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Effect of Irrigation Methods and Irrigation Levels on Yield and Water Productivity of Onion at Awash Melkasa, Ethiopia

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Abstract: Water is scarce resource in Central Rift Valley of Ethiopia and is major limiting factor for crop production. The field experiment was conducted in 2018 at Melkasa Agricultural Research Center during the off-season to identify irrigation method and irrigation application level that maximizes productivity of onion per unit of water consumed and enhanced onion crop production. The experiment was carried out using split plot design in RCBD having three replications. The experiment consisted of two irrigation methods viz., furrow and drip irrigation as main plot and three levels of manageable allowable depletion viz., 120%, 100% and 80% as sub-plot. The ANOVA revealed that their interaction had a significant ($p<0.01$) effect on bulb diameter, total bulb yield, marketable bulb yield and water productivity. The maximum total bulb yield (41.76 t/ha), marketable bulb yield (38.39 t/ha), bulb diameter (6.02 cm) and water productivity (13.05 kg/m^3) were observed from drip irrigation method at 80% management allowed depletion application, while significantly lower of 34.48 t/kg, 31.6 t/ha, 5.11 cm, and 6.84 kg/m^3 respectively were recorded from furrow irrigation method at 120% management allowed depletion application. Among all tested treatments drip irrigation method with 80% MAD was the best practice because of its high yield, water productivity.

Keywords: Drip Irrigation, Furrow Irrigation, MAD, Onion, Water Productivity

1. Introduction

Water is man kind's most vital and versatile natural resource. It is also considered as an essential resource for irrigation. Irrigation is an artificial application of water to soil for the purpose of supplying the moisture essential in the plant root-zone to prevent stress that may cause reduced yield and/or poor quality of harvest of crops [1].

Irrigated agriculture is the largest water-consuming sector and it faces competing demands from other sectors, such as the industrial and the domestic sectors. With an increasing population and less water available for agricultural production, the food security for future generations is at stake. Hence the key challenge for future is growing more food with less water by way of increasing crop water productivity (CWP). A higher CWP results in either the same production from fewer water resources, or a higher production from the same water resources, so this is of direct benefit for other water users [2].

The competition for existing freshwater supplies will require a paradigmatic shift from maximizing productivity per unit of land area to maximizing productivity per unit of water consumed [3].

Irrigation development is increasingly implemented in Ethiopia more than ever. Expansion of irrigated area combined with the efficient management of water will enhance the attainment of food security and poverty alleviation goals of the country. Although the country is well known for its vast water resources potential its erratic distribution both in space and time coupled with limited capacity is the most challenging problem that limited the contribution of the resources to the socio-economic development of the country [4].

Agricultural production particularly vegetable crops are intensively cultivated under irrigation in Central Rift valley (CRV) Ethiopia. The region is a semi-arid with limited water resources. Considering increasing demand for water combined with high evapotranspiration rates in the region, effective and efficient use of existing water resources need to be discovered.

Onion (*Allium cepa L.)* is one of the most important vegetable crops commercially grown in the world [5]. It is estimated that around the World, over 3,642,000 ha of onions are grown annually. On a worldwide scale, around 80 million metric tons of onions are produced per year [6]. It is also widely cultivated as source of income by many farmers in many places of Ethiopia. The country has a great potential to produce the crop throughout the year both for local consumption and export. The total area under onion production was estimated to be 24, 375.7 ha with an average yield of about 9.02 tons per hectare and estimated a total production of greater than 2, 19, 735.27 tons [7]. Traditionally, farmers in the CRV of Ethiopia have been using the most conventional surface irrigation system, most commonly the furrow irrigation system, for growing the crops. Furrow irrigation is characterized by low irrigation efficiency. The crop productivity under furrow irrigation can be achieved by applying the required amount at the right time. The crop is shallow rooted and sensitive to water stress. As a result it is commonly given light and frequent irrigation to avoid water stress [8].

Drip irrigation is one of the most efficient forms of irrigation technology currently available. It is a technology by which water can be conserved and yield increase for farmers, especially those who are cultivating in semi-arid conditions of the world or in areas where competition over water resources is escalating. Drip irrigation offers many advantage over furrow irrigation including water saving, reducing labor required for irrigation, reducing soil erosion and increasing crop productivity. Therefore, the efforts are now warranted to harness the available quantities of water and put them to efficient use to realize higher productivity per drop [9].

On-farm water use efficiency and hence water productivity can be improved by moving to a more efficient irrigation system. Sprinkler and drip irrigation can save non-effective water loss [10]. Modernization and optimization of irrigation systems can contribute to increasing water productivity [11].

Management allowed depletion (MAD) is the fraction of the total available soil water which is most easily extracted by the plant roots without creating stress. The water content approaching permanent wilting point (PWP) cannot be easily extracted by the plant roots. As evapotranspiration occurs, the soil water reservoir begins to be depleted. As the soil dries, the remaining water is held more tightly by capillary forces in the soil, making it more difficult for the plant to extract it. For this reason, ET will start to decrease long before the PWP is reached. Since the lowest ET will generally reduce yields, growers should irrigate before the root zone water content reaches the level that restricts ET [12]. The study was conducted to evaluate the effects of furrow and drip irrigation methods under different soil moisture depletion levels on yield, yield components and water productivity of onion.

