Ethiop. J. Agric. Sci. 30(3) 155-176 (2020)

Effect of Deficit Irrigation Levels at Different Growth Stages on Yield and Water Productivity of Onion (Allium *cepa L.)* at Raya Azebo Woreda, Northern Ethiopia

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Abstract

The scarcity of water is the most severe constraint for the development of agriculture in arid and semi-arid areas. Under such conditions, the need to use the available water economically and efficiently is unquestionable. The important strategy for increasing water productivity and improving water use *efficiency in the area of water scarcity was deficit irrigation. A field experiment was conducted at Mehoni Agricultural Research Center during offseason aimed at investigating the effect of deficit irrigation levels on water productivity of onion (Bombey Red variety) and the most sensitive growth stages of onion crop. The experiment was carried out in split plot design with sixteen treatment combinations and three replications. The treatments include four growth stages (initial, development, bulb formation and maturation) as main plot, and three deficit irrigation levels (80%, 60% and 40% of evapotranspiration of crop (ETc)), and one control irrigation of 100% ETc as subplot. Crop water requirement was estimated using actual daily climatic data. The result showed that deficit irrigation levels, time of deficit irrigation and their interaction had significant ($p< 0.01$) effect on bulb yield and yield components. The treatment received 100% ETc at the time of development stage gave the highest total bulb yield of 30.67 t/ha with no significant difference from 60% deficit treatments during initial and maturation stages. The result showed that initial and maturation stages were the right time to practicing deficit irrigation without significant yield reduction. Water productivity was the highest with 60% deficit irrigation at maturation stage (8.96 kg/m^3), and 0.17ha additional area to be irrigated by saved water. The yield response factor (Ky) was higher (1.98) when 40% deficit occurred at development stage. The result revealed that onion bulb yield was most sensitive to water deficit that occurred at development and bulb formation stages. While maximum yield was obtained when the whole crop water requirement was applied, implementing deficit irrigation at appropriate stage could increase the irrigated area as a result of high water productivity.*

Introduction

Agriculture is one of the main consumers of fresh\-water resources in the world. It is consuming more than-two-thirds of total withdrawals (Gan *et al*. 2013). In many parts of the world, irrigation water has been over-exploited and over-used, and freshwater shortage is becoming critical in the arid and semiarid areas of the world. About 70% of total consumptive water use consumed in irrigation (Huffaker and Hamilton, 2007).

The sustainable use of water in agriculture has become a major challenge in the world. The adoption of strategies for saving irrigation water and maintaining acceptable yields may contribute to the preservation of this ever more restricted resource (Topcu *et al*., 2007). In areas of water shortage and long summer droughts, maximizing water productivity may be more beneficial to the farmer than maximizing crop yield. A recent innovative approach to save agricultural water is conventional deficit irrigation (DI). Deficit irrigation is defined as a practice whereby a crop is irrigated with an amount of water below the full requirement for optimal plant growth. This is to reduce the amount of water used for irrigating crops **(**Chai *et al*., 2016). It is a water-saving strategy under which crops are exposed to a certain level of water stress, either during a particular developmental stage or throughout the whole growing season. The expectation is that any yield reduction will be insignificant compared with the benefits that are gained from the conservation of water.

Smallholder irrigation schemes in Ethiopia are generally characterized by poor on-farm water management practices and hence poor performances (Eguavoen *et al*., 2012). The poor on-farm water management emanates from both excesses and insufficient allocation of resources that enables optimum and timely water supply. Farmers' lack sound knowledge on on-farm water management. Particularly on how much to irrigate and when to irrigate. Because of they tend to over-irrigate as long as water is available, results in water shortages and conflicts in other parts of the schemes. Over irrigation is also a source for raising the water table increasing the salinity of the soils (Amare *et al*., 2016).

In Ethiopia, the area cultivated under irrigation, growing onion crop is increasing from time to time, mainly due to its high profitability per unit area and ease of production, and the increases in small-scale irrigation areas (Weldemariam *et al.*, 2015). However, the expansion of irrigable land is highly constrained by shortage of irrigation water in potential area mainly arid and semi-arid area. Specially Raya Valley area has limited amounts of rainfall and cannot cultivate without irrigation. In addition, the area is a semiarid with limited water resources and increasing demand for water combined with high evapotranspiration rates; limit the productivity of the crop as well as it restricts the expansion of the production area under irrigation. Hence, alternatives need to be explored for effective and efficient use of the existing water resources. To alleviate these constraints, practicing deficit irrigation could increase the irrigation area with a limited yield reduction, which is likely to be more than compensated by a substantial increase in economic returns.

According to the data of Raya Azebo Woreda Agricultural Office, the district area was a potential irrigable area of 6,330 ha. Due to water shortage, much of the potential farmland is not cultivated during the dry season and only 2,311 ha was cultivated using irrigation, despite having surplus labor and fertile land suitable for growing a variety of vegetables in the area. From total cultivated area using irrigation (2,311 ha), 220 ha was covered with onion (RAWAO, 2018). Therefore, the competition between farmers for the limited irrigation water is frequent in the area. To satisfy many farmers in the area, water productivity should be increased. Deficit irrigation is known to increase water productivity with insignificant or minimum yield reduction. Therefore, the objective of the study was to investigate the effect of deficit irrigation levels at different growth stages on yield and water productivity of the onion and to identify the most sensitive growth stages of onion to deficit irrigation levels.

Materials and Methods

Description of Study Area

The study was conducted at Mehoni Agricultural Research Center (MehARC). Mehoni is located in the Raya Valley, Northern Ethiopia. The study was undertaken from November 2017 April 2018. Geographically, the study site is located at 12° 51'50" North and 39° 68'08" East at an altitude of 1578 m.a.s.l. The site receives annual rainfall ranging 450-600 mm with an average minimum and maximum temperatures of 18 and 29°C, respectively (Moges, 2015). The area is characterized by low annual rainfall, which is not adequate for the whole crop growing season.

