Original Research Article||

Effect of deficit irrigation levels at different growth stages on yield and water productivity of furrow irrigation on onion (*Allium cepa* L.) in Silte Zone, Ethiopia

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Abstract

Water scarcity is the most severe constraint for crop production in arid and semi-arid areas. To overcome this challenge, there is a need to use the scarce water efficiently and economically as an important strategy to address present and future gaps in water needs. This study was conducted for two years in Misrak Azernet Berbere Woreda starting in 2017/18 to investigate the effect of deficit irrigation levels on yield and water productivity at different growth stages of onion. The experiment had nine deficit irrigation levels as a treatment with a control of 100% water application. The experiment was laid out in a randomized complete block design with three replications. The results indicated that deficit irrigation levels at different growth stages had a significant effect ($p< 0.05$) on the yield and water productivity of onion. The highest marketable yield (28.68 ton ha^{-1}) was obtained from 20% deficit irrigation at the late growth stage whereas the lowest yield (14.42 ton ha^{-1}) was recorded from 40% deficit irrigation in all growth stages. Treatment T9 (20% L), T2 (20% IDML), T6 (20% I and T8 (20% M) were not statistically different in terms of yield. The highest water productivity (8.77 kg m^{-3}) was obtained from treatment T2 (20% deficit irrigation throughout the season). The lowest marginal rate of return (5.17 birr) was obtained from treatment (20% at the development stage (40% deficit irrigation at mid stage and 20% at the late growth stage). These results confirm that deficit irrigation practices can increase water productivity while saving water and enhancing income Therefore, it is recommended to apply deficit irrigation at 20% of crop water requirement throughout the season in four days irrigation intervals for optimum onion yield and increased water productivity. The result also indicated that farmers could also use deficit irrigation of 20%; 40% and 20% of crop water requirement at development, mid and late growth stages) to save scarce irrigation water and gained better economic return.

Key words: Deficit irrigation, crop water requirement, water productivity, marginal rate of return

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INTRODUCTION

Ethiopia is the second most populous country in Africa next to Nigeria and a large part of its population is dependent on agriculture that is characterized by a low level of productivity (Awulachew *et al*., 2010). Agricultural production of the country is mostly a rain-fed type which accounts for 40% of the gross domestic products, (IWMI, 2010).

Due to climatic variability from time to time, water is becoming an economically scarce resource even in areas of the world that have relatively plentiful reserves (FAO, 2012). Agriculture under unfavorable climatic conditions and limited water resources cannot be a profitable business unless on-farm water management techniques are designed to meet the growing demands for food production (Oad *et al*., 2001; Levidow et al., 2014; Fernández et al., 2020). Continuous decreases in water availability coupled with an increasing demand for irrigation water use has forced farmers to look for water saving technologies. Irrigated agriculture is the main strategic focus for Ethiopia for ensuring food security by implementing small scale irrigation schemes which reduce dependency on rain-fed production and increase food self-sufficiency for the rapidly increasing population, (GTP, 2010). To achieve sustainable irrigated agriculture by using limited water resources, different water saving technologies and guidelines are advisable (Geerts *and* Raes, 2009; Pereira et al., 2012; Chartzoulakis and Bertaki, 2015).

In scarce water resource conditions, deficit irrigation is one of the ways to maximize agricultural water use efficiency (Bekele and Tilahun, 2007). Deficit irrigation is a technology that improves water productivity by exposing crops to a certain level of water stress either during a particular period or throughout the whole growing season (English and Raja, 1996; Patanè et al., 2011; Comas et al., 2019). This technology has been widely investigated as a valuable and sustainable crop production strategy in arid and semi-arid regions to maximize water use efficiency for higher yields per unit of irrigation water applied (Fereres and Soriano, 2007; Michelon et al., 2020; Raza et al., 2021).

Onion *(Allium cepa* L.*)* is one of a popular vegetable crops in Ethiopia and its area coverage is increasing from time to time mainly due to its high profitability per unit area, ease of production and importance in the daily culinary practices (Lemma and Shimelis, 2003; Koye et al., 2022). The country has high potential to benefit from onion production as the crop contributes significant value to the national economy. Higher yield potential, availability of desirable cultivars for various uses, ease of production by seed, high domestic and export marketing were making onions increasingly important in Ethiopia (Lemma and Shimels, 2003; Teshome et al., 2015).

Goda small scale irrigation scheme at Misrak Azernet Barbere woreda is one of the major sources of income for the rural communities in Silte Zone. The scheme is facing high water scarcity during the dry season (October to April); during this season crop water supply is low while its demand is high and the scarce irrigation water application is practiced based on farmers' judgment which is resulting in competition among the farmers. The assessment conducted by (Tagesse *et al*., 2021), indicated that despite the significance of the problem of water scarcity and inefficient irrigation water use, the studies that could improve water productivity were not done many crops including onion. Onion is the most potential crop in the study area for income generation and household consumption. People in the area highly compete for water to produce this potential crop. Even though crops response to soil moisture level depends on growth stage and variety, no investigations have been reported on onion at different growth stages. This study was conducted to examine the effect of deficit irrigation levels at different growth stages on onion yield and water productivity of furrow irrigation.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted at Goda kebele in Misrak Azernet Berbere Woreda in Silte Zone, SNNPR, and Ethiopia (Figure 1). The study site is located approximately 221 km from Hawassa. The site is geographically located at 7.854°N latitude, 38.046°E longitude and at an altitude of 2300 m above sea level (GPS measured data). .