2. Materials and Methods

The study was conducted at Melkasa Agricultural Research Center during off season (2018 cropping season). The center is located in Oromia regional state, Adama woreda, central rift valley of Ethiopia, at a geographical location of 8°24'36" - 8°26'24" N latitude and 39°19'12" - 39°19'48" E longitude, with an average altitude of 1,550 m above mean sea level (Figure 1). The average annual rainfall of the area was 824.92 mm. The site has a mean maximum and minimum temperature of 28.72°C and 13.82°C, respectively.

Table 1. *The long-term (1977-2017) monthly climate data of MARC.*

Month	Tmin (°C)	Tmax (°C)	RH (%)	U_2 (m/s)	n (hr)	RF (mm)	ETo (mm/day)
January	11.71	27.93	51.04	8.59	9.05	16.02	6.30
February	13.42	29.12	48.74	9.08	9.17	24.05	7.14
March	15.06	30.47	49.21	8.63	8.52	52.31	7.47
April	15.47	30.49	50.76	7.84	8.23	53.88	7.20
May	15.54	31.00	51.17	7.46	8.76	61.03	7.13
June	16.37	30.19	53.11	9.00	8.36	69.01	7.25
July	15.67	26.85	66.36	9.07	7.03	204.21	5.39
August	15.36	26.31	69.20	6.97	7.07	183.07	4.87
September	14.47	27.62	65.76	4.88	7.32	99.75	4.90
October	11.68	28.76	50.02	6.58	8.66	39.35	6.22
November	10.76	28.33	46.67	8.26	9.60	12.64	6.63
December	10.37	27.55	48.76	8.87	9.47	9.60	6.33
Average	13.82	28.72	54.23	7.94	8.44	68.74	6.40

T_{max} and T_{min}=maximum and minimum air temperature (°C) respectively, RH=relative humidity (%), u=Wind speed at 2 m height (m/sec), n=sunshine hour (hr) and ETo=potential evapotranspiration (mm/day).

Source: Melkasa Agricultural Research Center (MARC) meteorological station.

