well prepared experimental plots and the seedlings were established in both sides of a ridge with

row and plant spacing of 20cm and 10cm, respectively.

Cultural practices are dates of site selection, Land preparation, soil sampling, amount and frequency of pre irrigation, seedling preparation, transplanting, treatment application, crop management practice like weeding, cultivating and pesticide application, maturity and harvest recording of, Fertilizer Application time, crop growth length period and harvesting date.

When the crop approaches to maturity simply by observing leaves of onion when 50% of its leaves dawn off harvested on the field.

Marketable bulb yield (kg ha^{-1}) refers to yield of onions, which are not under sized ($>5\text{cm}$ in diameter), free from physiological disordered and pest damaged bulbs. It was determined from weight of bulbs harvested from the net plot using digital balance.

Unmarketable bulb yield (kg ha^{-1}) refers to sized, color, physiological disordered and pest damaged bulbs which was determined from weight of bulbs harvested from the net plot using digital balance. (Moray *et al.*, 2012). Onion bulbs with less than 5cm diameter were categorized under unmarketable (Moray *et al.*, 2012). The source of irrigation water in the study area is ground water with the depth of 20m.

Treatments and Experimental Design

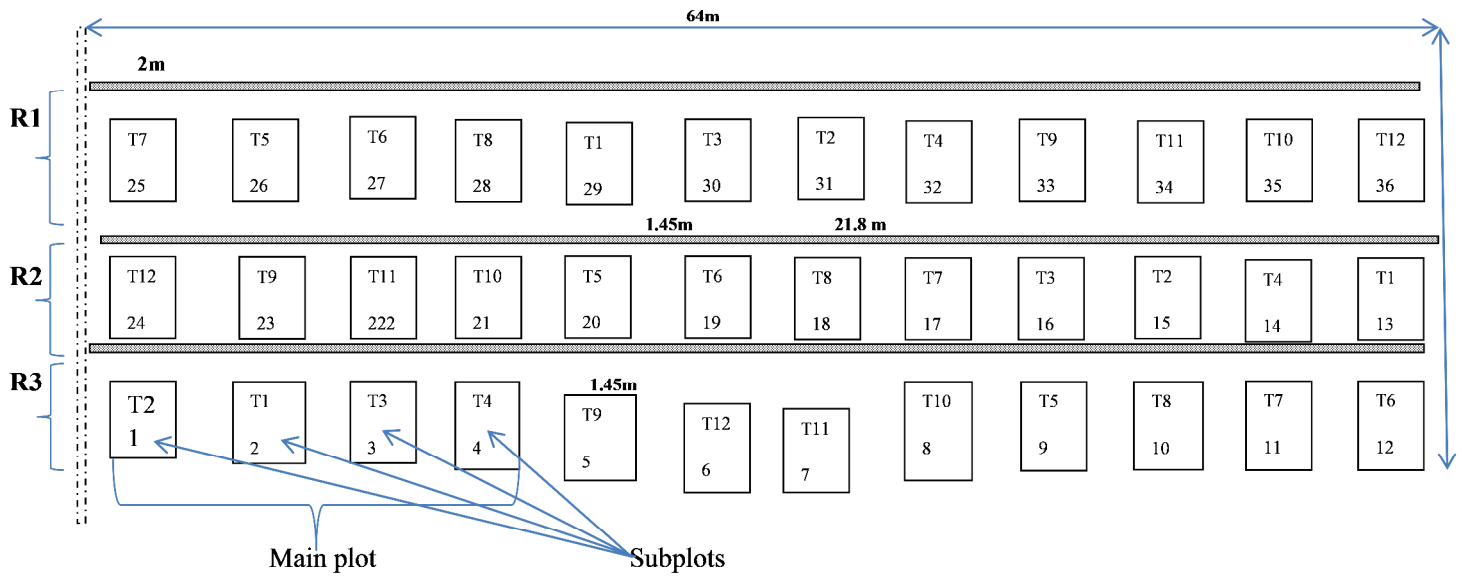
The Experiment was conducted in 2017/18 cropping season at Debre Zeit Agricultural Research Center. The experimental treatments had three furrow irrigation methods, viz., alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI) and three deficit irrigation levels of application, viz., 85 % ETc, 70 % ETc and 55% ETc, and a control irrigation of 100%ETc. Crop water requirement or crop evapotranspiration (ETc). The design of the experimental plot was split plot in RCBD arrangement and replicated three times. The three furrow irrigation methods were arranged as main plots and the deficit levels as sub plots. The experiment had a total of twelve (12) treatment combinations. The experimental field was divided into 36 plots with 3.6m by 4m plot size to accommodate six furrows with spacing of 60cm having row and plant spacing of 20cm and 10 cm, respectively. The plots and replications had a buffer zone of 2m for canals carrying no irrigation water and 2.5 m for canals carrying irrigation water supply canals between plots to eliminate influence of lateral water movement and also 1m between plots. The experimental treatment combination and designation are given in Table 1 and 2.