Climate Condition

The average annual rainfall of the area varies from 600 to 1200 mm and the mean annual minimum and maximum temperatures are 11°C and 27°C, respectively. Seasonal rainfall pattern is characterized (Figure 2) by a unimodal distribution extending from mid-February to the peak levels in July every year. Figure 2 shows that the area has a high evapotranspiration rate except for the months between September and May.

Reference Evapotranspiration

Reference evapotranspiration (ET_o) was calculated by the modified FAO Penman-Monteith method using FAO CROPWAT 8.0 software. The method is preferred for determining crop water requirement (CWR) because it considers multiple important climatic data including temperature, sunshine, humidity, radiation and wind-speed (Allen *et al.*, 1998 and Solangi *et al.*, 2022). Since there was no meteorological station in the study area, monthly climatic data were obtained for four meteorological stations near to the study area (Wulbarag, Hosaina, Silti and Butajira) from the Hawassa district of the Ethiopian Meteorological Agency. The average data were used to determine the reference evapotranspiration values of the study site.

Soil Sampling and Analysis

The composite soil samples were collected using auger from the experimental field diagonally from five locations before starting field operations. The samples were collected at 30 cm depth interval up to 60 cm (0 – 30 cm and 30 – 60 cm) to characterize it in terms of physical and chemical properties (texture, pH, electrical conductivity (EC), bulk density (BD), field capacity (FC) and permanent wilting point (PWP)).