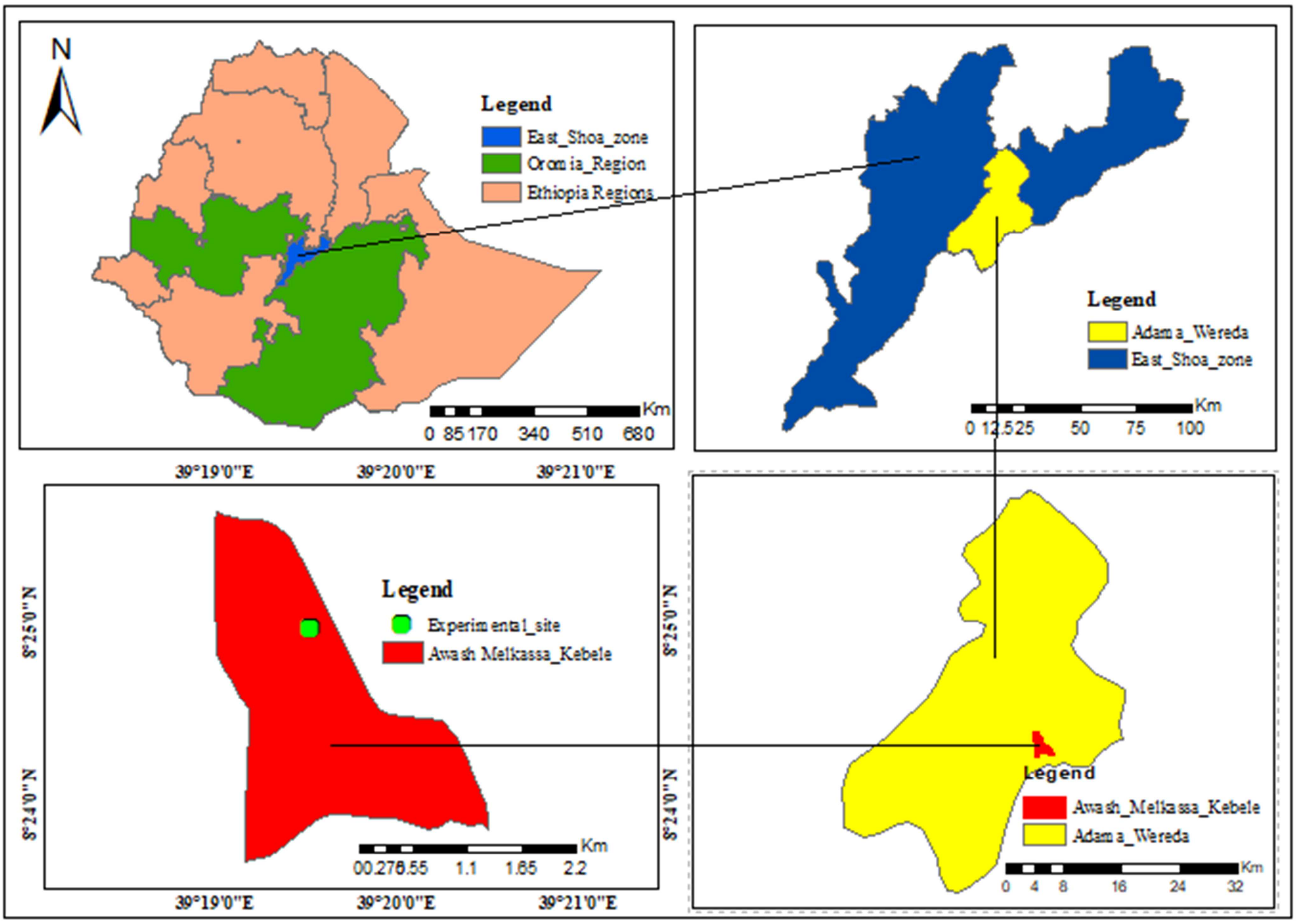

Figure 1. *Location of the study area (MARC).*

2.1. Experimental Design and Treatments

Treatments of the experiment consisted of two irrigation systems: furrow irrigation (FI) and drip irrigation (DI) and three level of management allowed depletion (MAD) viz., 120% MAD, 100% MAD and 80% MAD. The experimental design was split plot in a randomized complete block design with three replications, in which irrigation methods were assigned as the main plots and level of MAD as sub-plots. Each experimental plot has a plot size of 3.6 m by 4 m to accommodate five furrows with a spacing of 60 cm. The plots and blocks had a buffer zone of 1 m and 1.5 m between plots and blocks, respectively.

Table 2. *Treatments combination and descriptions.*

Treatment	Description
T1	Furrow irrigation method with 120% of MAD level
T2	Furrow irrigation method with 100% of MAD level
T3	Furrow irrigation method with 80% of MAD level
T4	Drip irrigation method with 120% of MAD level
T5	Drip irrigation method with 100% of MAD level
T6	Drip irrigation method with 80% of MAD level

2.2. Installation of Drip Irrigation Sets

The drip irrigation system was designed and installed in such a way to maintain the required pressure at the end of the plot so that uniform water distribution at each emitter was obtained. Five drip laterals per plot having 4 m length, 60 cm spacing between laterals and 20 cm interval between emitters with discharge rates of 2 lit/hr were installed. The drip lines (laterals) of 16 mm diameter were unrolled and laid along the middle of two rows of the crop separated by 20 cm spacing. The drip system was served by water storage tank placed at 2 m height from the ground. The water distribution system components diameter of 32 mm mainline, 25 mm sub-main line were laid and connected to the water container to the individual drip lines. Gate valve was fixed on a mainline next to the filter to control the water flow to the field. The irrigation water delivered to each experimental plot was controlled by gate valve fixed on the manifold.

2.3. Crop establishment and Management Practices

Onion (*Allium cepa* L) seed variety Nafis was used as seed material for the experiment. The seeds were sown on well-prepared nursery fields on January 24, 2018. The seedlings were then transplanted on March 18, 2018, on well-prepared experimental plots on both sides of ridges at row and plant spacing of 20 cm and 10 cm, respectively. Each plot consisted of ten rows with a total number of 400 plants per plot. After transplanting, up to the tenth day, common irrigation (100% ETc) was applied to all plots for the better plant establishment. The control treatment (100% MAD) received irrigation water at management allowed soil moisture depletion (ρ=0.25) of the total available soil moisture throughout the crop growth stage. Other treatments received 120% and 80% of the control treatment.

Weeding and cultivation were performed by hand hoeing when deemed necessary. The recommended rate of 200 kg/ha DAP and 100 kg/ha Urea were uniformly applied to the plots. DAP was applied at planting time only whilst urea was applied in split application, half at planting and another half fifteen days after transplanting [13]. The chemicals Selecron and Redomil Gold were used according to the recommended rate, to protect the crop against harmful insects and fungus. The growing period of the crop was categorized into four distinct growth stages based on FAO's recommendation [14]. Initial (20 days), crop development (25 days), mid-season (45 days) and late season (20 days).

2.4. Irrigation Water Management

Crop water requirement

The reference evapotranspiration (ETo) was estimated using the FAO Penman-Monteith method. The crop water requirements (ETc) over the growing season were determined by multiplying the daily ETo value with the Kc-value. The Kc value was taken as $K_{c\ ini}$ (0.5), $K_{c\ mid}$ (1.05) and $K_{c\ end}$ (0.85) respectively. For developmental stage ($K_{c\ dev}$) and late-season ($K_{c\ late}$), K_c values were determined by graphically [14].

$$ETc = Kc \times ETo \tag{1}$$

where: ET_c is crop evapotranspiration (mm/day), ETo is reference crop evapotranspiration (mm/day) and Kc=crop coefficient.