Table 1. Treatment combination

Sub-plot Irrigation Level	Main-plot - Furrow Irrigation Method		
	AFI	FFI	CFI
100% ETc	T1	T5	T9
85% ETc	T2	T6	T10
70% ETc	T3	T7	T11
55% ETc	T4	T8	T12

Table 2. Treatment arrangement

Treatment	Description
T1	Alternate furrow (AFI) and 100% ETc application
T2	Alternative furrow (AFI) and 85% ETc application
T3	Alternative furrow (AFI) and 70% ETc application
T4	Alternative furrow (AFI) and 55% ETc application
T5	Fixed furrow (FFI) and 100% ETc application
T6	Fixed furrow (FFI) and 85% ETc application
T7	Fixed furrow (FFI) and 70% ETc application
T8	Fixed furrow (FFI) and 55% ETc application
T9	Conventional furrow (CFI) and 100% ETc application
T10	Conventional furrow (CFI) and 85% ETc application
T11	Conventional furrow (CFI) and 70% ETc application
T12	Conventional furrow (CFI) and 55% ETc application



Note: R1, R2 and R3 represent the first, second and third replications, respectively
Figure: 2. Experimental treatments layout



Figure: 3. Experimental treatments on field

Statistical Analysis

The collected data were statistically analyzed appropriate to Split-plot design using statistical software which is Statistical Analysis System (SAS). Whenever the treatment effects were found significant, least significant difference (LSD) test was performed to assess any significant difference among treatments means.

RESULTS AND DISCUSSION

The different deficit irrigation levels under alternate, fixed and conventional furrow irrigation methods had shown a significant effect on onion growth, yield and yield components. The results are shown in sub-section below together with analysis of the experimental soil and climate characteristics.

Soil Sampling and Analysis

The results of soil analyses and field tests on physical and chemical characteristic are given in Table 3 and 4.

Soil Physical Characteristics

The laboratory analysis indicates that the basis particle size distribution in the soil was average value of 53.60% clay, 22.53% sand and 23.87% silt at experimental site. Therefore based on soil textural class determination triangle of international soil society (ISSS) system (Rowell, 1994) the soil of the experimental site was clay in texture. The bulk density of the experimental site showed slight variation with depth and varied from 1.04 to 1.15g/cm³. This could be because of slight decrease of organic matter with depth and compaction due to the weight of the overlying soil layer (Brady and Weil, 2002). The weighted bulk density (BD) and Total Available Water (TAW) of the experimental site are given in Table 3.