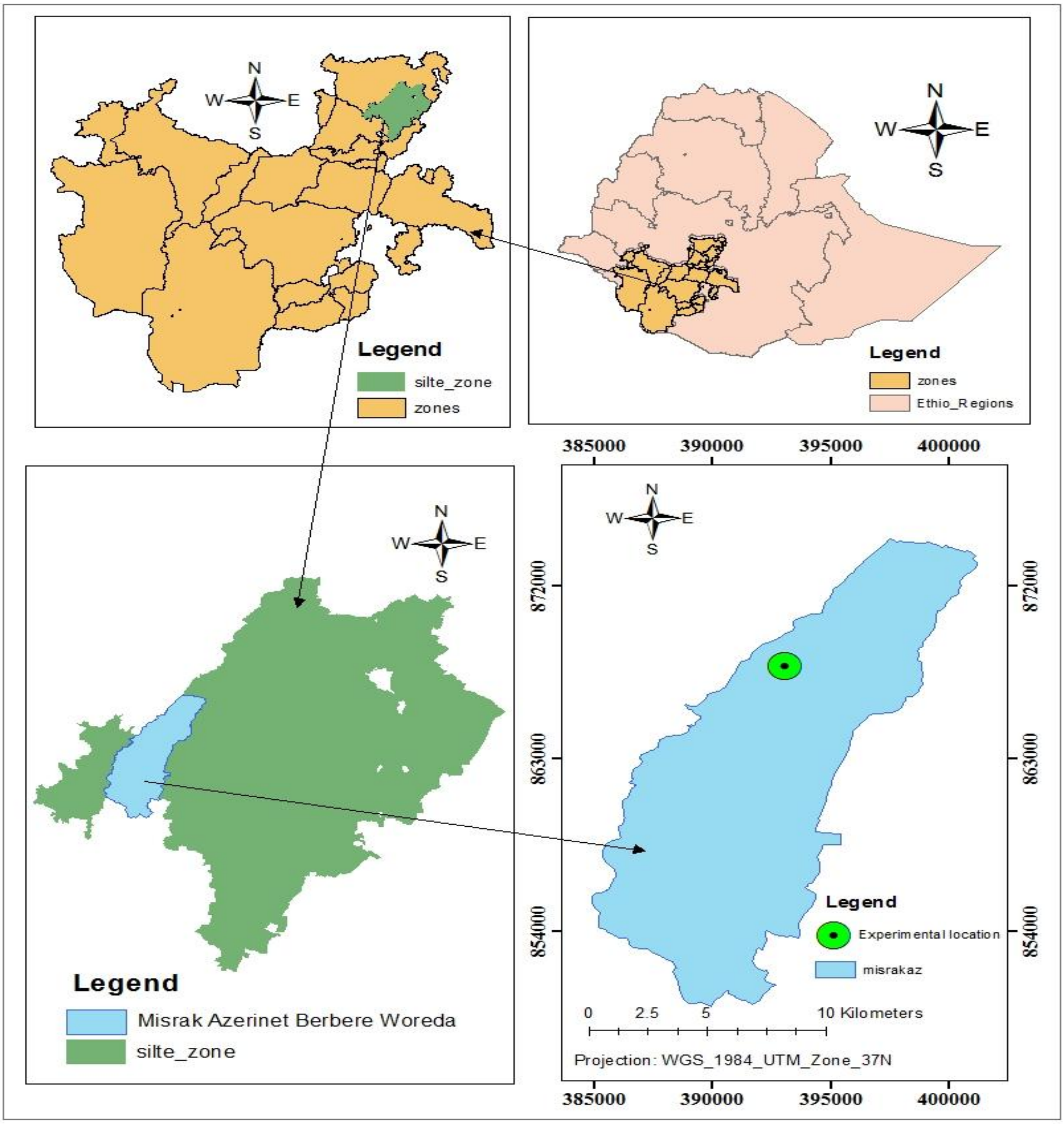

Figure 1. Map of the study area

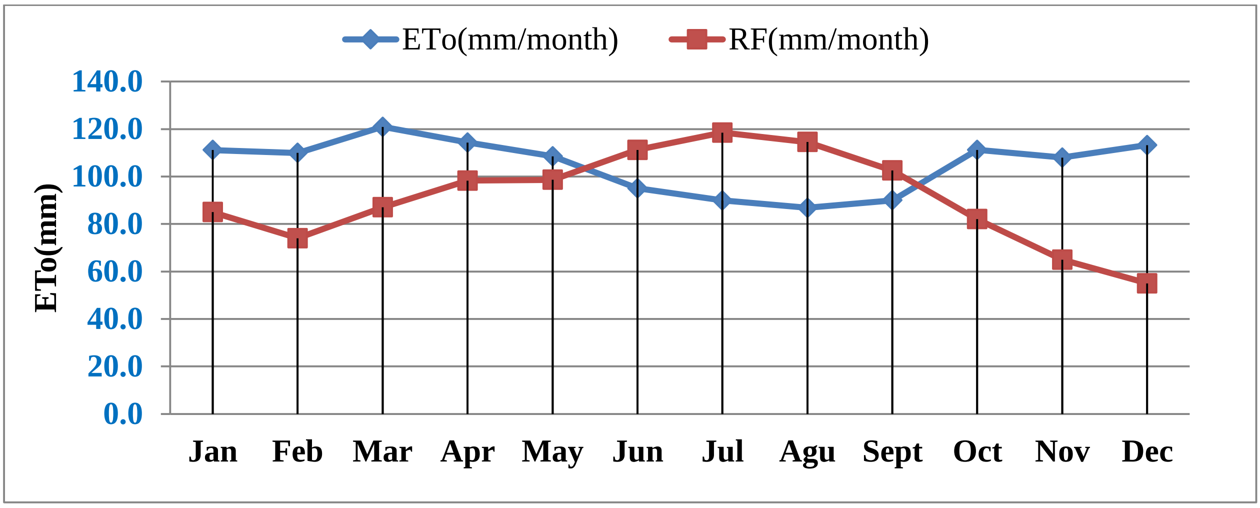

Figure 2. Climatic water balance for evapotranspiration rate (ETo) and rainfall

Experimental Treatments and Design

The experiment had 9 treatments (Table 1), which were 8 combinations of different soil moisture deficit irrigation applications and a control treatment of 100% ETc application in four growth stages (initial, development, mid-season and late-season). The experiment was laid out in a randomized complete block design (RCBD) with three replications. Experimental plot size was 3.2x4 m^2. The spacing between plots and replications were 1.5 and 2 m, respectively. The gross size of experimental plot site was (20x43.8) m^2 which was a total of 876 m^2. Surface drainage system was provided to protect excess flow of water to other plots.

Table 1. Treatments combinations

Treatments	Growth stages			
	Initial	Development	Mid	Late
T_1 (100% IDML)	100% ET_c	100% ET_c	100% ET_c	100% ET_c
T_2 (20% IDML)	80% ET_c	80% ET_c	80% ET_c	80% ET_c
T_3 (40% IDML)	60% ET_c	60% ET_c	60% ET_c	60% ET_c
T_4 (20% D/40% M/20% L)	100% ET_c	80% ET_c	60% ET_c	80% ET_c
T_5 (40% I/20% D/20% L)	60% ET_c	80% ET_c	100% ET_c	80% ET_c
T_6 (20% I)	80% ET_c	100% ET_c	100% ET_c	100% ET_c
T_7 (20% D)	100% ET_c	80% ET_c	100% ET_c	100% ET_c
T_8 (20% M)	100% ET_c	100% ET_c	80% ET_c	100% ET_c
T_9 (20% L)	100% ET_c	100% ET_c	100% ET_c	80% ET_c

I, D, M and L indicates initial, development, mid and late growth stages, respectively

Agronomic Practices

The experimental area was kept weed free by ploughing the land before transplanting the onion. The experiment was executed between December and March of 2017 and 18. Agronomic management practices such as hand digging, pulling of weeds and chemical applications were done during the cropping seasons starting from December through February, as it is being practiced by the farmers in the study area. The recommended NPS (200 kg ha^{-1}) fertilizer was applied during transplanting and urea (200 kg ha^{-1}) was applied in splits where half was applied during planting and the other half after 6 weeks of transplanting. Redomil Gold (3 liters ha^{-1}) was used to control against fungi infestation.