Treatments and Experimental Design

The experimental treatments were four crops growing stages (initial, development, bulb formation and maturation stages) and three deficit irrigation levels (80% ETc, 60 % ETc and 40% ETc levels) and control irrigation of 100% ETc. The design of the experiment was split plot design with three replications. The growing stages were arranged as a main plot and the deficit irrigation levels as sub-plot.

Experimental Material

Bombay Red onion variety was used as experimental material. It is well adapted in the altitudes ranging between 700-2000 m.a.s.l. and widely cultivated in the study area and also has light red skin color, reddish white bulb flesh color, light pungent smell, flat globe shaped bulb with bulb size of 85-100 cm and can mature in 100 - 120 days. The variety was released from Melkasa Agricultural Research Center in 1980. Its yield potential is 30 t/ha. Bombay Red is susceptible to purple blotch disease; however, it is successfully produced by small farmers and commercial growers in most regions of the country (EARO, 2004).

Crop Establishment and Management Practices

The seeds were sown in a well-prepared seedbed of 1 m x 5 m at a seed rate of 100 grams/bed in November 17, 2017. The seedling management practice was made as per the MeARC recommendation until seedlings reached the stage of transplanting. The seedlings were then transplanted on 2nd January 2018 on well-prepared experimental plots on both sides of a ridge at row and plant spacing of 20 cm and 10 cm, respectively. Onion seedling transplanted to the experimental field received one common irrigation (12.31mm) to ensure better plant establishment.

Water Sampling and Analysis

Water samples were collected using sampling bottle and proper sampling kit which was used for the irrigation application. The collected irrigation water samples were analyzed for pH, electrical conductivity of water (ECw), basic cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}), and anions (HCO_3^{-} and CO_3^{2-}) contents in the laboratory. Furthermore, sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) were estimated from the measured parameters. The RSC and SAR were determined from the concentrations of HCO_3^-, CO_3^{2-}, Na^+, Ca^{2+} and Mg^{2+} using equations 1 and 2:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad \text{Equation 1}$$

$$RSC = [(HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})]$$

Equation 2

Where, the concentration of ions was expressed in meq/L (USSLS, 1954).

Soil Sampling and Analysis

Before transplanting of the crop, soil samples were taken randomly from the experimental field and produce three composite samples. The composite soil samples were, air-dried, ground, mixed and passed through a 2mm sieve and analyzed for different physical and chemical characteristics. The samples were taken from four depths (0-15cm, 15-30cm, 30-45 cm and 45-60 cm). The composite soil samples were analyzed in order to determine its physical and chemical properties. The soil properties analyzed include: soil texture, organic matter content, electrical conductivity and bulk density, water retention at field capacity (FC) and permanent wilting point (PWP) and pH.

Irrigation Scheduling and Management

Daily reference evapotranspiration (ETo) was calculated by applying the modified FAO Penman-Monteith equation based on the daily record of climatic data (Allen *et al*., 1998) using FAO CROPWAT software version 8.0. The input data for the CROPWAT software includes. Altitude, daily values of maximum and minimum air temperatures, relative humidity, sunshine duration and wind speed.

Crop and irrigation water requirement

The amount of water needed (CWR) to balance the amount of water lost through evapotranspiration (ETc), is calculated from reference evapotranspiration (ETo) and onion crop coefficient (Kc) as per Allen *et al*. (1998). The crop coefficient values were adopted from Dirirsa *et al*. (2015) as 0.61 for the initial stage, $0.61<Kc<1.02$ for the crop development stage, 1.02 for the mid-season stage and $0.8<Kc<1.02$ for the late season stage. The crop water requirement (ETc) was then calculated using CROPWAT software over the growing season from ETo and the crop coefficients (Kc) indicated above.

$$\mathbf{ETc = ETo * Kc} \qquad \textbf{Equation 3}$$

Where ETc = crop evapotranspiration (mm/day), Kc = crop coefficient, and ETo = reference crop evapotranspiration (mm/day).

Total available water was computed from the moisture content at field capacity and permanent wilting point using the following equation as indicated by Allen *et al*., (1998).

$$TAW = (\theta FC - \theta PWP) * \frac{\rho b}{\rho w} * Dz$$

Equation 4

Where TAW = total available water in the root zone (mm), θ_{FC} and θPWP are moisture content at field capacity and permanent wilting point in % (weight basis), respectively, ρb is the bulk density of the soil, ρw is density of water in g/cm^3, and Dz is the maximum effective root zone depth of onion at times of each irrigation water application (mm).

Readily available water was computed using the following equation:

$$RAW = \rho * TAW \qquad \text{Equation 5}$$

Where RAW = readily available water in mm, ρ = allowable (permissible) soil moisture depletion and taken as 0.25 for onion based on FAO's recommendation for onion (FAO, 1996) and TAW = total available water in mm.

The net irrigation requirement was calculated using the CROPWAT software based on Allen *et al*., (1998) as follows:

$$IRn = ETc - Pe \qquad \textit{Equation 6}$$

Where IRn =Net irrigation requirement (mm), ETc in mm and Pe = effective rainfall (mm) which is part of the rainfall that enters into the soil and makes available for crop production. The effective rainfall (Pe) was estimated using the methods (Allen *et al*., 1998).

$$Pe = 0.6 * P - 10 \; for \; month \; P \leq 70 \; mm$$

Equation 7

$$Pe = 0.8 * P - 24 \; for \; month \; P > 70 \; mm$$

Equation 8

Where Pe (mm) = effective rainfall and P (mm) = total rainfall.

The gross irrigation requirements account for losses of water incurred during conveyance and application in the field. The gross irrigation requirement was computed by adopting a field application efficiency of 60 % because the experiment was conducted at the research center site. As stated by (Bakker *et al.*, 1999), furrow irrigation application efficiencies normally vary between 45 and 60%. This is expressed in terms of efficiencies when calculating project gross irrigation requirements from net irrigation requirements, as shown below:

$$IRg = IRn/Ea \qquad \textit{Equation 9}$$

Where IRg = gross irrigation requirement (mm), IRn = net irrigation and Ea = irrigation efficiency.