Irrigation water application

The soil water use in the experiment was obtained from routine measurements of soil moisture content by the gravimetric method. In this method, soil samples were collected with soil auger just before and after irrigation to compute soil water contents. The wet soil samples were placed in an oven dry at a temperature of 105 °C and dried for 24 hours. The gravimetric water content was converted to equivalent depth (D) from the expression:

$$\mathrm{D} = \left(\frac{\mathrm{W_w} - \mathrm{W_d}}{W_d}\right) \times \mathrm{BD} \times \mathrm{drz} \tag{2}$$

where: D is the depth of available soil moisture in mm, W_w is wet soil weight in gm, W_d is dry soil weight in gm, BD is the soil dry bulk density in g cm^{-3} and drz is the sampling depth within the crop root depth in mm.

The soil moisture depleted between irrigation was obtained from:

$$dn = Fc - D \tag{3}$$

where: dn is the net irrigation requirement in mm and FC is the soil moisture content at field capacity in mm.

Irrigation scheduling

Total available water (TAW) was computed from the soil moisture content at field capacity and permanent wilting point using the following equation as indicated by Allen et al [14].

$$TAW = (FC - PWP) \times BD \times D_z \tag{4}$$

where: TAW is the total available water in the root zone (mm), FC and PWP are moisture content at field capacity and permanent wilting point (%), respectively and D_z is the maximum effective root depth of onion at times of irrigations (mm).

For maximum crop production, the irrigation schedule was fixed based on MAD. The value of MAD was used as a guide for deciding when to irrigate. Irrigation water was applied when the soil water deficit approaches or equal MAD to minimize water stress on the crop. The MAD for onion used in this study was 25% (ρ=0.25) of the total available soil moisture [8]. Readily available water (RAW) was computed from the expression:

$$\mathrm{RAW} = \mathrm{TAW} \times \rho \tag{5}$$

where: RAW is in mm, ρ is allowable permissible soil moisture depletion and TAW is in mm.

Irrigation frequency which is defined as the frequency of applying water to a crop at a certain stage of growth was estimated using the following equation [15].

$$f = \frac{RAW}{ETc} \tag{6}$$

where: f is irrigation frequency in day, RAW is in mm, and ETc is in mm.

The net depth of irrigation supplied at any time was obtained from a simplified water balance equation expressed as:

$$I_n = ETc - P_{eff} \tag{7}$$

where: I_n is the net irrigation depth in mm, ETc is in mm and P_{eff} is effective rainfall in mm.

The effective rainfall was estimated using the method given in CROPWAT software using dependable rain (FAO formula).

$$\mathrm{P_{eff}} = 0.6 \times \mathrm{P} - 10 \text{ for month} \leq 70 \text{ mm} \tag{8}$$

$$\mathrm{P_{eff}} = 0.8 \times \mathrm{P} - 24 \text{ for month} > 70\text{mm} \tag{9}$$

where: P is rainfall in mm and P_{eff} is effective rainfall in mm

The gross irrigation requirement was computed by adopting a field application efficiency of 60% for furrow and 90% for drip irrigation method [16].

$$I_g = \frac{I_n}{E_a} \tag{10}$$

where: I_g is gross irrigation depth in mm, I_n is in mm and E_a is application efficiency (%).

In the case of furrow irrigation, the determined amount of irrigation water applied to the plots was measured using a 3 inch Parshall flume. Accordingly, the time required to deliver the desired depth of water into each plot was calculated using the equation given below.

$$T = \frac{A \times I_g}{6 \times q} \quad (11)$$

where: T is application time (min), I_g is in mm, A is the area of the experimental plot (m^2), and q is flow rate (l/s) at specific Parshall flume head.

In the case of drip irrigation, the gross irrigation requirement was computed as:

$$I_g = \frac{I_n \times Wa}{E_a} \quad (12)$$

where: I_g is gross irrigation requirement in mm, wa is the wetting area in%, I_n is the net irrigation depth in mm and Ea is drip irrigation application efficiency in%.

Time required to deliver the desired depth of water into each plot was computed from:

$$T = \frac{Ig\ x\ A}{Nl\ x\ Ne\ x\ q} \quad (13)$$

where, T is time in hours, A is the plot area in m^2, Nl is the number of lateral, Ne is number of emitters per lateral and q is emitter discharge in l/hr.

2.5. Data Collection

Climatic data

Daily climatic data such as rain fall, temperature, relative humidity, sunshine hours and wind speed were obtained from meteorological station of the MARC. These data were used to determine the ETo and effective rainfall by CROPWAT 8.0 software.