Table 3. Soil physical properties

Depth (cm)	BD (g/cm ³)	FC(%)	PWP (%)	TAW (mm)	Clay (%)	Sand (%)	Silt (%)	Textural class
0-20	1.04	39.35	23.76	32.43	53.6	23.2	23.2	Clay
20-40	1.1	41.94	24.58	38.19	55.6	25.2	19.2	Clay
40-60	1.15	39.9	24.94	34.41	51.6	19.2	29.2	Clay
Average	1.01	40.40	24.43	35.01	52.93	22.53	23.87	Clay

Note: FC: Field Capacity
PWP: Permanent Wilting Point

Soil Chemical Characteristics and Water Properties

Soil PH is an important parameter which measures hydrogen ion concentration in the soil to indicate its acidic and alkaline nature of the soil. According to Murphy (1968) rating scale, the pH value of the current experimental site soils was near to neutral (pH 7.07). Onion can grow well in soil pH range from 6.0 to 8.0 (Olani and Fikre, 2010). The soil had a Cation exchange capacity (12.77meq/100g) through 60 cm profile and average electrical conductivity of (0.280ds/m) which is below the threshold value for onion yield reduction, i.e. 1.2 dS/m (Smith *et al.*, 2011). Organic matter content (OM) improves water-holding capacity, nutrient release and soil structure. The OM content and OC content of the soil had average values of 1.80% and 1.05%,

respectively which is rated as low. The findings of Tekalign (1991) who reported that soils having OM value in the range of 0.86-2.59% are considered low.

The laboratory result of the irrigation water showed the pH value of 7.47 and EC_w value of 0.67 dS m⁻¹ (Table 4). According to Bryan *et al.* (2007), the irrigation water is classified in terms of pH as low (below 7), slight to moderate (7-8) and severe (above 8). Based on this classification, the characteristics of the irrigation water in the study area are found slight to moderate (Table 4).

Bauder *et al.* (2014), who reported that, irrigation water quality salinity hazard, has four categories: (≤ 0.75 dS m⁻¹ none), (0.76-1.5 dS m⁻¹ some), (1.51-3.00 dS m⁻¹ moderate) and (≥ 3.00 dS m⁻¹ severe). Based on the above categories the irrigation water quality of the study area was classified at none.

Table 4: Soil chemical and Water properties

Depth(cm)	pH	CEC(meq/100)	EC(ds/m)	OC (%)	OM (%)
0-20	7.10	14.7	0.298	1.15	1.98
20-40	7.11	13.9	0.265	1.12	1.93
40-60	7.00	9.7	0.278	0.87	1.50
Average	7.07	12.77	0.280	1.05	1.80
Irrigation Water					
pH	7.47				
ECw	0.67ds/m				

Note: OC: Organic Carbon

Crop water requirement and Irrigation water management

The ETo value of the experimental site ranged between 4.62 mm/day in December to 5.95mm/day in March, with an average of 4.89 mm/day for the whole growth period. Using the reference evapotranspiration (ETo) and crop coefficient value (KC), calculation of the total seasonal onion crop water requirement or crop evapotranspiration (ETc) was found to be 436.14mm (Table 5). This amount was needed for full irrigation level treatments (100%ETc). Accordingly, the 85%ETc, 70%ETc and 55%ETc of irrigation level with the furrow irrigation methods of CFI were applied 370.72mm, 305.30mm and 239.88mm with AFI and FFI with the same value of 100%ETc, 85%ETc, 70%ETc and 55%ETc were 218.07mm, 185.36mm, 152.65mm and 119.94 mm respectively (table 5). The Crop water requirement (ETc) values were low at the beginning of the initial growing season, increased gradually to attain a maximum during development and mid stage and subsequently decreased based on crop growth stages and climate data.

Table 5. Irrigation interval, number and depth of irrigation

Treatments		Number of irrigation	Days between irrigation (interval)	Net Irrigation (In) (mm)	Gross Irrigation (I _g) (mm)
Furrow Irrigation	Irrigation level (%)				
CFI	100%	17	6	436.14	726.9
	85%	17	6	370.72	617.9
	70%	17	6	305.30	508.8
	55%	17	6	239.88	399.8
AFI	100%	17	6	218.07	363.5
	85%	17	6	185.36	308.9
	70%	17	6	152.65	254.4
	55%	17	6	119.94	199.9
FFI	100%	17	6	218.07	363.5
	85%	17	6	185.36	308.9
	70%	17	6	152.65	254.4
	55%	17	6	119.94	199.9