The Bombay red onion variety released by Melkassa Agricultural Research Center was used for this study (EARO, 2004). It has light red bulb skin color, dark green leaf color, flat globe bulb shape and reddish white bulb flesh color. The variety is known to take 110−120 days for bulb maturity. The seed was prepared in the nursery transplanted on the main field. When seedlings reached 12−15 cm height or 3−4 true leaves, they were carefully uprooted from the nursery bed and transplanted. One day before transplanting of seedlings, the nursery beds were provided light irrigation for the safe uprooting. During planting only healthy, vigorous and uniform seedlings were used. To ensure the plant establishment, full irrigation was applied to all plots at two days interval with 7.76 mm of water for a total of 8 days before the beginning of the differential irrigation experimentations (EARO, 2004). As per EARO (2004) and FAO irrigation and drainage paper No.33, onion is planted in ridges with spacing of 40cm between furrows, 20 cm between rows on the furrow bed and 10 cm between plants (Doorenbos *et al.*, 1986). Plants were grown in both ridges of furrows each plot had 8 rows and 80 plants per row, where a total of 640 plants were cultivated per plot.

Crop water Requirement

Crop Water Requirement (CWR) is the depth of water needed to compensate for the depth of water lost through evapotranspiration and needs ET_o and onion crop coefficient (K_c) as suggested by Allen *et al.*, (1998). The K_c for onion were 0.7 at the initial stage, $0.7 < K_c < 1.05$ during development stage, 1.05 during mid-season stage and $0.95 < K_c < 1.05$ during late-season stage. ET_c was obtained using CROPWAT 8.0 software over the growing season.

$$ET_c = K_c \times ET_o \text{ (mm/day)} \qquad (1)$$

The effective rainfall was calculated from the expression (Brouwer and Heibloem, 1986):

$$Pe = 0.8\,P - 25 \text{ for } P > 75 \text{ mm/month} \qquad (2)$$

Or

$$Pe = 0.6\,P - 10 \text{ for } P < 75 \text{ mm/month} \qquad (3)$$

Since, there was rainfall during the experimental period, p_e and IR_n values were determined using equation 3 and 4, respectively.

$$IR_n = ETc - P_e \qquad (4)$$

Where, P_e is effective rainfall (mm/day) P is rainfall (mm/day), IR_n is net irrigation requirement (mm) and ETc is crop water requirement (mm/day)

Gross Irrigation Requirement

Gross irrigation requirement (d_g) is the ratio of net irrigation to application efficiency of furrow irrigation (FAO, 2002). By taking application efficiency of a short, end diked furrow as 60% (Brouwer and Prins, 1989), the gross irrigation requirement was obtained from:

$$dg = \frac{IRn}{E_a} \qquad (5)$$

Where: dg is gross irrigation application (mm), IRn is net irrigation requirement (mm) and E_a is application efficiency (%).

Application Time

Application time (t_a) scheduled amount of irrigation water was applied to the plots being measured using a 3 inch Parshall flume set up. The time required to deliver the desired depth of water into each plot was calculated (equation 6; Kandiah, 1981).

$$t_a(\text{min}) = \frac{d_g * A}{6 * Q} \qquad (6)$$

Where: d_g is gross depth of irrigation water in cm, A is plot area in m^2, Q is flow rate (L/s)

Crop water productivity

The crop water productive (CWP) is one of the most important indices for determining optimal water management practices. It quantifies the efficiency with which economic yield is produced as a function of water used by the crop in the field. The CWP in this study was determined by dividing the onion bulb yield by the net amount of irrigation water used by the crop as indicated by the following equation (Ali *et al.*, 2007).

$$CWP = \frac{\text{Yield}}{ET_c}\left(\frac{kg}{m^3}\right) \qquad (7)$$

Data Collection

Data recorded at the end of each growth stage were plant height and number of leaves per plant. These were collected from 12 random tagged plants of 6 central rows excluding 2 border rows at the end of each growth stages. Plant height was taken by measuring the height of the main stem from the ground level up to the tip of the leaf with the ruler expressed in centimeter (EARO, 2004). Similarly, bulb diameter (mm) of the sample plants were measured at the middle portion of the mature bulb using a slide digital caliper. All completely developed leaves were counted and recorded per plant. The harvested yield data from each plot was then expressed as tons per hectare (t ha^{-1}).