Soil data

Representative soil samples were taken to investigate some properties of the soils such as moisture content at field capacity (FC) and permanent wilting point (PWP), bulk density (ρ_b), organic matter (OM), texture, electrical conductivity (EC) and (pH) of the study area. The samples were taken at 15 cm depth interval within the effective root zone, which was considered to be 50 cm for onion. The analysis was conducted at Oromia Water Works Design and Supervision Enterprise Laboratory. Before the experimental work was started, the soil infiltration test was determined using double ring infiltrometer.

Soil ρ_b was determined by taking undisturbed soil samples using a known volume of core sampler. The soil samples were oven dried for 24 hours at a temperature of 105°C. Then ρ_b was determined as [17]:

$$\rho b = \frac{M_s}{V_b} \quad (14)$$

where M_s=the mass of soil after oven dry (g) and V_b=bulk volume of soil (cm^3), ρ_b is in g/cm^3.

Drip uniformity parameters

The performance of drip irrigation system was evaluated using commonly used performance indicators such as distribution uniformity and coefficient of uniformity.

Distribution uniformity (Du)

DU is the ratio between the average discharge in the quarter receiving less water and the average discharge at the system level. It is used to describe the predicted emitter flow variation along a lateral line. DU (%) was estimated as:

$$DU = \frac{\bar{q}\ lowest\ 25\%}{\bar{q}} \times 100 \quad (15)$$

where, $_{\text{lowest 25\%}}$ is average of the lowest quarter discharge, is average discharge

Coefficient of uniformity (CU)

It is also known as Christiansen's uniformity coefficient is the ratio of the difference between the average amount applied and the average deviation from the average amount applied to the average amount applied.

$$CU = \left(1 - \left(\frac{\sum |q_i - \bar{q}|}{n\bar{q}}\right)\right) \times 100 \quad (16)$$

where: q_i is dripper discharge,=average discharge and n=number of drippers

Agronomic data

Agronomic data including plant height and a number of leaves per plant were taken from five plants randomly tagged from each experimental unit excluding the border rows and border plants, in the central rows. Plant height was taken by measuring the main stem height from the ground up to the tip of the leaf with the help of a ruler. All completely developed leaves of the same plants were counted. The leaf length of the same plants was measured from the leaf base to the tip. Yield parameters data such as bulb height, bulb diameter, and bulb weight were also recorded from the same plants used for recording previous parameters. The increase in yield due to drip irrigation was computed using the following equation [18]:

$$Increase\ in\ yield = \left(\frac{Y_1 - Y_2}{Y_1}\right) \times 100 \quad (17)$$

where, Y_1 and Y_2 are yields obtained from drip and furrow irrigation respectively in kg/ha.

Water productivity

Water productivity (WP) was determined by dividing the total onion bulb yield to the net amount of irrigation water applied to the crop [19]:

$$\mathrm{WP} = \frac{\mathrm{Y}}{\mathrm{ETc}} \quad (18)$$

where: WP is water productivity (Kg/m^3), Y is total bulb yield per unit area (Kg/ha), ETc is crop evapotranspiration (mm).

Water saving

The water saving in drip irrigation method over furrow irrigation method was calculated as:

$$W_s = \frac{W_f - W_d}{W_f} \times 100 \quad (19)$$

where: W_s is water saving (%), W_f and W_d are total water used in furrow and drip irrigation method (m^3/ha).

2.6. Data Analysis

Data collected were subjected to statistical ANOVA appropriate to split plot in RCBD using SAS 9.0 software. Whenever treatment effects were found significant, treatment means were compared using the least significant difference (LSD) method. Pearson correlation analysis was also used to determine the association of onion bulb yield and yield components.

3. Results and Discussions

3.1. Soil Characteristics at the Study Area

The particle size distribution of the soils at experimental site at different soil depths were presented in table 3. The percent particle size determination revealed that the soil texture is dominated by loam.

Table 3. *Summarized soil particle size distribution.*

Soil depth (cm)	% Particle size distribution			Textural class
	Sand (%) (2-0.05)	Silt (%) (0.05-0.002)	Clay (%) (<0.002)	
0-15	36	38	26	Loam
15-30	30	44	26	Loam
30-45	36	40	24	Loam
45-60	34	36	30	Clay loam
Average	34	39.5	26.5	Loam

The bulk density of soil of the area shows a variation with depth (Table 4). It varies between 1.09 to 1.23 gcm^{-3} and generally; the top surface soil has slightly lower bulk density than the subsurface. This may be due to compaction of soil in the lower depth of soil layer. The weighted average bulk density of the soil in the experimental station was 1.14 gcm^{-3}.

Table 4. *Soil moisture constants and bulk density of experimental site.*

Sampling depth (cm)	Bulk density (gcm^{-3})	FC (% wt.)	PWP (%wt.)	TAW (mm/m)
0-15	1.09	35.5	20.6	162.4
15-30	1.12	37	21.2	177.0
30-45	1.12	39	21.8	192.6
45-60	1.23	39.9	22.8	210.3
Mean	1.14	37.8	21.6	185.6

The moisture content at FC and PWP varies with depth that ranged between 35.5% and 39.9% and 20.6% and 22.8% respectively on a weight basis. The top soil surface was having lower values than subsurface soil layers for both parameters. The average value TAW was found to be 185.6 mm per meter depth of soil (Table 4). The basic infiltration rate was about 12 mm/hr (Figure 2). This rate of infiltration is in the range of infiltration characteristics of loam soils [20].