Table 6. Crop water requirement and Irrigation water requirement of onion (100% ETc)

Date	ETo Mm	Kc	CWR/ ETc (mm)	Rainfall (P) (mm)	P _{eff} (mm)	In (mm)	Ig (mm)
9-Dec	32.3	0.4	12.92	0	0	12.93	21.55
15-Dec	31.8	0.4	12.72	0	0	12.72	21.2
22-Dec	31.4	0.4	12.56	0	0	12.56	20.93
29-Dec	32.3	0.4	12.92	0	0	12.93	21.55
5-Jan	32.7	0.5	16.37	0	0	16.37	27.28
12-Jan	29.2	0.6	17.82	0	0	17.82	29.7
19-Jan	33.6	0.7	24.51	0	0	24.51	40.86
26-Jan	37.8	0.8	31.78	0	0	31.78	52.96
2-Feb	34.5	1	32.77	0	0	32.77	54.61
9-Feb	35.9	1.1	38.39	0	0	38.39	63.99
16-Feb	41.4	1.1	45.49	0	0	45.49	75.81
23-Feb	37.1	0.9	31.49	0	0	31.49	52.49
2-Mar	31.8	0.9	27.02	0	0	27.02	45.04
9-Mar	32.2	0.9	27.34	0	0	27.34	45.57
16-Mar	32.3	0.9	27.43	0	0	27.43	45.72
23-Mar	34.4	0.9	29.20	0	0	29.2	48.66
30-Mar	41.7	0.9	35.40	0	0	35.4	59
Total			436.14	0	0	436.14	726.9

Note:CWR/ETc: Crop Water Requirement/Crop Evapotranspiration P_{eff}:-Effective Rain fall

ETo:-Reference Evapotranspiration

Kc: - Crop Coefficient

ETc= ETo *Kc

Marketable Bulb Yield

Marketable bulb yield are not under sized (>5cm in diameter), free from physiological disordered and pest damaged bulbs. Onion bulbs with greater than 5cm diameter were categorized under marketable and less than 5cm diameter unmarketable bulb yield (Moray *et al.*, 2012).

Analysis of variance has shown that marketable bulb yield of onion was significantly affected ($P<0.01$) by the furrow irrigation methods and irrigation level. Similarly, interaction effect of furrow irrigation methods and irrigation level has significantly ($P<0.05$) affected marketable bulb yield of onion.

The CFI practice with irrigation scheduled at the control (100%ETc) application gave significantly highest marketable bulb yield of (42219 kg ha⁻¹). This result seems closely related to that of Yemane *et al.* (2018), who reported that CFI methods with 100%ETc deficit irrigation application gave the highest marketable bulb yield. Among the deficit irrigation levels, 85%ETc and 70%ETc under the CFI and the AFI practices have shown no significant difference on marketable bulb yield. The deficit irrigation application of 55%ETc under the FFI gave significantly the lowest marketable bulb yield of (23772 kg ha⁻¹). Generally, among the furrow irrigation

methods, CFI and AFI produced the best marketable bulb yield and while significantly lowest mean marketable bulb yield were obtained from FFI and 55%ETc application.

Yemane *et al.* (2018) 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 study.

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). Similar to the present observation Patel and Rajput (2013) also reported that water application with no deficit (100 % full Crop water requirements) at any stage of plant growth gave highest marketable yield. Results of De santa *et al.* (1994), Neeraja *et al.* (1999) and Bosch sera and Currah (2002) also showed that marketable bulb yield of onion increased with increasing irrigation water amount is a linear fashion.

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 i.e., if the amount of water applied decreases similarly the crop yield will also drop.

Table 7. Effects of furrow irrigation methods and deficit irrigation levels on marketable bulb yield of onion.