Economic Analysis

To evaluate the economic cost and benefit of irrigation under different amounts of water applied, the Partial Budget Analysis (PBA), which includes the Dominance Analysis (DA) and Marginal Rate of Return (MRR), was used following the CYMMYT procedure (CIMMYT, 1988). Yield and economic data were computed to compare the advantage of the application of different levels of water in different deficit irrigation treatments. Economic data include input costs such as water pricing.. As an output, total gross benefit was calculated from bulb yield of onion. The local market price of onion was assessed during the harvesting and was changed to a hectare bases. In the analysis, the estimated price of different application of water and yield price in each treatment was considered as a total return (TR). The net income (NI) was calculated by subtracting total variable cost (TVC) from TR and is computed as:

$$NI = TR - TC \quad (8)$$

The change in net income (ΔNI) was calculated as the difference between the change in total return (ΔTR) and the change in variable cost (ΔVC) and change in fixed cost (ΔFC). The change in net income (ΔNI) is computed as:

$$\Delta NI = \Delta TR - (\Delta VC + \Delta FC) \quad (9)$$

Although the calculation of net benefit accounts for the costs that vary, it was necessary to compare the extra or marginal costs with the extra marginal net benefits. Higher net benefits may not be attractive if they require very much higher costs (CIMMYT, 1988). The marginal rate of return (MRR) in Birr/Birr measures the increase of the net income, (ΔNI) which is generated by each additional unit of expenses and is computed as:

$$MRR = \Delta NI / \Delta VC \quad (10)$$

Data Analysis

The collected data were subjected to statistical analysis of variance (ANOVA) using SAS software version 9.1. Whenever treatment effects were found significant, treatment means were compared using the least significant difference (LSD) method (Steel *et al.*, 1997).

RESULTS AND DISCUSSION

Soil Characteristics

According to (USDA, 1999) soil textural classification, the dominant textural class of the experimental site was clay loam with an average soil bulk density of 1.13 g cm^{-3} which is below the critical threshold soil bulk density of 1.4 g cm^{-3}. This allows for easier movement of air and water in soil for crop root being suitable for growth (Hunt and Gilkes, 1992).

Soil moisture contents at FC for the experimental soil varied between 28.93% and 26.50% for the considered soil depth levels (0 – 30 cm and 30 – 60 cm, respectively). Moisture content at PWP also ranged between 14.02% and 13.80% for the considered soil depth. The higher total available water (TAW) obtained was associated with the higher clay content of the soil (USDA, 1998). The average soil pH of 7.35 was found within the recommended limit (6.0 − 8.0) for onion production (Olani and Fikre, 2010). The basic infiltration rate was 6.72 mm hr^{-1} which means water layer of 6.72 mm on the soil surface will take one hour to infiltrate.

Table 2. Soil physical and chemical properties

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

According to FAO (1979) the infiltration rate ranges between 2.5 and 15 mm hr^{-1} for clay loam soil. Hence, the field infiltration test results were within the recommended range of FAO (1979).

Before the experimental work was started, soil infiltration rate was conducted using double ring infiltrometer for a total of 207 minutes (3 hours and 27 minutes) continuously until the drop in water level over equal time intervals remains the same and the depth of water levels infiltrated were measured at increasing time intervals starting from 1 second to 25 minute. The field test was conducted at three locations. Drop in water level in the inner ring was recorded using the measuring rod and the level of water was brought back to approximately the original level to maintaining the water level of outside ring. The average infiltration and cumulative infiltration rate curves of the field were generated (Figure 2).

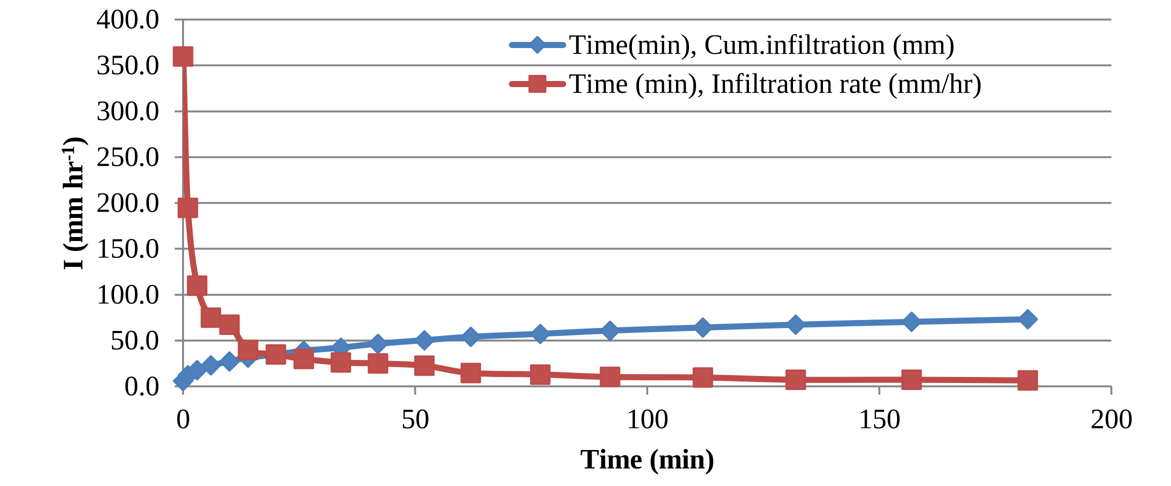

Figure 3. Soil infiltration rate and cumulative infiltration curves of experimental field

Reference Evapotranspiration

The monthly average climatic data of the experimental nearby station was presented in Table 3. The results show that ET_o of the site was minimum (2.8 mm day^{-1}) in July and maximum (4.2 mm day^{-1}) in March, respectively. If the evaporative power of the atmosphere was within 3 to 5 mm day^{-1} range, it indicates a moderate ET_o (Allen *et al*., 1998). The calculated IR_n of the season was 366 mm which matched the acceptable range (FAO, 2010) for optimum onion yield that requires 350 − 550 mm of water.