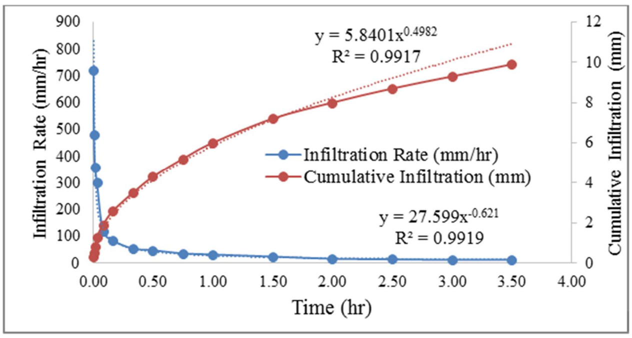

Figure 2. *Soil infiltration rate of the experimental field.*

As shown in table 5, the organic matter (OM) content decline with depth. The highest (2.07%) and the lowest (1.5%) OM contents were recorded at the surface (0-15 cm depth) and bottom (45-60 cm soil depth) layers respectively. The average OM content of the soil was about 1.8%. The average value of the PH of the soil was about 6.47. This showed that the PH of the site is nearly neutral and suitable for onion production [13]. The average value of the ECe of the soil was about 0.16 ds/m.

Table 5. *Selected soil chemical properties of the surface of the experimental field.*

Soil depth (cm)	PH	ECe (ds/m)	OM (%)
0-15	5.81	0.18	2.07
15-30	6.65	0.16	1.88
30-45	6.50	0.15	1.74
45-60	6.91	0.16	1.50
Average	6.47	0.16	1.80

3.2. Distribution Uniformity of Drip Emitters

Analysis of data on emitter discharge observation under all parameters has shown better performance. The values of Du and Cu were 97.57% and 98.20%, respectively (Table 6). The DU was excellent according to Bralts [21] emitter flow variation was acceptable.

Table 6. *Uniformity of drip irrigation.*

Parameters	Units	Average
Distribution uniformities (Du)	%	97.57
Emitter flow variation (q_V)	%	6.77
Coefficient of variation (Cv)	%	2.10
Uniformity coefficient (Cu)	%	98.20

3.3. Crop Water Requirement

The crop water requirements of onion under FI and DI with 100%MAD were 498.65 mm and 326.66 mm, respectively. The applied common irrigation water was 27.26 mm which was applied two times from transplanting up to ten days of crop growth. Relatively 2.59%, 59.51%, 60% and 61.04% of water were saved due to T3, T4, T5 and T6 respectively as compared to T2.

***Table 7.** Crop and irrigation water requirement of onion crop.*

Parameters	Units	Average
Distribution uniformities (Du)	%	97.57
Emitter flow variation (q_V)	%	6.77
Coefficient of variation (Cv)	%	2.10
Uniformity coefficient (Cu)	%	98.20

IRn=net irrigation requirement, IRg=gross irrigation requirement, CWR=crop water requirement, P_{ef}=effective rainfall and Rws=relative water saved.

3.4. Effects of Irrigation Methods and MAD Levels on Crop Growth

Number of green leaves per plant

The ANOVA indicated that there was a significant (P<0.05) effect on number of leaves per plant due to irrigation methods. As shown in table 8, the highest leaf number per plant (13) was observed from the DI method while lower number of leaves per plant (12) was obtained from FI method. Based on the results, the DI method resulted in increased leaf number by 7.7 % as compared to FI method. Bagali et al [5] also reported that scheduling of DI significantly increased the growth parameters.

***Table 8.** Effects of irrigation methods and MAD levels on crop physiology.*

Treatments	Number of Leaves per plant	Plant height (cm)	Leaf height (cm)
120% MAD	11^{c}	61.40^{b}	56.93^{b}
100% MAD	12^{b}	64.73^{ab}	60.40^{ab}
80% MAD	13^{a}	67.30^{a}	62.83^{a}
LSD (0.05)	0.39	3.56	3.62
CV (%)	2.39	4.15	4.53
F	12^{b}	62.60^{b}	58.27^{b}
D	13^{a}	66.36^{a}	61.84^{a}
LSD (0.05)	0.58	2.74	2.16
CV (%)	2.36	2.10	1.77

*Means followed by the same letter in a column per treatment factor are not significantly different from each other at a 5% probability level.

The ANOVA also has shown that the MAD levels had a highly significant (P<0.01) effect on a number of green leaves per plant. The result indicated that the highest green leaf number per plant (13) was observed at 80% MAD while the lowest number of leaf per plant (11) was observed from 120% MAD level. The result indicated that it is preferable to irrigate onion at shorter interval than recommended. Similar results of improved crop growth with irrigation or re-watering near field capacity were reported by Kumar et al [22] for growth parameters. The ANOVA also showed that the interaction effect of irrigation methods and MAD levels was not significant for the number of green leaf per plant.