Irrigation Water productivity (IWP)

The water use productivity was calculated by a ratio of total bulb yield (kg/ha) to the total ETc (m^3/ha) through the growing season and it was calculated using the following equation (Zwart and Bastiaanssen, 2004).

$$IWP = (Y/ETc) \qquad \textit{Equation 10}$$

Where IWP = irrigation water productivity (kg/m^3), Y= crop yield (kg/ha) and ETc = the seasonal crop water consumption by evapotranspiration (m^3/ha).

Water saving with deficit irrigation as compared with full irrigation was calculated according to Jemal and Mukerem (2017) as:

$$WS\ (\%) = \frac{(TWUFI - TWUDI)}{TWUFI} * 100 \qquad \textit{Equation 11}$$

Where WS is water saved due to DI, TWUFI is total water using full irrigation (mm) and TWUDI is total water using deficit irrigation (mm).

Percent of yield increase/decrease in deficit irrigation (%) as compared to full irrigation was calculated using the following equation (Jemal and Mukerem, 2017).

$$YI/D\ (\%) = \frac{(YFI - YDI)}{YFI} * 100 \qquad \textit{Equation 12}$$

Where YI/D is percent of yield increase or decrease due to deficit irrigation, YFI is yield in (kg/ha) obtained from full irrigation and YI/D is yield in (kg/ha) obtained from deficit irrigation.

Yield response factor (Ky)

The relationship between the evapotranspiration deficit [1 – (ETa/ETc)] and yield depression [1 – (Ya/Ym)] is always linear. The slope of this linear relationship is called yield response factor or crop response factor (Ky). It is defined as the decrease in yield per unit decrease in ET (Singh *et al*., 2010). This relationship is expressed by the equation:

$$[1 - (Ya/Ym)] = Ky[1 - \left(\frac{ETa}{ETm}\right)] \qquad \textit{Equation 13}$$

Where Ym (kg/ha) and Ya (kg/ha) are the maximum (from a fully irrigated treatment) and actual yields, respectively. The ETm (m^3/ha) and ETa (m^3/ha) are the maximum/fully irrigated treatment and actual evapotranspiration, respectively, while Ky is the yield response factor.

Statistical Analysis

The collected data were analyzed using SAS 9.0 statistical software appropriate for the split plot design. When treatment effect was found significant for a parameter the mean separation was carried out using Duncan's Multiple Range Test (DMRT) at 5% probability level. The experiment was two factors (growth stages and DI level) with split plot design during the analysis. Pearson correlation analysis was also used to determine the association of onion bulb yield and yield components.

Results and Discussion

Chemical Composition of Irrigation Water

The result of the laboratory analysis indicated that the pH value of the irrigation water was 8.58 (Table 1). As the pH of irrigation water increases above 8.2, the potential for sodium problem increases and destroys the structure of the soil (Bryan *et al*., 2007). According to Bryan *et al*. (2007), classification, the irrigation water quality of the study area was classified as severe in degree of restriction to use (potential irrigation problem) with regard to its pH value. Similarly, electrical conductivity of irrigation water (ECw) was 0.36 dS/m. Accordingly, based on USSLS (1954), the irrigation water quality of the study area was classified as a class two (C2) which is a medium salinity hazard. Among the cations, Na^+ was dominant and HCO_3^- was dominant among the anions. The sodium adsorption ration (SAR) of the irrigation water in the study area was suitable (low) for irrigation purpose (USSLS, 1954). In the SAR, the Ca^{2+} and Mg^{2+} ions are important since they tend to counter the effects of Na^+ hazard (Dhembare, 2012). According to USSLS (1954), the irrigation water quality of the study area was above the standard (2.5) with regards to residual sodium carbonate (RSC).

Table 1 Chemical compositions of irrigation water in the study area

Sample Code	pH	ECw (dS/m)	Cations (meq/L)				SAR
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	4.93
Fgw	8.58	0.36	3.58	3.50	9.28	0.48	
			Dissolved Anions (meq/L)				RSC(meq/L)
			CO_3^{2-}	HCO_3^{-}			3.20
			Trace	10.28			

Fgw= Fachagama ground water; ECw = Electrical conductivity of irrigation water; SAR= Sodium adsorption ratio; RSC= Residual sodium carbonate.

Soil Physicochemical Properties of the Experimental Site

Selected physiochemical properties of the soil at the experimental site are presented in Table 2. Based on the USDA soil textural classification, the dominant textural class of the experimental site was classified as clay loam. The top surface soil layer had to some extent lower bulk density than the subsurface and this might be due to high organic matter contents in the top soil surface. Average bulk density was 1.15 g/cm^3 which is in the desirable range for optimum movement of air and water in the soil for crop root growth (Hunt and Gilkes, 1992).

Moisture retention capacity at field capacity of the soil at the experimental site varies between 36 and 38.55% for the soil depths considered. Moisture content at the permanent wilting point also showed variation with depth and the average values ranged between 21 and 22.95% for the soil depths considered. The value of total available water (TAW) obtained was 174.2mm/m. Soils with high water holding capacity are better able to provide moisture to the shallow rooting system, but must also drain well to be suitable (Birhanu, 2016).

The pH of the soil was found to be at the optimum value (7.6), which is within the ideal preferable limit (6.0 - 8.0) for onion production (Brewster, 1994). The electrical conductivity of the soil (ECe) obtained was 0.0975 dS/m and that was a value for salt free soil (Ethiosis, 2014). The weighted average organic matter content of the soil was about 1.44%. As reported in Tekalign (1991), the organic matter content of the soil (0.86-2.59 %) is low.

Depth of Irrigation Water Application

The net depth of irrigation water applied to the different treatments during the experimental period is shown in Table 3. The total net irrigation depths applied varied from the lowest 311.06 mm (T12) to the highest 385.69 mm (T1, T5, T9 and T13) excluding common irrigation given during establishment period (12.31 mm) and including two-time effective rainfall of (7.5+7.8=15.3) mm that occurred during the field trial. The maximum total net depth of water was applied to the control treatments, which received 100% ETc at all growth stages, while the lowest was applied to the treatment which received 40% ETc at mid-season stage due to kc value reach’s maximum at this stage.