Treatments	Marketable bulb yield of onion(kg ha ⁻¹)				Mean
	Deficit Irrigation level (%)				
Furrow Irrigation method	100	85	70	55	
CFI	42219 ^a	34489 ^c	32930 ^{cd}	28340 ^e	34494.5 ^a
AFI	38823 ^b	34348 ^c	32117 ^{cd}	28337 ^e	33406.3 ^a
FFI	31449 ^d	28237 ^e	27337 ^e	23772 ^f	27698.8 ^b
Mean	37497 ^a	32358 ^b	30794.8 ^c	26816.3 ^d	
LSD(P=0.05)	2371.8				
CV1 (%) Main plot	10.21				
CV2 (%) Sub plot	4.34				

Means in a Column with the same superscripts are not significantly different at $P \geq 0.05$

Unmarketable bulb yield

The analysis of variance has shown that unmarketable bulb yield was not significantly affected by interaction effect of furrow irrigation methods and irrigation levels. Furrow irrigation methods and irrigation levels had a highly significant ($P < 0.001$) influence on unmarketable bulb yield (Table 9).

The CFI gave the lowest unmarketable bulb yield and was not significantly different from AFI. The control irrigation (100%ETc) also had the lowest unmarketable bulb yield and among the deficit irrigation levels, the 85%ETc application gave significantly lowest unmarketable bulb yield. Moreover, the highest unmarketable bulb yields were recorded from the FFI practice and deficit irrigation application of 55%ETc.

Stressed onion plants may bulb too early, produce small-sized bulbs and 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, Martin *et al.* (2004), Olalla *et al.* (2004) and Zayton (2007) reported that plots which received the lowest amount of water during the development and maturing 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

The total bulb yield which is the sum of unmarketable and marketable bulb yield. The furrow irrigation method

and irrigation level have shown a highly significance ($P < 0.01$) difference on total bulb yield (Table 9). The analysis of variance has shown that unmarketable bulb yield was not significantly affected by interaction effect of furrow irrigation method and irrigation level.

The AFI gave the maximum total bulb yield of (35920kg ha⁻¹) and had no significant difference with CFI practice. In fact significantly highest bulb yield was obtained from the control irrigation (100%ETc). However, from deficit irrigation levels, the 85%ETc application gave the highest total bulb yield and significantly different to all other deficit irrigation levels. Significantly lowest total bulb yield was obtained from the FFI practice and from deficit irrigation application of 55%ETc application.

The increment in onion total bulb yield might be attributed to large size of onion bulb due to application of maximum amount irrigation water. This is because that it encourages cell elongation, above ground vegetative growth and imparts dark green color of leaves, which is important for more assimilate production and partition that favors onion bulb growth. Crops irrigated under AFI physiologically respond the water stress by producing signals to control the leaf water potential, so that transpiration loss can be significantly reduced (Kang *et al.*, 2000; Zhang *et al.*, 2000).

The increased total bulb yield by applying full 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 55% ETc to 100% ETc, the total bulb yield increased.

Table 9. Effect of furrow irrigation methods and irrigation levels on Unmarketable Bulb Yield (UMBY) and Total Bulb Yield (TBY).

Furrow Irrigation method	UMBY(kg ha ⁻¹)	TBY(kg ha ⁻¹)
CFI	1335.4 ^b	35830 ^a
AFI	1679.9 ^b	35920 ^a
FFI	2554.3 ^a	30253 ^b
LSD(P=0.05)	481.6	4842.4
Irrigation level (%)		
100	1449.87 ^d	38947 ^a
85	1705.57 ^c	35175 ^b
70	1951.93 ^b	32747 ^c
55	2318.74 ^a	29135 ^d
LSD(P=0.05)	182.12	2130.9
CV1 (%) Main plot	22.89	12.56
CV2 (%) Sub plot	9.9	6.33

Means with the same superscript in a column are not significantly different at $P \geq 0.05$