Table 3. Average monthly ETo data of four nearby stations

Months	T_{min} **(°C)**	T_{max} (°C)	Hum (%)	Wind (km hr^{-1})	Sun (hr)	Rad (**MJ m^{-2} day^{-1}**)	ET_o **(mm day^{-2})**
January	7.80	25.50	81.30	121.30	8.20	19.90	3.60
February	8.90	26.40	77.30	124.00	7.80	20.50	3.90
March	10.20	26.40	80.00	130.00	8.00	21.70	4.20
April	11.00	24.50	90.70	118.30	7.40	20.90	3.80
May	10.30	24.30	92.70	118.30	7.60	20.60	3.70
June	10.00	22.90	95.70	126.70	6.10	18.00	3.10
July	10.10	21.60	95.30	98.00	4.20	15.30	2.70
August	10.00	21.50	91.70	80.30	4.60	16.30	2.90
September	9.60	22.80	97.00	92.00	5.20	17.30	3.00
October	8.50	23.80	87.00	112.00	7.50	20.20	3.60
November	8.50	24.40	88.00	135.30	8.90	21.10	3.60
December	7.40	25.40	75.70	138.00	8.30	19.60	3.70

Irrigation Water Requirement and Scheduling

For the sake of time, lack of daily soil moisture determination instruments and shortage of labor, daily ET_c value was scheduled to be applied in four days irrigation intervals delivering water (ET_c) every four days. The values (Table 3) indicated that low ET_c values were observed at the beginning of the growing season. The ET_c was observed increasing gradually and attained a maximum during mid-season crop growth stage and subsequently decreasing through the late-season. The values of IR_n, IR_g and irrigation scheduling at four days irrigation interval during the growing season were applied considering the rainfall during the experimental season (February and March) which was subtracted from the scheduled ET_c value where only net irrigation requirement (IR_n) was applied to the intended treatments (Table 4). Gross irrigation (dg) was calculated by taking the different loses into account. The result indicated that the maximum amount of crop water requirement was applied at the mid growth stage.

Table 4. Crop water requirement in four days irrigation interval

Stages	Date /irr. interval/	ETo (mm)	Kc	ETc (mm d^{-1})	Eff. RF (cm)	IRn (mm)	Dg (mm)
Initial	18-Dec	14.80	0.60	8.88	0.00	8.88	14.80
17-days	22-Dec	14.80	0.60	8.88	0.00	8.88	14.80
	26-Dec	14.80	0.60	8.88	0.00	8.88	14.80
	30-Dec	14.80	0.60	8.88	0.00	8.88	14.80
	3-Jan	14.40	0.60	8.64	0.00	8.64	14.40
Devt	7-Jan	14.40	0.80	11.52	0.00	11.52	19.20
29-days	11-Jan	14.40	0.80	11.52	0.00	11.52	19.20
	15-Jan	14.40	0.80	11.52	0.00	11.52	19.20
	19-Jan	14.40	0.80	11.52	0.00	11.52	19.20
	23-Jan	14.40	0.80	11.52	0.00	11.52	19.20
	27-Jan	14.40	0.80	11.52	0.00	11.52	19.20
	31-Jan	14.40	1.10	15.84	8.00	7.84	13.07
Mid	4-Feb	15.60	1.10	17.16	8.40	9.16	15.27
37-days	8-Feb	15.60	1.10	17.16	14.00	3.16	5.27
	12-Feb	15.60	1.10	17.16	12.00	5.16	8.60
	16-Feb	15.60	1.10	17.16	0.00	17.16	28.60
	20-Feb	15.60	1.10	17.16	15.00	2.16	3.60
	24-Feb	15.60	1.10	17.16	13.00	4.16	6.93
	28-Feb	15.60	1.10	17.16	0.00	17.16	28.60
	4-Mar	16.80	1.10	18.48	15.00	3.48	5.80
	8-Mar	16.80	1.10	18.48	10.00	8.48	14.13
Late	12-Mar	16.80	0.90	15.12	9.50	5.62	9.37
21-days	16-Mar	16.80	0.90	15.12	9.00	6.12	10.20
	20-Mar	16.80	0.90	15.12	12.00	3.12	5.20
	24-Mar	16.80	0.90	15.12	11.00	4.12	6.87
	28-Mar	16.80	0.90	15.12	0.00	15.12	25.20
	1-Apr	4.20	0.90	3.78	0.00	3.78	6.30
104-days	Total			365.58	136.9	229.08	381.80

Net Irrigation Water Applied

Net irrigation water applied to each treatment determined by subtracting effective rainfall in table 5 below. The total effective rainfall during the experimental season was 136.9 mm.