Table 2 Physico-chemical properties of soils of the experimental site

Soil depth (cm)	Soil property											
	Particle size distribution (%)			Textural class	Bulk density (g/cm^3)	FC (%)	PWP (%)	SP (%)	TAW (mm/m)	pH	OM (%)	ECe (dS/m)
	Sand	Silt	Clay									
0-15	37	27	36	Clay loam	1.09	36	21	39.5	163.5	7.5	1.57	0.08
15-30	38	26	36	Clay loam	1.1	36.04	21.07	39.95	164.67	7.7	1.48	0.09
30-45	39	27	34	Clay loam	1.13	36.05	21.1	41.55	168.94	7.6	1.36	0.1
45-60	35	23	42	Clay	1.28	38.55	22.95	48.57	199.68	7.6	1.35	0.12
Mean	37.25	25.75	37	Clay loam	1.15	36.66	21.53	42.39	174.2	7.6	1.44	0.097

FC= field capacity; SP= saturation point; PWP= permanent wilting point; TAW= total available water; OM= organic matter; ECe electrical conductivity of soil

Table 3 Net irrigation depth applied at each growth stage (mm)

Treatments			Growth stages				Total
Code	Growth stages	Irrigation levels	IS	DS	BF	MS	
T1	Initial	100% of ETc	35.76	115.11	131.89	102.93	385.69
T2		80% of ETc	28.61	115.11	131.89	102.93	378.54
T3		60% of ETc	21.46	115.11	131.89	102.93	371.39
T4		40% of ETc	14.30	115.11	131.89	102.93	364.23
T5	Development	100% of ETc	35.76	115.11	131.89	102.93	385.69
T6		80% of ETc	35.76	92.09	131.89	102.93	362.67
T7		60% of ETc	35.76	69.07	131.89	102.93	339.65
T8		40% of ETc	35.76	46.04	131.89	102.93	316.62
T9	Bulb formation	100% of ETc	35.76	115.11	131.89	102.93	385.69
T10		80% of ETc	35.76	115.11	107.01	102.93	360.81
T11		60% of ETc	35.76	115.11	82.13	102.93	335.93
T12		40% of ETc	35.76	115.11	57.26	102.93	311.06
T13	Maturation	100% of ETc	35.76	115.11	131.89	102.93	385.69
T14		80% of ETc	35.76	115.11	131.89	83.90	366.66
T15		60% of ETc	35.76	115.11	131.89	64.88	347.64
T16		40% of ETc	35.76	115.11	131.89	45.85	328.61

Growth stage: IS =initial stage, DS =development stage, BF = bulb formation stage and MS = maturation stage

The irrigation water depth applied to the other deficit treatments were in accordance to their percentage proportion. The full ETc result was in agreement with Mengistu *et al*. (2009) report on onion which was 390 mm estimated using lysimeters in the Central Rift Valley of Ethiopia.

Effects of Irrigation Levels on Growth Parameters

Plant height

Plant height has shown non-significant difference due to the interaction of onion growth stage and irrigation levels. However, plant height was significantly affected at $P \leq 0.01$ due to time of irrigation level. The DI at maturation stage resulted in 60.92 cm height and this was significantly different with DI during development and bulb formation stages, nevertheless, there was non-significant difference with DI at the initial stage (58.33 cm tall). This is recognized for the ability of onion plant to recover from the effects of water deficit during the initial stage if cell multiplication and growth are not affected during the subsequent development stage as observed by others (Zheng *et al*., 2013).

The statistical analysis result indicated that plant height was not significantly ($p > 0.05$) affected by the deficit irrigation levels. The plant height ranged from 56.25 and 58.50 cm. The lowest and highest plant heights were observed from treatments receiving 40% of ETc and 80% of ETc, respectively. However, the control treatment gave below the treatment receiving 80% ETc (Table 4).

Days to maturity

Days to maturity were significantly ($P\leq 0.01$) affected by time of the irrigation level at different growth stages. Longer days to maturity were recorded in plants that received DI at maturation (101.34 days) and initial stages (100.5 days). Significantly lower days to maturity (97.58 days) was recorded from plants received DI at development stage.

The irrigation levels have shown a highly significantly ($P \leq 0.01$) affects days to maturity. Significantly longer days to maturity (101.42 days) was recorded from plants receiving100% of ETc irrigation level, however, the shorter days to maturity (97.67 days) was recorded from plant receiving 40 % of ETc irrigation level (Table 4).

This result is in agreement with that of Brewster (1994) who reported that treatments that lacked supplemental irrigation water enhanced bulb maturity of the onion. This could be due to the fact that plants under stress are inclined to complete their life cycle in shorter time, which enables them escape from the unfavorable conditions by ending lifecycle few days earlier than those under normal or high soil moisture conditions, thereby ensuring perpetuation of the species (Al-Suhaibani, 2009).

Table 4. Effects of irrigation levels and growth stages on plant height, number of leaves per plant and days to maturity of onion

Growth stages	Plant height (cm)	Days to maturation	Irrigation levels	Plant height (cm)	Days to maturation
Initial	58.33[ab]	100.50[a]	100% ETc	57.92	101.42[a]
Development	54.42[c]	97.58[b]	80% ETc	58.50	100.33[a]
Bulb formation	56.17[bc]	98.58[b]	60% ETc	57.17	98.58[b]
Maturation	60.92[a]	101.34[a]	40% ETc	56.25	97.67[b]
DMRT 5%	**	**		NS	**
CV (%)	13.66	1.5		3.65	1.49

Means with the same letter (s) in a column for a factor are not significantly difference at P ≤ 0.05; NS = non-significant (P>0.05); CV =coefficient of variation.

Effects of Deficit Irrigation on Yield and Yield Parameters

Bulb diameter and bulb length

Bulb diameter was significantly ($P \leq 0.01$) affected by time of the deficit irrigation practices. Highest bulb diameter (6.50 cm) was recorded from plants receiving deficit irrigation at the initial stage. The least bulb diameter (4.87 cm) was recorded from plants receiving deficit irrigation at the development stage was not significantly different with that of the bulb diameter at the bulb formation stages (4.99 cm) (table 5). In general, bulb diameter was decreased with the irrigation water deficit at the development and bulb formation growth stages of onion. The result was supported by Zheng *et al*. (2013) who indicated that water stress at the development and bulb formation stages of growth of onion significantly affected the size of onion bulbs.