Irrigation Level and Furrow Irrigation Methods on IWUE and CWUE

Irrigation water use efficiency

Irrigation water use efficiency (IWUE) is considered as relative bulb yield per unit of irrigation water used. The analysis of variance has shown that the interaction of furrow irrigation methods and deficit irrigation levels significantly ($P < 0.05$) affected IWUE and whilst a highly significant ($P < 0.01$) effect was observed from furrow irrigation methods and irrigation levels on IWUE (Table 10). The highest IWUE of (14.18 kg m⁻³) was recorded from AFI practice with the 55%ETc deficit irrigation application and significantly different from all other

treatments. The AFI practice gave best IWUE compared to other furrow irrigation methods. The lowest irrigation water use efficiency of (5.58 kg m⁻³) was obtained from CFI practice with 85%ETc deficit irrigation application and had no significant difference with control irrigation (100%ETc) application under CFI practices.

Generally, IWUE was influenced by crop yield potential, irrigation method, estimation and measurement of ET, and crop environment. The results related to the efficiencies showed that when irrigation water is limited, 70% and 55% 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 10. Effect of furrow irrigation methods and deficit irrigation levels on irrigation water use efficiency of onion

Treatments	irrigation water use efficiency (kg m ⁻³)				
	Deficit irrigation level (%)				
Furrow Irrigation method	100	85	70	55	Mean
CFI	5.81 ^g	5.58 ^g	6.47 ^g	7.09 ^f	6.24 ^c
AFI	10.68 ^d	11.12 ^{cd}	12.62 ^b	14.18 ^a	12.15 ^a
FFI	8.65 ^e	9.14 ^e	10.75 ^d	11.89 ^{bc}	10.11 ^b
Mean	8.40 ^c	8.61 ^c	9.95 ^b	11.10 ^a	
LSD (P=0.05)	0.87				
CV1 (%) Main plot	9.80				
CV2 (%) Sub plot	5.31				

Crop water use efficiency

The crop water use efficiency (CWUE) in the study measures the effectiveness of the irrigation levels and furrow irrigation methods in converting the total water applied to onion bulb yield. The analysis of variance has shown that the interaction of furrow irrigation methods and deficit irrigation levels significantly ($P < 0.05$) affected CWUE and whilst a highly significant ($P < 0.01$) effect was observed under furrow irrigation methods and irrigation levels on CWUE (Table 11).

As depicted in Table 11, the highest CWUE of (23.62 kg m^{-3}) was achieved with 55%ETc deficit irrigation application with AFI practice and this was significantly different from the CWUE in all treatment combinations. All deficit levels with AFI and CFI systems attained,

respectively, the highest and lowest CWUE. The results of these research findings are in agreement with Hamed *et al.* (2011), who reported that the reason of having more CWUE and lower reduction in the yield for AFI could be related to better distribution of the roots in both sides of the ridge. It could increase water and fertilizer uptakes by plants. The results showed that alternative drying of the root zone had better performance than the fixed drying of the root zone. The results showed that AFI increased CWUE for onion relative to CFI.

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), Kebede (2003), Kirnak *et al.* (2005) and Sarkar *et al.* (2008) reported that crop water use efficiency was higher at lower levels of available soil moisture.

Table 11. Effect of furrow irrigation methods and deficit irrigation levels on crop water use efficiency of onion

Treatments	Crop water use efficiency(kgm^{-3})				
	Deficit irrigation level (%)				
Furrow Irrigation method	100	85	70	55	Mean
CFI	9.68 ^g	9.30 ^g	10.78 ^{ig}	11.81 ^t	10.39 ^c
AFI	17.80 ^d	18.53 ^{cd}	21.04 ^b	23.62 ^a	20.25 ^a
FFI	14.42 ^e	15.24 ^e	17.91 ^d	19.82 ^{bc}	16.85 ^b
Mean	14.00 ^c	14.14 ^c	16.60 ^b	18.40 ^a	
LSD (P=0.05)	1.44				
CV1 (%) Main plot	9.80				
CV2 (%) Sub plot	5.31				