Table 5. Water applied and net irrigation (IRn) at each growth stage

Treatments	Growth Stages				IRn (mm)	RF (mm)	IR (IRn+RF)mm
	I	D	M	L			
T_1 (100% IDML)	44.20	77.00	70.10	37.90	229.10	136.50	366.00
T_2 (20% IDML)	35.33	61.57	56.06	30.34	183.30	136.50	320.00
T_3 (40% IDML)	26.49	46.18	42.05	22.73	137.40	136.50	274.00
T_4 (20% D/40% M/20% L)	44.16	61.57	42.05	30.31	178.10	136.50	315.00
T_5 (40% I/20% D/20% L)	26.49	61.57	70.08	30.30	188.40	136.50	325.00
T_6 (20% I)	35.33	76.96	70.08	37.88	220.20	136.50	357.00
T_7 (20% D)	44.16	61.57	70.08	37.88	213.70	136.50	350.00
T_8 (20% M)	44.16	76.96	56.06	37.88	215.10	136.50	352.00
T_9 (20% L)	44.16	76.96	70.08	30.30	221.50	136.50	358.00

I, D, M and L indicates initial, development, mid and late growth stages. 136.50 mm of rainfall was recorded in January, February and March, 8.00, 62.00 and 66.50 mm, respectively. It was subtracted from each treatment that is why its amount below the initial calculation. For each treatment the recommended deficit amount was subtracted in each stage and then added up. Finally, total rainfall amount (136.9 mm) was subtracted from each treatment.

Effect of Deficit Irrigation on Yield and Yield Components

The results (Table 6) indicated that the combined bulb yield was significantly affected ($p \leq 0.05$) by the deficit irrigation levels at different growth stages. The highest bulb yield of 28.68 t ha^{-1} was obtained from the control treatment T_9 (20% DI) at the late growth stage. There were no statistically different yield among treatments T_1, T_2, T_6, T_8 and T_9. In contrast, the lowest bulb yield 14.42 ton ha^{-1} was recorded from treatment T_3 which received 40% DI at all growth stages. This revealed that decreasing of irrigation water levels at specific stages or throughout growth stages significantly affected yield when compared with full irrigation throughout growth stages. This indicated that the 20% DI application at different growth stages did not give significantly different bulb yields for T_2, T_6, T_8 and T_9. The results in the present study are consistent with with the similar research reported by Samson and Ketema (2007) where applying deficit irrigation in some growth stages of onion did not significantly affect bulb yield.

The applied irrigation levels also had a significant effect ($p \leq 0.05$) on onion bulb diameter (Table 6). The bulb diameter of T_3 had significantly different with all treatments except T_4 and T_5. Treatments T_1, T_2, T_7, T_6, T_8 and T_9 were not significantly different from each other with the highest and lowest bulb diameters being 6.1 and 5.1 cm for T_1 and T_3, respectively. This implies that application of 40% DI throughout all growth stages had significantly reduced bulb diameter. This result were similar with earlier reports by David *et al*., (2016) that bulb size varied proportionally with the quantity of applied irrigation water.

Table 6. Results of deficit irrigation effects on yield and onion bulb diameter

Treatments	BD (cm)	PH (cm)	LNPP	Yield Year-1 (ton ha^{-1})	Yield Year-2 (ton ha^{-1})	Average Yield (ton ha^{-1})
T_1 (100% IDML)	6.10^{a}	71.3^{a}	9.7^{a}	29.32^{a}	27.63^{a}	28.47^{a}
T_2 (20% IDML)	5.98^{ab}	68.7^{a}	8.3^{bc}	28.56^{b}	27.50^{ab}	28.03^{ab}
T_3 (40% IDML)	5.10^{d}	53.7^{b}	6.7^{e}	15.22^{d}	13.61^{d}	14..42^{d}
T_4 (20% D/40% M/20% L)	5.34^{cd}	56.3^{b}	7.7^{bcde}	17.35^{c}	15.2^{cd}	16.23^{cd}
T_5 (40% I/20% D/20% L)	5.47^{bcd}	55.7^{b}	7.0^{de}	17.53^{c}	16.12^{c}	16.83^{c}
T_6 (20% I)	5.67^{abc}	68.0^{a}	7.4^{cde}	28.63^{b}	28.05^{ab}	28.34^{ab}
T_7 (20% D)	5.77^{abc}	68.7^{a}	8.3^{bc}	28.58^{b}	26.51^{b}	27.55^{b}
T_8 (20% M)	6.05^{a}	69.3^{a}	8.0^{bcd}	28.62^{b}	28.30^{ab}	28.46^{ab}
T_9 (20% L)	5.85^{abc}	69.3^{a}	8.8^{ab}	29.13^{ab}	28.23^{ab}	28.68^{ab}
CV	5.490	4.0	1.3	1.370	4.37	2.87
LSD(0.05)	0.54	3.6	9.5	0.60	1.78	1.19