Highly significant differences ($P \leq 0.01$) on bulb diameter were also observed among different irrigation levels. The highest bulb diameter was recorded from treatment, receiving 100% of the irrigation level (6.08 cm), followed by 80%, 40% and 60% of irrigation level with 5.85, 4.97 and 4.91 cm respectively. Water deficit up to 20% gave the bulb diameter above the mean value of 5.46 cm (Table 5). This result is in agreement with that of a study conducted by (Enchalew *et al.*, 2016), high amount of soil moisture application leads to a large photosynthesis area (plant height and large number of leaves), resulted in large bulb diameter. This implies application of 40% ETc irrigation level at either initial or maturity stages gave as well as bulb diameter. Conversely, 60% ETc irrigation level applied at the development and bulb formation stages resulted in significantly smaller bulb diameter than the control and other treatments.

Similarly, bulb length was significantly different in the interaction of irrigation levels and growth stages. Bulb length in T1, T2, T5, T9, T10, T14 and T16 had no significant difference with each other though the longest was observed from T5 (6.57 cm). The lowest bulb length of 4.37 cm was recorded from T8, T11, and T12 and those treatments were inferior to all other treatments except T7. This indicates that application of 60% ETc deficit at either initial or maturity stages gave appropriate bulb length. However, the 40 and 40% ETc irrigation level applied at development and bulb formation stage resulted in significantly smaller bulb diameter than the control and other treatments. The result also showed the detrimental effect of deficit irrigation application at development and bulb formation stages in reducing the bulb size of onion mainly the 60% and 40% ETc irrigation level.

In agreement with results analyzed above, the different size of bulbs was more or less comparable for treatments when water deficit at the initial and maturation periods does not affect yields; on the other hand, water deficit treatments during the development and bulb formation stages were resulted in significant reduction in bulb size of onion (Table 6). Similar results were reported by Pelter *et al.* (2004) and Martı´n de Santa Olalla *et al.* (2004). Similarly, Dirirsa *et al.* (2017) concluded that deficit irrigation at 50% ETc had a significant effect on bulb size, while the size from 75% ETc was not much different from 100% ETc treatment. David *et al.* (2016) concluded that bulb size varied proportionally with the quantity of irrigation water applied (the largest from the 100% ETc and smallest from 50% ETc).

Table 5 Effects of irrigation levels and growth stages on yield, yield parameters and water productivity of onion

Growth stages	BD (cm)	BL (cm)	ABW (g)	UMBY (t/ha)	MBY (t/ha)	TBY (t/ha)	WP (kg/m^3)
Initial stage	6.50^a	5.98^a	76.42^a	3.38^c	25.99^a	29.37^a	7.83^b
Development stage	4.87^c	5.22^b	59.71^b	5.24^a	20.89^b	26.13^b	7.42^c
Bulb formation stage	4.98^c	5.35^b	59.83^b	4.45^b	21.52^b	25.97^b	7.43^c
Maturation stage	5.47^b	5.90^a	80.25^a	3.11^c	26.55^a	29.66^a	8.33^a
DMRT 5%	**	**	**	**	**	**	**
CV (%)	9.53	8.17	24.51	9.26	8.15	6.88	7.30
Irrigation levels							
100% ETc	6.08^a	6.30^a	78.92^a	3.40^c	26.73^a	30.13^a	7.81
80% ETc	5.86^a	6.00^a	72.33^b	3.63^{bc}	25.18^b	28.81^b	7.84
60% ETc	4.91^b	5.05^b	62.38^c	4.28^{ab}	21.98^c	26.25^c	7.52
40% ETc	4.97^b	5.09^b	62.58^c	4.88^a	21.07^d	25.94^c	7.84
Mean	5.46	5.61	69.05	4.05	23.74	27.78	7.75
DMRT 5%	**	**	**	**	**	**	NS
CV (%)	7.02	6.91	6.89	22.96	3.75	4.01	4.19

BD=bulb diameter, BL=bulb length, ABW=average bulb weight, UMBY, MBY and TBY are unmarketable, marketable and total bulb yield, respectively; NS= non- significant; Means with the same letter(s) in columns are not significantly different at P ≤ 0.05; CV = coefficient of variation.

Marketable and Total Bulb Yield

The marketable bulb yield of onion was significantly ($P \leq 0.05$) affected by irrigation levels and time of application (Table 5). Similarly, the interaction effect and irrigation level was observed significant differences on the marketable bulb yield of onion (Table 6). Marketable bulb yield was significantly ($P \leq 0.01$) affected by irrigation level, producing higher marketable bulb yields of onion 26.73 t/ha with full irrigation (100% ETc) and followed by 80% and 60% of ETc irrigation level with the value of 25.18 t/ha and 21.98 t/ha, respectively whereas, the lower marketable bulb yield of 21.07 t/ha was recorded with 40% of irrigation level. 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 an increment in bulb length, bulb diameter and average bulb weight. According to Tsegaye *et al.* (2016) higher marketable bulbs of onion at higher irrigation levels might be due to the increase in the formation of growth measurements causing faster synthesis and transportation of photosynthates from source to sinks. The finding indicated that with 60% and below 60% of ETc irrigation level resulted in below mean value of marketable bulb yield. The result obtained agreed with the finding of Mubarak and Hamdan (2018) who concluded that significant linear increase in the total bulb yield was predicted with decreasing water deficit.