Onion bulb yield response to deficit irrigation

The response of onion yield to water supply as quantified through yield response factor (Ky) is given in (Table 12). The Ky ranged from 0.15 to 1.16, where both the lowest and the highest being from 85%ETc application under AFI and CFI, respectively. Generally, it can be observed that Ky decreasing with decreasing onion bulb yield and increasing in irrigation water deficit. The crop yield response factor (Ky) captures the essence of the complex linkages between production and water use by a crop. Crop yield response factor indicates a linear relationship between the decrease in relative water consumption and the decrease in relative yield. The ky

values greater than unity indicates the relative yield decrease is higher than the water deficit as stated by Smith and Kivumb (2002). According to Kirda *et al.* (1999), the ky value for field crops goes from 0.2 to 1.15 which agrees with the reported result.

Doorenbos and Kassam (1979) reported the effect of water deficit on crop yield, deficit occurring for the total growing period, the decrease in yield is proportionally less with the increase in water deficit. Under conditions of limited water distributed equally over the total growing season, involving crops with different Ky values, the crop with the higher Ky value will suffer a greater yield loss than the crop with a lower Ky value.

Table 12. The yield response factor values for irrigation treatments

Irrigation method	Deficit level (%)	Yield (kg ha ⁻¹)	ET _a (mm)	$\frac{ET_a}{ET_m}$	$\frac{Y_a}{Y_m}$	$1 - \frac{ET_a}{ET_m}$	$1 - \frac{Y_a}{Y_m}$	K _y
CFI	100	43251	436.14	1.00	1.00	0.00	0.00	-
	85	35756	370.72	0.85	0.83	0.15	0.17	1.16
	70	34296	305.30	0.7	0.79	0.30	0.21	0.69
	55	31523	239.88	0.55	0.73	0.45	0.27	0.60
AFI	100	40102	218.07	1.00	1.00	0.00	0.00	-
	85	36179	185.36	0.85	0.90	0.15	0.10	0.65
	70	33875	152.65	0.7	0.84	0.30	0.16	0.52
	55	31522	119.94	0.55	0.79	0.45	0.21	0.48
FFI	100	33488	218.07	1.00	1.00	0.00	0.00	-
	85	30589	185.36	0.85	0.91	0.15	0.09	0.58
	70	28069	152.65	0.7	0.84	0.30	0.16	0.54
	55	26866	119.94	0.55	0.80	0.45	0.20	0.44

NoteE_a: Actual EvapotranspirationE_{Tm}: Maximum EvapotranspirationY_a: Actual YieldY_m: Maximum YieldK_y: Yield Response Factor**CONCLUSION**

Based on the result arisen from the research when less irrigation water was applied, the conventional furrow irrigation techniques had the smallest bulb yield reduction. The maximum total bulb yield of (35920kg ha⁻¹) was recorded at Alternative Furrow Irrigation Method. Although 55%ET_c application under alternate furrow irrigation gave the highest Crop Water Use Efficiency and Irrigation Water Use Efficiency, yield penalty was significant compared to all other deficit irrigation. However, deficit irrigation of 70%ET_c under alternate furrow irrigation gave above the mean value of crop water use efficiency and irrigation use efficiency. The most important result arisen from this investigation was water under deficit irrigation with the combination of Alternative Furrow Irrigation (AFI) are a promising practice that can be adopted as alternative for irrigating intensive field crop like Onion; but more studies have to be conducted under similar field conditions.

ACKNOWLEDGMENTS

I would like to thank Ethiopian Institute of Agricultural Research, for providing funds for the experiment and technical support for masters of Thesis. I also very grateful to Debre Zeit Agricultural research center for all staff of Natural Resources Management Research core process and my friends for giving us support in field

management, suggestion and technical guidance during the course of the study experiment. Additionally Hawassa University Institute of Technology Water Resource and Irrigation Engineering Department Lecturers and Staffs giving support in my master's course I would like to thank.

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