Plant height

The ANOVA indicated that there was significant (p<0.05) effect on plant height due to irrigation application methods and MAD levels. The mean value of plant height recorded from DI method was higher than FI. This finding agrees with that of Bhasker et al [23] who reported that maximum plant height was recorded under DI method.

As shown in table 8, the highest plant height (67.30 cm) was obtained from 80%MAD level and was not significantly different from 100% MAD level, while the shortest mean plant height (61.40 cm) was observed on the application of 120% MAD level and statistically not different with 100% MAD. The reason for the better performance of this growth parameter due to the shorter interval of irrigation may be attributed to optimum soil water-air-balance around plant root zone. This study outcome is in line with the research that was conducted by El-Noemani et al [24] indicated that soil water supply is directly proportional with plant height growth. However, the ANOVA showed that the interaction of irrigation methods and MAD levels had no significant effect on plant height.

3.5. Effects of Irrigation Methods and MAD Levels on Yield and Yield Parameters

Total bulb yield

The ANOVA has shown that irrigation methods, MAD levels and their interaction had a highly significant (P<0.01) effect on total bulb yield. As shown in table 9, the maximum total bulb yield (41.76 t/ha) was obtained under drip irrigation method with 80% of management allowed deficit which was significantly different from all other treatments. The lowest total bulb yield (34.48 t/ha) was obtained under Furrow irrigation method with 120% of management allowed deficit. The total yield obtained under furrow irrigation method with 100% of management allowed deficit had no significant difference from drip irrigation method with 120% of management allowed deficit and total yield obtained under Furrow irrigation method with 80% of management allowed deficit had not significant difference from drip irrigation method with 100% of management allowed deficit. High irrigation frequency might provide desirable conditions for water movement in soil and for uptake by roots [25]. Several experiments have shown positive responses in some crops to high frequency drip irrigation [25, 26].

***Table 9.** Effect of irrigation method and MAD levels on total onion bulb yield (t/ha).*

Irrigation methods	MAD levels 120%	100%	80%	Mean
Furrow	34.48^{d}	37.14^{c}	40.60^{b}	37.41
Drip	36.35^{c}	40.74^{b}	41.76^{a}	39.62
Mean	35.41	38.94	41.18	38.51
LSD (0.05)	0.96			
CV (%)	1.16			

*Means followed by the same letter are not significantly different from each other at a 1% probability level.

Marketable bulb yield

The statistical analysis indicated that irrigation methods, MAD levels and their interaction had a highly significant (P<0.01) effect on marketable onion bulb yield. As shown in table 10, the highest marketable bulb yield of 38.39 t/ha was obtained from drip irrigation method with 80% of management allowed deficit and significantly different to all other treatments. The lowest yield of 31.6 t/ha was obtained from Furrow irrigation method with 120% of management allowed deficit and significantly different to all other treatments. The bulb yield obtained from Furrow irrigation method with 100% of management allowed deficit had no significant difference with drip irrigation method with 120% of management allowed deficit. The bulb yield obtained from Furrow irrigation method with 80% of management allowed deficit had no significant difference with irrigation method with 100% of management allowed deficit. The current result was in confirmation with study result of Bagali et al [5] who reported that scheduling of drip irrigation at shorter intervals significantly increased the growth parameters and significantly higher bulb yield as compared to flood irrigation. Onion performs better when irrigation is given on depletion of 15-20 percent soil moisture of the field capacity. This is the reason for higher yield by the treatments with drip irrigation method at shorter intervals of irrigations.

Table 10. *Effect of irrigation method and MAD level on marketable bulb yield (t/ha).*

Irrigation methods	MAD levels			
	120%	100%	80%	Mean
Furrow	31.60^{d}	34.05^{c}	37.30^{b}	34.32
Drip	33.28^{c}	37.39^{b}	38.39^{a}	36.35
Mean	32.44	35.72	37.85	35.34
LSD (0.05)	0.92			
CV (%)	1.17			

*Means followed by the same letter are not significantly different from each other at a 1% probability level.

Bulb diameter

The ANOVA indicated that MAD level had a highly significant (P<0.01) effect on bulb diameter. The irrigation method and interaction had a significant (P<0.05) effect on bulb diameter. As depicted in table 11, the highest bulb diameter of 6.02 cm was obtained from T6 and significantly different from all other treatments. This result was in line with the result of Enchalew et al [27]. The lowest bulb diameter of 5.11 cm was obtained from T1 and significantly different from all other treatments. The bulb diameter obtained from T2 had no significant difference from that of T3 and T5. The result indicated that it is preferable to irrigate onion at shorter interval with drip irrigation than furrow irrigation method. This may be because of moisture available in the root zone was enough for nutrient availability for the crop.