The statistical analysis indicated that marketable bulb yield was significantly ($p \leq 0.01$) different on the interaction of irrigation levels with time of deficit irrigation application. The highest marketable bulb yield was obtained from the control treatments and had highly significant difference from treatments received 40%, 60% and 80% of ETc at development stage and treatments received 40% and 60% of ETc at bulb formation stage. However, control treatments had no significant difference from all the treatments at the deficit level of the initial and maturity stages and 80% ETc irrigation level at bulb formation stage (Table 5 and 6). This reveals that 80% ETc irrigation application had no significant effect while practiced at different combinations of growth stages except with developmental stage. This result is supported by Pejic *et al.* (2011) who indicated the differences in bulb dry weight directly resulted in differences in yields for all treatments, which are related to the effects of irrigation amounts and timing of water stress on bulb size. The result obtained agrees with the finding of Ortola and Knox, (2014) who concluded that initial stage of onion crop is less water sensitive; however, if stressed during specific periods, this can lead to multiple centered bulbs. Similar research report indicated that water restrictions at development and bulb formation stages increased the weight percentage of small bulbs (Martin de Santa Olalla *et al.*, 2004). Total bulb yield is the sum of unmarketable and marketable bulb yields had highly significant difference between irrigation levels on total bulb yield at $P \leq 0.01$. The total bulb yield was highest in the control treatment (full irrigation) (30.13 t/ha) and this was highly significantly different from other treatments. The least total bulb yield (25.94 t/ha) was recorded from treatments receiving 40% ETc and statistically there was no significant difference from that of treatment receiving 60% ETc with value of 26.25 t/ha at $p \leq 0.05$ levels.

Table 6 Interaction effect of irrigation levels and growth stages on growth and yield parameters of onion

GS	Irrigation levels	Days to maturity (days)	Bulb diameter (cm)	Bulb length (cm)	Average bulb weight (g)	Marketable bulb yield (t/ha)	Total bulb yield (t/ha)	WP (kg/m^3)
I	100% of ETc	102.00^{a}	6.60^{ab}	6.5^{ab}	79.33^{ab}	26.60^{a}	29.87^{ab}	7.75^{cd}
	80% of ETc	101.00^{a}	6.80^{a}	6.30^{abc}	76.33^{ab}	26.70^{a}	29.77^{ab}	7.86^{bcd}
	60% of ETc	100.00^{a}	6.20^{abc}	5.50^{de}	73.67^{ab}	25.30^{ab}	28.77^{ab}	7.74^{cd}
	40% of ETc	99.00^{ab}	6.40^{ab}	5.60^{cde}	76.33^{ab}	25.36^{ab}	29.07^{ab}	7.98^{bc}
D	100% of ETc	100.67^{a}	6.03^{bcde}	6.57^{a}	82.33^{a}	26.53^{a}	30.67^{a}	7.95 ^{bc}
	80% of ETc	100.00^{a}	5.13^{f}	5.37^{e}	65.67^{abc}	22.93^{b}	27.40^{b}	7.55^{cde}
	60% of ETc	96.33^{b}	4.20^{g}	4.57^{f}	46.50^{d}	17.70^{c}	23.43^{c}	6.90^{e}
	40% of ETc	93.33^{c}	4.10^{g}	4.37^{f}	44.33^{d}	16.40^{c}	23.03^{c}	7.28^{cde}
B	100% of ETc	101.00^{a}	6.37^{ab}	6.47^{ab}	72.67^{ab}	26.53^{a}	29.87^{ab}	7.75^{cd}
	80% of ETc	100.33^{a}	6.10^{abcd}	6.20^{abcd}	64.67^{bc}	24.90^{ab}	28.67^{ab}	7.94^{bcd}
	60% of ETc	96.33^{b}	3.70^{g}	4.37^{f}	50.67^{cd}	18.33^{c}	23.10^{c}	6.87^{e}
	40% of ETc	96.67^{b}	3.77^{g}	4.37^{f}	51.33^{cd}	16.33^{c}	22.23^{c}	7.15^{de}
M	100% of ETc	102.00^{a}	5.33^{ef}	5.67^{cde}	81.33^{ab}	27.23^{a}	30.10^{ab}	7.80^{bcd}
	80% of ETc	100.00^{a}	5.40^{def}	6.13^{abcd}	82.67^{a}	26.20^{a}	29.40^{ab}	8.02^{bc}
	60% of ETc	101.67^{a}	5.53^{cdef}	5.77^{bcde}	78.67^{ab}	26.60^{a}	29.70^{ab}	8.54^{ab}
	40% of ETc	101.67^{a}	5.60^{cdef}	6.03^{abcde}	78.33^{ab}	26.17^{a}	29.43^{ab}	8.96^{a}
	DMRT 5%	**	**	**	**	**	**	**
	CV (%)	1.72	7.36	7.04	12.93	5.71	5.06	5.31

Means with the same letter (s) in columns are not significantly different at P ≤ 0.05; GS = growth stage; I = initial; D = development; B = bulb-formation; M = maturation; CV = coefficient of variation; NS= non-significant.

Total bulb yield of onion was also increased with increase in irrigation level up to 100% ETc. This result clearly indicates that an increased photosynthetic area in response to moisture availability had substantially contributed to enhance onion productivity that could be through the production of more assimilates. This result is aligned with Pejic *et al*., 2011 and Tsegaye *et al.*, 2016 working with onion. Total bulb yield also had highly significance ($P \leq 0.01$) effect on interaction of irrigation levels and time of application. The lowest yield of 22.23 t/ha was obtained from treatment which received 40% ETc at bulb formation stage. This was followed by 23.03, 23.10 and 23.43 t/ha obtained from treatment received 40% ETc at developmental stage, 60% ETc at bulb formation stage and 60% ETc at developmental stage, respectively. Results may be explained by the already formulated hypothesis on cells multiplication and expansion. Similar results were observed by others (Eg. Metwally, 2011).

Moreover, the result obtained from this study is supported by Zheng *et al.* (2013) who indicated that water stress at the development and bulb formation growth stages significantly reduced the onion bulb yield by 15 and 20 %, respectively, related to the non-stressed. Results clearly indicated that onion bulb production was highly sensitive to water stress during the development and bulb formation growth stages and not sensitive during the establishment and ripening stages. Onion can grow to maturity under different soil moisture deficit levels while higher yields are generally associated with high irrigation depth that avoid any water stress particularly at the time of bulb formation. Canopy formation and maturation are less water sensitive; however, during bulb formation the crop is very sensitive, especially during rapid growth, to both water stress and water excess, which causes rapid bulb expansion (Ortola and Knox, 2014).