BD = bulb diameter, PH = plants height, LNPP = leaves number per plant and

Water Productivity

The analysis indicated that (Table 7) there was a significant difference ($p \leq 0.05$) on water productivity of the various deficit irrigation application levels. Applying 80% of ET_c (T2) throughout the whole growth season resulted in the highest water productivity (8.77 kg m^{-3}), while the lowest water use efficiency (5.17 kg m^{-3}) was obtained from T_4 which received water deficit levels of (20% D/40% M/20% L) of ET_c at the development mid and late stages, respectively. Additionally, higher water use efficiency was obtained from treatments supplying 20% of ET_c than full irrigation (T_1); which shows that onion is more efficient in using 20% of ET_c than full irrigation to save scarce water and obtain optimum yield.

Table 7. Net irrigation, yield and water productivity

Treatments	Water Applied (m^3 ha^{-1})	Yield (kg ha^{-1})	WP (kg m^{-3})
T_1 (100% IDML)	3656	28480	7.79
T_2 (20% IDML)	3197	28030	8.77
T_3 (40% IDML)	2740	14420	5.26
T_4 (20% D/40 % M/20 % L)	3146	16280	5.17
T_5 (40 % I/20 % D/20 % L)	3249	16830	5.18
T_6 (20 % I)	3567	28340	7.95
T_7 (20 % D)	3502	27550	7.87
T_8 (20 % M)	3516	28460	8.09
T_9 (20 % L)	3580	28680	8.01

Net Crop Water Requirement and Yield Relationship

The result of net crop water requirement (IRn), yield and water productivity (WP) relationship (Figure 4 - right) shows that the amount of irrigation water has positive effect on yield and WP. The relationship was especially high for T_2 in terms of WP than all other treatments. Low amount of WP was obtained for treatment T_5, indicating that onion is not tolerant to maximum deficit irrigation at initial and development stages

Economic Analysis

The economic analysis (Table 8) indicated that the highest marginal rate of return (MRR, 911%) was obtained for treatment T_4 (20 % D/40 % M/20 % L) meaning that farmers inversing one birr will get 9.11 birr which is double of the investment cost. Treatments T_5, T_8 and T_9 were considered dominant, meaning that irrigators who invested one birr gained less than the investment cost. Based on the result it was recommended that farmers and commercial farms use T_4 (20 % D/40 % M/20 % L) in scarce water conditions as an option for better onion yield.

Table 8. Economic analysis

Treatments	AW (m^3 ha^{-1})	Yield (kg ha^{-1})	10% Adjusted Yield (kg ha^{-1})	TC (birr ha^{-1}) in increasing order	TR (birr kg^{-1})	NI (birr ha^{-1})	MRR (%)
T_3 (40% IDML)	2740	14420	12978	6850	142758	135908	17
T_4 (20 % D/40 % M/20 % L)	3146	16280	14652	7865	161172	153307	911
T_5 (40 % I/20 % D/20 % L)	3197	28030	25227	7992.5	277497	269505	D
T_6 (20 % I)	3249	16830	15147	8122.5	166617	158495	167
T_2 (20 % IDML)	3502	27550	24795	8755	272745	263990	256
T_8 (20 % M)	3516	28460	25614	8790	281754	272964	D
T_7 (20 % D)	3567	28340	25506	8917.5	280566	271649	103
T_9 (20 % L)	3580	28680	25812	8950	283932	274982	D
T_1 (100 % IDML)	3656	28480	25632	9140	281952	272812	30

AW-applied water, TC–total cost, TR-total revenue, NI-net income and MRR-marginal rate of return

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that 20% deficit irrigation of ETc at late growth stages (in treatment T_9) has the highest bulb yield (28.68 ton ha^{-1}). Similar bulb yield (28.03 ton ha^{-1}) was recorded in treatment T_2. Among treatments T_1, T_2, T_7, T_6, T_8 and T_9, no statistically significant differences on bulb yield were observed. The highest water use productivity (8.77 kg m^{-3}) was obtained for the samples receiving treatment T_2 (20%) deficit of ETc application at all growth stages. Therefore, to achieve higher onion bulb yield and water productivity, it is recommended that farmers in the study area adopt 20% DI of ETc irrigation water application throughout the season. As option farmers could also be advised to use T_9 (20%) ETc deficit irrigation water application at late stage to get higher yield (28.68 ton ha^{-1}). When water is highly scarce to save, using T4 (20 % D/40 % M/20 % L) DI might also be recommended without significant yield reduction.

CONFLICTS OF INTEREST

Authors declare that they have no conflicts of interest regarding the publication of this paper in the Journal of Science and Development.

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APPENDIX

Figure 3. Field infiltration rate measurement and transplanting

1st –stage

2nd -stage

3rd-stage

4th-stage

Figure 4. Growth stages

Figure 5. Field data collection and illustration