Table 11. *Effect of irrigation method and MAD level on bulb diameter (cm).*

Irrigation methods	MAD levels			
	120%	100%	80%	Mean
Furrow	5.11^{d}	5.70^{b}	5.72^{b}	5.51
Drip	5.45^{c}	5.72^{b}	6.02^{a}	5.73
Mean	5.28	5.71	5.87	5.62
LSD (0.05)	0.24			
CV (%)	1.75			

*Means followed by the same letter are not significantly different from each other at a 1% and 5% probability level.

Bulb height

The ANOVA indicated that irrigation methods and MAD levels had a highly significant (P<0.01) effect on bulb height while the interaction was not significant. The bulb height for DI method was higher (5.9 cm) and highly significantly (p<0.01) different from that obtained from FI method (5.7 cm). DI method resulted in bulb height increment by 3.4% as compared to FI method. These results were in line with the results of Bagali et al [5]. As indicated in table 12, the highest bulb height (6 cm) was obtained from 80% MAD level though it is not significantly different from that of 100% MAD level. The lowest bulb height (5.53 cm) was recorded from 120% MAD application and significantly different to all other MAD levels. Increased bulb height by ashorter intervals of irrigation may be due to the better performance of growth parameters like plant height and number of leaves. The shorter interval of irrigation ensures the optimum growth of the crop by assuring balanced water and nutrient supply throughout the crop growth period. The current result agreed with study result of Bagali et al [5].

Table 12. *Effects of irrigation methods and MAD levels on bulb height.*

Treatments	Bulb height (cm)
120% MAD	5.53^{b}
100% MAD	5.87^{a}
80% MAD	6.00^{a}
LSD (0.05)	0.18
F	5.70^{b}
D	5.90^{a}
LSD (0.05)	0.04
CV (%)	0.35

*Means followed by the same letter in a column per treatment factor are not significantly different from each other at a 1% probability level.

3.6. Water Productivity

The ANOVA had shown that irrigation methods, MAD levels and their interaction had a highly significant (P<0.01) effect on water productivity (WP). The highest WP (13.05 kg/m^3) was obtained from T3 and statistically different for all other treatments. The lowest WP (6.84 kg/m^3) was obtained from FI method at 120% MAD application and significantly different to all other treatments. It is indicated that irrigating with DI method even at 120% MAD level resulted in higher WP than irrigating with FI method. As shown in table 13, the WP decreased as the MAD levels increased from 80% MAD to 120% MAD under both irrigation methods. This might be because of increase in yield when increased as frequent and light irrigation was applied by maintaining favorable soil moisture conditions throughout the cropping season. These results are in agreement with that of Teferi [18] reported the higher mean value of irrigation water use efficiency was observed under drip method with mean value of 7.1 kg m^{-3} which is 33.8% higher than that is obtained in furrow method (4.7 kg m^{-3}).

Table 13. *Effect of irrigation methods and MAD levels on water productivity.*

Irrigation methods	MAD levels			
	120% MAD	100% MAD	80% MAD	Mean
Furrow	6.84[f]	7.45[e]	8.32[d]	7.54
Drip	11.01[c]	12.48[b]	13.05[a]	12.18
Mean	8.93	9.97	10.69	9.86
LSD (0.05)	0.24			
CV (%)	1.28			

4. Conclusions and Recommendations

4.1. Conclusions

Irrigation treatments had significant effect on yield and yield components considered in the study. Irrigation methods and MAD levels had a significant ($p<0.05$) effect on onion vegetative parameters like number of leaves per plant, plant height and leaf height and yield parameters like bulb diameter, bulb height, total bulb yield, marketable bulb yield, and water productivity. Further, their interaction had a significant effect on bulb diameter, total bulb yield, marketable bulb yield and water productivity. Nonetheless, they had no significant effect on number of leaves per plant, plant height, leaf height and bulb height. Generally, drip irrigation method was recorded higher vegetative and yield parameters than furrow irrigation method. The maximum total bulb yield (41.76 t/ha), marketable bulb yield (38.39 t/ha), bulb diameter (6.02 cm) and water productivity (13.05 kg/m^3) were observed from treatment combination of drip irrigation method and 80% MAD level (when water was applied at frequent intervals).

4.2. Recommendation

From the observation made during this research, the following points were further recommended:

a) The study suggests farmers in the study area, having limited amount of water for irrigation, should adopt drip irrigation method at the light and frequent (80% MAD level), instead of surface irrigation method especially where high-value crops require frequent water applications to achieve a high production potential.
b) Growers will need to exercise flexibility in managing the rate, frequency, and duration of water supplies to successfully allocate limited water resource.
c) The experiment needs to be repeated across locations and time so as to see the residual effect of irrigation methods and MAD levels on onion.
d) The experiment was a one season and in one place. Hence, the experiment needs to be repeated across locations and time to improve the validity of the findings.
e) The gravimetric method was used to monitor soil moisture content, but it is also advisable to use other modern soil moisture monitoring instruments to effectively account the in-situ and real-time soil moisture to apply the right amount of water at the right time.

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