Therefore, it can be concluded that the highest yield reduction was occurred when the stress was applied at the bulb formation and development stage. Thus, bulb formation and developmental stages was observed to be the most sensitive stages to water stress.

Water Productivity (WP) and Opportunity Cost

It is observed that water productivity was significantly ($P \leq 0.01$) affected due to the deficit irrigation application at different growth stages and the interaction of irrigation levels and time of application. However, WP was not significantly affected by irrigation levels (Table 5). Applying 40% of the full irrigation at maturation stage resulted in the highest water productivity (8.96 kg/m^3 while the lowest WP of 6.87 kg/m^3 was obtained from the treatment with receiving 60% ETc at bulb formation stage (Table 6).

The higher water productivity was obtained from treatments stressed at initial and maturation stages than development and bulb formation stages. The opportunity cost of deficit irrigation express the amount os saved water in terms extra land to be irrigated and its compensated yield. Hence; It has been observed that amount of water saved from T16 (14.8%) could compensate the decrease in crop yield in relation to unstressed plot which amounted to be 4.44 ton more bulb yield on additional 0.17 ha by using the 14.8% of saved water. Moreover, T15, T14 and T4 also could compensate for the yield reduction occurred and resulted in additional yield (2.85, 0.83 and 0.91 ton) than the control with the saved 9.87%, 4.93% and 5.56% of water, respectively (Table 7). Under deficit irrigation practices it has ebeen also observed that time of irrigation water application also significantly enhances the water productivity of onion. Onion bulbs as part of the root system and their growth was improved when plants had been under water stressed developing the root system and creating water reserves in the bulb as a surviving strategy which is supported by Zheng *et al.*, 2013).

Table 7. Relative yield reduction of onion and water saved (WS) due to irrigation levels and deficit irrigation at different stages

T	TBY (t/ha)	Igross (m^3/ha)	WS (m^3/ha)	WS (%)	YL (%)	YL (t/ha)	AA irrig. by WS (ha)	YG from AA (ton)	YG-YL (ton)
T1	29.87	6428.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	29.77	6309.00	119.20	1.85	0.33	0.10	0.02	0.56	0.46
T3	28.77	6189.80	238.40	3.71	3.68	1.10	0.04	1.11	0.01
T4	29.07	6070.60	357.60	5.56	2.68	0.80	0.06	1.71	0.91
T5	30.67	6428.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T6	27.40	6044.50	383.70	5.97	10.66	3.27	0.06	1.74	-1.53
T7	23.43	5660.80	767.40	11.94	23.61	7.24	0.14	3.18	-4.06
T8	23.03	5277.10	1151.10	17.91	24.91	7.64	0.22	5.02	-2.62
T9	29.87	6428.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T10	28.67	6013.50	414.70	6.45	4.02	1.20	0.07	1.98	0.78
T11	23.10	5598.80	829.40	12.90	22.66	6.77	0.15	3.42	-3.35
T12	22.23	5184.30	1243.90	19.35	25.58	7.64	0.24	5.33	-2.31
T13	30.10	6428.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T14	29.40	6111.00	317.20	4.93	2.33	0.70	0.05	1.53	0.83
T15	29.70	5794.00	634.20	9.87	1.33	0.40	0.11	3.25	2.85
T16	29.43	5476.80	951.40	14.80	2.23	0.67	0.17	5.11	4.44

T=treatments, TBY= total bulb yield, WS= saved water, AA irrig. =additional area irrigated due to saved water, YG= yield gain by additional irrigated area and YL =yield loss due to deficit irrigation

Yield Response Factor (Ky)

The observed yield response factors (Ky) for onion bulb production ranged between 0.13 and 1.98. The highest Ky was 1.98 at 40% deficit at development stage followed by 1.79, 1.76, 1.39 and 1.32 from T6, T11, T8 and T12, respectively. The lowest Ky was 0.13 at 40% deficit at maturation stage, followed by 0.15, 0.18, 0.47 and 0.48 obtained from T16, T2, T14 and T4, respectively. The Ky observed was comparatively higher at deficit irrigation water application during development and bulb formation stages. On the other hand, lower values were obtained from deficit irrigation water application during initial and maturation stages of onion (Figure 1).

The higher Ky values indicate that the crop would have a greater yield loss and inversely the lower the Ky values indicate the smaller the yield reduction because of the water stress. The result indicated that DI applied at development and bulb formation stages resulted in considerable yield loss occurred compared to the initial and maturation stages with the same deficit level application. Deficit irrigation applied at initial and maturation stages did not result in remarkable bulb yield reduction. This shows that deficit levels distributed at different growth stages could result in remarkably different yield reductions. Generally, the result indicates that the sensitivity of the crop to soil moisture deficit at specific growth stages. Therefore, deficit irrigation practices should be avoided for Ky values that are greater than one. This conclusion is in line with a statement given by Dirirsa *et al*. (2017). Similarly, the value of Ky greater than one, then the relative yield decrease is greater than the relative evapotranspiration deficit, and vice versa. Ky values of 1.10 and 1.50 were estimated by Kadayifci *et al*. (2005), respectively for onion entire growing season. According to Ortola and Knox (2014) research report, the values of Ky between 0.45 and 0.42 were estimated for the vegetative period, 0.80 and 1.02 for yield formation and 0.30 and 0.32 for the ripening stage. These show that the relative deficit in evapotranspiration at the time of development and bulb formation stages has a much greater effect on yield than the same level of relative deficit during 'other' crop development stages.

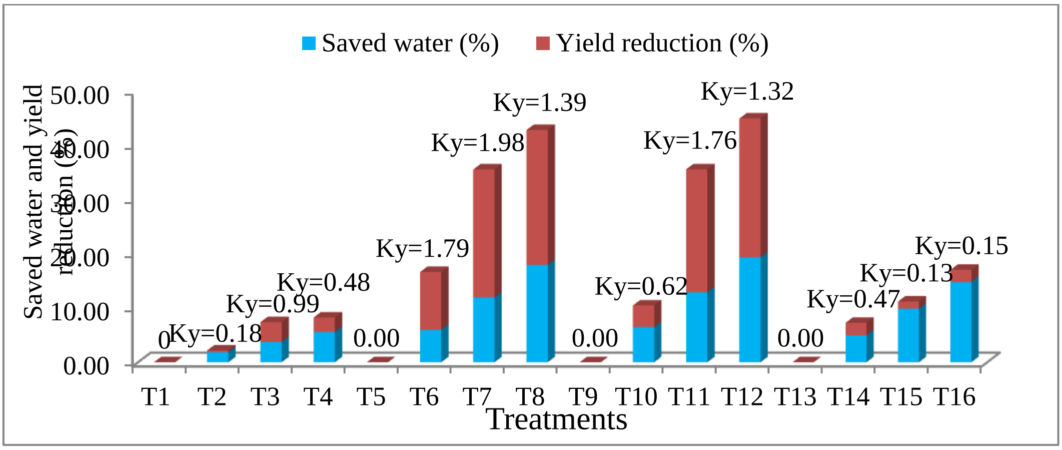

Figure 1 Crop yield response factor, water saved and yield reduction percentages as function deficit irrigation levels and time of application

Economic Comparison of Stage Specific Deficit Irrigation

The partial budget analysis revealed that the highest net benefit of 113922 ETB with lower cost was obtained from treatment 16. However, the lowest net benefit of about 47529 ETB with lower cost was obtained from treatment T8.

Benefit cost ratio (BCR) of onion was computed for each treatment combination as the ratio of yield earned to the cost expended. Accordingly, treatments 40% and 60% ETc water application levels at maturation stage had the highest BCR of 1.64 and 1.57 respectively. However, the lowest BCR was recorded under treatments receiving 40% and 60% ETc for the period of development and bulb formation stages (Table 8). It is observed that T16 was better treatment with lower cost of production and higher benefit. This could be due to this treatment had experienced no water deficit during development and bulb formation stage but saved water during maturation stage, thus resulted with optimum bulb yield and benefit-cost ratio. On the other hand, the lowest benefit-cost ratio obtained from T12, T11, T8 and T7 might be attributed to water deficit imposed at both developmental and bulb formation stages, which are the critical stages for onion bulb production.

Table 8. Benefit cost ratio per hectare of onion production under different irrigation levels and time of DI application

Trt.	Water applied (m^3/ha)	Cost of labor and water (VC)	Operation cost (FC)	Total cost (TC) (ETB/ha)	Marketable Yield (kg/ha)	Gross Revenues (GR) in ETB	Net Return (NR) in ETB	BCR
T1	6428.20	67282	11500	78782	26600	186200	107418	1.36
T2	6309.00	66090	11500	77590	26700	186900	109310	1.41
T3	6189.80	64898	11500	76398	25300	177100	100702	1.32
T4	6070.60	63706	11500	75206	25360	177520	102314	1.36
T5	6428.20	67282	11500	78782	26530	185710	106928	1.36
T6	6044.50	63445	11500	74945	22930	160510	85565	1.14
T7	5660.80	59608	11500	71108	17700	123900	52792	0.74
T8	5277.10	55771	11500	67271	16400	114800	47529	0.71
T9	6428.20	67282	11500	78782	26530	185710	106928	1.36
T10	6013.50	63135	11500	74635	24900	174300	99665	1.34
T11	5598.80	58988	11500	70488	18330	128310	57822	0.82
T12	5184.30	54843	11500	66343	16330	114310	47967	0.72
T13	6428.20	67282	11500	78782	27230	190610	111828	1.42
T14	6111.00	64110	11500	75610	26200	183400	107790	1.43
T15	5794.00	60940	11500	72440	26600	186200	113760	1.57
T16	5476.80	57768	11500	69268	26170	183190	113922	1.64

BCR= Benefit cost ratio, VC= Variable cost (ETB/ha), FC= Fixed cost (ETB/ha), T1, T2, T3 and T4 for application level of 100%, 80%, 60% and 40% ETc respectively, during initial stage; T5, T6, T7 and T8 for application level of 100%, 80%, 60% and 40% ETc respectively, during development stage; T9, T10, T11 and T12 for application level of 100%, 80%, 60% and 40% ETc respectively, during bulb formation stage; T13, T14, T15 and T16 for application level of 100%, 80%, 60% and 40% ETc respectively, during maturation stage; ETB= Ethiopian Birr (Hint the home currency up to the paper of completion is 1 ETB = 0.036 US $.

Conclusions

Irrigated agriculture is the most important and widely practiced in the world. Competition for water from other sectors is forcing irrigation to operate under water scarcity. The right irrigation water management in agriculture adopted to have significant impact on water saving is the use of deficit irrigation. Deficit irrigation improves water productivity through consumption of less water but producing comparable yield with that of unstressed crop. However, this requires identification of suitable crop type, crop variety, sensitivity of crop to deficit irrigation and local environment.

The results of the study revealed that, the deficit irrigation can improve the water productivity without significant yield reduction, considering the sensitive stage of the irrigated onion. However, applying of water for onion either by 40% or 60% of ETc at the development and bulb formation stage resulted in lower yield. This indicates that the most critical period for irrigation is the development and bulb formation stage. Therefore, application of deficit irrigation with scarce water resource for onion bulb production, it is recommended to avoid stressing the onion during the development and buld formation stages. Additionally, if water deficit is unavoidable at the development and bulb formation stages, it is better to deficit the crop not more than by 20% of ETc. The total yield differences are insignificant between a full irrigation and 40% ETc irrigation level at initial and maturity stages. The treatments receiving 40% ETc were most economically attractive with lower cost of production and higher benefit and having better CBR value. Thus, when water is scarce, adopting the 40% ETc irrigation water application level for two growth stages are recommended.

Acknowledgements

We would like to acknowledge Mehoni Agricultural Research Center (MehARC) of the Ethiopian Institute of Agricultural Research (EIAR) for funding this experimental study. Our heartfelt thanks also go to the natural resource management research process staffs of the MehARC and Haramaya University.

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